Option Pricing for Electricity Market based on the Equilibrium Point of Day-Ahead and Option Markets

Abstrcat

Considering the increasing expansion of electricity markets, the producers need to use new pricing methods for investigating the maximum risk in different markets. It is necessary to use the pricing method to cover the combined risks of producers in physical and financial markets, concerning the attendance of the producers in the physical and financial markets, simultaneously. In this study, a new methodology has been provided for pricing put option contracts based on the equilibrium conditions of the day-ahead and the option electricity markets. By the provided model, a case study is introduced for the options contract area which represents the part of the strike price-option price where financial market players are willing to enter into options contracts. The results of the simulation on a sample power system showed the capability of provided pricing model and the mutual influence of put option contracts and the electric energy day-ahead market.

Keywords: Put option market; Equilibrium of the markets; Option contract pricing; Mutual influence of the physical market and the financial market

Introduction

the base price of electricity financial derivatives contracts or electricity financial contracts is usually determined by the operator of the electricity financial market. The electricity financial market operator provides a signal to the market players by the pricing [1-2]. However, the final price of derivative contracts is determined by the competition of the market players. The market players offer their prices in the financial market based on their estimation of the market conditions, using common pricing of financial derivatives contracts or the pricing by the financial market operator. Considering the relationship between the electricity financial market operator and the regulation board of the physical and financial electricity markets, predicting the future conditions of the two markets can help the electricity financial market operator for accurate pricing of financial derivatives contracts [1-2]. In some studies, the impact of financial electricity markets on physical electricity markets has been studied from the perspective of market players. In this section, the studies to determine the optimal strategy of producers in the physical and financial markets are reviewed, considering the financial transactions of electricity options as one of the considerable tools to cover the risk of producers due to uncertainties. The objective pursued in this reference was to determine the optimal strategy of players to participate in the physical market. A stochastic optimization model is provided in reference [3] to determine the optimal strategy of a producer in the options market. In this model, manufacturers offer the option and implementation prices to the market. In reference [4] option contracts are defined on the future contract. In this reference, the optimal strategy of producers is presented to use option contracts on the future contract to cover the price risk in the energy market. In reference [5], producers participate in the financial market to cover the risk of the production power volume in the energy market. For this purpose, the optimal strategy of producers to cover the power risk by the purchase of future and option contracts is presented in reference [5]. In reference [6], the options market is considered alongside the energy market. In this reference, a method is presented for calculating optimal strike prices from a market maker's point of view. In references [7] and [8], a multi-stage stochastic model has been presented to determine the optimal strategy of risk-averse producers in future, option, and pool contracts. The price risk in the energy market and the risk of unavailability of units at the time of energy delivery are considered in this model. An integrated risk management framework for strategic transactions of a producer in the physical market, the options market, and the fuel market is presented in reference [9]. Researchers have studied the impact of the financial market on the physical electricity market from different perspectives. Some researchers have discussed the impact of the financial market on the physical market by providing methods to determine the optimal strategy of producers. Some researchers have investigated the effect of the financial market on the physical market by calculating the equilibrium point of the physical and financial markets. However, the mutual influence of the two markets has not been considered in the research background. In most of the methods, the impact of the financial market on the physical market has been investigated, while the selective strategies by producers in the physical market have not affected their strategy in the financial market. In these studies, the price of the underlying asset or its volatility in the financial market model is obtained using the historical data of the physical market. Since the producers' strategy affects the physical market price, the price of the basic asset or its volatility will also be affected by the selective strategy of producers in the physical market. The balance model of the physical and financial market is defined in this study. Then, the mutual effects of physical and financial markets are examined. Finally, a new method for pricing electricity put option contracts is provided using the equilibrium conditions of physical and financial electricity markets.

Equilibrium modeling of the day-ahead and put option markets

There are various financial instruments such as futures, forward, or options contracts to cover the risk of producers in physical markets. A put option contract provides more flexibility for a producer than futures contracts or forward contracts. Because the holder of the put option right or the producer can decide to make the option contract based on the availability of the unit and market price changes [8]. In the studied financial market, it is only possible for players to trade European put option contracts with physical delivery. In this financial market, producers propose their volume and price to the market operator. Consumers, in the form of aggregated consumers, perform the role of central counterparty (CCP) in front of producers. Figure 1 shows the curve of aggregated demand functions of consumers in the physical and financial markets, as well as the marginal cost curve and the aggregated supply function of producers in the day-ahead market.

