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Application of Designing Economic Mechanisms to Power Market - Part 2 Characteristic Analysis of Generation Side Power Market

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Abstract

The incentive power market may lead to a high information cost if it is not informationally efficient. The paper analyzes the characteristic of the generation side power market mechanism model based on the designing economic mechanisms theory by the three GENCOs (Generation Companies) case. The result of analysis is that the mechanism model has four main features: the informationally efficient which means that the mechanism meets requirements of the observational efficiency, the communication efficiency and the low complexity of computing; the incentive compatibility which indicates that the resource allocation of the power market is Pareto Optimality and the social benefit achieves the maximization when GENCOs also achieve profit maximization; the decentralized decision which refers to preserving the privacy information of GENCOs; encouragement of competition which suggests that the mechanism encourages GENCOs to compete with each other healthily.

Keywords*: power market, informationally efficient, incentive compatibility*

1. Introduction

The research on the power market mechanisms design is always a hotspot around the world. With the development of related theories and the accumulation of power markets practical experience, the trend of designing auction mechanisms has changed obviously. As other asymmetric information systems, the private information distributes in each participant of the power market. In traditional uniform clearing price mechanisms, GENCOs (Generation Companies) could bid strategically and hoard capabilities to hold market power for earning more profits, which leads to the large price increases [1-2]. After that, researchers begin to seek for other auction mechanisms. The FERC (Federal Energy Regulatory Commission) requires relevant authorities to study the alternative scheme of the uniform clearing price mechanism, for example, adopting the pay-as-bid mechanism by which researchers hope to reduce strategic behaviors from GENCOs [3]. But with the deepening of research and practice, more and more scholars find that the pay-as-bid mechanism is not the fundamental solution to stopping strategic game actions from GENCOs [4, 5].

Recent years, researchers introduce the concept of incentive compatibility which belongs to the mechanism design theory to the power market design. We call this kind of the market mechanism as the incentive power market which can fundamentally reduce GENCOs market power; meanwhile, the market efficiency is uninfluenced [6-13].

But, there is a problem that if the incentive power market didn't consider about the *informationally efficient*, the information cost of running the mechanism would increase sharply [14]. In decentralized mechanisms, the market resource allocation is decided by outcomes of every agent's decision which is made through vast information exchanges. According to the information economics theory, agents transact with each other by exchanging information, a market is a network delivering information with which agents are interconnected. The *informationally efficient* is relevant close with the information cost which is the most important part of transaction cost in power market [15]. Compared with the traditional power market mechanism, the incentive power market needs more information exchanges to achieve the incentive compatibility during operating the market. So the information cost of the incentive

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power market without the *informationally efficient* will be increased. Thus, it should be taken into consideration that how to design an incentive power market mechanism with the *informationally efficient*. Considering the feasibility of operating power markets, it is very significant to study on the *informationally efficient* and incentive compatible power market mechanism for promoting the further marketization progress of power markets.

2. A Case of Generation Side Power Market Competitive Mechanism Based on the Designing Economic Mechanisms Theory

In the paper "Application of Designing Economic Mechanisms to Power Market Part 1 Generation Side Power Market Design", based on the designing economic mechanisms theory, we have studied a new approach to designing the incentive power market. The incentive compatible, *informationally efficient* and decentralized generation side power market competitive mechanism model π has been constructed.

$$\pi = [M,\ g_1(m,a), g_2(m,b), g_3(m,c),\ h_1(m), h_2(m), h_3(m)] \tag{1}$$

Where, $g_1(m,a) = a_1(-2m_1 + m_2 + m_3 + P_L) + 3a_2 - (m_1 + m_2 + m_3 + P_L)$, $h_1(m) = (-2m_1 + m_2 + m_3 + P_L)/3$,
$g_2(m,b) = b_1(-2m_2 + m_1 + m_3 + P_L) + 3b_2 - (m_1 + m_2 + m_3 + P_L)$, $h_2(m) = (m_1 + m_2 - 2m_3 + P_L)/3$,
$g_3(m,c) = c_1(-2m_3 + m_1 + m_2 + P_L) + 3c_2 - (m_1 + m_2 + m_3 + P_L)$, $h_3(m) = (m_1 + m_3 + m_2 + P_L)/3$.

