Determining the lower limits of the electricity price in the Iran Energy Exchange Market through bilateral contracts

Abstract

The direct electricity supply by power plants to final consumers was raised years ago. According to the platforms created by the Ministry of Energy, all industrial subscribers with a power of more than five megawatts can supply all or part of their energy needs through the energy exchange or by concluding bilateral contracts with power plants. In this area, one of the main challenges faced by the electricity supplier is to offer the right price in terms of production costs and other sales opportunities. For this purpose, in this study, a model was proposed to determine the lower limits of the proposed price in the energy exchange or in the form of bilateral contracts. According to the analysis of the costs and sales opportunities faced by the electricity supplier, two quantities of the discounted average variable cost of the power plant and the discounted rate of the sales opportunity in the day market are introduced and modeled as the lower limits of the proposed price in this study. The results of the proposed model have shown the importance of identifying and modeling the key elements considered to determine the lower limits of the proposed sale price in the energy exchange or bilateral sales. Also, the analysis provides the possibility of facilitating decision-making at managerial levels.

Keywords: Energy exchange, Bilateral contract, Low limits of the offered price, Day market, Discount rate, Utilization factor

Introduction

One of the basic goals of setting up the electricity market has been to create a competitive environment for trading electric energy between producers and consumers. In the current structure of Iran's electricity market, Iran's Electricity Network Management Company, as the network operator, determines the economic composition of the day electricity market. Indeed, in the current structure, Iran's electricity network management company has the proxy to buy and sell electricity in the most economical way, and transactions between buyers and sellers were indirectly conducted. Setting up a bilateral trading market is an effective step towards direct trading of electric energy between buyers and sellers [1]. According to the regulations of Iran's electricity market, electricity consumers and suppliers can interact directly by signing an electricity supply contract [2]. According to the fourth plan of economic development, the suppliers can sell their electricity to their desired consumers using the facilities of the country's electricity network. Also, the regional power companies are obliged to establish the connection to the country's power grid for the production units as well as the consumers who are parties to the contract with the suppliers who have met the technical standards and paid the network connection fee [3]. In the meantime, power plants, as electricity sellers, should have a suitable price. Among the advantages of bilateral electricity supply contracts for suppliers, it can be mentioned separating a part of our production capacity from the competitive environment and eliminating the risks of being in the competitive market and cash receipt for the sale of electricity to the intended buyer to our desired buyer [4]. Bilateral contracts, while providing the supplier with the above-mentioned benefits, also provide benefits for the consumer, including the possibility of buying electricity from different suppliers, determining the economically agreed price, and the possibility of a commodity exchange for the Ministry of Energy to reduce the burden of buying and selling electricity. Also, in the conditions of network limitation, consumers with bilateral contracts will be the last priority of network shutdown [5]. According to the existing mechanisms in Iran's electricity industry, electricity is sold bilaterally through two sales methods in the form of energy exchange and bilateral sales outside the energy exchange (transit contracts). The energy exchange is a place for pricing all types of energy based on the supply and demand mechanism. Currently, the energy exchange has active trading environments of the physical market, the wholesale electricity market, and the market of large electricity consumers. Among the features of the sales method in the energy exchange, we can mention things such as guaranteeing the settlement of the transaction between the buyer and the seller by the energy exchange, recording the details of the transaction in the exchange board, and flexibility in the volume and duration of electricity supply.

In the method of bilateral sales outside the energy exchange (transit contracts), Common industrial electricity needs will be provided by the supplier according to the agreement between the parties according to the necessary approvals by the parties from the Iran Electricity Network Management Company for at least one year. One of the characteristics of this method is the ambiguity of the details of the contract, especially the agreed price between the supplier and the industrial partner for others. For example, in "Figure 1" the relations between different players in the topic of bilateral sales are shown for both sales methods outside the energy exchange and in the form of the energy exchange. According to the investigations, the identification and modeling of the lower limits of the proposed price in the energy exchange or bilateral contracts and the introduction of its constituent elements have not been considered in previous studies. In this study, a model for determining the lower limits of the offered price in the energy exchange or bilateral contracts was provided, taking into account the difference in the settlement times of the transactions in the forward markets of the electricity supplier and also the effect of sales in these markets on the utilization factor of the power plant as one of the innovative aspects of this study. The bases and legal supports established regarding bilateral transactions and the energy exchange market are stated in the second part. The third part is dedicated to the identification and introduction of the lower limits of the proposed price in the energy exchange or the bilateral contracts. The proposed mathematical model is presented in the fourth section. The results obtained from the implementation of the proposed model are discussed in the fifth part.

