Considering Effect of Energy Market on Reactive Power Market

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Abstract

In this paper, a new structure for reactive power market is presented. Considering reactive power losses caused by active power flow in the reactive power market is the main purpose of this paper. Hence, this study tries to improve reactive power market and create fair competition in reactive power generation.

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1. Introduction

In recent decades, electrical grids have been restructured around the world and changed from the previous exclusively vertical state to the competitive one. This change has been achieved by the complete separation of generation and transmission activities and also the development of competition in the generation sector. Such restructuring has led to the separation of different services, which had been previously supplied by electricity companies. Although energy exchange is the main purpose of electricity markets, in order to have a secure and reliable power system, ancillary services are vital and should be appropriately supplied. In most of the electricity markets, these services are supplied by system operators via commercial contracts with the market participants.

Among the six ancillary services defined in Order No. 888 of Federal Energy Regulatory Commission (FERC) [1], supplying reactive power is one of the most important services, which has a very effective role in the secure operation of power systems. Nowadays reactive power market in different countries such as Canada, India, Australian, Japan, Argentina, Netherlands, Belgian, Sweden, Britain and etc. is implemented. In a competitive electricity market, the appropriate components of this market are formed by the proper selection of the following factors:

- *Market structure*
- *Payment mechanism*
- *Pricing model*

Reactive power market structure is chosen according to environmental and political circumstances. This ancillary service is usually separated from real power, and an independent market is implemented for it. Nevertheless, in some references, by simultaneously executing active and reactive power markets, integrated optimization has been performed on the costs [2]. In order to prevent the interference of reactive power market and energy market, independent markets are used for both powers [3-5]. In this model, the output of active power market is used as the input of this market. Because of different constraints in a reactive power market, the amount of active power cannot be always constant in all generators and has to change in order to maintain the stability of the grid. As a result, one of the important issues in the separated active and reactive power markets is how to face this issue, which is directly related to the lost opportunity cost. In [6-8], by considering a combined objective function, a framework has been presented for optimization on all the active and reactive power costs. Reactive power may be implemented as real time, day-ahead, seasonal, or a combination of the mentioned time frames. In [3, 7, 9], daily market structure has been followed. In the day-ahead reactive power market, reactive power suppliers declare the amount of generated power as a curve for different hours to the independent system operator (ISO). Because of the market sensitivity to load and grid circumstances, the day-ahead reactive power market can make the market power and raise the total cost of the reactive power. Being close to consumption time and, consequently, making more precise predictions about generation and consumption amounts and better allocation of reactive power, which are the advantages of the day-ahead market. In contrast, in [10-14], the reactive power market has been seasonally implemented. Long-term market implementation solves the problem of creating market power, but cannot precisely predict grid status at consumption time. Ref [15] proposes a three-stage time frame for reactive power market. In the first stage, the ISO determines the technical requirements of the service considering different scenarios for the next year's period. In the next stage, in a day-ahead period after energy and frequency control service prices are determined, the ISO estimates the variable costs associated with the service by evaluating the contingencies required to apply a set of preventive reactive power and voltage control actions. The final stage consists of evaluating real variable costs, once these have been incurred, and added to the fixed costs to conform with the total costs of the service.

An appropriate payment structure should be considered for ancillary service providers of reactive power while giving attention to technical (for example, local nature of reactive power, generators' capacity curve, etc.) and economical (generation cost of reactive power for generators, including opportunity cost, sale type, market power, etc.) issues.

The pricing model is another important point in managing the ancillary services of reactive power and should reflect the generation cost of this power of different suppliers in a non-discriminative way. Besides, the pricing model should be such that the probable suppliers are encouraged to participate in this market. Pricing model refers to the allocation of reactive power costs for different participants[16]. In[3, 9, 17-19], the pricing model based on the capacity curve of power plants has been employed. In [20] nodal pricing scheme of reactive power is presented to improve this market.

