

# The Research about the Trans-provincial Centralized Bidding Trading Market of East China Power Grid --II: Model Analysis

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## Abstract

In this paper a novel cost function based on the relationship between operation cost of unit and generation load rate is employed in an agent-based model of Trans-provincial Centralized Bidding Trading Market of East China Grid. Simulation results are compared to real data to prove that the model is correct. Further analysis on simulation results point out the way to achieve an all-win game for power market members: generation companies improve their average load rates of the units by selling their electricity in the market, which makes units' cost drop and settlement price stay lower than benchmark price. Consequently electricity-demand provinces saved expenses, and units increase their profits. In conclusion, the trans-provincial electricity market of East China Power Grid is a successive case which improves the efficiency of the electricity industry by market-oriented measures.

**Keywords:** Power Market; Agent-based Simulation; East China Grid; Trans-provincial Centralized Trade; Partial Electricity Competition

## 1. Introduction

East China power grid is an interconnected power grid, which contains five provincial power grids, and each province power grid is a control zone. Each provincial power grid company is responsible for their respective provinces electricity and power balance. In order to meet the load demand, about 1% of the total energy needs to be exchanged among the provinces. The Trans-provincial Centralized Bidding Trading Market of East China Power Grid (TPM-ECPG) is designed to take advantages of competition to form energy exchange programs between provinces.

About 99% of the generating energy is arranged using so-called planned schedule method. In the method, each unit was allocated a certain amount of generating energy during the next year according to the installed capacity of the unit, the unit type and the forecasting load. Then, the power system operation schedules the unit output to meet the actual load and guarantees annual generating energy of the unit equal to the value to be assigned. And Electricity is purchased by the grid company with the benchmark price that is validated by the National Development and Reform Commission.

The TPM-ECPG that was put into operation in Dec. 2008, is the only one power auction. The result of last three-year operation indicates that market trading volume increased year after year, and to most degree electricity demand has been satisfied. The trans-provincial transaction platform has become the one of the main ways of the trans-provincial transaction in East China Power Grid.

In this paper agent-based model is proposed as the tool for the modeling and analysis of the trans-provincial centralized auction transaction platform of East China. In a lot of literatures, the agent-based model not only was employed to estimate market characteristic with different pricing method, namely uniform clearing pricing, mid-point pricing and pay-as-bid pricing<sup>[5-7]</sup>, but also used to discuss the influence on the power market exerted by blocking, collusionbid and emission trading of CO<sub>2</sub><sup>[11-18]</sup>. The method is able to show the basic features that market members bid as the behavior of maximizing their benefits, and its extensibility allows taking more practical market factors into consideration.

The important feature of the TPM-ECPG is a part of the electricity competition, part of electricity is scheduled using traditional cost-based method, and

another is sale by competition. What is the impact of the non-competitive part on the competitive market? In fact, the market shows some interesting phenomenon. For example, power generation companies are willing to participate in market competition, even if the market price is lower than the benchmark price.

This paper is one of the two-part series. This article will use an agent-based simulation method to model the TPM-ECPG. By doing so, it can help to analyze simulated cases based on realistic data of East China trans-provincial centralized power transaction.

## 2. Introduction of the TPM-ECPG

The TPM-ECPG functions as a double-auction market, basic rules are as follows: buyers and sellers initially report their respectively offered quantities of electricity (MWh) and bid prices (¥/MWh).

The approach of market clearing applies matchmaking tradeoff model. The highest bid of demand side would match the lowest ask price of supply side. Then the market clearing price is their average value of the two offered prices. The matchmaking procedure goes on by the price sequences of sellers and buyers.

The transmission fee and loss compensation fee belongs to demand-side power grid, while the trans-provincial transmission fee and loss compensation fee belongs to the East China Power Grid. The loss compensation fee is 1% of benchmark price, and the transmission fee is the difference between demand price and supply price in principle. But if the sum of transmission fee and loss compensation fee is more than 0.03 ¥/KWh, then the transmission fee is 0.03 ¥/KWh. More detailed market rules References [1].

