

# Overview of Risk Management in Electricity Markets Using Financial Derivatives

Aparna Viswanath

**Abstract**—Electricity spot prices are highly volatile under optimal generation capacity scenarios due to factors such as non-storability of electricity, peak demand at certain periods, generator outages, fuel uncertainty for renewable energy generators, huge investments and time needed for generation capacity expansion etc. As a result market participants are exposed to price and volume risk, which has led to the development of risk management practices. This paper provides an overview of risk management practices by market participants in electricity markets using financial derivatives.

**Keywords**—Financial Derivatives, Forward, Futures, Options, Risk Management.

## I. INTRODUCTION

RESTRUCTURING in electricity industry has created a market place where electricity, just like any other commodity, is bought and sold by market participants. The price and quantity trades of all the market participants is determined by the market operator based on the supply and demand bids submitted by the generators and Load serving Entities (LSE).

Spot prices are highly volatile under optimal generation capacity scenarios due to factors such as non-storability of electricity, peak demand at certain periods, generator outages, fuel uncertainty for renewable energy generators: e.g., wind for wind generators and water for hydro power plants, huge investments and time needed for generation capacity expansion etc. As a result, market participants are exposed to price and volume risk which has led to the development of risk management practices.

This paper presents an overview of risk management practices by market participants in electricity markets using financial derivatives. The paper is organized as follows. In Section II a review about various types of financial derivatives is presented. The various methods for pricing financial derivatives are presented in Section III. An overview of the risk management practices by market participants is described in Section IV followed by conclusions in Section V.

## II. OPTION THEORY

In this section, we provide a review of the various financial derivatives [1] that can be used for risk management.

### A. Forward and Futures

A forward contract is a non-standardized contract to buy or sell electricity at a specified future time for a price agreed by both parties in advance. The agreed price is called the forward price and is denoted here as  $F_T$ . A futures contract is similar to the forward contract except that it is standardized and is traded in the exchange.

### B. Call Option

It is a financial contract between the buyer and the seller of the option, which offers its buyer the right, but not the obligation to buy a fixed quantity of the underlying at a pre-specified strike price by the option expiration time. The seller is obligated to sell the underlying if the buyer exercises the right to buy. The buyer of the call option pays a premium to the seller to purchase this right. The buyer will exercise the right when the spot price is more than the strike price and the payoff is the difference between spot price and strike price. If the Spot price is less than the strike price then the option will expire worthless.

The payoff of an electricity call option is  $\max(S_T - K, 0)$ , where  $S_T$  is the spot price of electricity at time  $T$  and  $K$  is the strike price.

### C. Put Option

It is a financial contract between the buyer and the seller of the option, which offers its buyer the right, but not the obligation to sell a fixed quantity of the underlying at a pre-specified strike price by the option expiration time. The seller is obligated to purchase the underlying if the buyer exercises the right to sell. The buyer of the put option pays a premium to the seller to purchase this right. The buyer will exercise the right when the spot price is less than the strike price and the payoff is the difference between the strike price and spot price. If the strike price is less than the spot price then the option will expire worthless.

The payoff of an electricity put option is  $\max(K - S_T, 0)$ , where  $S_T$  is the spot price of electricity at time  $T$  and  $K$  is the strike price.

Call and put options can be used by power market players for mitigating their risks.

### III. PRICING OPTIONS

In this section, we present a review on the pricing of options using Black Scholes method [2], Binomial tree method [3] and Monte Carlo method [4].

#### A. Black Scholes Method [2]

The price of option over time, under certain assumptions, can be described by Black Scholes formula [2]:

$$\frac{\partial V}{\partial t} + \frac{1}{2}\sigma^2 S^2 \frac{\partial^2 V}{\partial S^2} + rS \frac{\partial V}{\partial S} - rV = 0 \quad (1)$$

where  $S$  is the stock price;  $V$  is the price of the option as a function of  $S$ ;  $t$  is time (continuous variable);  $r$  is risk free interest rate;  $\sigma$  is the volatility of the stock.