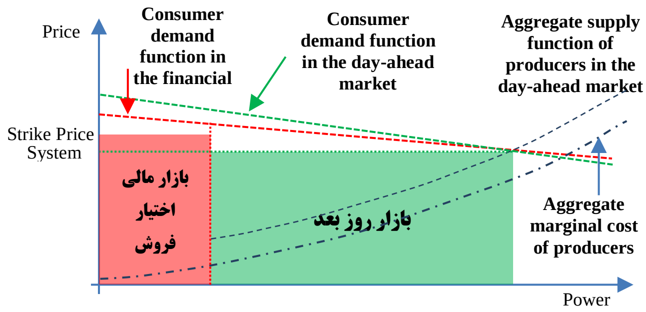

Figure 1) Marginal cost curve and aggregate supply function of producers

According to Figure 1, CCP trades in the options market as long as the price offered by producers is lower than the aggregated demand function of consumers in the financial market. According to Figure 1-3, the demand function slope in the financial market is lower than the demand function slope in the day-ahead market, because the elasticity of demand in the financial market is greater than the elasticity of demand in the day-ahead market. The physical market is considered a day-ahead market with uniform pricing. Competition in the physical market can be modeled as a Cournot or as a supply function.

Assumptions

In this study, consumption is considered a random variable with constant demand elasticity. Participants in the day-ahead physical market have the option of concluding standardized put option contracts in the financial put option market. Each standardized put option contract has a specified volume in megawatts, a specified strike price, and a specified delivery period. The delivery period and the strike price of each standardized option contract package are determined by the operator of the put option financial market. A put option market player can choose her desired put option package based on the desired delivery period and the desired strike price. Then, propose the size of the package and the price of the option (option right) to buy or sell it. If the offers of the buyer and the seller match each other, the desired package transaction will be conducted between the buyer and the seller. After that, in the delivery period of the traded package, if the day-ahead market price is lower than the strike price of the desired package, the buyer of the put option package, which is the energy producer, executes that package, and then all or part of the volume agreed in the contract is sold to the option seller, who is the same consumer, at the agreed strike price. Although the put option and day-ahead markets operate independently, the players of these markets, including energy producers and consumers, make the two markets interdependent, especially when put option contracts have physical delivery [10]. The delivery period of an option contract can usually include all hours or specific hours of a week, a month, a season, or even a specific year. In this article, it is assumed that the delivery period includes certain hours of T consecutive days, which is indicated by j=1,2,..., T, tj. To consider the uncertainty in the consumption load, S scenarios for the consumption load in the delivery interval are considered based on the distribution function of the consumption load. For a specified delivery period, producers should consider the following decisions to maximize their profit in the put option and the day-ahead markets in the delivery period:

1. After selecting the desired put option package, each producer must decide on the trading volume and option price of the desired package several months before the start of the delivery period. As shown in Figure 1-1, at time of t_f producer i determines the quantity of Q_i^O and the option price of f_{iK} for the package with a strike price of K.
2. Considering the used Cournot competition model in this section, one day before each day of the delivery period, each producer must also decide on the production volume offer at hour t from the day-ahead market. It is assumed that producer i offers the power Q_{it}^{Dh} MW for hour t of the day-ahead delivery period in the market. Since the markets are studied a long time before the execution of the day-ahead market, different scenarios are considered due to the uncertainty. Therefore, it is assumed that producer i offers $\mathrm{Q}_{\mathrm{ist}}^{\mathrm{Dh}}$ megawatt power for hour t of scenarios s of the delivery period in the day-ahead market.
3. Each producer must make a decision regarding the implementation of all or part of the volume of the put option contract every hour of the day-ahead. In this modeling, it is assumed

that producer *i* executes Q_{it}^{O}MW of trading volume Q_i^O MW at hour *t* of the delivery period. In order to consider different scenarios, it is assumed that producer *i* executes Q_{ist}^{O}MW of trading volume Q_i^OMW at hour *t* of scenarios *s* of the delivery interval. It is assumed that the applicable volume is a continuous variable. In real option markets, this volume is considered as a factor of one megawatt.

