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# A Peer-to-Peer Electricity System and Its Simulation

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# A Peer-to-Peer Electricity System and Its Simulation

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**Abstract**. There are many problems with the present centralized energy systems. With the advancement of distributed energy systems and the advancement of renewable energy technologies, the supply of electricity and heat will be gradually decentralized, forming the Energy Internet combined with information technology that makes energy transactions easier and more efficient. In this research, a bidding mechanism of peer to peer electricity system is proposed for supplier nodes and consumer nodes to sell or buy energy on the market. And computer simulation is applied to test and optimize the mechanism. The results indicate that the proposed mechanism conforms to the market regularity and can improve the efficiency of local energy utilization compared with the traditional centralized system, reduce the cost of consumers, propel the utilization of renewable energy, and make the market more flexible and transparent.

## 1. Introduction

### *1.1. Peer to peer energy system*

Traditional energy systems are centralized and always come with high-volume equipment and large transportation and distribution system is indispensable for wide-range use. In this way, uneven terminal usage is difficult to balance, and a long-distance system can be faced with the problem of natural disasters and energy losses. Furthermore, it is tough to engage the huge waste heat generated by the power station and low-density regenerative energy in the urban area into the energy system. To address these issues, the idea of Distributed energy system was proposed [1]. The distributed energy system is a series of modular facilities that generate and store electricity and other sorts of energies (cooling, heat, gas, etc.) approaching the consumption sites. On the basis of the traditional central supply system and the new distributed energy system and with the development of information and communication technologies, the idea of Energy Internet [2] came up and broke the long-time monopoly of the energy market. The traditional energy market is regulated and controlled by energy companies, the source and price of energy are relatively opaque. As for the Energy Internet, the principal feature is peer to peer: generation nodes and consumption nodes are scattered featured and each node optimizes according to the outside circumstances and the current conditions of the Energy Internet to fit in the Energy Internet so that the Energy Internet achieve its optimum and become smarter. In this way, Energy Internet provides such an open and transparent platform where unlimited providers and consumers trade.

### *1.2. Related work*

After NIST (National Institute of Standards and Technology) proposed the idea of “Smart Grid”[3], many researches have been conducted to study the framework of P2P energy system and its performance. Chenghua et al [4] introduced game theory into the bidding system of P2P trading and the simulation result validate the technical feasibility that P2P can be applied to balance local supply and consumption. Chankook et al. [5] compared 5 P2P electricity trading cases about their business entities, customers, trading channels, value propositions and profit structures and attached great importance to energy storage devices in the future P2P energy system. Chao et al. [6] achieved an equilibrium between the supplier nodes and consumer nodes based on k-means analysis and linear optimization of historical smart metering data, providing guidelines for better planning P2P networks. Yue et al [7] propose a general evaluation method to evaluate the economic performance of P2P energy system and the simulation results showed that it can be applied to identify the possible value and generate the performance index of P2P systems.

## 2. P2P electricity system model

### *2.1. Model component*

The demand side of the electricity system is users that consume electricity while the supply side consists of PV panels, wind turbines, cells and state grid. We supposed the price of state grid to be stable compared with other models in the system and its affordable load is large enough to sustain the peak demand and the volume of cells meet 24 hours demand in the net. Thus, we built up a P2P electricity system model as shown in figure 1. In this P2P net, renewable stations such as PV panels and wind turbines are purely supplier node, they can sell generated power to state grid or to the consumer nodes in the net. And state grid and cells can buy or sell its electricity.