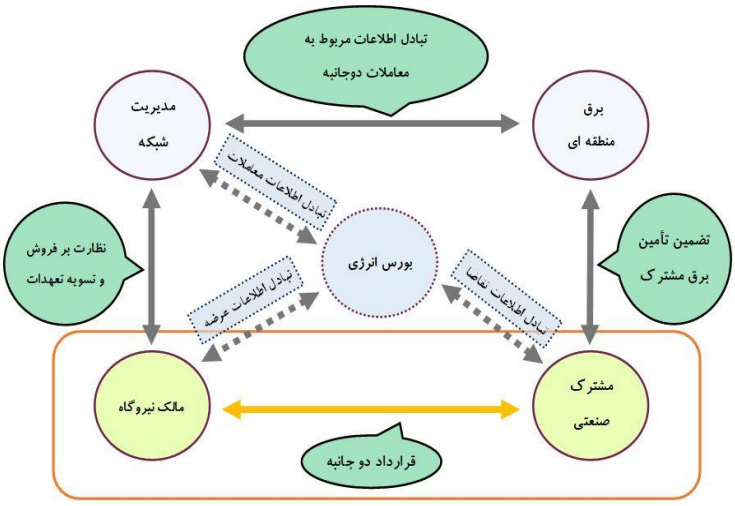

Figure 1) Relationships between different players in the method of bilateral sale of electricity in the form of the energy exchange (taking into account the line relations) or in the form outside the energy exchange (without considering the line relations)

Legal background of bilateral contracts and energy exchange transactions

A general policy was determined for the Ministry of Energy to create a mechanism for bilateral contracts for energy exchange transactions according to the instructions of paragraph (v) of the article (133) of the law of the fifth five-year development plan of the Islamic Republic of Iran [6]. Following the above-mentioned instructions, The Cabinet of Ministers signed a letter of approval on 30/1/2016, by which it was decided that the Ministry of Energy while guaranteeing transit and delivery of energy, will improve the conditions for those customers whose contracted power is above 5 megawatts and who wish to obtain all or part of their electric energy needs through their power plants or energy exchange or bilateral contracts with power plants [7]. After that, on 21/05/2016, the Minister of Energy issued an act titled "electricity supply conditions for applicants above five megawatts", by which all subscribers with a power of more than five megawatts who have an electricity branching (supply) contract can get all or part of their required energy, and all applicants with a requested power of more than 5 megawatts (subscribers with a network connection contract) are required to supply all their needed energy through their power plants, the energy exchange, or bilateral agreements with power plants [8]. Also, on 25/02/2017, the Minister of Energy announced how to calculate the price of electricity supplied by the network owner for new applicants [9]. On 12/21/1996, an order was issued to stop the issuance or renewal of the electricity purchase license bilaterally or through the energy exchange for subscribers with electricity distribution (supply) contracts in Tawanir Company. However, it was decided that the possibility of supplying electricity to subscribers with network connection contracts continues through bilateral contracts or the energy exchange [10]. Finally, the Minister of Energy announced the rates and conditions of the energy transit in the country's power grid through an act on 8/07/2019. Following this act, the monthly transit rates of electrical energy were notified to all regional power companies and power distribution companies on 5/08/2019, and the possibility of conducting bilateral transactions was again provided for industrial customers with electricity branching contracts through a contractual power of more than 5 megawatts [11, 12].

Introduction of low price limits for the sale of electricity in the energy exchange or in the form of bilateral contracts

In a general view, the electricity seller (the owner of the private power plant) who intends to supply a part of the ready production capacity of the power plant in the energy exchange or in the form of bilateral contracts, should be consider tgis issue that in the short term, how much does it should be paid for a unit of energy production and secondly, what sales opportunities can it have besides the mentioned markets, which will be discussed in detail in the following.