The image of the demand function at hour t from the scenario s is considered as follows:

$$\lambda_{st} = N_{st}^{Dh} - \gamma^{Dh} Q_{st}^{L}, \qquad t = t_1, t_2, \dots, t_T, s = 1,2,\dots,S \qquad (1$$

where λ_{st} and Q_{st}^{L} are the price of electricity in the day-ahead market and the demand load at hour *t* of scenario *s*, respectively. N_{st}^{Dh} and γ^{Dh} are the width from the origin and the reverse slope of the demand function at hour *t* of scenario *s* in terms of $/MWh and $/MW²h, respectively. The production cost function by producer *i* at hour *t* of scenario *s* is considered as follows.

$$C_i\left(Q_{ist}^{O} + Q_{ist}^{Dh}\right) = a_i\left(Q_{ist}^{O} + Q_{ist}^{Dh}\right) + \frac{1}{2} b_i\left(Q_{ist}^{O} + Q_{ist}^{Dh}\right)^2 \qquad (2$$

where a_i and b_i are the cost function coefficients of producer *i* in terms of $/MWh and $/MW²h, respectively.

Competition modeling by the Cournot model

In this study, only producers are considered as strategic players of markets. Therefore, each producer seeks to maximize the expected profit in the delivery period according to the decision variables in the option and the day-ahead markets. In this section, it is assumed that the producers consider the option price and the contract volume as the decision variables of the put option market in their optimization problem. Also, due to the Cournot competition in the day-ahead market, the producible volume by each producer in the day-ahead market is also considered as a decision-making variable in this market. As mentioned before, producers are divided into two groups A and B. Group A producers participate in both options and day-ahead markets, while group B producers only participate in the day-ahead market. The optimization problem of producer *i* from group A can be considered as follows:

$$\max_{Q_i^O, Q_{ist}^O, f_{iK}, Q_{ist}^{Dh}} \sum_{s=1}^{S}\sum_{t=t_0}^{t_T} p_s\Bigg(Q_{ist}^{O}K + Q_{ist}^{Dh}\lambda_{st} - \bigg(a_i\left(Q_{ist}^{O} + Q_{ist}^{Dh}\right) + \frac{1}{2} b_i\left(Q_{ist}^{O} + Q_{ist}^{Dh}\right)^2\bigg)\Bigg) - Q_i^O f_{iK} T e^{rT_C} \qquad (3$$

s. t.:

$$Q_{ist}^{O} + Q_{ist}^{Dh} \le \overline{Q_i}, \qquad \forall s \in \Omega, \forall t \in \mathcal{T}: \mu_{ist} \qquad (4$$

$$Q_{ist}^{O} \le Q_i^{O}, \qquad \forall s \in \Omega, \forall t \in \mathcal{T}: \omega_{ist} \qquad (5$$

$$\lambda_{st} = N_{st}^{Dh} - \gamma^{Dh}\left(\sum_{m\in A}\left(Q_{mst}^{O} + Q_{mst}^{Dh}\right) + \sum_{m\in B} Q_{mst}^{Dh}\right), \quad \forall s \in \Omega, \forall t \in \mathcal{T}: \theta_{st} \qquad (6$$

$$K - f_{iK} e^{rT_C} \le N^O - \gamma^O \sum_{m\in A} Q_m^O, \qquad : \beta_i \qquad (7$$

$$Q_i^O \ge 0, Q_{ist}^O \ge 0, f_{iK} \ge 0, Q_{ist}^{Dh} \ge 0, \quad \forall s \in \Omega, \forall t \in \mathcal{T} \qquad (8$$

Where *K* is the option contract price in terms of $/MWh, f_{iK} is the option price of producer *i* in terms of $/MWh, *r* is the interest rate, T_C is the trading duration or the time remaining until the start of the delivery period (year), N^0 and γ^0 are the width from origin and the reverse slope of the demand function in the put option financial market, respectively; $\overline{Q_i}$ is production capacity related to producer i by MW, T is the set of delivery interval hours, Ω is the set of consumption load scenarios in the delivery interval, p_s is scenario probability of s, μ_{ist} is binary variable limiting the production capacity of producer i at hour t of scenario s, ω_{ist} is binary variable limiting the strike power of the manufacturer at hour t of scenario s, at the put option market, and β_i are the binary variable related to the aggregated consumer in the put option financial market. The first and second sentences of the objective function (3) express the expected income of producer i from the put option financial market and the day-ahead market, respectively during the delivery period. The third to sixth sentences of the objective function (3), expresses the expected production cost by producer i in the delivery period. The last sentence (3) is the purchase prices of the put option package by producer i in the desired delivery period.