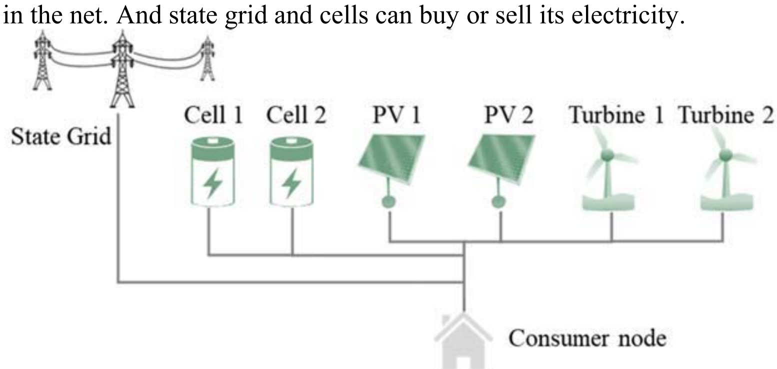


**Figure 1.** P2P electricity system model

There are two different electricity pricing modes. The buying and selling price of state grid is fixed ($P_{grid}$ and $P_{ongrid}$) and only change with different time periods (peak period and valley period). The price of selling to consumer nodes is varying according to the market and lower than the fixed selling price ($P_{grid}$) because the state grid can always supply enough electricity to the net. And the real-time selling price should be higher than both its cost and $P_{ongrid}$to get higher profit.

$$E_{supply} \approx Demand \tag{1}$$

$$P > P_{ongrid}, P > Cost, P < P_{grid} \tag{2}$$

Considering that the demand of consumer nodes changes frequently, in order to simulate real-time trading, the trading frequency should be as small as possible, therefore in this research we set the transaction to 1 minute. The price is adjusted automatically based on previous transactions. Then if the price is adjusted after every single transaction, the price may be increased or decreased rapidly, so the price is adjusted every 60 transactions (1 hour) in this model. In this way, the selling price is adjusted in real time and can reflect the different price during peak period or valley period. And we set the period of the model to 24hours according to the demand pattern.

### *2.2. Transaction flow*

In the P2P net model, solar panels and wind turbines can sell the electricity to consumer nodes, state grid and cells, cells can output its electricity to consumer nodes or grid, and the grid can sell its power to cells or consumer nodes. The electricity flow is depicted as figure 2.

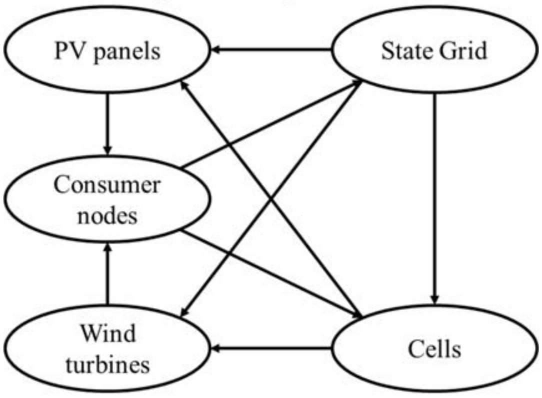


**Figure 2.** Electricity flow of the P2P electricity net

Different from the traditional centralized electricity transaction, the P2P transaction signal is sent out by consumer nodes, and the supplier nodes (state grid excluded) give the available power and price (The price on the electricity is measured by power). The prices are ordered from lowest to highest and consumer nodes buy electricity from the lowest price to a higher price until the total demand is satisfied. If there is surplus electricity, it will be sold to the grid. And if the demand cannot be satisfied, the grid will fill the shortage. After the transaction is completed, each supplier node adjusts its price of the next transaction according to the transaction result. The transaction interval is 60s and the output power of every supplier nodes is constant. The transaction flow is shown in figure 3, where $P$ stands for electricity price, $E$ stands for output power, and $Tr$ stands for the trading amount.

