An Assessment of Electricity Transmission Pricing Methods and Finding Suitable One for Iran's Electricity Industry

Abstract

If we functionally categorize the electricity industry into three areas including production, distribution, and transmission, the transmission sector is priced on a command economy due to the nature of natural monopoly and the high fixed cost required for the start-up. Therefore, the challenge of fair pricing meeting all current and future costs is one of the problems for policymakers and decision-makers. In this research, while introducing different pricing methods for electricity transmission services and stating the shortcomings of each one, a new method has been provided for electricity transmission pricing considering Iran's electricity industry. Provided method for electricity transmission pricing was described taking into account the information on the regional electricity of Khorasan.

Keywords: Electricity transmission services, Pricing, Market structure, Natural monopoly

Introduction

Restructuring in electricity power systems has been seriously proposed since 1370. The objective of restructuring in the electricity industry is market formation and optimal allocation of resources (Bayat, 2009). To restructure the electric power system, the following steps are required: unbundling, reregulation, competition, and privatization. Each section of production, transmission and distribution in the power systems can follow the mentioned steps of transmission separately (Vahdati, 2011). The transmission network is one of the important parts of competitive electricity markets. An efficient and non-discriminatory energy market is created due to an efficient and secure transmission network. However, the inherent monopoly of the transmission sector can affect the competition in the production and sales sectors. Any producer or consumer who uses transmission lines must pay in the restructured system. For the proper allocation of resources and development of the system, the transmission cost should be determined by a reasonable mechanism. It means that it is necessary to regulate fair rules to allocate the costs of transmission services based on the actual usage of market players. Transmission pricing should consider line density and encourage investors to build a new production and transmission capacity. The research on electricity transmission pricing has revealed disagreement on the pricing method. Indeed, any country or any restructuring model has chosen a method based on its characteristics (Shahidpour et al., 2005). The electricity industry in our country as one of the institutions operating in a monopolistic way faced the problems of pricing and market regulation. Since the private sector in our country is getting stronger over time through the received support and is entering many industrial and governmental fields of our country, the importance of problems in the field of the electricity industry is boosted. Because one of the first requirements for the formation of a market for any product (or private sector participation) is market transparency and a predictable (modelable) cost mechanism. Marginal cost, MW-Mile, post stamp, contract path, and MVA-Mile are among the most important methods proposed in the pricing electricity transmission services. In this research, an optimal method for pricing transmission services in Iran's electricity industry was proposed by comparing the methods and regarding Iran's conditions. The main aim of this study was to select a method for pricing electricity transmission services by reviewing the various methods. In this regard, the regional electricity data of Khorasan Razavi province in 2012 was used. The reason for using these data was the non-disclosure of relevant information by the by the Iran Electricity Network Management Company. Indeed, the main question of this research was as follows: What are the methods for determining the rates of transmission services? What is the most suitable method for Iran, and how much does the rate of the transmission services?

We overviewed the theoretical foundations and research background, and then we examined the electricity market system and the pricing of electricity transmission in several selected countries.

Research background

The theoretical bases and research background have been investigated in the following:

Theoretical bases

Transmission services in Iran's electricity industry

Restructuring of power systems in our country has been implemented sometimes in the production and distribution sectors; however, the transfer sector remains exclusive (Hosseini & Kheradmandi, 2003). Currently, six regional electricity companies own and manage the production, transmission, and distribution of their area in Iran (Fig. 1). Regional transmission companies are responsible for managing the transmission and dispatching systems of their power plants.

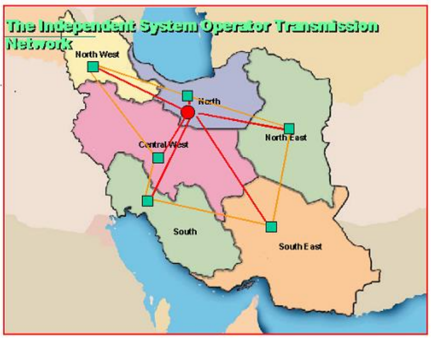

Fig. 1) Six regional electricity companies in Iran (regulations for determining rates, terms, and methods of purchasing transmission services in the country's electricity network, 2006)

The operating environment of transmission companies has been presented in Figure 2.