Short-term variable cost per unit of electricity production

In a general classification, the costs of electricity generation in power plants can be examined from two general perspectives (short-term or long-term) and variability per generation (variable or fixed). Since the studies in the field of determining the optimal electricity sales price for the upcoming short-term time horizon are in the field of short-term exploitation studies, among the 4 possible modes, only the mode of short-term variable costs is considered under the title of average variable cost (AVC). In general, the average variable cost consists of two parts, including fuel and depreciation of production units, so repair costs are the main influencing factor in the depreciation rate of production units, the repair costs are the main influencing factor in the depreciation rate of the production unit.

Opportunity selling rate of electricity in the daily market

Given that the supply in the energy exchange or bilateral contracts will cause the loss of the opportunity to sell electricity (in the amount of the corresponding volume sold) to the grid (day market), therefore, the rate of the lost sales opportunity in the daily market should be considered as a lower limit for the proposed price in the energy exchange. In an overview, the income from selling electricity to the network consists of 3 main parts as described in Table 1:

Table 1) The main elements of electricity income in the daily market

Row	Title	Description

1	Readiness	Cost paid for the ready production capacity of the power plant.
2	Energy	Cost paid for the energy produced by the power plant.
3	Extra service	Cost paid for the participation of the power plant in the extra services of frequency control and voltage control.

According to the type of payments by Iran Network Management Company to competitive power plants, in case of sale in the energy exchange or bilateral contracts, only the rates of readiness and proposed energy (in this article, the number of steps accepted by the market manager) to the volume sold in the stock market can be considered to determine the opportunity rate of selling electricity to the network.

Modeling

Taking into account the general principle of electricity transactions in Iran's electricity network, all transactions of buying and selling electricity, including the daily market, bilateral transactions, and the energy exchange, are carried out at the reference point of the network [13]. Therefore, it is necessary to calculate the lower limits considered for the proposed price in the energy exchange or bilateral contracts at the reference point of the network. The reference point is abstract in the network where, regardless of transit and network losses, only energy is exchanged; this means that all electricity trades are done at the abstract point and the transit cost and energy losses are zero at the same voltage levels. With this explanation, in the following, the mathematical relationships related to the lower limits are provided for the price offered in the energy exchange or bilateral contracts.

Calculating the average variable cost (AVC) at the network reference point

As stated in the previous section, the average variable cost consists of two parts: fuel and depreciation; depreciation rate is considered per kilowatt hour of electricity produced at the output point of the production unit. The price of power plant fuel (in Rials per cubic meter) announced by the Ministry of Energy is determined at the entry point of the production unit. Therefore, to calculate the average variable cost at the reference point of the network, it is enough to convert the fuel and depreciation rates to the corresponding values at the reference point of the network (in Rials per kilowatt hour) by applying appropriate coefficients. Figure 2 shows the stages of transferring the power plant fuel rate (in Rials per cubic meter) and the depreciation rate (in Rials per kWh) to the grid reference point (in Rials per kWh). The average variable cost at the grid reference point, the power plant fuel rate, and the depreciation rate at the mentioned point are calculate by equations 1, 2, and 3, respectively by Rials per kilowatt hour.

$$AVC = NAVC + FC \quad (1$$

$$FC = \frac{Fm^3P}{(1 - HUB) * (1 - ICR) * eff * m^32\ kWh} \quad (2$$

$$NAVC = \frac{INAVC}{(1 - HUB) * (1 - ICR)} \quad (3$$

In these equations, AVC, NAVC, and FC showed the average variable cost of the power plant, the depreciation rate of the power plant and the fuel rate, respectively, which all are in Rials per kWh at the reference point of the network. Fm^3P: Fuel price in Rials per cubic meter; $INAVC$: Depreciation rate at the output of the production unit; HUB: The coefficient of energy transfer losses from the power plant to the network reference point, ICR: Internal consumption coefficient of the power plant; eff: Power plant efficiency; $m^32\ kWh$: Conversion ratio of cubic meters to kilowatt hours of fuel thermal energy.