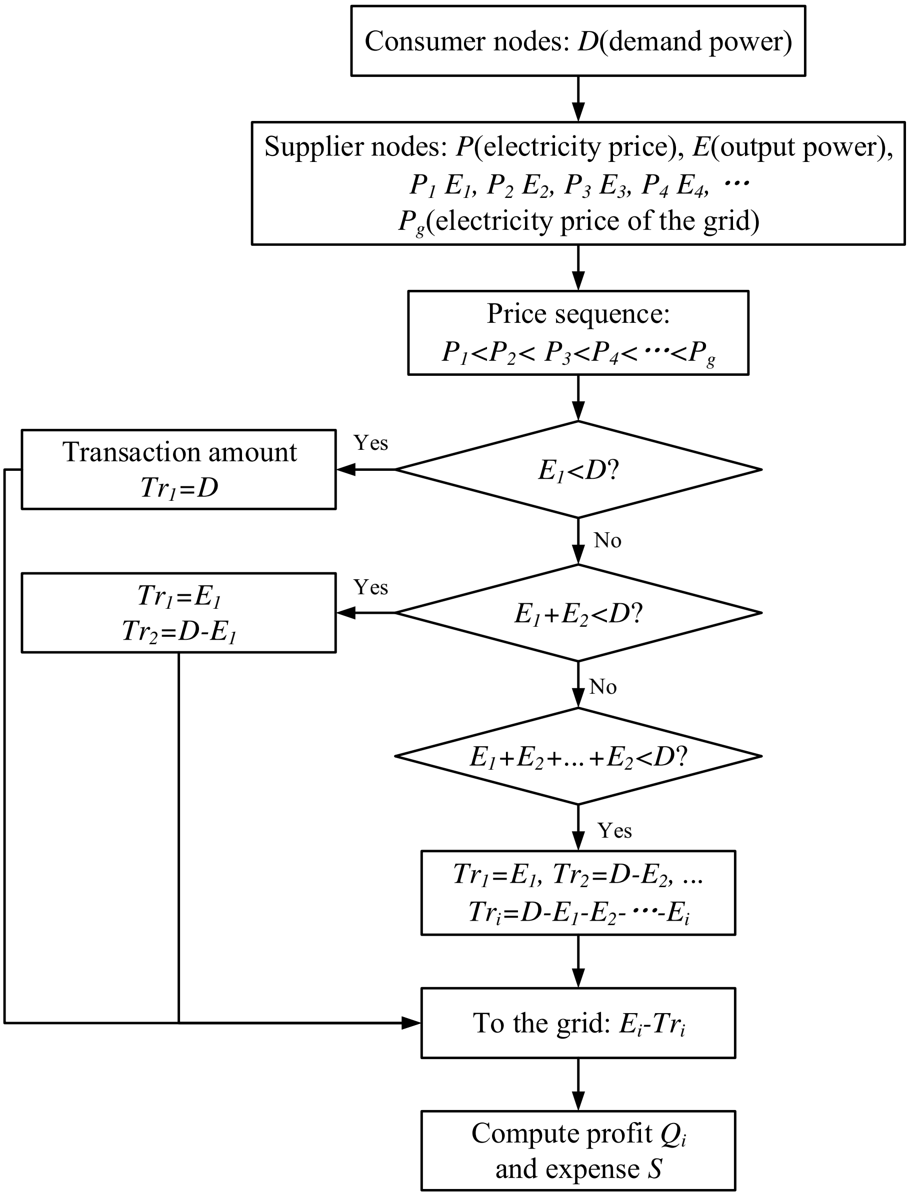


**Figure 3.** P2P transaction process for the proposed system

Total profit of a supplier node is:

$$Q_i = T \cdot (Tr_i \cdot P_i + P_{ongrid} \cdot (E_i - Tr_i)) \tag{3}$$

where $T$ denotes the transaction period (60s in this model).

Total expense of the consumer node is:

$$S = T \cdot (Tr_1 \cdot P_1 + Tr_2 \cdot P_2 + \ldots + Tr_i \cdot P_i) \tag{4}$$

It is worth noting that in a single transaction, each supplier node except for the grid can only have one role, that is, the supplier or the consumer, and the total transaction revenue is the difference between the profit of supplier nodes and expense of consumer node. If the demand increases between two transactions in one minute, the grid fills the electricity gap. If the demand decreases, the excess power is connected to the Internet, and the fluctuation duration is less than 60s. Consumers should bear the additional cost caused by fluctuations.

In addition to the above trading ideas, P2P transaction can also adopt two modified trading methods as follows:

1) Non-fixed cycle transactions measured by electricity. This method follows the measurement method of traditional power transaction, consumer nodes give the electricity demand rather than power demand during the transaction, and each power supplier provides the output power and price, and the consumer nodes select the lowest price preferentially to complete the transaction. However, under this transaction mode, the user's power consumption will change from time to time, making it hard to determine both transaction duration and supply power and eventually influence the next transaction.