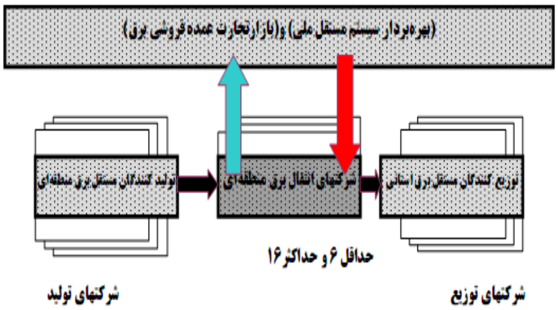

Fig. 2) Operating environment of the transmission companies (regulations for determining rates, terms, and methods of purchasing transmission services in the country's electricity network, 2006)

Currently, the price of each company's transmission service is determined through the sum of the preparation price, energy price, and other services of each company (regulations for determining rates, terms, and methods of purchasing transmission services in the country's electricity network, 2006).

- The price of preparation
- The price of preparing a transmission line: the readiness rate of the lines (Riyal per megawatt per kilometer) multiplied by the ready capacity of the line (megawatt) and the length of the line (kilometer).
- The cost of preparing a transformer: the readiness rate of the transformers (Rials per megavolt ampere) multiplied by the ready capacity of the transformer (megavolt ampere).
- Energy cost
- Energy cost of a transmission line: the energy rate of the lines (Rials per megawatt hour per kilometer) multiplied by the energy transferred through the line (megawatt hour) and the length of the line (kilometer).
- Energy cost of a transformer: Multiplier of the energy rate of transformers (Rials per megavolt ampere-hour) in the energy moved by the transformer (megavolt ampere-hours)
- The cost of other services
- The cost of other services corresponding to a transmission line: The multiplication of the rate of other services corresponding to the lines (Rials per megavolt) by the ready capacity of the line (megavolt)
- The cost of other services corresponding to a transformer: The multiplication of the rate of other services corresponding to the transformers (Rials per megavolt ampere) by the ready capacity of the line (megavolt ampere)

Pricing methods of electricity transmission services

There are many different methods with different applications according to their conditions and characteristics for allocating the cost of electricity transmission services. The 5 methods of a post stamp, contract path, MW-Mile, MWA-mile, and marginal cost are the most applicable.

Post stamp: This is the simplest pricing method. By this method, each entity pays a fixed price for each unit of transmitted energy in the system. Post-stamp costs are based on average system costs. This method is independent of transmission distance and network topology and does not require load distribution calculations (Shahidpour et al., 2005).

Contract path: By this method, transmission services are priced based on the transmission physical path between two users. After determining the contract path, the transfer price is determined and applied. One of the most important features of this method is its simplicity, generality, and considering the distance between the transfer parties. One of its disadvantages is the mismatch of the contract path with the actual path of power lines based on calculated load distribution in transmission networks (mostly non-radial) (Mapna, 2010).

MW-Mile: The pricing is based on the real transmission power and the length of the line in miles. This method requires load distribution calculations and reflects the actual use of transmission systems. This method is considered a complicated method due to the need for the entire network information and load distribution (Mapna, 2010). In pricing by the marginal cost method, which is one of the first scientific methods for pricing, the goal is to maximize society's welfare (consumer's welfare + producer's welfare). Although this method is considered simple and applicable at the beginning, in practice, some parameters and assumptions make some probabilities, which are as follows:

- Some parameters are different in the long or short term.
- There is an assumption of settlement of the markets in this method, which of course is not the case in many situations.
- Since the goal is to maximize the level of "total" welfare, the surplus welfare of the consumer (or producer) may differ unfavorably compared to the other.
- Or that the relevant reasoning in this method takes place in a static (and not dynamic) space.

Therefore, the mentioned cases reduce the use of this method, although it is sometimes welcomed by monopolies and government markets. In this method, each consumer must pay for the last cost imposed on the system.

The marginal cost method in implementation, in addition to guaranteeing high efficiency, is responsible for the most justice in cost allocation. Because, for example, if the network is in a critical state (state n-1 in conventional literature), as soon as a new user enters the system, an exorbitant cost will be incurred in the network (clogging of power transmission lines, etc.). In other methods, if an additional cost is incurred, all consumers must pay for it. While this exorbitant cost was imposed on the system by only one consumer.

Research background

Regarding the pricing of electricity transmission services, one should be informed about the transmission processes and their proposed methods, the market conditions, and supply and demand. The reviewed studies on the pricing of transmission services have been presented in two sections internal and external studies.

Internal studies

Goldani et al(2017) in a study entitled “Evaluation and ranking of the pricing methods of Iran's electricity transmission services using the gray relationship analysis method and the AHP technique” compared and ranked the pricing methods of transmission services and analyzed the sensitivity of each position using Gray analysis and Delphi techniques in collecting primary information, through AHP method.

