Creating an educational computer game “Modeling bid auction in the electricity market”

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Abstract. The goal of the game created by the authors is to study the mechanisms of the electricity market and to shape students' economic knowledge. In the course of the game, abilities are formed to analyze the current situation on the electric power industry market, to plan and predict the development of events one step further in order to achieve their goals. And within the framework of difficult situations, make the choice of the most effective ways to solve economic problems.

1. Introducing
A pedagogical game is a process of interaction between a teacher and a student. As a result of the interaction, the transfer and assimilation of competencies provided by the content of training takes place. An important task of gaming technology is educational tasks. Games should help students learn material and broaden horizons. Professional games contribute to the activation of students, train memory and allow students to develop professional speech skills [1]. The most effective when learning new material are operating games. The authors developed an operating game that has no analogues in Russia.

2. Electricity market participants in Russia

2.1. Electricity markets
In Russia, in the wholesale market, we will call them market players: sellers, buyers, infrastructure organizations. In general, in the wholesale market generating companies, consumers, international power trading operators, distribution networks and grid companies may be both sellers and buyers of electricity and power [2].

2.2. Markets participants
Suppliers are generating companies whose installed capacity is at least 5 MW for groups of points of delivery. In the game they are represented by Generator-players [3].

Buyers include all legal entities that have met the requirements of the trading system administrator to join the wholesale market. This category includes independent energy sales companies, guaranteeing
suppliers, large consumers of electricity and PJSC Inter RAO UES to purchase for the supply of electricity to neighboring countries [4].

Infrastructure organizations include entities that do not directly generate or consume electricity, but somehow provide for their delivery from the generator to the consumer, as well as payment for the services delivered. As part of the business game, infrastructure organizations appear in the teams of the Technical and Commercial Operators and make various adjustments and external disturbances into the game.

2.3. Playground
A commercial wholesale market operator enables trading in electricity market. Commercial operator accepts bids from wholesale market buyers and sellers. Suppliers and consumers bids indicate volumes of electricity purchased or produces broken down by hours for the next day. The price is determined by balancing supply and demand, even before the start of the actual delivery, on the basis of the received bids. The price is determined for each node in accordance with the calculated market model and is calculated for each hour of trading day [5].

In this game, buyers are not considered active players. Only sellers (Generators), Commercial Operator and Technical Operator are involved. Competition in the power industry is a struggle between participants in the energy market, which leads to the modernization and development of the industry, improving the quality of a product or service. Competition forces participants to reduce the price of their product or service, reducing production costs, and introducing new technologies into the production process in order to be in demand in the market [6].

Based on the analysis of models for the qualitative presentation of competition mechanisms occurring in the electricity market, the pool market model shown in figure 1 is selected as optimal for the gaming environment. The mechanism for determining the equilibrium price based on bids submitted for auction is shown in figure 2.

![Figure 1. Model “Pool”](image1)

![Figure 2. Determination of the equilibrium price in a pool market.](image2)

When the costs of generated power are optimized (or, in the case of the market, for the amount of electricity supplied), linear approximation [7] of the non-linear relationship \(E_{gen} = f(W_{gen})\) is performed:

\[
E_{gen,i} = E_{gen,0} + P_{gen,i} \cdot W_{gen,i}
\]

where:
- \(W_{gen,i}\) is the volume of electricity supply;
- \(E_{gen,i}\) - the cost of the volume of electricity supply;
- \(P_{gen,i}\) - relative cost increase (RCI) or cost;
- \(E_{gen,0}\) - initial costs (fixed).

3. Game stages description
The starting point of the game will be the system scheme is presented in figure 3.
Figure 3. System scheme

Generators own power plants of different types, a certain starting capital. Power plant production is characterized by the relative cost increases (RCI) [8]. This game is designed to qualitatively reflect the processes occurring in the electricity market, so a number of assumptions have been made: the network is homogeneous; losses in the network are not taken into account, incorporated into the load value; generation provides all consumers without shedding.

The following restrictions are taken into account: restrictions on the power of generators; restrictions on power flows.