2) Non-fixed cycle transactions measured by power. First, the consumer nodes gave the power demand, each power supply node provides the output power and price, and the consumer nodes select the lowest price preferentially to complete the transaction, and the final billing is the product of power, price and time, wherein the power supply time is determined by the user, and the supply time is obtained when the transaction is accomplished. If a new consumer node enters or some nodes quit, the next transaction is started, and each supply nodes give the output power and updated price. The advantage of this transaction mode lies in that the transaction is flexible and can be performed in real time according to the change of demand.

## 3. P2P strategies

In free bidding market, unlike centralized markets, each node should develop his own operation strategy and bidding strategy. In this research different operation strategies and bidding strategies were formulated for different suppliers to make the model more accurate. Also, these strategies were applied in the following verification section.

### *3.1. Operation strategies*

Operation strategies were developed to control the output power of each supplier node. If the node does not participate in the transaction, the output power is zero, and the transaction process is independent of operation strategies. The operating strategies for each power supplier nodes are as follows:

The access to the grid is to make the P2P network more flexible, and it acts as a supplier node when selling electricity to other nodes and consumer when buying.

The operation of PV panels and wind turbines depends on their running costs that are always low once the facilities are established. Therefore, in order to ensure the maximum profit, they should be involved as online suppliers when electricity can be generated. Since the power generation capabilities of the two kinds of suppliers depend on weather conditions, the output power and operation condition vary over time.

The main role of cells in the net is peak shift, so it is advisable to sell electricity during peak hours of demand of valley hours of power generation and to buy electricity during valley hours of demand of peak hours of power generation to increase the use of local renewable energy. And considering the necessity to maximize the income in the transaction, three strategies with increasing complexity are proposed:

- Strategy 1. The running time and power record of PV panels and wind turbines are obtained according to the historical weather data. Cells buy electricity from the market when PV panels and wind turbines are running and sell electricity when not.
- Strategy 2. Cells sell electricity when PV panels and wind turbines are not running or during the peak hours and buy electricity in the rest time according to the historical data of daily electricity consumption of consumer nodes. PV and wind output power are acquired by real-time monitoring rather than historical data.
- Strategy 3. First cells get involved in pre-transactions and set initial selling price according to historical data, if the later selling price is lower than the initial price, cells buy electricity from

the market. And if the later selling price is higher than the initial price, cells sell electricity to the market. In addition, the output power of PV panels and wind turbines is monitored in real time, and cells sell its electricity when the output is zero. Since there is a waste of energy when multiple cells participate in the pre-transaction stage, a probability is set that cells will also purchase electricity even when the pre-transaction price is higher than the initial price.

Operation strategies for cells:

$$V < E_{out}, E_{out} = 0 \tag{5}$$

$$V > Capacity - E_{in}, E_{in} = 0 \tag{6}$$

*3.2. Bidding strategies*

In this model, bidding strategies were developed to simulate the real market among those supplier nodes. The supplier nodes need to adjust their prices according to the previous transaction result. The transaction result refers to the power supply of the supplier nodes, the transaction profit, and $P_{ongrid}$.

*3.2.1. Bidding conditions.* Four bidding conditions are listed as follows:

Condition 1: according to profit expectation. Each supplier node should set a profit expectation, and if the profit in the previous 60 transactions in an hour (bidding period) is larger than profit expectation, the node raises its selling price and lower its price otherwise. And the profit expectation should be larger than $60\Sigma E \cdot P_{ongrid}$ (the profit expectation than can get if sell the electricity to the grid).

Condition 2: according to the ratio of the profit $Q_i$ to transaction amount $Tr_j$. If the ratio gets higher, then the node raises its selling price and lower its price otherwise.

$$P_{j+1} > P_j, \ if \ \frac{\sum_t Q_{i,j.t}}{\sum_t Tr_{i,j.t}} - \frac{\sum_t Q_{i,j.t}}{\sum_t Tr_{i,j.t}} > 0 \tag{7}$$

$$P_{j+1} < P_j, \ if \ \frac{\sum_t Q_{i,j.t}}{\sum_t Tr_{i,j.t}} - \frac{\sum_t Q_{i,j.t}}{\sum_t Tr_{i,j.t}} < 0 \tag{8}$$

where subscript index $j$ denotes the $j$th bidding and $\sum_t Q_{i,j.t}$ denotes the total profit of the $i$th supplier node during the $j$th bidding (60 transactions).