Ghasemi-Nejad et al. (2013) in a study implemented the spatial marginal pricing method on the electricity transmission network of Kerman province in 2011.

Sedaghati (2017) investigated the new long-term marginal cost pricing method to compensate for the lack of transmission network income in the restructured power system.

The results show that the prices obtained from the proposed method include not only the costs of the future development of the network but also depend on the distance between production and consumption. Bayat investigated the pricing of the transmission system from the point of view of combined pricing in the form of a master's thesis. In his research, he has used a combination of node methods for pricing.

External studies

Yang et al. (2020) in research investigated the allocation of target transmission costs based on the final use of the power grid in the regional market. Their proposed method is compatible with the current market standards and practices in America, China, and many other countries.

Bushnell et al. (2019) in an article titled "electricity transmission of cost allocation and network efficiency, implications for Mexico's liberalized power market" found that the Mexican market is well able to absorb cost density and motivate efficient behavior. They highlighted some of the potential problems in increasing local production regarding Mexico's current approach and transfer tariffs.

By introducing the value-based method for the pricing of transmission services and by defining the reliability and commercial capacities for transmission, Raushit et al. (2014) showed that the cost of transmission services is allocated only to those who benefit from the presence of the equipment.

Nikokar et al. (2012) in an article investigated the allocation of transmission cost based on the use of the system and considering the cost of congestion. Their goal was to provide a simple transmission-pricing scheme using the tracking method, in which fixed transmission cost, congestion cost, and loss cost are considered. Nikokar et al. (2012) in an article entitled transmission cost allocation based on the modified Z-bus investigated transmission allocation cost in a deregulated electricity market. The mentioned research presents a method for the allocation of transmission costs based on power flow. The proposed method can allocate the total cost of electricity loads separately.

Transmission pricing services in a few selected countries

In England and Wales, prices vary based on transmission system usage and geographic location. In this method, tariffs are calculated by the marginal cost model of investment in the transmission system. Transfer tariff determination in Norway is based on marginal cost under the constraint of revenue or rate of return approach. That is, the income necessary to cover the cost of creating a system is determined by providing a sufficient return on investment for the shareholders. In America, transmission is priced by considering the cost of the system including operating cost, depreciation and rate of return on investment, congestion cost, and tradable transmission capacity rights.

In New Zealand, to achieve economic efficiency, fixed costs of transmission are provided through fixed prices, and variable costs are provided by variable prices.

Transmission prices in Argentina consist of three components: energy price, capacity price, and installation cost. In Chile, tariffs are derived from the sum of nodal prices and distribution-added value. This tariff consists of three components: fixed price, demand price, and energy price. The price of energy includes the price of the node plus the cost of energy loss in distribution networks. (Green, 1997).

Selecting the proper pricing method for electricity transmission services requires the following cases:

- Checking the features and conditions of the studied system (such as the access to facilities and equipment or the electricity transit network)
- Knowing the methods in terms of the type of cost allocation and the purpose of the method in terms of reflecting different cost sectors.

Methodology

Determining the price of transmission services

Before assessing the pricing process, the influencing elements in the pricing process should be determined; for this purpose, we must specify our aims of pricing the transmission services.

There are different aims for pricing the transmission services. Facilitating the process of supplying demand from the supply quantity the priority in payment should be given to applicants for whom transmission services are more essential (we recognize this using the prices that each of the applicants is willing to pay for the rate of received transmission services). In other words, we are going to make the trading environment of electricity transmission services more marketable through appropriate pricing.

1) Determination of the costs and the effective factors on it to the consumers. For example, when we want to include the environmental costs imposed on the line owners in the cost of the transmission lines; or when we want to get more profit from providing transmission services (or increase our profit).

2) Proper management of transmission services in the country regarding line owners (Transmission service providers) to their motivation for the construction and development of transmission lines and reduce the price of transmission services.

According to the research background, the marginal cost method is the most efficient method respecting the supply and demand of transmission services. However, this method cannot be used in Iran due to the exclusive nature of the electricity transmission service industry and the pricing procedure of transmission services in the electricity industry. The second approach is technical which is not of much interest at present based on the managers' opinions. Therefore, the third method or approach is chosen to determine the optimal price.

There are different methods for the marginal cost method and the method of differential equations in dynamic mode was used in this study (Bayat, 2009).