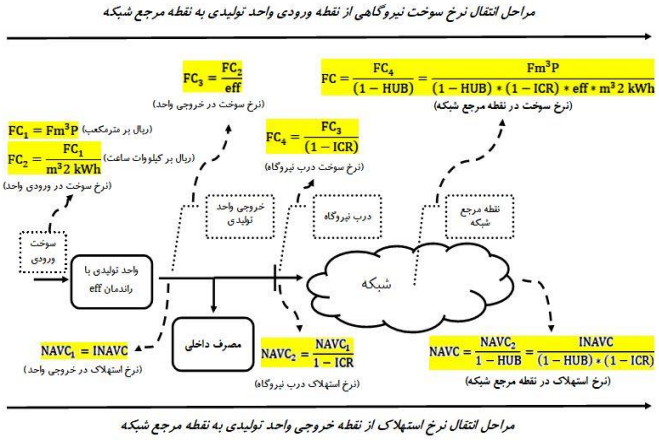

Figure 2) Steps of transferring the depreciation rate and fuel rate to the network reference point (in Rials per kWh) based on the single-line diagram of the single-car system connected to the network

Calculating the opportunity rate of selling electricity in the day market, taking into account the increase in the utilization factor of the power plant

Considering the priority of supplying electricity to consumers with bilateral contracts, as well as the definitive winning of power plants in the daily market for the corresponding sales volume in the energy exchange or through bilateral contracts (due to the fact that the steps of the price offer of power plants corresponding to the amount supplied in the energy exchange or trough bilateral contracts in Iran's daily market settlement model are considered as zero) often, this type of sale increases the utilization factor of power plants (increasing the amount of energy produced) especially in the cold seasons and low load for power plants with a low utilization factor, as far as possible, it even prevents the shutdown of the production unit. Considering the above explanations, if we assume that *EXE* is the energy sold is in the energy exchange or through bilateral contracts, the energy will be increased by $\alpha * EXE$ compared to the situation where all the capacity is offered in the daily market of the Iranian Electricity Network Management Company. Since the energy increase will cause a profit proportional to the coefficient of α for the producer from the daily market, therefore, its effect should be considered as a reducing factor in the opportunity rate of sale in the daily market. Indeed, the effect of profit, obtained by supply of electricity in the energy exchange or through bilateral contracts from the daily market, appears as a factor to reduce the lower limit of the price offered by the exchange or bilaterally. Vice versa, if the sale in the energy exchange or bilaterally causes a loss to the revenue opportunity of the daily market, it will have an increasing effect on the lower limit of the offered price to compensate for the loss.

$$EMP = AVP + ENP - \alpha * (ENP - AVC) \quad (4$$

In equation (4), EMP is the electricity sales opportunity rate in the day market, AVP is the readiness rate of the day market, and ENP id the accepted energy rate in the day market (Rials per kilowatt hour).

Modeling the effect of time element on electricity price

An important factor that will affect the low limits of electricity price in the energy exchange or bilateral contracts is the time value of money, or in other words, the difference at the time of settlement of transactions in any of the day trading, bilateral, or energy exchange markets. Currently, the competitive power plants participating in the daily market usually face one to two years of delays in the payment of transaction amounts from the Iranian Electricity Network Management Company. While in terms of sales in the energy exchange or bilateral contracts, the settlement of transactions in cash (immediately after the time of energy delivery) or even in

advance payment or in advance (before the time of energy delivery) is also possible for the suppliers. Therefore, in the first step, in order to determine the optimal minimum price for trading electricity through the energy exchange or bilateral contracts, the electricity supplier must identify the daily interest rate, which is usually higher than the bank interest rate, so that by applying this rate, suppliers can adjust time difference effect in the settlement of transactions in different markets [14]. Considering the above explanations, among the rates defined in this article, power plant fuel cost (FC) and opportunity rate of electricity market price (EMP), are considered as the rates that are in the invoices of the Iranian Electricity Network Management Company for suppliers participating in the daily market, which should be discounted by applying the appropriate interest rate (discount rate) from the time of settlement of transactions in the day market to the time of settlement of transactions in the energy exchange market or bilateral contracts. Therefore, the lower limits of the electricity price in the energy exchange market or bilateral contracts can be calculated by equations (5) and (6), and the minimum suggested price in the mentioned markets can be calculated by equation (7).

