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Innovative Applications of O.R.

On the determination of European day ahead electricity prices: The Turkish case

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ABSTRACT

Day ahead electricity prices in European markets are determined by double-blind auctions. That is, both buyers and sellers may place anonymous orders with different prices and quantities. The market operator has to solve an optimization problem within an hour to clear the auction and determine the prices for the Day Ahead Market (DAM) which are used as a reference point for the other electricity contracts. All electricity traded at the same time period is traded at the same price, called *market clearing price*. The market operator has to end the algorithm with a feasible solution if the algorithm could not find the optimal solution within the time limit. In this paper, we develop an optimization model to solve the problem with day ahead electricity prices including all the practical considerations in the Turkish DAM. We present a mixed integer formulation and provide methods based on aggregation techniques and variable elimination to solve the problem within the limits of the practical requirements. Using real market data, we show that, aggregation reduces the problem size approximately 60 percent whereas variable elimination provides another 30 percent reduction. We also propose an IP-based large neighborhood search to obtain an initial solution. Empirical evidences coming from the Turkish DAM data indicate the heuristic has a substantial solution quality and the overall suggestions deliver remarkable solution time improvements. This is the first paper in terms of formulating DAM problem in Turkey, developing new approaches to solve it within the time limits of the market, and using real data.

1. Introduction

Electricity energy can be seen as a tradable commodity. It differs from other commodities because it is difficult to store. Therefore electricity generation and consumption have to be in constant balance. This distinct feature of electricity energy makes the trading mechanism both technically and economically complicated. The supply-demand balancing problem and other system constraints require a central authority and a common market structure.

The liberalization politics around the world lead to fundamental changes in the electricity markets. Sioshansi and Pfaffenberger (2006) provide the liberalization experiences of several countries during early periods. Starting with liberalization of electricity markets, the traders are capable of buying and selling electricity energy for their needs. Electricity energy could be traded either bilaterally or via an exchange. In long-term trades, two participants – one buyer and one seller – negotiate and agree on the terms of bilateral contracts. The price and other detailed information are limited to the parties involved. Using an exchange system, traders offer their bids in the markets such as day-ahead and day-in (a few hour-ahead). Among these trading mechanisms, determination of the day ahead electricity prices is of central importance in all deregulated electricity markets.

In Europe, power exchanges organize a daily auction to determine the electricity prices for the delivery of electricity next day. The prices established in this market form a reference point for the transactions in the intra-day, futures, forwards, and over-the-counter markets. Power exchanges are synchronized with Transmission System Operators (TSOs) to get technical clearance over the grid. Exchanges provide transparency and help the traders to find a better market price and an appropriate counterpart for their transactions. Bichpuriya and Soman (2010) give a brief review on these exchanges worldwide and their trading mechanism. There is also a real-time market for balancing and ancillary services usually operated directly by the TSO.

A TSO is responsible for the physical operations of the electricity market and each country has a single national TSO (Meeus, 2011) that is responsible for its single zone. On the other hand, there is an increasing desire for trading electricity among the different zones to operate the electricity grid systems more efficiently (Serralles, 2006). This trade could happen either by participating competition among zones or by merging multiple zones into one complex-zone.

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In Europe, independent power exchanges operate the financial markets under the physical network constraints. Some power exchanges split their markets into different zones so that each zone may lead to different market price. For instance European Power Exchange (EPEX) divides its network into three zones (France, Germany/Austria and Switzerland) so that different prices could appear in different zones after this market splitting procedure (Martin, Müller, & Pokutta, 2014). On the other hand, several exchange companies also act together to couple their markets. For instance, Nordic NPS region has coupled Denmark, Estonia, Finland, Lithuania, Norway, and Sweden markets by using SESAM coupling system since 2007 (SESAM, 2014) whereas CWE region has coupled Belgium, France, Germany, Luxembourg, and the Netherlands markets by using COSMOS coupling system since 2010 (COSMOS, 2010).

On top of these exchanges, European Market Coupling Company (EMCC) was founded in 2008 (EMCC, 2009) to control the flow between regions under the principles of ITVC (Interim Tight Volume Coupling). In addition, seven power exchanges (APX, Belpex, EPEX SPOT, GME, Nord Pool Spot, OMIE and OTE) have been working on PCR (Price Coupling of Regions) project since 2010. EMCC system closed down after its successor NWE region (Denmark, Finland, Norway, Sweden, Great Britain, Belgium, France, Germany, Luxemburg and the Netherlands) price coupling was launched in February 2014. Lastly, PCR solution was achieved for NWE and SWE (France, Spain and Portugal) regions by using EUPHEMIA (Pan-European Hybrid Electricity Market Integration Algorithm) in May 2014 (EUPHEMIA, 2014). However, market splitting and coupling problems are beyond the scope of this article.

Among electricity markets, the Day Ahead Market, which determines the electricity prices for the delivery of electricity next day, has the central attention. The prices coming from this market are usually accepted as a reference point for the other electricity markets and bilateral contracts. There are two main approaches to Day Ahead Market design: USA Pool Models and European Exchange Models. Maria (2010) provides advantages and disadvantages of these approaches as well as their pricing regimes.