$g_1(m,a)$, $g_2(m,b)$ and $g_3(m,c)$ correspond to equilibrium message functions of GENCO 1, GENCO 2 and GENCO 3. Outcome functions $h_1(m)$, $h_2(m)$ and $h_3(m)$ correspond to P_1 the output of GENCO 1, P_3 the output of GENCO 3 and p the uniform clearing price. Assume that the requirement of the next period load is 100MW, the generation cost is given by the Equation (2) and the relevant data of three GENCOs are listed in Table 1.

$$C_i(P_i) = \alpha_i + \beta_i P_i + \gamma_i P_i^2 \tag{2}$$

Table 1. The Data of Three GENCOs

GENCO i	α_i	β_i	γ_i	Minimum Output (MW)	Maximum Output (MW)
1	22	10.125	0.7865	15	100
2	12	9.588	0.5195	10	80
3	46	15.897	0.949	20	150

The parameter space of GENCOs is obtained through making parameter transformation based on the algorithm in Part 1. The parameter space $\theta = (a,b,c)$ is shown in Table 2. Because the power market is an asymmetric information system (decentralized system), GENCO i only knows its parameters a_i and b_i which belong to GENCO i 's private information, and the market operation department doesn't know the parameter space.

Table 2. The Parameter Space of Three GENCOs

GENCO 1		GENCO 2		GENCO 3	
a_1	a_2	b_1	b_2	c_1	c_2
1.573	10.125	1.039	9.588	1.898	15.897

The market operation department is in charge of constructing outcome functions $h(m)$ and equilibrium message functions $g_i(m,\theta)$ by the algorithm of the designing economic mechanisms theory. The $g_i(m,\theta)$ will be sent to GENCO i only. Then, GENCO i uses its parameters a_i and b_i to figure out the equilibrium message function given by the Equation (3), (4) or (5) which is waiting for being verified.

$$g_1(m,a) = -4.146m_1 + 0.573m_2 + 0.573m_3 + 87.675 \quad (3)$$

$$g_2(m,b) = 0.039m_1 - 3.078m_2 + 0.039m_3 + 32.664 \quad (4)$$

$$g_3(m,c) = 0.898m_1 + 0.898m_2 - 4.796m_3 + 137.491 \quad (5)$$

The next step is the *verification scenario* process. The operation flow of the generation side power market based on the designing economic mechanisms theory is shown in Figure 1.

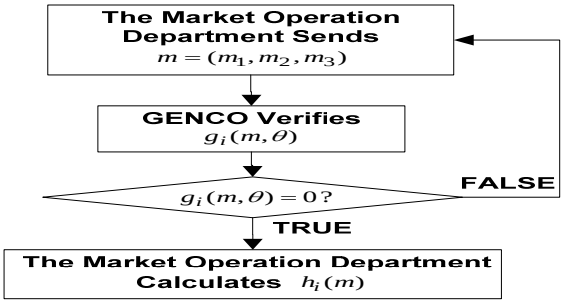

Figure 1. The Operation Flow of the Generation Side Power Market

The market operation department sends a set message $m = (m_1, m_2, m_3)$ which is obtained by some certain rules or algorithms to each GENCO. The GENCO i plugs $m = (m_1, m_2, m_3)$ into its equilibrium message function $g_i(m,\theta)$ to calculate whether or not $g_i(m,\theta) = 0$. The result should be reported back to the market operation department.

If $g_i(m,\theta) = 0$ is true, GENCO i is in the equilibrium condition of $MR_i = MC_i$ and can achieve the profits maximization in the current market resource allocation which is determined by the message set. We assume that every GENCO is rational, so they are willing to report real results of calculating their equilibrium message functions. If any GENCO i's $g_i(m,\theta) = 0$ is false, the market operation department has to select a new message set and start a new round of *verification scenario*.

Repeat the *verification scenario* process until every GENCO's $g_i(m,\theta) = 0$ is true, at the moment, the current equilibrium message set $m' = (m'_1, m'_2, m'_3)$ is named the group equilibrium message. Finally, the market operation department plugs the group equilibrium message $m' = (m'_1, m'_2, m'_3)$ into outcome functions $h_1(m)$, $h_2(m)$ and $h_3(m)$, then P_i the output of GENCO i and p the uniform clearing price could be obtained. In the case, the group equilibrium message is $m'_1 = 27.6994, m'_2 = 11.4191$ and $m'_3 = 35.9924$ and the whole generation side power market clearing information of the three GENCOs case is listed in Table 3.

Table 3. The Market Clearing Information of the Three GENCOs Case

Uniform Clearing Price: 58.3703 (¥/ MW)			
GENCO i	Output (MW)	Total Revenue (¥)	Marginal Revenue (¥/ MW)
1	30.6709	1790.27	58.3703
2	46.9512	2740.56	58.3703
3	22.3779	1306.21	58.3703

3. The Characteristic Analysis of Generation Side Power Market Competitive Mechanism based on the Designing Economic Mechanisms Theory

(1) The power market mechanism is decentralized decision and privacy preserving.