## 3. Agent-based simulation model

Unlike the model of the conventional electricity market, the model of the East China power market must take into the planned generation. The proposed model in this paper employs the characteristics as followed: 1) Market members in the TPM-ECPG always bid for profit maximization; 2). Generated electricity and price of planned generation is described through a cost function, which can embody the influence exerted on the power auction market. 3). Transaction rules are set up in accordance with practical regulations of the TPM-ECPG. To sum up, the model possesses the most market characteristics of TPM-ECPG, and is expected to explore the inner market mechanism by simulation.

### 3.1 Cost function model

The generator's cost model presented is divided into two parts of the operating cost and capacity cost. Capacity cost is a constant during the modeling and simulation.

The main operation cost is fuel cost, in order to represent the impact of the planned generation, the power generation load rate is employed to calculate the operation cost of the generating unit in this paper.

For any one of the power supplier  $i$ , its planned generating quantity of electricity is divided into two parts: electricity on peak periods and electricity on valley periods, the accepted quantity of electricity is classified into peak and valley part as well.

$$\begin{cases} Q_i = Q_{ip} + Q_{iv} \\ Q_{ip} = Q_{ipp} + Q_{ips} \\ Q_{iv} = Q_{ivp} + Q_{ivs} \end{cases} \quad (1)$$

Where  $Q_i$  denotes total generating electricity of Unit  $i$ ;  $Q_{ip}$ ,  $Q_{iv}$  denote generating electricity of Unit  $i$  on peak period and valley period respectively;  $Q_{ipp}$ ,  $Q_{ivp}$  denote planned generation of Unit  $i$  on peak period and valley period respectively;  $Q_{ips}$ ,  $Q_{ivs}$  denote accepted bid of Unit  $i$  on peak period and valley period respectively.

In this paper one month is set up as observation period. The average load rates of Unit  $i$  on peak/valley period are as followed:

$$\begin{cases} \bar{r}_{i,lp} = \frac{Q_{ip}}{P_{i,max} \times 30 \times 14} \\ \bar{r}_{i,lv} = \frac{Q_{iv}}{P_{i,max} \times 30 \times 10} \end{cases} \quad (2)$$

Where  $\bar{r}_{i,lp}$ ,  $\bar{r}_{i,lv}$  denote average load rate of Unit  $i$  on peak/valley period.  $P_{i,max}$  is unit's maximum output.  $30 \times 10$ ,  $30 \times 14$  represent valley-period of 10 hours per day, peak-period of 14 hours per day. Each month has 30 days on an average.

The average output of Unit  $i$  on peak/valley period is as followed:

$$\begin{cases} \bar{r}_{i,lp} = \frac{Q_{ip}}{P_{i,max} \times 30 \times 14} \\ \bar{r}_{i,lv} = \frac{Q_{iv}}{P_{i,max} \times 30 \times 10} \end{cases} \quad (3)$$

Where  $P_{ip}, P_{iv}$  denote average output of Unit  $i$  on peak/valley period

Coal consumption of Unit  $i$  can be calculated by coal consumption curve in Figure.1, which is expressed as quadratic function:

$$r_i = a_i \times P_i^2 + b_i \times P_i + c_i \quad (4)$$

where  $a_i, b_i, c_i$  are coefficients for different types of generator units,  $P_i$  is unit's output. Reference [19] shows that the way to estimate coal consumption can be accepted.

The running cost of power generation companies expressed as the product of the coal consumption,

electricity generation and coal prices

$$\begin{cases} C_{ip} = r_{i,pc} \times Q_{ip} \times p_c \\ C_{iv} = r_{i,vc} \times Q_{iv} \times p_c \end{cases} \quad (5)$$

Where  $C_{ip}$ ,  $C_{iv}$  denote operation cost of unit  $i$  on period/valley period.  $p_c$  denotes coal price,  $r_{i,pc}$ ,  $r_{i,vc}$  can be obtain from (4).