$$\text{Present AVC} = \frac{\text{FC}}{(1+\frac{\text{dr}}{365})^{\text{d}}} + \text{NAVC} \quad (5$$

$$\text{Present EMP} = \frac{\text{AVP} + (1-\alpha) * \text{ENP}}{(1+\frac{\text{dr}}{365})^{\text{d}}} + \alpha * \text{Present AVC} \quad (6$$

$$\text{EXP} \geq \max(\text{Present AVC}; \text{Present EMP}) \quad (7$$

Present AVC: Average variable discounted cost of the power plant; Present EMP: Discounted rates for the opportunity to sell electricity in the day market; and EXP: Offered price in bilateral contract or energy exchange; dr: Discount rate; and d: The number of days between the settlement times of transactions in the energy exchange or bilateral contract and the day market.

Analysis of the results

The results obtained for the lower limits of the proposed electricity price in the energy exchange or bilateral contracts is discussed in this section. The assumptions considered for a sample power plant in Iran's electricity network assuming a low load period are shown in Table 2.

Table 2) Assumptions considered for input parameters

Row	Parameter	Value	Row	Parameter	Value
1	NAVC	18.74	**6**	$m^3$2 kWh	9.53
2	Fm^{3}P	607	**7**	α	0
3	HUB	0.05	**8**	d	420
4	ICR	0.015	**9**	AVF	150
5	eff	0.33	**10**	ENF	320

Figure 3 shows the results obtained for the low limits of the proposed electricity price in the energy exchange or bilateral contracts for different discount rates. According to the figure, the discount rate increase has a significant effect on the lower limit reduction of the offered price, to the point where a 20% increase in the interest rate causes a decrease of 82 Rials (per kilowatt hour) in the opportunity rate of trading electricity in the day sale market; such a reduction will be very effective in the financial calculations of a large-scale power plant.

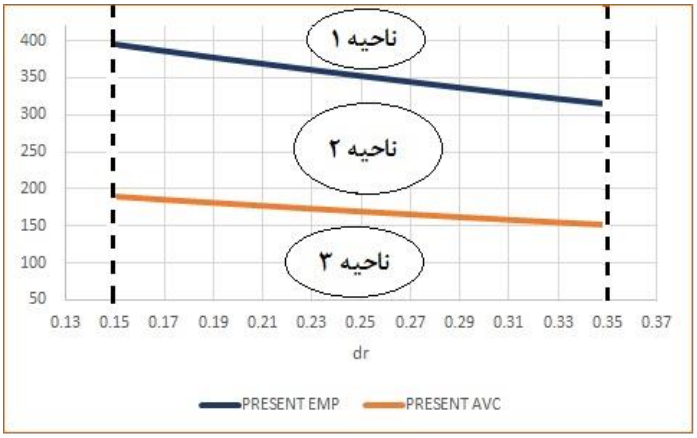

Figure 3) Suggested pricing areas in the energy exchange or bilateral contracts for different discount rates.

According to "Figure 3", the description of each pricing area in the energy exchange or bilateral contracts is as follows:

Area 1: In this area, the offered price is at least equal to the discounted rate of the opportunity to present electricity market price (Present EMP). Currently, due to the relative monopoly on the buying side of the energy exchange market and the low prices, power plants are often not able to make transactions in this price range, and only during limited days of the year and cold seasons, it may be possible to make a transaction with the suggested price in this area.

Area 2: In this area, the proposed price is at least equal to the discounted average variable cost (Present AVC) and at most equal to the discounted rate of the opportunity to sell electricity to the daily market. Most of the transactions take place in this price range due to the serious financial problems of the power plant owning companies and the strong need for liquidity and the possibility of meeting this need (to a limited extent and only for current affairs) through transactions in the energy exchange.