It is assumed that the company's current and past production has an effect in determining the conditions of cost, demand, and also profit of the entire period.

In relation 1, x(t) represents the number of sales (or demand) and p(t) represents the price of transmission services at the time of t.

$$\frac{dx}{dt} = f\big(x(t), p(t)\big) \qquad (1$$

$$f_x = \frac{\partial f}{\partial x} > 0(< 0)$$

The phenomenon of diffusion and saturation occurs considering that the dynamics of the demand, diffusion, and saturation depend on the number of sales.

In any case, sales (selling transmission services from the point of view of the network owner) have a reverse relationship with price. It means that:

$$f_p = \frac{\partial f}{\partial p} < 0 \qquad (2$$

By integrating the effect of demand uncertainty using applying changes in cumulative sales, it can be represented as a stochastic process as follows:

$$dx(t) = f\big(x(t).p(t)\big)dt + \sigma\big(x(t)\big)d\omega \qquad (3$$

In equation 3, σ(x(t)) represents the standard deviation of the sales function and dω is the added factor of the Weiner process.

In the case of:

$$dx(t) = x(t + dt) - x(t) \qquad (4$$

Equation 4 shows random changes in cumulative sales in the interval of [t.t+dt].

Based on equation 3, sales changes are the result of the sum of a definite and certain component (sales and price function) and a probabilistic component (with the standard deviation of the sales function).

It is possible to examine possible changes due to the uncertainty of demand during the studied period by fitting the variance as a function of x(t). If we consider the profit function as follows, the problem will change to the following maximization:

$$\underset{p(t)}{Max}\, E[\int_0^\infty e^{-rt}(p(t) - c(x(t))dx(t)]$$

$$s.t.$$

$$dx(t) = f(x(t)).p(t)dt + \sigma(x(t))d\omega$$

$$x(0) = 0 \qquad (5$$

By substituting the equations and the assumption that:

$$E[\int_0^\infty e^{-rt}(p(t) - c(x(t))\sigma(x(t))d\omega] = 0$$

we can reach expression 6:

$$\underset{p(t)}{Max}\, E[\int_0^{\infty} e^{-rt}(p(t)-c(x(t))f(x(t),p(t))dt]$$ (6

Now by applying the profit maximization process according to Bellman's optimization equation in dynamic optimization and applying the necessary and sufficient first and second-order conditions according to equation 10, we reach the optimal price:

$$rV(X) = Max\left[\left(p(x) - c(x)\right)f(x,p) + V_x f(x,p) + \frac{1}{2}V_{xx}Q^2(X)\right]$$ (7

Which *V(x)* shows expected profit maximized in the interval of (t, ∞) according to current values; in other words:

$$V(x)=e^{rt}\{Max\ E\left[\int_0^{\infty} e^{-rt}\left(p(r)\right)f\left(x(\tau)\right)f\left(x(\tau),p(\tau)\right)d\tau\right]\}$$ (8

V_x and V_{xx} are the first and second derivatives of V relative to x, respectively. When P(t) satisfies the first optimization condition:

$$V_x f_p + f + (p-c)f_p = 0$$ (9

Therefore, the optimal price is reconstructed as follows:

$$p^* = c - \left(f / f_p\right) - V_x$$ (10

To maximize the profit function according to the second optimization condition:

$$2f_p - f.f_{pp}/f_p \le 0 \Leftrightarrow 2 \ge f.f_{pp}/f_p^{\ 2}$$ (11

When $f_p < 0$, the following ratio is maintained

$$\eta = -f_p p / f$$ (12

Finally we reach to the following formula:

$$p^* = \frac{\eta}{\eta - 1}(c - \lambda)$$ (13

Determining a price that can take feedback from changes in supply or demand and adjusted, is the idea for the pricing of transmission services in the first approach. By this method, we actually express the amount of change in demand as a function of the demand at that moment and its price. Then, we use formula 13 to get the new price path. To use this formula, we must provide its requirements (including λ, c, η):

η: It is the price elasticity of demand, which is required using demand equation (or the equation of the amount of demand for transmission services according to its price or tariff). Therefore, we must have a list of prices and demands to have this equation. Before examining these values, we must define their meaning properly: What is the meaning of demand for electricity transmission services? For this purpose, there are two categories of people in the transmission service industry:
- Line owners as transmission service providers
- Transmission service applicants

To determine the demand for transmission services, the demands are grouped into the following four sections:
- Energy passing through power transmission lines (in megawatt hours per kilometer)

- Energy passing through transmission transformers (in megavolt ampere per hour)
- Energy passing through the superpower transformers (in megavolt ampere per hour)

To find the proposed prices for the above four sections, we start with the pricing of the energy passing through the transmission lines. For this purpose, we must calculate the parameters mentioned in equation 13 separately.