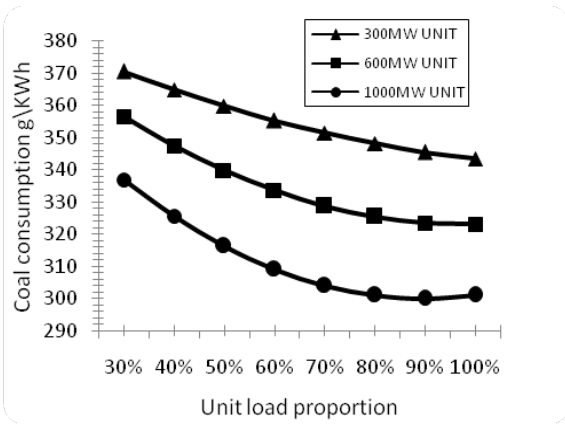


Figure.1 coal consumption curves of 3 types of units

### 3.2 Decision - making model

The decision-making model of the power supply company is just maximizing profit based on its objective function, and decision variable is the ask price  $p_{i,sell}^{bid}$ ,

$$\max_{p_{i,sell}^{bid}} R_{i,sell} = p_{i,bm} \times Q_{i,plan} + p_{i,bm} \times Q_{i,plan} - (C_{i,peak} + C_{i,valley} + C_{i,cap}) \quad (6)$$

where the planned quantity of generating electricity is scheduled by provincial regulators and its price is benchmark price of the respective provinces. Owing to the proposed model, which is based on load rates, the impacts of generating plans can be involved in decision making smoothly.

In terms of electricity-demand provinces, they purchase insufficient power through the trans-provincial auction after implementing generating plans, so insufficient power can also be regarded as a known constant in the model. The power-demand provinces expect to bid to satisfy their demand. Similarly, the decision-making model of such provinces is maximizing profit of their objective function, and decision variable is the bid price  $p_{i,buy}^{bid}$ :

$$\max_{p_{i,buy}^{bid}} R_{i,buy} = \bar{p}_{i,r} \times Q_{i,s} - p_{i,buy} \times Q_{i,buy} \quad (7)$$

Where,  $R_{i,buy}$ ,  $\bar{p}_{i,r}$ ,  $p_{i,buy}$  and  $Q_{i,buy}$  denote profit, retail price, closing bid price, accepted quantity of bid of electricity-demand province  $i$  respectively.

### 3.3 Agent-based simulation

Both the power supply company's decision-making model (6) and power-demand province's decision-making model (7) cannot be directly solved by optimization methods, for they are all game procedures. The agent-based simulation is appropriate to deal with the game problems.

According to historical data, planned peak/valley period generating electricity, quoted quantity, quoted price, probable quotation set and other arguments can be set up before simulation, reference [7] introduced this method in detail. Simple agent-based simulation procedure is as followed:

Step 1: In according to the roulette-like method, which acquires selective probability, quotations can be pick up for both units and buyers.

Step 2: After executing market-clearing, profits of units and buyers can be calculated by (6) and (7).

Step 3: Units and buyers amend their selective probability of quotation sets based on profit changes. The target is to increase the probabilities of one quotation which makes higher profit.

Step 4: Iteration pluses one. If any quotation in the two sets does not converge, go to Step 1.

The selective probability learning process, i.e., step 3, using the Roth-Ere algorithm [7][8][9], detailed discussion of the algorithm exceeds the scope of this article, please refer to the literature [7][8][9].

Table.1 Data of generators' units

NO.	Installed Capacity MW	Province	Offered	Planned
			Quantity ¥/MWh	Generation MWh
1	300	A	6480	179280
2	600	A	12960	358560
3	1000	A	21600	597600
4	600	A	12960	358560
5	300	A	6480	179280
6	1000	A	21600	597600
7	1000	B	21600	597600
8	300	B	6480	179280
9	600	B	12960	358560
10	600	B	12960	358560
11	1000	B	21600	597600
12	300	B	6480	179280
13	600	B	12960	358560

## 4. Case Study

### 4.1 Data setting

In order to keep accordance with actual operating data of the trans-provincial centralized bidding transaction

platform of East China, the experimental environment for power supply companies and their units in this paper are set up and present in Tab.1. These power companies with the sole unit are affiliated to two different provinces of A and B, the electricity-demand provinces are C and D. It is assumed that the coal price of province A is 720 Yuan/ton, and the coal price of B is 750 Yuan/ton.