Deciding to implement the put option contract of producer i at hour t from scenario s, is modeled by maximizing the expression $\left(Q_{ist}^{O}K + Q_{ist}^{Dh}\lambda_{st}\right)$ in the objective function. In each hour of the delivery period, if the strike price of K is higher than the day-ahead market price λ_{st}, the producer's profit is maximized if Q_{ist}^{O} is at its maximum value, i.e. equal to Q_{i}^{O}, which indicates the automatic execution of the put option contract of producer i. Conversely, if the strike price of K is lower than the day-ahead market price λ_{st}, the producer's profit will be maximized when Q_{ist}^{Dh} is maximized, which according to condition (4), in this case, Q_{ist}^{O} should be zero, which indicates the non-implementation of the put option contract of producer i. Constraint category of (4) expresses the limitation of production capacity related to producer i in each hour of each scenario in the delivery period. The set of inequalities (5) models the constraints related to the maximum power applicable by producer i in each hour of each scenario in the delivery interval. Constraint category (6) expresses the relationship between the market price of the next day and the consumption of the entire network. Inequality (7) also models the elasticity of load demand in the financial market in the strike price and the option price of producer i. According to clause (7), the contractual volume of the aggregated consumer in the put option financial market is limited to the demand function in the financial market. Manufacturer k from group B only participates in the physical market. Therefore, the decision variables of this player will only be the proposed producible power in the physical market. The optimization problem related to this manufacturer can be defined as follows:

$$\max_{Q_{kst}^{Dh}} \sum_{s=1}^{S}\sum_{t=t_0}^{t_T} p_s\left(Q_{kst}^{Dh}\lambda_{st} - \left(a_k Q_{kst}^{Dh} + \frac{1}{2}b_k {Q_{kst}^{Dh}}^2\right)\right) \tag{9}$$

s. t.:

$$Q_{kst}^{Dh} \le \overline{Q_k}, \qquad \forall s \in \Omega, \forall t \in \mathcal{T}: \mu_{kst} \tag{10}$$

$$\lambda_{st} = N_{st}^{Dh} - \gamma^{Dh}\left(\sum_{m\in A}\left(Q_{mst}^{O} + Q_{mst}^{Dh}\right) + \sum_{m\in B} Q_{mst}^{Dh}\right), \forall s \in \Omega, \forall t \in \mathcal{T}: \theta_{st} \tag{11}$$

$$Q_{kst}^{Dh} \ge 0, \qquad \forall s \in \Omega, \forall t \in \mathcal{T} \tag{12}$$

In order to obtain the equilibrium point of the day-ahead and the put option markets, should solve the optimization problems of all the producers in the physical and financial markets.

Option Contract Area (OCA)

In order to make the right decisions about the operation and development of the network, the legislative body of the financial markets needs to analyze the performance of the players of this market in its various working points. Two basic variables for the decision-making of players in option financial markets are option price and option exercise price. The players of these markets make decisions regarding the volume of their proposed package in the financial markets considering the strike price and predicting the option price in different ways. Therefore, the legislative committee of option financial markets seeks to examine the performance of the financial market in different option prices and different exercise prices. In option financial markets, usually the option price for a specific period and the specific strike price changes little during a day of the trading period. At the end of each day of the trading period, a price is determined as the settlement price for that day. To study market performance in different option prices, it is assumed that the option price of all strategic producers in the put option financial market in one day is the settlement price of that day. With this assumption, now the option price can be considered as a predetermined variable in the optimization of producers. Therefore, the performance of the option financial market can be analyzed on the option price-strike price page. The equilibrium point of the option market and the day-ahead market, the price of the day-ahead market, the production capacity of the producers in the day-ahead market and their executed capacity in the option market are obtained for each point on this page that shows an option price and a specified strike price. In this study, a set of points on the option price-strike price screen is defined as the option contract area, for which the put option contract is concluded and executed in the financial market. Determining the scope of the option contract area can help better decision-making by the financial market legislator. The option contract area is defined by the following inequality on the option price-strike price screen.

$$\left\{(f, K) \mid Tfe^{rTc}/\eta + \overline{\lambda^0} < K < N^O + fe^{rTc}\right\} \tag{13}$$