The first one is the price elasticity of demand or η in the above equation. However, there is no price list needed to calculate the demand equation and the demand elasticity.

In other words, the price list for the 12 months under review is fixed and equal to 25 Rials per megawatt kilometer by the notification of the minister on 2010/08/03. Therefore, determining the demand equation (where the amount of demand is regressed by prices) is irrelevant. The mentioned approach is applicable in the case of price transparency and its change even for a specific period and its results can be interpreted. However, the proposed approach cannot be used to determine the equilibrium price of transmission services. Because in this industry, the price that can affect the demand has not yet been determined and for more than 3 years, a single price rate has been used for the whole country. Therefore, it is currently not possible to use this method for pricing. Therefore, we used its theoretical foundations and try to use the third approach in targeting stated above for pricing.

The main idea is that in the long term and equilibrium conditions (taking into account all the influencing factors and lack of ambiguity regarding the input data), the revenues collected from providing these services are equal to the costs incurred, as follows:

$$Y^d = Y^s \qquad (14$$

Y^d is the same revenues and Y^s is the total costs imposed on the supplier for providing transmission services. It is assumed that the income earned from the applicants is according to the amount of flow that each of them uses. This assumption is not unreasonable. Since the costs paid by every consumer for transmission services are made up of two categories of costs, including fixed and variable costs. With this assumption, both costs are included in the user flow rate of each applicant.

Therefore, assuming that X_j^L and X_j^T are the amount of flow passing through the line and transformer at the jth time, respectively (according to the separation of the pricing transmission services into two parts including line and trans), and P^L and P^T are the prices of the byte transfer services through the line and transformer (the prices are fixed at all j times), then the income obtained from transmission services in the period from t=1 to t=T is equal to:

$$\sum_{t=1}^{T}(X_t{}^L.P^L + X_t{}^T.P^T) = \sum_{t=1}^{T} Y_t^d = Y^d \qquad (15$$

To obtain Y^s, all costs imposed on the supplier (line owner) are calculated. In the current situation, transmission services for the whole country are calculated at a fixed price. In other words, it has been several years since P^L=50 and P^T=3350 Rials have been calculated for the whole country. However, these electricity prices can be different in different regions and seasons. P^L and P^T of the relevant regional electricity are determined with assume of having X_t^L and X_t^T for the desired period. To find P^L and P^T, it is enough to estimate the following regression equation:

$$X_t{}^L.P^L + X_t{}^T.P^T = Y_t^d \qquad (16$$

There are various methods for this estimation, the most efficient of which is the Ordinary Least Square (OLS). In this method, if $(\widehat{P^L})$ and $(\widehat{P^T})$ are our marginal costs, then we assume:

$$X_t^L\hat{P}^L + X_t^T\hat{P}^T = \hat{Y}_t^d \qquad (17$$

Which $\widehat{y_t^d}$ is obtained by $\widehat{P^L}$ *and* $\widehat{P^T}$ and therefore differs from y_t^d. We call this difference e_t. In other words:

$$\widehat{y_t^d} - y_t^d = e_t$$

In the Ordinary Least Square (OLS) method, it is tried to determine $\widehat{P^L}$ and $\widehat{P^T}$ in such a way that the expression of $\sum(y_t^d - \widehat{y_t^d})^2 = \sum e_t^2$ to be minimized. For this purpose, we have:

$$Min\ S = \sum_t e_t^2 = \sum_t (Y_t^d - \hat{Y}_t^d)^2 = \sum_t (Y_t^d - (X_t^L.\hat{P}^L + X_t^T.\hat{P}^T))^2 \Rightarrow$$

$$\begin{cases} \frac{\partial S}{\partial \hat{P}^L} = 0 \Rightarrow -2\sum_t (Y_t^d - (X_t^L.\hat{P}^L + X_t^T.\hat{P}^T))X_t^L = 0 \qquad (1) \\ \frac{\partial S}{\partial \hat{P}^T} = 0 \Rightarrow -2\sum_t (Y_t^d - (X_t^L.\hat{P}^L + X_t^T.\hat{P}^T))X_t^T = 0 \qquad (2) \end{cases} \quad (18$$