Condition 3: according to the ratio of transaction amount $Tr_i$ and power output $E_i$.

$$P_{i,j+1} > P_{i,j}, \ if \ \frac{\sum_t Tr_{i,j,t}}{\sum_t E_{i,j,t}} > r_0 \tag{9}$$

$$P_{i,j+1} < P_{i,j}, \ if \ \frac{\sum_t Tr_{i,j,t}}{\sum_t E_{i,j,t}} < r_0 \tag{10}$$

where $r_0$ denotes the defined baseline of the ratio.

Condition 4: according to the regularity of electricity demand. The price is increased when the demand increases and is reduced when the demand decreases.

*3.2.2. Bidding methods.* Two bidding methods are listed as follows:

Method 1: Random algorithm. The increase or reduction range is random but the basic principle that the electricity price shall be lower than $P_{grid}$ and higher than $P_{ongrid}$ should be met.

$$P_{i,j+1} = P_{i,j} + Rand \cdot \left(P_g - P_{i,j}\right), \ if \ P_{i,j+1} > P_{i,j} \tag{11}$$

$$P_{i,j+1} = P_{i,j} - Rand \cdot (P_{i,j} - Min\left(P_{ongrid}, Cost\right), \ P_{i,j+1} < P_{\boldsymbol{i},j} \tag{12}$$

where $Rand$ is a random number varies from (0,1).

Method 2: Proximity random algorithm. The increase or reduction range is random and determined by the distance to the maximum or minimum price in the last bidding. Also, the basic principle should be met.

$$P_{i,j+1} = P_{i,j} + Rand \cdot (\underset{i}{Max}(P_{i,j}) - P_{i,j}),\ if\ P_{i,j+1} > P_{i,j} \tag{13}$$

$$P_{i,j+1} = P_{i,j} - Rand \cdot (P_{i,j} - \underset{i}{Min}(P_{i,j})),\ P_{i,j+1} < P_{i,j} \tag{14}$$

## 4. Simulation result

Since we adopted the random value in the bidding strategies, we simulated the model for 30 times to get more reliable results.

### 4.1. Initial value

Initial values of this model are listed in table 1.

**Table 1.** Initial values of the P2P model

| | |
|---|---|
| $P_{grid}$ | 6 am~10 pm:￥0.617/kWh<br>10 pm~6 am:￥0.307/kWh |
| $P_{ongrid}$ | ￥0.127/kWh |
| Demand | Collected real-time data |
| Cell volume | 60kWh×3 |
| Cell power | Input: 6kW<br>Output: 5kW |
| PV output power | Real-time ideal data |
| Wind turbine output power | Calculated real-time data |
| Initial price in a transaction period(24h) | $Rand \cdot P_g$ |
| PV panel cost | ￥0.280/kWh (calculated value) |
| Wind turbine cost | ￥0.300/kWh (calculated value) |
| Cell cost | ￥0.285/kWh (calculated value) |

Initial strategies of this model are listed in table 2.

**Table 2.** Initial strategies of the P2P model

| | |
|---|---|
| Cell operation strategy | Bidding strategy 1 |
| Cell bidding condition | Bidding condition 1 |
| PV bidding condition | Bidding condition 1 |
| Turbine bidding condition | Bidding condition 1 |
| Cell bidding method | Bidding method 1 |
| PV bidding method | Bidding method 1 |
| Turbine bidding method | Bidding method 1 |

### 4.2. Result analysis

Figure 4 shows the price curves of each supplier nodes in the 30 simulations. Though the initial price is random in a specific range (from 0 to $P_g$), the final prices tend to converge to the same value. Figure 5 shows the mean prices of the 30 simulation results. Supplier nodes with the same type have a similar pattern. The prices of these nodes will approach $P_g$ gradually and affected by different prices of the grid in different time. Also, the prices of PVs and turbines react to the grid with a certain delay.