#### 4.2 Analysis on market equilibrium

Based on the data setting, market equilibrium results can be obtained by agent-based simulation. Table.2 shows the market clearing results of electricity-demand provinces and units. The average bid prices of C and D in Tab.3 is close to the actual bid of demand provinces in 2010 transactions(422.26 ¥/MWh vs 421.00 ¥/MWh), relative error is about 0.3%. In addition the average units' ask prices(335.82 ¥/MWh) also approximate to those in 2010(335.82 ¥/MWh), which leads to a relative error of 4.6%.

**Table.2 Simulation results on the offer and bid**

Market players	Quotation ¥/MWh	Winning Bid ¥/MWh	Accepted
			Quantity MWh
Province C	416	400	79000
Province D	426	389	79000
300MW Unit	368	367	3400
600MW Unit	330	359	12960
1000MW Unit	326	358	21600

Further analysis on the results of Table.2 show that the average winning bid prices of units and electricity-demand provinces compare to their actual transaction data respectively, relative errors are 1.6% and 1.8%(absolute errors are 6.23 ¥ /MWh and 6.51 ¥/MWh). All the results and analysis figure out that market equilibrium of the model in this paper is close to real market operation, and the model can embody most of trans-provincial electric auction market.

According to Table.2, average ask-prices of 300 MW units, 600MW units and 1000MW units are sorted in descending order, which is as same as their operation cost sorted order. It is indicated that generation companies who owe auction units always bid on the basis of units' cost. The market characteristic makes low-cost units take advantages in market auction.

The simulated winning bid prices of province C and D(416.00 ¥/MWh and 426.00 ¥/MWh) are lower than

their benchmark prices(430.00 ¥ /MWh and 457.00 ¥/MWh) respectively, that saves expenses for both demand-province C and D.

Simultaneously the average winning bid price of units in province A and B (359.27 ¥/MWh and 359.42 ¥/MWh) are also lower than their benchmark prices (410.00 ¥/MWh and 400.00 ¥/MWh) respectively.

To find out why generation companies are willing to bid at a low price, average profit per unit (total profit divide total generation) and average load rate are put into consideration as shown in Table.3.

As it presents in Table.3, load rate increases after generation companies participate in auction market. That makes running cost go down. Moreover, when total generation increases by 3%, the settlement price of incremental part decreases nearly by 10% comparing to benchmark price. Whereas the cost drops, total profit grow by 9% and unit profit also goes up.

**Table.3 the profits and load rate of the power suppliers participating or not in inter-provincial transaction**

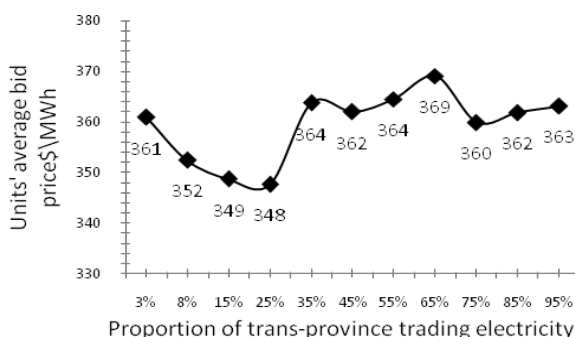
	Total generation MWh	Total profit ¥	Profit per unit ¥/MWh	Load rate	
				P	V
Without auction transaction	4900320	220961865	45.09	75%	89%
With bid transactions	5058320	241412193	47.72	77%	91%

In order to further study the characteristics of the TPM-ECPG, in this paper 11 trading scenarios on different market scales, of which total installed is fixed, are set up. Owing to a small wiggle room for buyers' quoted prices, units' average winning bid price can mostly indicate market trading status(As shown in Figure.2, where the horizontal axis represents the percentage of maximum offer of electricity in market bidding to total installed capacity, namely market scale).

As can be seen from the simulation results of Figure.2, When the TPM-ECPG maintain in a small transaction volume, namely the competitive part of electricity accounted for less than 25%, units average clearing price overall keeps a downward trend. It is pointed that the market within a certain small size has the ability to reduce the generation costs continually, to promote generation companies to participate in bidding, and possesses the conditions to expand transaction scale.