In [21], by correcting the above-mentioned model, the model of payment cost function was tried to be completed in the reactive power absorption region. Moreover, the payment function was corrected considering the constraints due to the stability and end region heating limit. In [22], to simplify and avoid the complexities of the above model, the quadratic function was used for the payment function of the generators. Although this model facilitated the optimization procedure, it had less accuracy than the previous method. In [19], the cost curve was linearized and modeled as four working regions with different line slopes in order to avoid using non-linear functions. To continue the optimization trend, this linearization could remove most of the complexities associated with non-linear methods and be found as a fast and robust method. In [7, 23], by connecting the reactive power to the active one for the generator, the cost function was extracted as a quadratic function. By neglecting the initial costs and generation losses of reactive power, in [24], only the lost opportunity cost was taken into consideration.

It is usually mandatory to generate some reactive power by generators in reactive power markets. There are different methods for determining this amount in different markets all over the world. The most conventional method is to use power coefficients for both reactive power absorption and generation regions and generators should supply this amount of reactive power. In this paper, a new method is proposed for considering mandatory generation range of units, which is based on the active power transaction amount between units and loads.

In the second section, In the second section, modeling of reactive power losses in the reactive power market is studied. Reactive power market clearing according to the mentioned cases in the previous section is studied in the third section. In the fourth section, the simulation results are presented and, finally; in the fifth section, the conclusion is made.

2. Considering Reactive Power Losses in cost function

Since the generators with high power exchange with distant loads have a more contribution in losses, the existing markets are not appropriate for market settlement. In other words, a power plant with high active power generation must have a more contribution in reactive power losses, and payment must be done for the reactive power generation exceeding allocated losses. On the other hand, a power plant close to the consumer does not need reactive power generation to compensate for the reactive power losses and can generate more reactive power. For this purpose, first, allocation of reactive power losses as a result of active power flow must be done. In accordance with the described method in [25], reactive power losses can be obtained as follows steps:

Step 1) Obtaining current of all the branches from the solved load flow;

$$\bar{I}_k = I_{kx} + jI_{ky},\ k = 1,2,\ldots.,NB \tag{1}$$

Step 2) Assuming the inactivation of transaction T^i, load flow is implemented again and the currents of the branches are obtained:

$$\bar{I}_k^{Ti} = I_{kx}^{Ti} + jI_{ky}^{Ti},\ k = 1,2,\ldots.,NB,\ i = 1,2,\ldots..,NT \tag{2}$$

In this step, the generator is kept active while its active power is equal to zero.

Step 3) As a result, contribution of each transaction Ti in branch k is as follows:

$$\begin{aligned} &\bar{I}_k^{Ti} = I_{kx}^{Ti} + jI_{ky}^{Ti},\ k = 1,2,\ldots.,NB,\ i = 1,2,\ldots..,NT \\ &\bar{I}_{k,cont}^{Ti} = \bar{I}_k - \bar{I}_k^{Ti} \end{aligned} \tag{3}$$

Step 4) Considering the non-linear nature of the grid when the transactions are implemented simultaneously, the obtained sum in step 3 will not be equal to the amount of step 1.

$$\bar{I}_k \neq \sum_{i=1}^{N_T} \bar{I}_{k,cont}^{Ti} \tag{4}$$

So, the following current adjustment coefficient is used to adjust the current obtained in step 3:

$$\bar{I}_k = CAF \sum_{i=1}^{N_T} \bar{I}_{k,cont}^{Ti} \tag{5}$$

Step 5) The new adjusted currents are obtained:

$$\bar{I}_{k,adj}^{Ti} = CAF_k \times \bar{I}_{k,cont}^{Ti} \tag{6}$$

Step 6) Reactive power loss for each transaction is obtained as shown below:

$$Q_{loss}^{Ti} = \sum_{k=1}^{NB} \begin{bmatrix} \left(I_{kx,adj}^{Ti}\right)^2 + \left(I_{ky,adj}^{Ti}\right)^2 + C_k^{\mathrm{Re}} \times \dfrac{\left(I_{kx,adj}^{Ti}\right)^2}{I_k^{\mathrm{Re},sum}} \\ + C_k^{\mathrm{Im}} \times \dfrac{\left(I_{ky,adj}^{Ti}\right)^2}{I_k^{\mathrm{Im}\,e,sum}} \end{bmatrix} \times XL_k \tag{7}$$

where:

$$I_k^{\mathrm{Re},sum} = \sum_{i=1}^{NT}\left(I_{kx,adj}^{Ti}\right)^2,\ I_k^{\mathrm{Im},sum} = \sum_{i=1}^{NT}\left(I_{ky,adj}^{Ti}\right)^2 \tag{8}$$

$$C_k^{\mathrm{Re}} = \sum_{i=1}^{NT}\sum_{\substack{j=1 \\ i\neq j}}^{NT}\left(I_{kx,adj}^{Ti} \times I_{kx,adj}^{Tj}\right), C_k^{\mathrm{Im}} = \sum_{i=1}^{NT}\sum_{\substack{j=1 \\ i\neq j}}^{NT}\left(I_{ky,adj}^{Ti} \times I_{ky,ad}^{Tj} \tag{9}$$

Statement (7) can be divided into two parts: 1) Reactive power loss caused by active power flow, and 2) Reactive power losses caused by reactive power flow. Considering that the objective of implementing reactive power market is to omit the losses by active power flow, therefore allocated reactive losses for transaction Ti will be:

$$Q_{loss,p}^{Ti} = \sum_{k=1}^{NB}\left[\left(I_{kx,adj}^{Ti}\right)^2 + C_k^{\mathrm{Re}} \times \frac{\left(I_{kx,adj}^{Ti}\right)^2}{I_k^{\mathrm{Re},sum}}\right] \times XL_k \tag{10}$$

So, the allocated reactive losses for unit u in bus i is:

$$Q_{loss}^{i,u} = \sum_{j=1} Q_{loss,p}^{Tj} \tag{11}$$

In (11), the summation is done on all transaction associated with unit u in bus i.

3. Reactive power market by considering reactive losses

To execute the reactive power market, the units present their offers as equation (12). The coefficients (m_1, m_2, m_3) in this equation represent unit offers for each working region. In order to model the losses in the payment structure, a novel method is proposed. In this method, reactive losses are considered for reactive market clearing. In the following, this method is explained in details.

In this structure, units for participating in the reactive market must generate more than allocated reactive losses. In the other word, the units which win in the reactive power market must generate their allocated reactive losses for free and participate in the reactive power losses of the network. So, the ISO doesn't have any payments to the units for this generated reactive power. This structure is similar to traditional one except the Q_{base} is replaced with Q_{loss}:

$$Q_{loss}^{i,u} = \sum_{j=1} Q_{loss,p}^{Tj} \tag{12}$$

$$J_{payment}^{i,u} = \begin{pmatrix} \rho_0 \times W_0^{i,u}\left(Q_{\max}^{i,u} - Q_{\min}^{i,u}\right) - \rho_1 \times W_1^{i,u} \\ + \rho_2 \times W_2^{i,u} \times \left(Q_2^{i,u} - Q_{loss}^{i,u}\right) \\ + \rho_2 \times W_3^{i,u} \times \left(Q_3^{i,u} - Q_{loss}^{i,u}\right) \\ + \frac{1}{2}\rho_3 \times W_3^{i,u} \times \left(Q_3^{i,u} - Q_{A,new}^{i,u}\right)^2 \end{pmatrix} \tag{13}$$