1. At the first stage of the game, generators submit price offers, taking into account the type of fuel. A price offer is a document reflecting the intention of a wholesale market player to buy or sell electrical energy in a certain group of supply points and establishes the player’s planned purchase (sale) volumes of electrical energy for each hour of the day, indicating the proposed purchase (sale) prices for each of the planned volumes electric power [9].

In the competitive selection of the day-ahead market, the volume corresponding to the total power of the player takes part. The price offer consists of 24 one-hour sub-offers. Each one-hour sub-offer consists of three monotonously increasing price-volume steps. For clarity and speeding up the process of the game, the day is conventionally divided into 4 stages. It is accepted as 4 game hours per day.

2. At the second stage, the initial offer of the player-generator is modified by the Commercial Operator [10]: for the volume corresponding to the minimum value of the adjustment range (Pmin), the price-receiving part is added; the volume of the last stage is limited to the volume corresponding to the maximum value of the adjusting range (Pmax); prices of volumes are limited to the offer for selection of the composition of the included generating equipment.

The technical operator, in turn, sends to the market players a preliminary trading schedule.

3. Here external influences can come into play, in the form of accidents at generating equipment, power supply outages, flow restrictions, which will accordingly affect the generation and consumption of electricity, and hence the volume of purchases and sales in the day-ahead market.

Financial calculations between the players are carried out by commercial operator. In the game, the calculation is carried out at the end of one day [11].

4. Discussion
At the first stage, all teams receive the initial data for the game. The system scheme, shown in figure 3, will have a connection between the two systems, so that the random event in the form of a flow restriction on this connection plays a role in the formation of the node prices, rather than the equilibrium price.

The game begins with the fact that the Generators form price offers for each game hour in graphical form (figure 4) for themselves and in the table 1 form for the Commercial Operator.

| Hour | Gname | P, MW | C, rub/MWh |
|------|-------|-------|------------|
| 1    | G1    | 100   | 38         |
|      | G1    | 100   | 67         |
The Technical operator gives the forecast load schedule to the Commercial operator. After receiving all the necessary data, the Commercial operator forms an equilibrium price for each hour of the day and sends this data to the Technical Operator to determine trading schedules for each Generator. The mechanism for determining the equilibrium price based on bids submitted for auction by Generators and the load value for each hour is shown in figures 5, 6, 7, 8.

![Figure 4. Offers of Generators for the 1st hour.](image)

![Figure 5. Determination of the equilibrium price for the 1st hour.](image)
Figure 6. Determination of the equilibrium price for the 2nd hour.

Figure 7. Determination of the equilibrium price for the 3rd hour.

Figure 8. Determination of the equilibrium price for the 4th hour.

Equilibrium prices for each hour of the day:
1st hour - 72 rubles / MW * h;
2nd hour - 50 rubles / MW * h;
3rd hour - 80 rubles / MW * h;
4th hour - 100 rubles / MW * h.
On the basis of equilibrium price data, the Technical Operator generates charts with power distribution for each hour and trading schedules for each Generator for a day are presented in table 2.

Table 2. Trading schedules for Generators.

| Hour | 1  | 2  | 3  | 4  |
|------|----|----|----|----|
| G1   | 200| 100| 200| 250|
| G2   | 200| 100| 250| 250|
| G3   | 100| 0  | 150| 250|
| G4   | 300| 200| 300| 150|

The above trading schedules are sent to Generators, this is their power generation plan for the next day.

5. Conclusion

The basis of the gaming environment is the day-ahead market. Competitive selection of bids from generating units and forming of trading schedules for each Generator is carried out. Random events are introduced into the game in the form of generation outages and load decrease, flow restrictions over the section, in order to cause deviations from the trading schedule. Generators form their prices for generated power within the limits of cost characteristics. Each Generator-player knows only his own initial data and the optimal solution to the problem does not come immediately.

The developed game is a complete analogue of the existing electricity market in Russia. This interactive technology will allow students to study the material not only theoretically, but also become full-fledged participants in the electricity market.

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