When a GENCO verifies whether or not it is in equilibrium, they just need to know its private information like parameters of the generation cost, and it is not necessary to report its private information to other GENCOs or the market operation department.

(2) The power market mechanism is incentive compatibility.

If the power market operation follows the principle of profit maximization, the output P_i of GENCO i should have a relationship shown as the Equation (7) with the uniform clearing price p.

$$MR_i = MC_i \tag{6}$$

$$P_i = (p - \beta_i) / (2\gamma_i) \tag{7}$$

According to the parameter transformation in Table 2, we obtain:

$$P_i = (p - \theta_2) / \theta_1 \tag{8}$$

Where $\theta_1 = (a_1, b_1, c_1)$, $\theta_2 = (a_2, b_2, c_2)$.

Plug the market clearing information listed in Table 3 into the Equation (8), verify whether or not the market operation follows the principle of profit maximization. The result of verification is shown in Table 4.

Table 4. The Verification of the Profit Maximization

GENCO i	Marginal Revenue (¥/ MW)	Output (MW)	θ_1 (a_1、b_1、c_1)	θ_2 (a_2、b_2、c_2)	Marginal Cost (¥/ MW)
1	58.3703	30.6709	1.573	10.125	58.3703
2	58.3703	46.9512	1.039	9.588	58.3703
3	58.3703	22.3779	1.898	15.897	58.3703

Table 4 presents that the power market based on the designing economic mechanisms theory follows the principle of profit maximization to clear the market. At the moment, each GENCO gets the maximum profits in corresponding outputs, and the entire market resource allocation achieves the Pareto Optimality.

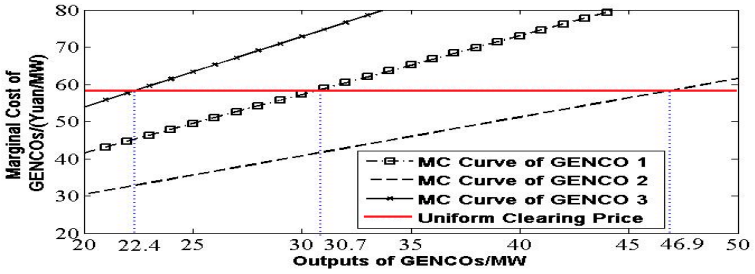

Figure 2. The Marginal Cost Curve of GENCOs

(3) The power market mechanism is *informationally efficient*.

1) Due to the decentralized decision, GENCOs just require to know their private information, which is helpful for GENCOs to improve their observational efficiencies.

2) Compared with the traditional power market with the uniform clearing price, the market based on the designing economic mechanisms theory uses fewer size of the message space.

3) The power market based on the designing economic mechanisms theory can reduce the computing complexity of the market operation department, and improves the ability of the

entire system's information processing through using the distributed (cloud) computing [16]. In general, the generation side power market based on the designing economic mechanisms theory is *informationally efficient*.

(4) The power market encourages GENCOs to compete with each other healthily.The relationship between GENCOs outputs and marginal cost is shown in Figure 2. The oblique lines are the marginal cost curve of GENCOs, the red line is the market uniform clearing price, the cross point correspond to each GENCO's outputs at the uniform clearing price.

Figure 2 shows that GENCO 2's output and total revenue are most for its least generation cost (the lowest marginal cost curve). On the contrary, GENCO 3's output and total revenue are least for its most generation cost. We can get the same result by observing the market clearing information in Table 3.

Thus, the generation side power market based on the designing economic mechanisms theory encourages GENCOs to cut down the generation cost. That is, whose generation cost is low, who gets more revenue. In this kind power market mechanism, GENCOs will compete with each other healthily by updating generation equipment and technologies, importing advanced management philosophy, improving the resource utilization efficiency.

4. Conclusion

According to the information economics, the paper suggests that the information cost will increase sharply if the incentive power market is lack of the *informationally efficient*. The generation side power market based on the designing economic mechanisms theory introduces the philosophy of the *informationally efficient* to the incentive power market, which makes the power market own features of the incentive compatibility, the *informationally efficient* and the decentralized decision.

By analyzing the case of three GENCOs, the paper finds that the power market designed by the designing economic mechanisms theory follows the principle of profit maximization, which means the mechanism leads to the Pareto Optimality of resource allocation; meanwhile GENCOs are permitted to pursue profits maximization. And this kind of power market can reduce the information cost during running the entire market obviously. Besides, the generation side power market has the characteristic of encouraging GENCOs to compete with each other healthily, which makes the power market develop further competition.

Now, China is perfecting the generation side power market. The research of this paper could provide some new ideas and helpful exploration to the practice and theoretical research of Chinese power markets.

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