Where f is the option price in the put option market and η and $\overline{\lambda^0}$ are defined as follows:

$$\eta = \sum_{\{s,t \mid K > \lambda^0_{st}\}} p_s \tag{14}$$

$$\overline{\lambda^0} = \left({}^{1}/_{\eta}\right) \sum_{\{s,t \mid K > \lambda^0_{st}\}} p_s \lambda^0_{st} \tag{15}$$

Where λ^0_{st} is the market price of the day-ahead at hour t of scenarios when there is no options market or no option contract is concluded. Inequality of (13) allows the operator of the financial market to determine the option contract prices in which producers and consumers are willing to enter into a put option contract. Inequality of (13) depends only on the parameters of the day-ahead market without the existence of a put option contract. Therefore, before concluding the option contract, the operator of the option financial market can obtain an estimate of the appropriate strike prices in the option financial market for a specific delivery period, using this inequality and the past information of the day-ahead market. Appropriate contract prices create the best joint working point for the simultaneous operation of the options financial market and the day-ahead market. Considering a delivery interval, there is only occurred scenario in the day-ahead market. Therefore, η is the sum of hours of this delivery interval in which the assumed contract price is more than the day-ahead market price. Also $\overline{\lambda^0}$ is the average market price of the day-ahead in the hours of this delivery interval when the assumed contract price is higher than the market price of the day-ahead in those hours. On the other hand, inequality of (13) specifies the option prices in which the option contract is concluded for each specific contract price. Therefore, this inequality can be used to determine an interval for pricing option contracts.

Simulation

In this section, the model presented in this study is applied to a power system including the day-ahead market and the put option financial market. The option contract area is specified and the simulation results of different models are analyzed.

Studied network

The studied power system includes four producers. The information related to each producer is obtained by aggregating the information of the generators in the four areas of the IEEE 300-node network. In each area of the IEEE 300-node network, there are several generators with specific marginal cost functions. The marginal cost functions of each area are calculated and approximated with a linear function. The linear function of the i-th region of the IEEE 300-node network is assigned to the i-th producer generator of the studied network. The information on the marginal cost and capacity of the studied power system producers is provided in Table 1. The studied power system includes a financial market of put options and a day-ahead market. In this article, the trading period of the put option market, i.e. the interval between the put option contract and the start of the delivery of the traded packages, is considered to be one year. The delivery period of the put option contract is also assumed to be a certain hour of the day in ten consecutive days. The interest rate is also considered to be 10%. In this power system, it is assumed that the first and second producers participate in the day-ahead market and the put option market. And the third and fourth producers only participate in the day-ahead market. In other words, the first and second producers are in group *A* and the third and fourth producers are in group *B*. The width from the inverse origin of the demand functions for different hours of the delivery period is listed in Table 2.

Table 1) Specifications of generating units in the power system

Group	Manufacturer number	Coefficients of the linear cost function of units		Production capacity (GW)
		a($/MWh)	b($/MW^{2}h)	
A	1	3.657	0.001869	11.40
	2	9.054	0.000742	12.00
B	3	9.533	0.000888	8.721
	4	6.472	0.076850	0.558

Table 2) Invers width from the origin of the demand function at different hours of the delivery interval

Day t of the delivery period	1	2	3	4	5	6	7	8	9	10
Mean N_{st}^{Dh} ($/MWh)	92.4	81.9	102.9	100.8	101.85	98.7	100.8	90.3	84	96.6
SD N_{st}^{Dh} ($/MWh)	2.22	1.31	3.29	2.82	3.26	2.92	2.66	2.17	1.61	2.78

In this study, it is assumed that the consumption load has uncertainty. The load uncertainty is modeled by assigning a normal probability distribution function. Table 2 shows the average and standard deviation of the load at different hours of the delivery period. The inverse slope of the aggregated load demand function of this power system is considered to be 0.003 $/MW^{2}h. It's assumed the constant slope of the demand function at different hours. The width from the origin and the reverse slope of the demand function in the financial market are 54$/MWh and 0.002$/MW^{2}h, respectively. If there is no put option in the financial market and all producers produce their power in the day-ahead market, the minimum and the maximum market price of the day-ahead market in the delivery period is 29.87 $/MWh and 39.23 $/MWh, respectively by calculating the equilibrium point of the next day market for different working points of the above power system. In the put option financial market, the contract price is determined by the financial market operator. It is assumed that the contract price will change from 25$/MWh to 60$/MWh with steps of 1$/MWh to conclude option contracts in the money, at the money, and out of the money. The equilibrium point of the options market and the day-ahead market is calculated in each contract price.