The market value for the European put and call option can be derived using (1). The market value for European call option is expressed as:

$$C = SN(d_1) - Ke^{(-rt)}N(d_2) \quad (2)$$

The market value of the call option is the difference in the expected benefit from acquiring a stock outright and the present value of paying the exercise price on the expiration day as shown in (2). Here the returns on the underlying stock is assumed to be normally distributed where  $C$  is call premium;  $K$  is the option strike price;  $N$  Cumulative standard normal distribution;  $S$  is standard deviation of the stock.

$$d_1 = \frac{\ln(\frac{S}{K}) + (r + \frac{\sigma^2}{2})t}{\sigma\sqrt{t}} \quad (3)$$

$$d_2 = d_1 - \sigma\sqrt{t} \quad (4)$$

#### B. Binomial Tree Method

Binomial option pricing is based on the description of the underlying financial instrument over a period of time rather than a single point. It uses a discrete time model. Usually the stock price is assumed to follow a Gaussian distribution. A binomial tree showing the changing stock price at different time steps is constructed [3] as described below.

Let  $T$  be the number of steps and  $\sigma S$  be the volatility of the stock for the specified period and  $rS$  is the  $(1 + \text{interest rate})$ . At each step  $t$ , the price  $S$  can move upward or downward.

The up and down factors are calculated as:

$$S_{up} = uS = e^{\sigma S \sqrt{\frac{1}{T}}} \quad (5)$$

$$S_{down} = dS = e^{-\sigma S \sqrt{\frac{1}{T}}} \quad (6)$$

The probability of stock price moving up can be calculated as:

$$pS = \frac{(rS - dS)}{(uS - dS)} \quad (7)$$

Using (5), (6) and (7), it can be written as:

$$f(\sigma S) = [uS, dS, pS] \quad (8)$$

The probability for reaching the  $j$  th node in the final  $T$ th time step is:

$$\text{probability} = \left(\frac{T!}{j!(T-j)!}\right) pS^j (1-pS)^{T-j} \quad (9)$$

The possible value of stock at  $j$  th node of the  $T$  th time step is:

$$uS^j . dS^{T-j} . S \quad (10)$$

The probable value of the call option at the  $j$  th node of the  $T$ th time step considering a possible strike price of  $KSc$  is

$$\left(\frac{T!}{j!(T-j)!}\right) pS^j (1-pS)^{T-j} \max\{0, uS^j . dS^{T-j} . S - KSc\} \\ \forall j = 0, 1, \dots, T. \quad (11)$$

The total call option considering the entire time is given as

$$\sum_{j=0}^T \frac{T!}{j!(T-j)!} pS^j (1-pS)^{T-j} \frac{\max\{0, uS^j . dS^{T-j} . S - KSc\}}{rS} \quad (12)$$

Binomial tree model can be used to value American options that are exercisable at any time in a given interval. The binomial model is a discrete time approximation to the continuous process underlying the Black-Scholes model. It is computationally slower than the Black-Scholes formula.

#### C. Monte Carlo Method

Monte Carlo methods are a broad class of computational algorithms where the random behavior of the system is simulated a large number of times, like a series of experiments and then the results are estimated. The random sampling may be based on different probability distributions such as Exponential, Normal, Lognormal, Beta distributions, etc. [4].

Monte Carlo method is used for pricing the option based on risk neutral valuation. The technique is to generate a large number of random prices for the underlying. The price of the option value is calculated for each sample. The experiment is repeated a number of times to find the average discounted expected price of the option.

Monte Carlo methods are used for options with several sources of uncertainty and for options with complicated features, which would have been difficult to value using Black Scholes model or Binomial tree model. Monte Carlo method is

relatively straightforward, and allows for increasing complexity. Monte Carlo methods will usually be too slow than the Black Scholes method or binomial tree method.

#### IV. RISK MANAGEMENT IN ELECTRICITY MARKET

##### *A. Price and Volume Risk Mitigation for Load Serving Entities*

Electricity is purchased by Load serving Entities (LSEs) from the market at a price determined by the market operator based on the supply and demand bids submitted by the generators and LSEs respectively. LSE is obligated to supply electricity to retail customers at a fixed price and the required quantity as demanded by retail customers. In other words, an LSE purchases electricity from the market at spot price and sells it to the customers at fixed price. Therefore, LSE is exposed to price risk. Furthermore, LSE purchases fixed quantity from the market and is obliged to sell whatever quantity the customers require. The customers demand is uncertain and thus results in quantity or volumetric risks to the LSEs [5], [6]. Profit depends on the product of price and quantity. Small change in demand or fluctuation in price will lead to significant change in profits. Therefore profits of LSE can vary significantly due to price risks and quantity risks.