When the transaction scale goes up, average clearing electricity price rebounded, and presents a substantial rebound trend constantly. As the market expands to the

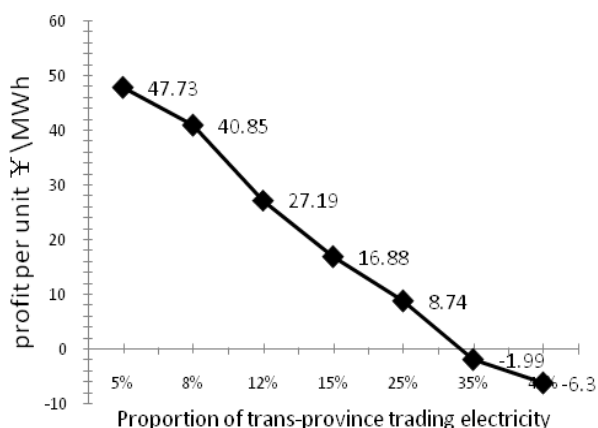
scale of trans-provincial trading electricity accounting for more than 75%, then, the total capacity which can be put into auction is large enough to approach to



**Figure.2 Units' average bid price under different market scale**

deregulated electricity competition scenario, and the average clearing price is slightly lower to medium-sized market, but still higher than smaller one.

In order to study the root cause of this situation, the study focused on the units' average unit profit (total revenue / (planned generation + accepted bided generation)) under different market size when the simulated market get an equilibrium, as showed in Figure. 2.



**Figure.3 Units' margin profit under different market scale**

As can be seen from Figure.3, the units' average unit profit decrease constantly when the market scale gradually expands. On the one hand it is indicated that the planned power generation is still as dominant position in both supply and demand side, and generation companies which participate in electricity auction cannot get enough profit caused by coal consumption reduction to compensate the loss of planned generation. On the other hand, before the trans-provincial transactions accounts for 25% of total capacity, the unit profit is greater than zero, so the power companies' profitable

opportunities still exist until profit is less than zero as the scale of market transactions expand. That is to say generation companies have to bid at a high price level in a larger auction market with current rules. It is also explained why there is a sudden rebound of price in Figure.2.

Combining all above simulation analysis, the planned generation as the main method of electricity supply and demand in the current market environment cannot be shaken, but TPM-ECPG makes a better market efficiency, and to some extent be on the potential for further expansion.

## 5 Conclusion

In this paper, the trans-provincial centralized bidding trading market of East China is modeled by an agent-based method, a novel cost function and cases based on actual data are employed to simulate the operation of the market. The simulation results are used to analyze market characteristics on the equilibrium status. Here I summarize what we can learn from the modeling and simulations:

- 1) The proposed model in this paper reflects basic characteristics of the trans-provincial centralized transaction platform, in which its market equilibrium accord with practical statistics of the power auction market.
- 2) The generation companies that participate in the trans-provincial auction platform possess restricted strategy space, they bid base on cost, so that is possible for efficient units to acquire more available electricity to generate. It helps to achieve the goals of energy saving and emission abatement
- 3) Trans-provincial transactions make the electricity-demand side save purchasing cost, the supply side cut down operating cost, and it is a well designed power market which satisfy the society, electricity generation enterprise and grid companies. The essence of the all-win game is that the generation companies bid base on their cost, and the transactions make the generating cost cutoff by increasing the units' load rates. For all the reasons above, both buyers and sellers can gain profit when the market closing prices are lower than benchmark prices.
- 4) Simulated results indicate that the trans-provincial centralized bidding transaction platform can preserve basic market characteristics after expanding its transaction scale within constraints.
- 5) Trans-provincial centralized auction platform can further expand on the existing basis, but planned generation is still the main profitable part for generation companies, to expand the scale is not easy to be too large.