Simulation results

The simulation results of the presented model on the studied power system are examined in this section. The option contract area is determined in the conditions of the balance of the options market and the day-ahead market by considering the option price as a known input variable in the put option financial market. Then, considering the option price as a decision variable for group *A* producers, the equilibrium points of the options market and the day-ahead market are determined for different contract prices. For this purpose, the equilibrium point of both the options market and the day-ahead market is calculated at each contract price. Figure 2 shows the optimal option price of each of the producers of group *A* in the conditions of equilibrium of the options market and the day-ahead market. The optimal option prices of the first and second producers in group *A* are equal to each other under the equilibrium conditions of the markets. If these prices are not the same, the entire share of the options market will be captured by the manufacturer offering the lower option price. In some option markets, the settlement premium price is determined for that day based on the last trades on each day of the trading period, which is the basis for mark-to-marketing. The settlement premium price on each day is equal to the weighted average of the option price of the options contracts traded on that day or on a part of that day [11]. As shown in Figure 2, since the optimal option price of all producers is equal in the equilibrium conditions of the option and the day-ahead markets, the settlement premium price is also equal to the optimal option price of each of the producers in group *A*. Therefore, calculating the equilibrium point of both the options market and the day-ahead market can be considered as a method for pricing option contracts. Therefore, the curve shown in Figure 2 can be used for the pricing of options contracts in the studied power system one year before the delivery time.

The pricing results of the electricity put option in the Australian Stock Exchange (ASX) on February 28, 2016, are shown in Figure 3 [12]. In this figure, put option pricing for NSWs Base Load Strip Options Calendar Year 2017 package is shown. A comparison of Figure 2 and Figure 3 shows that in terms of the general shape, the option price curve obtained by the method presented in this article is similar to the actual option price curve occurring in the Australian put option market.

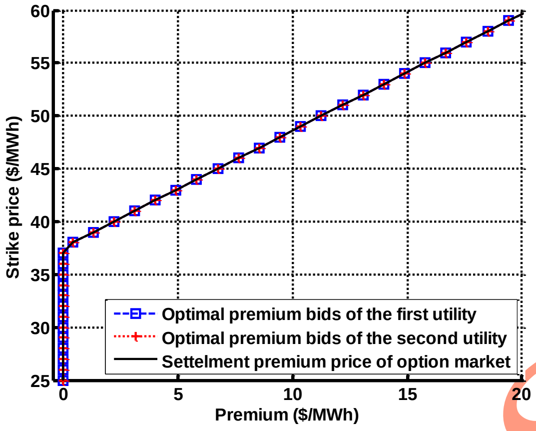

Figure 2) Optimal premium bids of the first and second utility and the settlement premium of the option market at the equilibrium point of the two markets

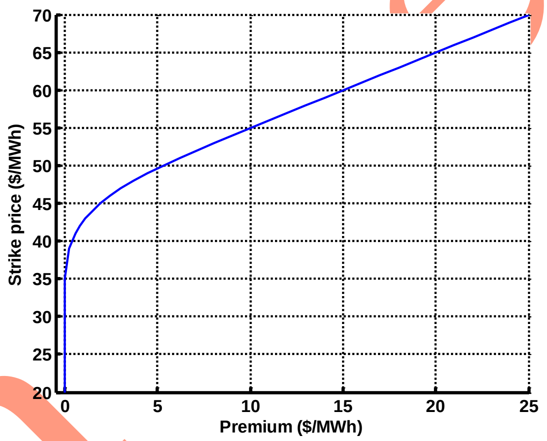

Figure 3) Pricing of NSWs Base Load Strip Options Calendar Year 2017 on the Australian Stock Exchange [12]

Option Contract Area (OCA)

To determine the option contract area in this power system, it is assumed that the strike price will change from 25$/MWh to 60$/MWh with steps of 1$/MWh. In each strike price, the option price changes from 0$/MWh to 7$/MWh in steps of 2$/MWh. Then, for each pair of strike prices and option prices, the equilibrium point of the option and the day-ahead markets is calculated by considering the option price as a known variable. The expected price of the day-ahead market over all possible hours and scenarios in the delivery period is shown on the option price-strike price page in Figure 4. Now suppose the option price as a decision variable for each producer of group A and the equilibrium point of both the options market and the day-ahead market is calculated by considering the option price as a decision variable. In this situation, the expected value of the day-ahead market price at each strike price is according to the solid black curve in Figure 4. Two parts of the horizontal page can be seen in this figure. Based on the results of the simulation, no options contracts are traded in this part of the pages. Therefore, the expected value of the day-ahead market price is a constant value and equal to the expected price of the day-ahead market in the absence of a put option market. The curve in Figure 4 is shown on the option price-strike price screen in Figure 5. Since no options are traded in the horizontal segments, these areas are called no-option contract areas (NOCA).