There are many financial derivatives such as Forward, Futures, Call option, Put option etc. that can be used to hedge price risk but the demand is a fixed quantity. It is relatively simple to hedge price risk for a fixed demand. Unfortunately, there are no financial derivatives that can be used directly to hedge quantity or volumetric risk. However in [6] the author suggests some alternative financial derivatives based on the following observation.

Volumetric risks are significant to the LSE because there is strong correlation between the demand and price. This can be explained as follows: Let us suppose an LSE purchases a forward contract for a fixed quantity. If the demand for electricity suddenly increases the spot price is usually very high and hence the product of price and quantity is a significant loss for the LSE. Similarly if the demand is less than the forward contract the price is usually less and the surplus has to be sold by the LSE below its purchase price, again, resulting in losses.

A similar strong correlation exists between demand and temperature. When demand is high, due to heat wave, the spot prices will be high or vice versa. In most markets the most important factor affecting the price of electricity is the demand.

Due to the strong correlation between demand and temperature, weather derivatives have been suggested in [6] as an effective way for volumetric risk management.

##### *B. Modeling Interruptible Load*

Utilities implemented load curtailment program, where customers would agree to reduce their demand, in case of generation shortfall or excessive peak load demand. After deregulation of power markets, the quantity measure for load curtailment program was replaced by monetary incentives schemes. Customers, who had the flexibility to shift or reduce

their demand, would bid in the market for load curtailment for monetary benefits. Increase in demand and/or generations shortages can result in increase in spot price of electricity. Instead of costly spinning reserves or investing in generation expansion, an alternative cheaper solution for the system operator would be to pay to customers who are willing to curtail their load. Customers who had the flexibility to reduce their demand could profit when the spot price is high. However, this requires the customers to consistently monitor the spot prices and to take risk due to price fluctuations. Risk averse customers can opt for fixed interruptible load payments for voluntarily reducing their consumption when the spot prices are high. This can be done by entering into an interruptible load agreement with the market operator. In [7]-[11] such an interruptible load incentive is shown to be equivalent to a callable forward.

A callable forward is a bundle of a forward contract and a call option. The forward contract is purchased by the customer from the utility to deliver a fixed quantity  $Q$  of electricity at a particular Time  $T$  for agreed price  $F_T$ . The second part of the callable forward contract is the call option, which is purchased back by the utility from the customer for quantity  $Q$  at the strike price  $K$ . The premium for the call option is equal to the interruptible rate discount.

The forward contract guarantees the customer that the utility will deliver  $Q$  units of electricity at time  $T$  for the forward price  $F_T$ . The price of the forward contract is equal to the spot price.

The call option gives the right to the utility, but not the obligation, to purchase back electricity from the customer at the strike price. In the case of a call option two cases arise. First case, if the spot price  $S_T$  is greater than the strike price  $K$ , the utility will exercise call option because it can buy back energy from the customer at strike price  $K$ , which is lower than the spot price. The call option is worth  $(S_T - K)$ . In the second case, if the spot price is less than the strike price then the option will expire worthless. Therefore the price of the call option is  $\max(S_T - K, 0)$ .

The bundling of the forward and the call option means that the utility either delivers electricity or pays the strike price  $K$  and interrupts the load. The price of callable forward is  $\{S_T - \max(S_T - K, 0)\}$  or  $\min(S_T, K)$ .

##### *C. Options to Mitigate Exposure to Generation Inadequacy*

In this method, the peak demand of a risk averse Load serving Entity (LSE) may be secured through a simple bilateral contract and the reserve margin requirements is obtained by purchasing a call option from the generator [12]. Call options gives the LSE a right but not the obligation to purchase a contracted amount of Energy, so it is more suitable for securing reserve capacity. The call option contracts and bilateral contracts must be backed by generation capacity or interruptible load contracts in order to assure adequate generation capacity. The proposed technique does not need any introduction of artificial products such as capacity payments, capacity obligations or strategic reserves

procurement by system operator or operating reserve pricing for ensuring adequate generation capacity [12].