## References

- [1] ZOU Bin, WANG Xiaojun, The Research about the Trans-provincial Centralized Bidding Trading Market of East China Power Grid --I: Empirical Analysis, Power and Energy Engineering Conference, 2013
- [2] Ross Baldick, Udi Helman, Benjamin F. Hobbs, Richard P. O'Neill, Design Of Efficient Generation Markets, Proceedings Of The IEEE, 2005, 93(11):1198-012.
- [3] National Electricity Regulatory Commission, The instruction that accelerating the development of the trans-provincial centralized bidding transactions in East China[R], 2009(in Chinese):  
<http://www.eceeb.gov.cn/publicJsp/detail.JSP?inforId=8586>
- [4] East China Electricity Regulatory Commission, East China Trans-provincial Centralized Auction Power Market Achieved Remarkable Success on Energy Saving and Emission Reduction[R], 2010(in Chinese):  
[http://www.serc.gov.cn/jgdt/pcjg/2010004/t20100402\\_12861.htm](http://www.serc.gov.cn/jgdt/pcjg/2010004/t20100402_12861.htm)
- [5] Eric Guerci, Mohammad Ali Rastegar, and Silvano Cincotti. Agent-based Modeling and Simulation of Competitive Wholesale Electricity Markets[J], Handbook of Power Systems II, Energy Systems, Springer-Verlag Berlin Heidelberg, 2010, Part3:241-286
- [6] Anke Weidlich, Daniel Veit. A critical survey of agent-based wholesale electricity market models[J], Energy Economics 2008, 30:1728-1759
- [7] Zou Bin, Yan Maosong, Xie Guangqian, Comparisons Among Pricing Methods in Pool-based Electricity Market by Agent-based Simulation Part One: Model and Algorithm [J], Automation of Electric Power Systems, 2004, 28(15):7-14.
- [8] Nicolaisen J, Petrov V, Tesfatsion L. Market Power and Efficiency in a Computational Electricity Market with Discriminatory Double-auction Pricing. IEEE Trans on Evolutionary Computation, 2001, 5(5): 504-523
- [9] Roth Alvin. Erev Ido. Learning in Extensive-form Games: Experiment Data and Simple Dynamic Model in the Intermediate Term. Game and Economic Behavior, 1995(8): 164-212
- [10] Yan Maosong, Modern Power Market and Electricity Value Equivalent Pricing System[M], Beijing: China Power Press, 2008(in Chinese)
- [11] LIU Guozhong, WEN Fushuan, XUE Yusheng. Impacts of Emissions Trading and Renewable Energy Sources Development Schemes on Electricity Market Operation[J]. Automation of Electric Power Systems, 2010, 34(7):21-25.
- [12] WANG Yeping, JING Zhaoxia, CHEN Haoyong1, et al. A Method for Designing Agent-based Electricity Market Simulation Experiments[J], Automation of Electric Power Systems, 2009,33(17):57-60,85.
- [13] Eric Guerci, Stefano Valdi, Silvano Cincotti, Learning Agents in an Artificial Power Exchange: Tacit Collusion, Market Power and Efficiency of Two Double-auction Mechanisms[J], Comput Econ, 2008, 32:73-98
- [14] Audun Botterud, Matthew R. Mahalik, Thomas D. Veselka, Heon-Su Ryu, Ki-Won Sohn, Multi-Agent Simulation of Generation Expansion in Electricity Markets[C]. Power Engineering Society General Meeting, IEEE, 2007:1-8
- [15] Anke Weidlich, Frank Sensfuß, Massimo Genoese, Daniel Veit, Studying the effects of CO2 emissions trading on the electricity market: A multi-agent-based approach [J]. Emissions Trading, Springer, 2008, Part B:91-101
- [16] ZHOU Hai-ming, WANG Hai-ning, SHI Shu-hong, et al, Development of Electricity Market Simulation System and Its Application[J]. Power System Technology, 2010, 34(1):117-121
- [17] TAN Zhong-fu, LI Li, WANG Jian-jun, et al. A Fuzzy Bayesian Learning Model in Agent-based Electric Power Bilateral Negotiation[J]. Proceedings of the CSEE, 2009, 29(7):106-113.
- [18] TIAN Jian-wei, HU Zhao-guang, WU Jun-yong, et al. Dynamic Economy and Power Simulation System Based on Multi-agent Modelling[J]. Proceedings of the CSEE[J], 2010, 30(7):85-91.
- [19] Liu Fu guo, Jiang xuexia, Li zhi, Investigation on Affects of generator Load on Coal Consumption Rate in Fossil Power Plant. Power System Engineering, 2008, 24 (4): 47-49.
- [20] Yan Maosong, Modern Power Market and Electricity Value Equivalent Pricing System[M], Beijing: China Power Press, 2008(in Chinese)