As a result, total payment is:

$$TPF = \sum_{i=1}^{NG}\sum_{u=1}^{NU_i} J_{payment}^{i,u} \tag{14}$$

$$\begin{aligned} &W_1^{i,u} \times Q_{\min}^{i,u} \leq Q_1^{i,u} \leq 0 \\ &W_2^{i,u} \times Q_{loss}^{i,u} \leq Q_2^{i,u} \leq W_2^{i,u} \times Q_{A,new}^{i,u} \\ &W_3^{i,u} \times Q_{A,new}^{i,u} \leq Q_3^{i,u} \leq W_3^{i,u} \times Q_{B,new}^{i,u} \\ &W_1^{i,u} + W_2^{i,u} + W_3^{i,u} \leq 1 \\ &Q_g^{i,u} = Q_1^{i,u} + Q_2^{i,u} + Q_3^{i,u} \end{aligned} \tag{15}$$

The total payment function is the cost which ISO pays to each provider ($J_{payment}^{i,u}$) for reactive power generation. It is the total summation of EPF with uniform market prices. Uniform market prices, ρ_0, ρ_1, ρ_2, ρ_3, will be determined in the market clearing process. The reactive power market will clear with TPF (14) as the objective for minimization. The uniform auction is chosen for market clearing, which means the highest priced offer selected determining the market price. The market clearing is done with additional system constraints. These constraints will be explained in next subsection. Statements (15) are the units working region limits as discussed before. These algebraic relations ensure appropriate allocation of reactive in different regions.

A) Constraints in the reactive power market

The aim of implementing reactive power market is to optimize the total payment function (14), while $J^{i,u}_{payment}$ is equal to (13), while different system constraints are satisfied. These constraints explained in the following subsections:

B) Power flow equations:

$$\sum_{u=1}^{NU_i} P^{i,u}_{g,con} - P^i_d = \sum_j V_i V_j Y_{ij} \cos(\theta_{ij} + \delta_j - \delta_i) \tag{16}$$

$$\sum_{u=1}^{NU_i} Q^{i,u}_g + Q^i_C - Q^i_d = -\sum_j V_i V_j Y_{ij} \sin(\theta_{ij} + \delta_j - \delta_i) \tag{17}$$

C) Operational constraints of generators

$$\begin{cases} Q^{i,u}_A = \sqrt{\left(\dfrac{V_t^{i,u} E^{i,u}_{af}}{X_s^{i,u}}\right)^2 - (P_g^{i,u})^2} - \dfrac{\left(V_t^{i,u}\right)^2}{X_s^{i,u}} & if\ P_g^{i,u} < P^{i,u}_{g,rated} \\ Q^{i,u}_A = \sqrt{S^{i,u}_{rated} - (P_g^{i,u})^2} & if\ P_g^{i,u} > P^{i,u}_{g,ratec} \end{cases} \tag{18}$$

$$\begin{aligned} Q^{i,u}_{A,new} &= Q^{i,u}_A - Q^{i,u}_{base} \\ Q^{i,u}_{B,new} &= Q^{i,u}_B - Q^{i,u}_{base} \\ Q^{i,u}_{base} &= 0.1 \times Q^{i,u}_{\max} \end{aligned} \tag{19}$$

The output power of the generator is limited by capability curve limits of the unit. When active power output and terminal voltage are fixed, the field current and armature current limits determine the reactive power output of the unit. So, if $P_g^{i,u} < P^{i,u}_{g,rated}$ then the unit operates on field current limit region and the first constraint is correct. On the contrary, if $P_g^{i,u} > P^{i,u}_{g,rated}$ the unit operates on armature current limit region and second constraints is correct. Relations (19) ensure the correct cost function of payment.In relation (18), Eaf is the internal voltage of the synchronous generators, obtained from the below relation.

$$E^{i,u}_{af} = \frac{X_s^{i,u}}{V_t^{i,u}} \sqrt{P^{i,u}_{g,rated} + \left(Q^{i,u}_{g,rated} + \frac{\left(V_t^{i,u}\right)^2}{X_s^{i,u}} \right)^2} \tag{20}$$

D) Determining market prices:

Market prices are separately selected for every reactive power component. In this paper, the uniform auction is selected for market clearing. The following constraints assure that maximum offer prices are acceptable for a set of given offers:

$$W_0^{i,u} = W_1^{i,u} + W_2^{i,u} + W_3^{i,u} \tag{21}$$

$$W_0^{i,u} \times a_0^{i,u} \le \rho_0 \tag{22}$$

$$W_1^{i,u} \times m_1^{i,u} \le \rho_1 \tag{23}$$

$$\left(W_2^{i,u} + W_3^{i,u}\right) \times m_2^{i,u} \le \rho_2 \tag{24}$$

$$W_3^{i,u} \times m_3^{i,u} \le \rho_3 \tag{25}$$

E) Constraints of reactive power generation:

$$Q^{i,u}_{\min} \le Q^{i,u}_g \le Q^{i,u}_{\max} \tag{26}$$

$$Q^i_{C,\min} \le Q^i_C \le Q^i_{C,\max} \tag{27}$$

In (30), the upper limit for generation is $Q^{i,u}_{B,new}$. Statement (31) is the limits for other reactive power suppliers like as capacitors or shunt reactors.

F) Security constraints:

$$V_i^{\min} \le V_i \le V_i^{\max} \tag{28}$$

$$P_g^{slack} \le P^{slack}_{g,\max} \tag{29}$$

$$\left|S^{i,j}\right| \le S^{i,j}_{\max} \tag{30}$$

The voltage limits of each bus explain by (28). Statement (29) is constraints of the active power generations of the slack bus. Statement (30) is the limits of line loading. These constraints assure the secure operations of the network.

According to the mentioned points, after determining the amount of active power of the units, reactive power losses are calculated. After determining the losses, the offer prices, as well as minimum and maximum generating reactive power of the units, are presented to ISO.

Considering these amounts, ISO clears the market and determines the generation reactive power of the units and the market prices. At the end, ISO calculates the final payment to each producer.

4. Simulation Results

The proposed reactive power market was tested on IEEE 24-bus reliability network. This network had 32 synchronous generators, 1 synchronous condenser placed on bus 14, and 17 loads. Bus 13 was considered the reference bus, and the rests were PQ bus. The system total active and reactive loads are 2850MW and 580MVAr, respectively. The active power of the units determined in the energy markets is shown in Table 1.

The information and specifications of the network, including line impedance, maximum and minimum active and reactive power generated by generators, were presented in [26]. For the simulation, as mentioned previously, first, reactive power losses caused by active power flow were obtained and, then, according to this data and other data of the network, the reactive power market was implemented.

In this simulation, in order to get reactive power losses, MATLAB software was used and also the optimization problem of reactive power market clearing is in the form of MINLP, which is modeled in GAMS software using DICOPT solver [27].

In Table 1, the amount of active power by every generator winning in the energy market and the amount of reactive power losses caused by this energy exchange are shown.

Every participant in the reactive power market presents three components to the market, which are shown in Table 2. Minimum and maximum voltage limits for all buses considered as 0.95 and 1.05.Reactive power market clearing is an MINLP problem. This model is solved using GAMS, which is strong software for solving these problems. Considering the offer prices and the proposed market model, the market prices and total prices by ISO will be as in Table 3.

Although, the total payment in the conventional method is less than method A and C, but in this method the reactive power, which required by the generator for its auxiliary equipment, enters to the network. Also, clearing price of the lost opportunity in the method A and B are zero while in the conventional methods, clearing price of the lost opportunity is $0.27\$/(\text{MVar}-\text{h})^2$.

Entering to the third region of generation created an imbalance during reactive power market settlement which should be modified in the real-time market. So if any methods cause fewer imbalances, has priority to others. So this method is better than the conventional one.

The reactive power that each participant wins in two markets, and meanwhile the maximum produced reactive power by the generator, without any need to decrease the active power (Q_A), is shown in Table 4 (both according to the conventional method and the proposed method).

The bolded value in this table represents entering the unit to the third region. Also, as can be seen from this table, some units may not elect in the reactive power market. But these units due to their participation in the reactive power losses must pay the cost of their share of the losses.