In the Pool Models, typically demand is estimated and suppliers provide their capacities and cost information. Unit commitment and economic dispatch problems (Phan & Koc, 2013) are solved to maximize the amount of traded contracts. If the cost is not recovered for some agents, additional side payments (uplift, non-linear price regimes) are available for those agents (Gribik, Hogan, & Pope, 2007). Real life instances of unit commitment and economic dispatch problems generate large scale optimization problems. Industrial solutions of these problems typically concentrate on the Lagrangian relaxation methods (Araoz & Jornsten, 2011; Li & Shahidehpour, 2005; Phan, 2012). Recently, they also focused on the general purpose integer programming solvers by applying ingenious solution techniques. Carlson et al. (2012) describes the success story for the Midwest Independent Transmission System Operator, and it is a remarkable example for OR applications in energy markets. The problems appeared in the pool context are requiring different perspective with respect to exchange models so we will only focus on the exchange models to maintain the integrity of the paper. However, Van Vyve (2011) provides a noteworthy comparison of these models.

European Exchange Models include both demand and supply side into their combinatorial auction mechanisms. On these exchanges, orders are either accepted or rejected but no side-payment is available (linear price regimes). Some of the orders (e.g. block orders) cause the non-convexity in the mathematical model so the resulted auction problem is NP-Hard to solve (Bichpuriya & Soman, 2010). In most of the real instances, desired linear prices that maximize social welfare simply do not exist. The approaches developed for solving this issue is the main difference between US and the European markets. US markets prefer somewhat deviating from linear pricing whereas the European system solves true linear pricing but executes a suboptimal solution in terms of welfare (Van Vyve, 2011).

Finding an efficient pricing regime is the main challenge for the combinatorial auctions. When all the goods are divisible, the resulting auction problem is a linear programming problem (Xia, Koehler, & Whinston, 2004). The value of LP dual variables gives equilibrium prices. Similarly, strong duality holds if a constraint qualification is satisfied in convex optimization. In that case, the dual variables are also to be interpreted as equilibrium prices (Martin et al., 2014). One of the most important assumptions in a neoclassical economic model is the convexity assumption. Under convexity, it is well-known that the optimal dual variables (shadow prices) define the market clearing prices, where the social welfare is maximized (Araoz & Jornsten, 2011). However, electricity markets have several characteristics that are suffering from non-convexities. In this context, strong duality fails and market equilibrium with linear prices cannot be obtained (O'Neill, Sotkiewicz, Hobbs, Rothkopf, & Stewart, 2005; Ruiz, Conejo, & Gabriel, 2012). To deal with this non-convexity, O'Neill et al. (2005) proposes to take the dual variables of restricted primal problem after fixing integer variables to their optimal value and use optimal dual variables to form contracts yielding an equilibrium situation. Ruiz et al. (2012) minimizes the duality gap caused by integer constraints by using linear prices in such a way that producers recover their costs.

There are other models proposed in the literature to solve the day ahead problem but those models do not include all practical constraints used by current exchanges and there is no actual data provided to test these suggested models. Zak, Ammari, and Cheung (2012) develop their model based on *bilevel programming* where accept/reject decisions and price decisions are the levels. Meeus, Verhaegen, and Belmans (2009) investigate the restrictions of exchanges using MILP model under representative scenarios. Derinkuyu and Tanrisever (2013) analyze the matching algorithms for DAM in European Electricity Markets and show that those algorithms either heuristically solve the problem or even if optimization is intended, no public information are available about their time or gap performance.

Recently, European market coupling problem gets an attention. Martin et al. (2014) provide a full formulation of the market coupling problem between European day-ahead electricity exchanges. Madani and Van Vyve (2014) present a new formulation for the market coupling which avoids the use of complementarity constraints to express market equilibrium conditions. Both of the studies shows computational results based on real data. Lastly, Boomsma, Juul, and Fleten (2014) combine the day-ahead and day-in decisions, and formulate the bidding problem as a multi-stage stochastic program.

In the day-ahead market, next-day consists of non-overlapping time periods that could be 15 minutes, half an hour, an hour or several hours, and a *clearing price* is set by the auction for each time period. That is, all electricity traded at the same time period is traded at the same price, called *market clearing price*. Bidders can voluntarily participate in the market and give several types of orders (Fig. 1).

European Day Ahead Markets allow the market participants to place three different types of orders: single orders, block orders and flexible orders as explained below.

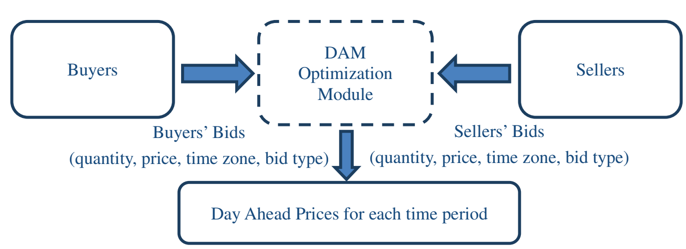

Fig. 1. Day Ahead Market structure.