Area 3: In this area, the maximum suggested price is equal to the variable average discounted cost. There is no economic justification for trading in this area; because trading in each of the target markets is expected to cover at least short-term variable costs.

Table 3 shows the results of the discounted rate of electricity market price, taking into account the effect of the energy production increase due to participation in bilateral sales or the energy exchange ($\propto$ take a non-zero value). Also, the price spectrum of the obtained results is shown in Figure 4.

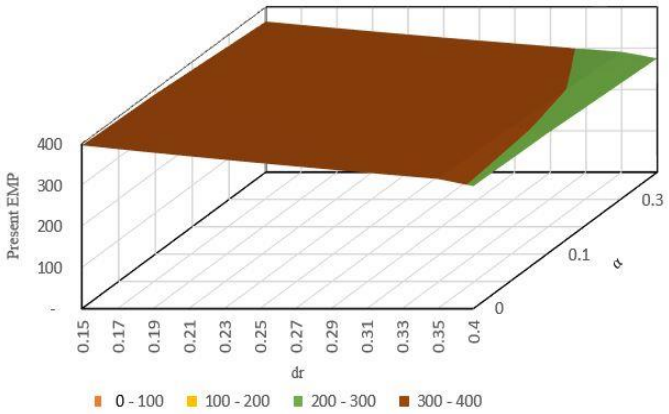

Figure 4) The range of changes in the discounted rate of the opportunity to sell electricity in the day market, taking into account the discount rate and the coefficient of increasing the energy production of the power plant

Table 3) Obtained results for the discounted rate of the opportunity to sell electricity in the day market

dr \ α	0	0.05	0.1	0.2	0.3	0.4
0.15	396	392	388	380	372	365
0.17	387	383	379	372	364	357
0.19	378	374	370	363	356	349
0.21	369	366	362	355	348	341
0.23	361	357	354	347	340	333
0.25	353	349	366	339	33	326
0.27	345	341	338	332	325	319
0.29	337	334	330	324	318	312
0.31	329	326	323	317	311	305
0.33	322	319	316	310	304	298
0.35	314	311	309	303	297	291
0.4	297	294	291	286	281	275

For the lowest value of $\propto$ ($\propto = 0$) and the lowest value of the discount rate ($dr = 0.15$), the discounted rate of the opportunity to sell electricity in the daily market reaxhes its highest value, i.e. 396 Rials per kilowatt hour. If $\propto$ and dr choose their maximum value ($\propto = 0.4$; $dr = 0.4$), this rate will reach the lowest value in its price range, i.e. 275 Rials per kilowatt hour. Also, if the effect of the increasing factor of the utilization ($\propto$) be considered alone, due to the participation of the power plant in the energy exchange or bilateral sales, the discounted rates for the opportunity to sell electricity will be decreased, for example by increasing this coefficient from zero to 0.4 for the discount rate of 0.15, the discounted rate of the opportunity to sell electricity in the day market will be 31 Rials and for the discount rate of 0.4, the rate will be reduced to 22 Rials per kilowatt hour. Therefore, modeling the $\propto$ coefficient and determining its value as important factors affecting the price offered in the energy exchange and bilateral sales should be considered by the experts of the electricity market.

Conclusion

This study aimed to identify and determination of the lower limits of the proposed price in the energy exchange or bilateral contracts for electricity sellers. According to the proposed model, the identified lower bounds are the average variable discounted cost and the discounted sales opportunity rate in the day sale market. In general, the achievements and innovative aspects of the study can be stated as follows:

- Modeling the effect of utilization factor increase of the power plant due to participation in the energy exchange or the sale of electricity through bilateral contracts has a significant effect on the proposed price.

- Determining the lower limits of the proposed price for the energy exchange or bilateral contracts, and analyzing the pricing areas in the mentioned markets, is an important matter to make a better decision for the power plant owners to participate in these markets.

- The longer duration between the settlement times of transactions in the day sale market and the energy exchange or bilateral sale market, the lower the value of the lower limit of the price offered in the energy exchange or bilateral sale. Also, the lower limits of the proposed price also decrease with the increase of the discount rate (the interest rate by the owner of the power plant).