In the conventional method, the share of reactive loss doesn’t take into account by any units. In the proposed market just generators who wins in the reactive market, produce their share of reactive loss. The payment of each generator in these markets is shown in Table 5. This table gives a good view to compare payments of different markets.

Table.1.
Amount of active power transaction and its corresponding reactive power losses

Bus number	***Unit***	***Contracted active power***	***Allocated reactive losses***
1	1	10	0.056
	2	10	0.056
	3	0	0.00
	4	60	0.5357
2	1	10	0.1140
	2	10	0.1140
	3	75	0.8548
	4	75	0.8548
7	1	0	0.00
	2	90	1.0873
	3	90	1.0873
13	1	186.51	13.7512
	2	186.51	13.7512
	3	186.51	13.7512
14	1	0	0.00
15	1	12	0.1509
	2	12	0.1509
	3	12	0.1509
	4	12	0.1509
	5	12	0.1509
	6	140	1.7606
16	1	140	1.817
18	1	400	9.9984
21	1	400	2.6242
22	1	0	0.00
	2	50	0.3255
	3	50	0.3255
	4	50	0.3255
	5	50	0.3255
	6	50	0.3255
23	1	155	3.6636
	2	0	0.00
	3	350	8.2726

Table.2.
Offers of generators in the reactive power market

Bus number	***Offered prices***			
	a_0	m_1	m_2	m_3
1	0.96	0.86	0.86	0.46
	0.95	0.82	0.82	0.45
	0.85	0.79	0.79	0.39
	0.83	0.82	0.82	0.4
2	0.5	0.54	0.54	0.28
	0.42	0.42	0.42	0.35
	0.69	0.68	0.68	0.39
	0.65	0.62	0.62	0.37
7	0.75	0.61	0.61	0.43
	0.8	0.75	0.75	0.36
	0.7	0.65	0.65	0.32
13	0.68	0.5	0.5	0.31
	0.7	0.54	0.54	0.39
	0.75	0.6	0.6	0.5
14	0.94	0.81	0.81	0
15	0.65	0.6	0.6	0.3
	0.5	0.58	0.58	0.25
	0.6	0.73	0.73	0.38
	0.55	0.61	0.61	0.27
	0.52	0.5	0.5	0.26
	0.51	0.51	0.51	0.27
16	0.5	0.5	0.5	0.3
18	0.9	0.85	0.85	0.48
21	0.8	0.75	0.75	0.41
22	0.42	0.42	0.42	0.17
	0.5	0.48	0.48	0.2
	0.45	0.42	0.42	0.38
	0.48	0.44	0.44	0.35
	0.49	0.45	0.45	0.33
	0.55	0.46	0.46	0.32
23	0.9	0.85	0.85	0.48
	0.95	0.89	0.89	0.55
	0.86	0.8	0.8	0.45

Table.3.
Reactive power market clearing

Prices	***Availability Price, ρ_0***	***Operation Price, ρ_1***	***Operation Price, ρ_2***	***Operation Price, ρ_3***	***Total Payment***
Conventional market	0.7	0	0.81	0.27	772.69
Proposed market	0.7	0	0.81	0	846.78