The author further suggests that the LSEs can secure reserves by contracting call options with high strike prices. Most of the time, call options with high strike prices expire worthless and so the premiums are relatively low. Further the call options premiums for LSE can be reduced by purchasing spark spread (the difference between the electricity spot price and the fuel spot price). The lower premiums for LSE are because the price risk associated with the fuel costs is now transferred from the generator to the LSE.

On the other hand the strike price of the call option should be significantly below the price cap for energy in the spot market. The gap between the spot price and the strike price for the undelivered energy would be the economic penalty of the generator for the undelivered energy. Similarly, let us assume that a call option is purchased by the LSE from the interruptible load. When LSE exercises its call option, and the interruptible load is not able to curtail the load then an economic penalty is imposed on the interruptible load which is the price difference between the spot price and the prevailing strike price. Options based generation adequacy assurances for Brazil market can be found in [13]-[15].

#### *D.Options for Mutual Benefit of Wind Generators and Reserve Providers*

In [3] a future electricity market is considered in which wind generators bid in the spot market like any other conventional generators. Generators will be penalized for underproduction and paid a discounted rate for over production. Wind generator output depends on the wind speed and any deviations in the forecasted wind speed may change the energy output leading to penalty or poor payment. Instead of penalty and discounted payments with the System operator, call and put option based profit sharing strategy between the wind generators and reserve providers, which is mutually beneficial for both the parties, is proposed.

The wind generator will buy a call option from the reserve provider at a premium and will exercise the right to buy electricity at strike price, in case of capacity shortage. The Wind Generator will also buy a Put option from the reserve provider at a premium and will exercise the right to sell electricity at strike price, in case of surplus capacity.

Profit sharing between wind generators and reserve providers is based on wind energy volatility and volume of energy traded. As the volatility increases the reserve providers get a better share than the wind generators. For zero and infinite volatility in wind output no contract exists with the reserve provider.

Let  $E$  be the forecasted wind energy and  $\sigma E$  the volatility of wind energy. Using a binomial tree method the maximum under production  $EC_{\max}$  and overproduction energy  $EP_{\max}$  is computed.

Let the forecasted spot price and the volatility of spot price be  $m$  and  $\sigma m$ . Using Binomial tree method the call premiums  $mc$  can be determined for a strike price  $Kmc$  and put option premium  $mp$  is determined for a strike price  $Kmp$ .

The optimal amount of energy to be procured or sold by the wind generator and the strike prices for calls and puts is to be determined so that the profits of the wind generation company from the call and put options with the reserve providers is maximized for a given wind energy volatility  $\sigma E$  and spot price volatility  $\sigma m$ . Here profit for the wind generator refers to the extra money gained through the options contracts as opposed to the penalty and discounted price with the market operator subject to the profit sharing agreement between the wind generator and the reserve producer. Recall that the profit sharing is based on wind energy volatility and volume of energy traded.

If the spot price volatility is small and wind volatility is large (deviation from forecasted wind out is large) then as per the profit sharing agreement it is more profitable for the reserve provider than the wind generator. The results of the optimization formulation shows higher Call option strike price and lower put option strike price meaning more profits for the reserve providers.

If the spot price volatility is large, the premiums for the call and put options increase thus reducing the profits of the wind generators.

Black Scholes and Monte Carlo pricing based Options hedging methods for wind power and pumped storage hydro units is described in [4].

#### V.CONCLUSION

In restructured electricity market, financial derivatives when properly designed and implemented can help the market participants in mitigating price and volume risk. Financial derivatives can be used to mitigate exposure to generation inadequacy. It can also be used to implement interruptible load based on the market price signals thus reducing investments on costly reserves. It is an effective tool to encourage mutual cooperation and profit sharing among market participants.

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**Aparna Viswanath** received her PhD from Nanyang Technological University, Singapore in 2007. She is currently working as Lecturer in University of Newcastle, Singapore Campus. Her research interests are in Power System planning and Power Market.