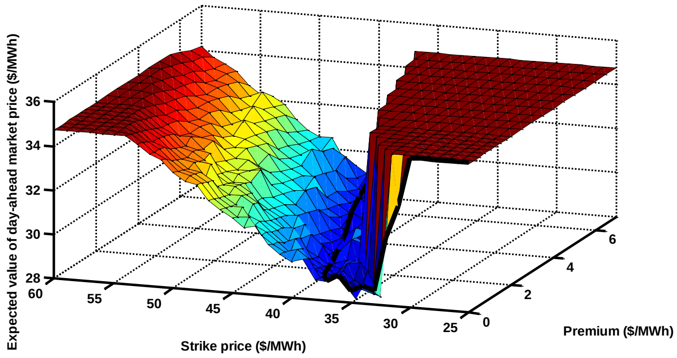

Figure 4) The expected market price of the day-ahead in the delivery period; procedure for the premium as a known variable, solid line for the option price as a decision variable

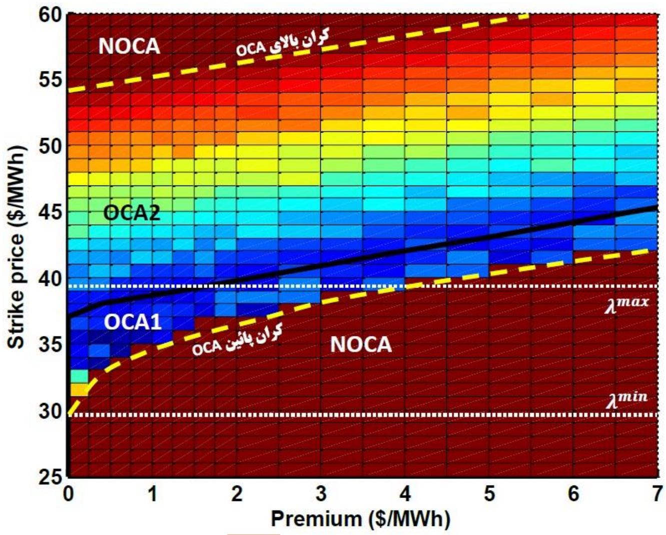

Figure 5) Image of the day-ahead expected market price on the premuim-strike price screen; the optimal premium curve is a solid black curve

Option Contract Area (OCA)

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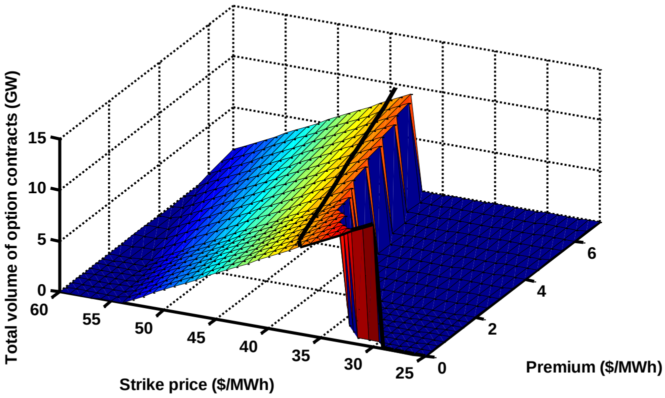

Figure 6) Total volume of option contracts; procedure for the premium as a known variable, solid line for the premium as a decision variable