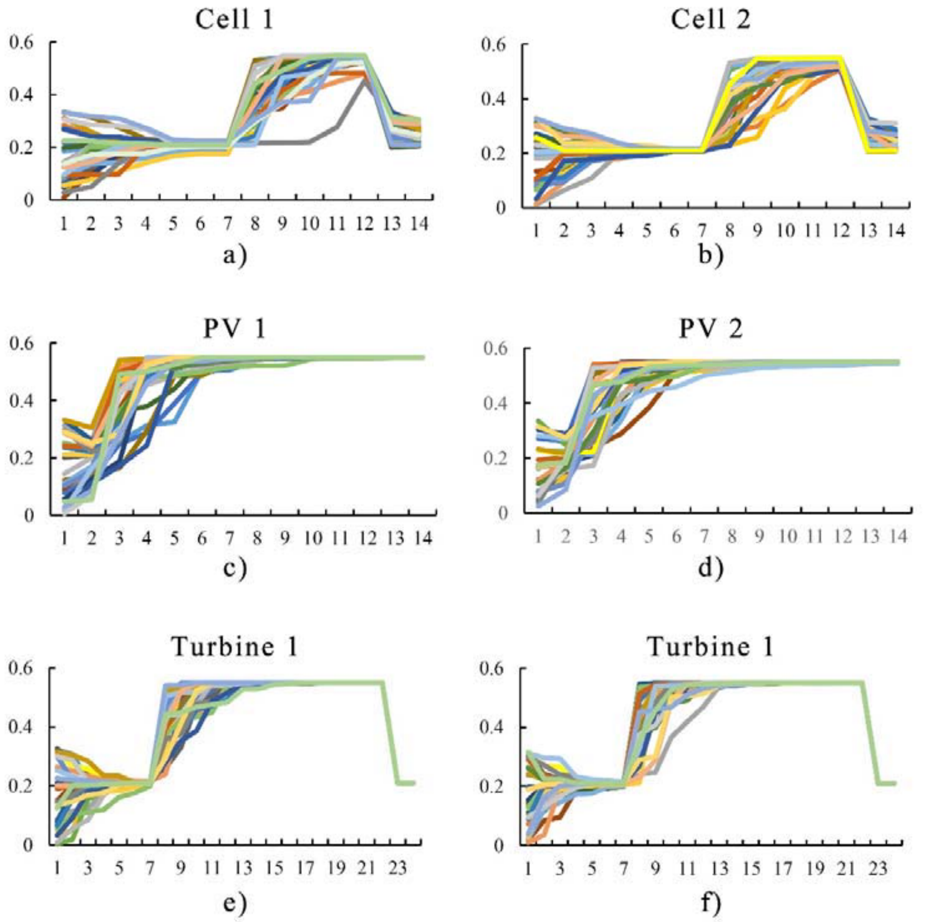


**Figure 4.** Prices of the supplier nodes in a transaction period(24h)

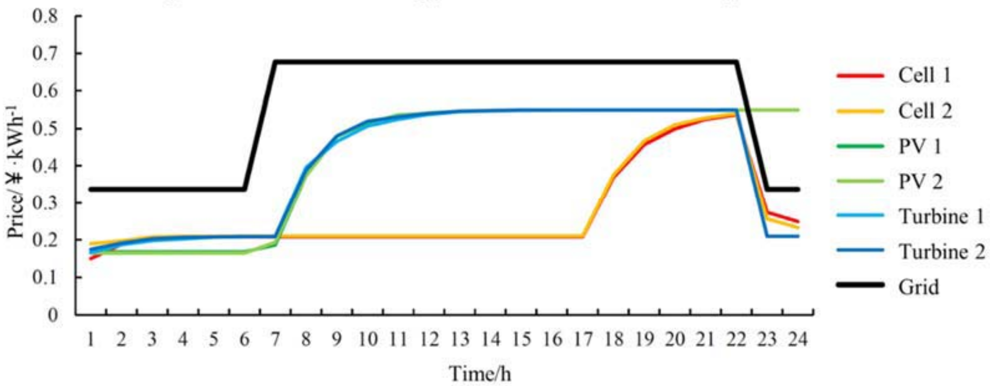


**Figure 5.** Mean prices of 30 simulation results

From figure 6, we can see that the supplier nodes with the same type have little difference in transaction amount. PV panels and wind turbines have the largest amount of output electricity followed by cells. The electricity bought from the grid is 13% as much as the electricity generated by a single PV panel. The standard deviation values show that transaction amount tends to be stable as the initial value varies. As figure 7 shows, the profit of PV panels and wind turbines is far larger than cells, but each node has positive profit, guaranteeing the long-term running of the system.

