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# Gaming Experiments for Analysis of Pricing Mechanisms at Electricity Markets

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**Abstract:** A method is proposed to support management policy design and verification in complex cyber-physical & human systems (CPHS). A hierarchy of interconnected formal models is built to provide the multi-faceted view of the conflict situation lying in the core of a certain management problem. Game-theoretical analysis reveals the problem and mechanism design suggests the alternative management policy. Its efficiency is verified by multi-agent simulations and gaming experiments with experts. The approach is illustrated using the examples of two market manipulation issues arising on the Russian wholesale electricity market.



*Keywords:* management policy verification, game theory, business games, locational marginal price, oligopoly, congestion management.

## 1. INTRODUCTION

A system including at least one human becomes a complex system from the point of view of control. According to Novikov (2016), the control strategy in such an *active system* (the concept suggested by Burkov and Lerner (1971)) must account for reactions and interests of individuals being a part of it. An administrative body should care for psychological aspects of employees, about their limited capabilities, predilections, opportunities of strategic behaviour, etc.

Unfortunately, nowadays no single theory or a methodology exists that could provide comprehensive look at all relevant aspects of control in such systems. Therefore, development of a reliable and efficient management policy demands multidisciplinary analysis and justification. We propose a technology for such analysis, which combines traditional managerial practices, economics, game-theoretical analysis, and policy appraisal with business games played by humans and software agents.

We illustrate some challenges of policy analysis on the example of locational marginal pricing (LMP) in electricity markets. The market pricing mechanism is considered as a management policy, which aims at efficient economic planning of power flows in a complex CPHS (an energy system) under technology and security constraints.

Congestions of power transmission lines brake market into a number of local markets with imperfect competition. The problem studied in this paper is a sort of a non-cooperative game, where a number of selfish market players share the electricity demand at one local market. In such a situation, each player attempts to maximize his/her profit independently. The criterion of rational players' behavior at an oligopoly market is the Nash equilibrium (i.e., a collection of players' strategies such that each player cannot increase his or her payoff by unilaterally changing the strategy).

When applied to electricity markets, our technology for the analysis of a management policy includes the following approach and challenges.

1. Evidence from industry provides motivation for the study. In particular, below we consider several cases of market manipulations from antitrust authorities. In order to detect such cases, it is important to classify possible strategies for all possible combinations of affiliation. Taking high probability of manipulation into account the market pricing mechanism can be modified to decrease the power of price-makers.
2. The economic theory, namely, equilibrium analysis applied to electricity markets (Harris, 2011) gives a normative view, an understanding of an ideal situation.
3. Game-theoretical analysis of selfish behavior of market parties (see Ayzenberg and Kiseleva, 2013 for the analysis of the oligopoly), instead, explains why the real world can deviate from the ideal model. The key challenge at this stage is to simplify the situation getting rid of irrelevant details that shade the main point.
4. Even after simplification the comprehensive theoretical analysis of real-world games can be very complex, so, when needed, it is accompanied with computer simulations of the

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conflict situation played by intellectual software agents (see Krauze et al., 2004) trying to learn the optimal strategy in a series of gameplays.

5. Although games with intellectual agents typically reveal the main pitfalls of the policy, the final conclusion on policy efficiency is made on the basis of games played by humans, preferably, by the experts in the subject area. However, we performed our experiments with students, who successfully "hacked" the standard LMP mechanism of using strategies predicted by game-theoretic analysis but also in some surprising and unpredicted ways.

Below we apply our approach to the existing policy (LMP), but the same analysis should be done when a prospective policy is implemented, which is to solve the revealed problems of the current policy.

## 2. ELECTRICITY MARKETS AND MANAGEMENT

The wholesale electricity market is an important element of a liberalized power supply system. Theoretically, market equilibrium based on nodal prices (locational marginal prices) (see Harris, 2011) is socially efficient, but transmission and voltage constraints in a grid may give market power to some parties (see Ayzenberg and Kiseleva (2013), Xu and Low (2015), and Saad et al. (2012)). As a result, calculation of the efficient outcome is distorted and social welfare optimality may be lost.

To cope with market manipulations numerous indicators of market power were proposed (e.g., Murillo-Sanchez et al. (2001)) and alternative market designs were considered by Singh (1998), Wilson (2002), Holmberg and Lazarczyk (2015), Biskas et al. (2014) and others.

We suggest a context-aware approach to the choice of an anti-trading solution. Firstly, the violated part of an electricity market should be localized by detecting deviations from perfect competition (similarly to congestion zone detection techniques by Lesieutre et al. (2005), Volodin and Vaskovskaya (2015)). Secondly, a classification of oligopolistic local markets and their problems should be proposed. Every class of zonal markets reduces to the game with relatively small number of players. This game is studied theoretically (Nash equilibria are found) and experimentally (behavioral patterns are learnt from experimental games with students and experts). Finally, the best market mechanism is proposed for every specific zonal market class.

Below we report the experiments for two topical issues met at the Russian electricity market: affiliation of large generators/loads, and congestion constraint manipulation. Both problems originate from the oligopolistic nature of electricity market.

## 3. EXPERIMENTAL SETUP

### 3.1 Gaming platform

The platform for gaming experiments is provided by zTree – Zurich Toolbox for Readymade Economic Experiments, Fischbacher U. (2007), gaming software. The market clearing price (MCP) is calculated either using zTree (for the single-location market) as a solution of a double-sided auction or using MATPOWER Matlab power system simulation package for optimal power flow problems by Zimmerman et al. (2011) (for the multi-location market).

Fifteen graduate and post-graduate students participated in all games divided into groups by 3-5 players in one group each playing together at one market and having $m_i$ generators or $l_i$ demands. Groups are independent of each other. The players were shuffled between games and did not know with whom they were playing. The game lasted 10 steps. At each step player submitted an admissible bid (depending on competition type) for each their generator/demand to the system. At the end of step player received his profit and his goal of game was to maximize his profit at final step. The payoff of generator $i$ was calculated as

$$U_i(t) = (MCP(t) - MC_i)\cdot W_i(t) \quad (1)$$

where $MCP_{(t)}$ is market clearing price; $MC_i$ – marginal cost of production for generators, $W_i$ – power produced and sent to the market.

The payoff of a load is calculated as

$$U_i(t) = (P_i - MCP(t))\cdot W_i(t), \quad (2)$$

where $P_i$ is the maximum price for the electricity that customer $i$ is ready to pay.

### 3.2 Organization of experiments

A series of games was conducted in Skolkovo Institute of Science and Technology in the framework of the educational course "Power markets and regulation". The main goal was to illustrate the effects of strategic behaviour on electricity markets and to give students understanding of how the real electricity market works and how one agent can influence the price. A traditional approach to delivering "Power markets and regulation" courses does not usually include deep knowledge of game theory. In our opinion, it is a big omission; to cope with it we created the software platform and planned experiments to illustrate the possibilities of gaming in electricity markets and to test some of regulation policies.

The first "basic" games (transmission losses and congestion were neglected, the demand was inelastic and known by all players) were conducted for educational purposes and to make students familiar with the system. Then "customized" games were played, those with active demand (designed by V. Chirkin and T. Sayfutdinov) and with congestion constraints (designed by A. Gorbunov and M. Goldstein). Three competition types were considered:

1. Cournot competition (CC): a player bid any capacity of his generator(s) or load(s) from 0 to the real maximum capacity of the generator or the load;
2. Bertrand competition (BC): a player bids any cost of his generator(s) or load(s);
3. Cournot + Bertrand competition (CBC): a player bids both the capacity and the cost.