As can be seen, there are two equations and two unknowns, which by solving these two equations according to $\widehat{P^L}$ and $\widehat{P^T}$, the optimal price are determined. Before this estimation, instead of Y_t^d, Y_t^L, Y_t^T, the mean deviation is used for statistical reasons. This does not change the estimation of the final data. Because, if P^L and P^T apply in $\bar{X}_t^L.P^L + \bar{X}_t^T.P^T = \bar{Y}_t^d$ so, by subtracting the two expressions from each other we will have:

$$x_t^L.P^L + x_t^T.P^T = y_t^d \quad (19$$

Statistical bases and results

Due to the non-disclosure of information by the Iran Electricity Network Management Company, Khorasan regional electricity data from 2012 in the spring season has been used to test the proposed method.

This section aims to determine the price of transformer and line in this regional electricity and this season. The study of "improving the pricing mechanism and cost allocation of transmission in Iran's electricity industry" has been used to calculate Ys (costs imposed on Khorasan's regional electricity).

The cost of transmission services for regional electricity of Khorasan is divided into two categories:

- Fixed costs (depreciation costs of Khorasan regional electricity)
- Variable costs (current costs)

Tables 2 and 3 show the total fixed and variable costs, respectively.

Table 2. Total depreciation of Khorasan Regional Electricity Company

	Formal cost	**Accumulated depreciation**	**Annual depreciation**
Sum of fixed costs (depreciation)	270389	108944	14047

Variable costs:

Table 3. Total variable cost of Khorasan Regional Electricity Company

	2010	**2011**
Total variable cost	454502	516477

Sources: The country's power grid management

To estimate the transmission costs for the first quarter of the year, we calculate the fixed and current costs for each day separately. If we consider the costs transferred in 2010 and 2011 at the beginning of each year, the growth rate of costs per day will be equal to the:

$$454502(1+r)^{365} = 516577$$
$$r = 0.000351 \quad (20$$

Therefore, since the flow data are related to the first quarter of 2012, considering the same cost growth rate and 516477 Rials costs at the beginning of 2011, we estimate the current costs as 516477 $(1.000351)^{365+t}$, for the *t*th day from the beginning of 2019.

Calculation of fixed costs of transmission services every day since the beginning of 2012: To calculate the amount of fixed cost, it is enough to consider the annual depreciation of transmission services (as the total cost imposed on the transmission service provider every year). The cost added to the depreciation costs daily is: $\frac{305699}{365} = 837.5315$

Therefore, the fixed and variable costs as well as their total in the first 93 days of the year will be as follows:

Daily price = fixed price + variable price

Thus, the total cost imposed on the regional electricity supplier of Khorasan was obtained. To obtain Y^d, it is enough to obtain the flow transferred from lines and transformers or X^L_t and X^T_t for the first 93 days of the year. Now, by estimating the mentioned regression equation by the software, the following equation is obtained:

$$x_t^L \times P^L + x_t^T \times P^T = y_t^d$$

$$x_t^L \times 0.005881 + x_t^T \times 0.127105 = y_t^d$$

$$R^2 = 0.8 \qquad (21$$

The price will be converted into Rials. The price of lines and transformers in Khorasan regional electricity is equal to:

P^T= Transformer readiness rate=1271 Rials

P^L= Line readiness rate=59 Rials

By comparing the prices obtained from the model output for transmission services in the country, the price obtained is less than the announced price by the minister (1675). However, the price of the lines is higher than the current price obtained from the Minister's notification (25).

Conclusion

The aim of this research was the optimal pricing of transmission services by dividing the price into two parts including transformers and transmission lines. In this regard, to determine the optimal price of regional electricity, the equations of supply and demand of transmission services for regional electricity were set separately and equally for three months (each season). The regional electricity data of Khorasan Razavi province in the first 3 months of 2012 was used since the data and information of the Iranian Electricity Network and Management Company cannot be disclosed and it was not possible to use new data. Network Management Company.

The marginal cost method has requirements, which its most important is a changeable market with prices. Currently, it was not possible to use this method due to the command prices by the minister, which have been ruling the market for a long time without change. Therefore, we used the usual OLS method to estimate prices through the regression equation which one side was the energy passing through the network by dividing the trans and the line in a specific time (t), and another side was the total amount of passing energy (except for the sum of line and transformer energy in the desired time). By comparing the prices obtained from the model output for transmission services in the country, the price obtained is less than the announced price by the minister (1675). However, the price of the lines is higher than the current price obtained from the Minister's notification (25).