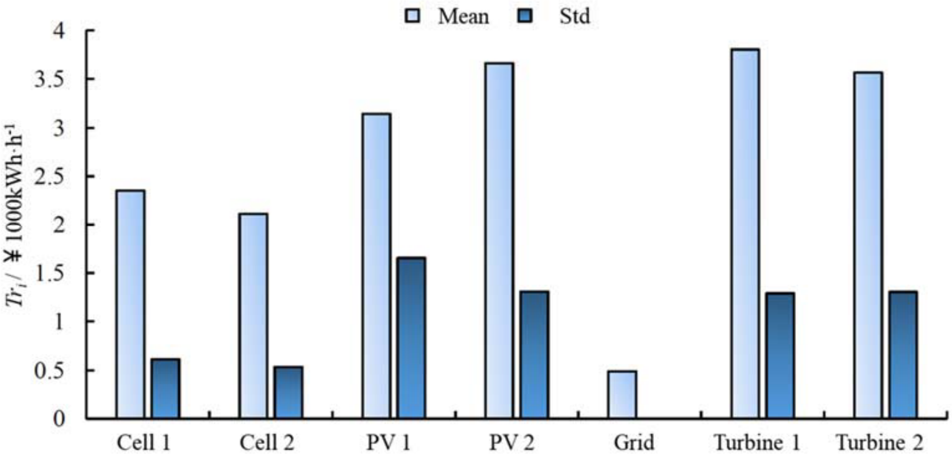


**Figure 6.** Mean value and its standard deviation of total transaction amount of each supplier node

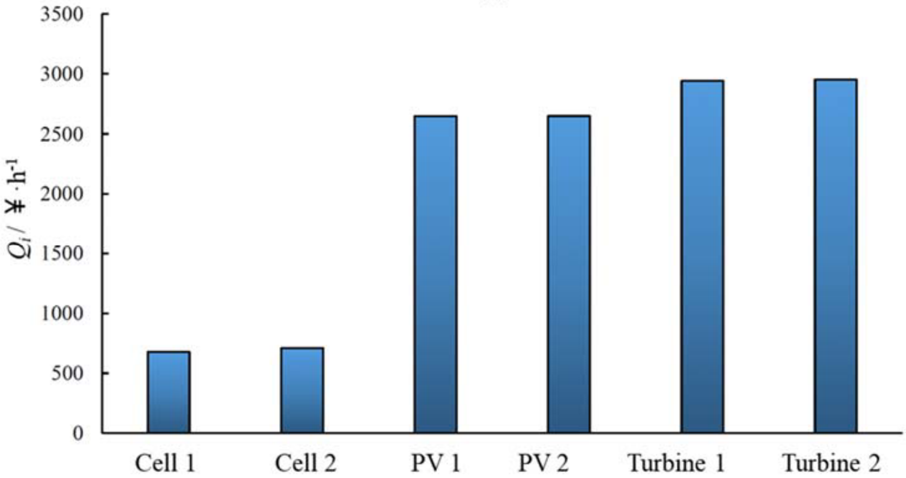


**Figure 7.** Mean value of total profit of each supplier node

## 5. Conclusion

In this paper, we proposed a new bidding mechanism of P2P electricity system for supplier nodes and consumer nodes. Basic strategies were developed for supplier nodes and the simulation results show that the proposed system and strategies worked well and could achieve benefits and thus could be applied to the real electricity market in a district with various kinds of renewable energy. Soon, we will make more comparison among those strategies we have proposed. As for the future research, we will develop more operation and bidding strategies and build up a more sophisticated system integrated with heating and cooling transaction.

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