Table.4.
Amount of reactive power generated in each power plant

Bus	***Unit***	Q_{min}	Q_{base}	Q_A	$Q_{A,new}$	***Allocated losses***	Q_g	Q_g
1	1	0.00	1.55	13.73	12.18	0.056	0.00	0.00
	2	0.00	1.55	13.73	12.18	0.056	0.00	0.00
	3	-25	5.056	50.32	45.26	0.00	0.00	0.00
	4	-25	5.056	43.73	38.67	0.5357	0.00	0.00
2	1	0.00	1.55	13.73	12.18	0.1140	0.00	0.00
	2	0.00	1.55	13.73	12.18	0.1140	0.00	0.00
	3	-25	5.056	39.95	34.89	0.8548	0.00	0.00
	4	-25	5.056	39.95	34.89	0.8548	0.00	0.00
7	1	0.00	7.439	67.8	60.36	0.00	0.00	0.00
	2	0.00	7.439	54.93	47.49	1.0873	0.00	0.00
	3	0.00	7.439	54.93	47.49	1.0873	38.6	42.2
13	1	0.00	14.577	118.75	104.17	13.7512	0.00	104.17
	2	0.00	14.577	118.75	104.17	13.7512	103.3	0.00
	3	0.00	14.577	118.75	104.17	13.7512	0.00	0.00
14	1	-50	20.00	200	180	0.00	200	180
15	1	0.00	0.865	6.65	5.79	0.1509	8.6	5.79
	2	0.00	0.865	6.65	5.79	0.1509	8.6	5.79
	3	0.00	0.865	6.65	5.79	0.1509	6.7	5.79
	4	0.00	0.865	6.65	5.79	0.1509	8.6	5.79
	5	0.00	0.865	6.65	5.79	0.1509	8.6	5.79
	6	-50	11.31	91.64	80.33	1.7606	0.00	80.3
16	1	-50	11.31	95.81	84.5	1.817	0.00	0.00
18	1	-50	30.36	242.45	212.09	9.9984	0.00	0.00
21	1	-50	2.398	242.45	240.05	2.6242	0.00	0.00
22	1	-10	2.398	23.5	21.10	0.00	0.00	0.00
	2	-10	2.398	15.86	13.46	0.3255	18.1	0.00
	3	-10	2.398	15.86	13.46	0.3255	0.00	0.00
	4	-10	2.398	15.86	13.46	0.3255	15.86	0.00
	5	-10	2.398	15.86	13.46	0.3255	15. 86	13.46
	6	-10	2.398	15.86	13.46	0.3255	15. 86	0.00
23	1	-50	11.31	83.59	72.28	3.6636	0.00	0.00
	2	-50	11.31	150.37	139.06	0.00	0.00	0.00
	3	-25	25.72	190.69	164.97	8.2726	0.00	0.00
			Total			***75.8033***	***448.8***	***449.1***

5. Conclusions

In this paper, a new method was presented for reactive power market structure, in which the reactive power losses caused by active power implementation were considered and, thus, a new method was presented for reactive power market clearing. In this method, ISO calculated the amount of reactive power losses after implementing the energy market and these amounts were used in the reactive power market. Since a large amount of the reactive power losses was compensated by using this method compulsively, then the payment costs by market were reduced. Consequently, the proposed method not only could improve justice among the market participants, but also could reduce the payment cost by ISO. Also, the mentioned method, due to less allocation of losses to the producers with fewer transactions in the energy market or those who exchange power with their close consumers, could encourage producers to effectively participate in the reactive power market.

Table.5.
Payments comparison of each power plant in the reactive power market

Bus number	***Unit number***	***Payments***	
		Conventional	***Proposed Method***
1	1	0.00	0.00
	2	0.00	0.00
	3	0.00	0.00
	4	0.00	0.00
2	1	0.00	0.00
	2	0.00	0.00
	3	0.00	0.00
	4	0.00	0.00
7	1	0.00	0.00
	2	0.00	0.00
	3	77.31	85.37
13	1	0.00	175.28
	2	173.90	0.00
	3	0.00	0.00
14	1	320.80	320.80
15	1	12.33	10.62
	2	12.33	10.62
	3	10.78	10.62
	4	12.33	10.62
	5	12.33	10.62
	6	0.00	177.79
16	1	0.00	0.00
18	1	0.00	0.00
21	1	0.00	0.00
22	1	0.00	0.00
	2	36.51	0.00
	3	0.00	0.00
	4	34.69	0.00
	5	34.69	34.42
	6	34.69	0.00
23	1	0.00	0.00
	2	0.00	0.00
	3	0.00	0.00
Total		***772.69***	***846.78***

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