Figure 6 confirms this content. In the OCA2 area, at the same time as the strike price is higher than λ^{max}, the option price is also high in this area. So, in the OCA2 area, consumers still tend to conclude put option contracts. In order to increase the volume of options contracts in the option financial market, it is better to focus the competition of players on the strike prices where it is possible to conclude a larger volume of options contracts. Therefore, the volume of strike prices should be selected in the appropriate range and its number should not be too much. According to Figure 6, if a limited number of strike prices are selected in the OCA1 area and placed in the put option market, the concentration of competition in the strike prices will increase and the volume of options contracts will increase. The total expected profit of utilities in group *A* is shown in Figure 7, concerning the option price for strike prices and different option prices. The total expected profit of group *A* utilities with the decision variable is also shown with a solid black curve in this figure considering the premium price. According to Figure 7, the total expected profit of group *A* producer increases in the option contract area. As shown in Figure 7, the expected profit of these utilities in the OCA2 area is higher than that in the OCA1 area. Because of the higher strike price than the market value of the day-ahead price in all hours and scenarios of the delivery period, the volume of options contracts in the OCA2 area is greater than the volume of options contracts in the OCA1 area. The total expected profit of utilities in group *B* is shown in Figure 8 taking into account the premium for strike prices and different option prices. The total expected a profit of group *B* producers with the decision variable considering the option price is also shown with a solid black curve in this figure. According to Figure 8, the total expected profit of group *B* utilities, which only participate in the day-ahead market has decreased in the area of options contract area compared to the non-option contract area. This is despite the fact that the profit of the utilities who participated in the options market has increased in the option contract area compared to the no-option contract area (Figure 7). The increase in the profits of group A utilities in the option contract area and the decrease in the profits of group B utilities in this area can be considered as an encouraging signal for the presence of producers in the options market.

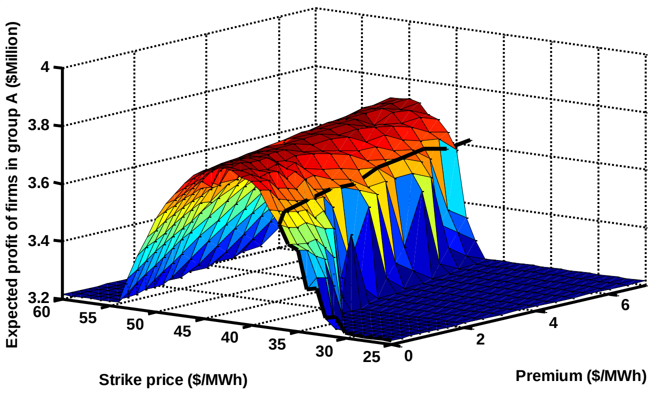

Figure 7) Total expected profit of group A producers in the conditions of equilibrium of two markets; procedure for the premium as a known variable, solid line for the premium as a decision variable

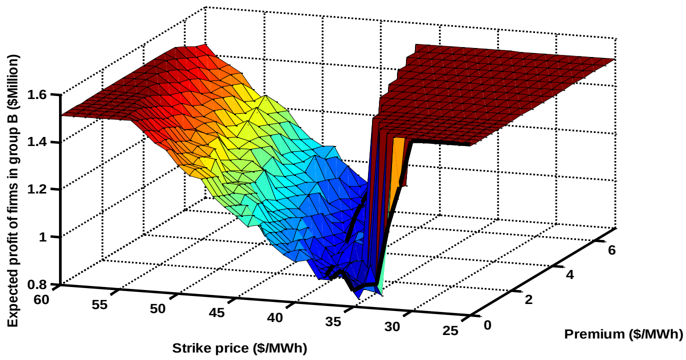

Figure 8) Total expected profit of group B producers in the conditions of equilibrium of two markets; procedure for the option price as a known variable, solid line for the option price as a decision variable

Conclusion

In this study, a new method for the pricing of put option contracts is presented based on the balance of the day-ahead market and the option market. The results of the simulations show that the strategic presence of producers in both the option market and the day-ahead market leads to an increase in their profits and a decrease in the profits of producers who only participate in the day-ahead market. The conclusion of option contracts leads to an increase in competition in the day-ahead market and, a decrease in the day-ahead market price. using the equilibrium model of the option market and the day-ahead market, the market regulation board can determine the appropriate range of strike prices in which the largest volume of option contracts are concluded. In this way, the focus of the options market players on these strike prices increases and so increases the social welfare in the two markets. Usually, in option financial markets, an estimate of the option price is announced to option market players. The combined equilibrium model of the option market and the day-ahead market, considering the option price as a decision-making variable of producers, can be considered a method for put option pricing in financial markets. The option contract area can be the possible price range of the put option contract, which is determined using the combined equilibrium model of the option market and the day-ahead market.