ARTICLE IN PRESS
JID: EOR [m5G;November 6, 2017;12:6]

European Journal of Operational Research 000 (2017) 1–14

Contents lists available at ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Innovative Applications of O.R.

Revisiting minimum profit conditions in uniform price day-ahead electricity auctions

Mehdi Madani[a,*], Mathieu Van Vyve[b,1]

[a] Louvain School of Management, Université Catholique de Louvain, Place des Doyens 1, bte L2.01.01, Louvain-la-Neuve 1348, Belgium
[b] CORE Voie du Roman Pays 34 bte L1.03.01, Louvain-la-Neuve 1348, Belgium

ARTICLE INFO

Article history:
Received 7 July 2016
Accepted 11 October 2017
Available online xxx

Keywords:
OR in energy
Auctions/bidding
Integer programming
Large scale optimization
Benders decomposition

ABSTRACT

We examine the problem of clearing day-ahead electricity market auctions where each bidder, whether a producer or consumer, can specify a minimum profit or maximum payment condition constraining the acceptance of a set of bid curves spanning multiple time periods in locations connected through a transmission network with linear constraints. Such types of conditions are for example considered in the Spanish and Portuguese day-ahead markets. This helps describing the recovery of start-up costs of a power plant, or analogously for a large consumer, utility reduced by a constant term. A new market model is proposed with a corresponding MILP formulation for uniform locational price day-ahead auctions, handling bids with a minimum profit or maximum payment condition in a uniform and computationally-efficient way. An exact decomposition procedure with sparse strengthened Benders cuts derived from the MILP formulation is also proposed. The MILP formulation and the decomposition procedure are similar to computationally-efficient approaches previously proposed to handle so-called block bids according to European market rules, though the clearing conditions could appear different at first sight. Both solving approaches are also valid to deal with both kinds of bids simultaneously, as block bids with a minimum acceptance ratio, generalizing fully indivisible block bids, are but a special case of the MP bids introduced here. We argue in favour of the MP bids by comparing them to previous models for minimum profit conditions proposed in the academic literature, and to the model for minimum income conditions used by the Spanish power exchange OMIE.

1. Introduction

1.1. Minimum profit conditions and Near-equilibrium in non-convex day-ahead electricity auctions

Day-ahead electricity markets are organized markets where electricity is traded for the 24 hours of the next day. They can take the form of single or two sided auctions (pool with mandatory participation to match forecast demand or auctions confronting elastic offer and demand). The prices set in day-ahead markets are used as reference prices for many electricity derivatives, and such markets are taking more importance with the ongoing liberalization and coupling of electricity markets around the world in general, and in Europe in particular.

Clearing these auctions amounts to finding – ideally – a partial equilibrium using submitted bids describing demand and offer profiles, depending on the utility, production costs and operational constraints of market participants. A market operator, typically power exchanges in Europe, is in charge of computing a market clearing solution.

It is well-known that for a well-behaved convex welfare optimization problem where strong duality holds, duality theory provides equilibrium prices. However, to describe their operational constraints or cost structure, participants can specify for example a minimum output level of production (indivisibilities), or that the revenue generated by the traded power at the market clearing prices should cover some start-up costs if the plant is started. Similar bids could be specified for the demand side. This leads to the study of partial market equilibrium with uniform prices where indivisibilities and fixed costs must be taken into account, deviating from a well-behaved convex configuration studied in classical microeconomic textbooks, e.g., in Mas-Colell, Whinston, and Green (1995). The need for bidding products introducing non-convexities is due in particular to the peculiar nature of electricity and the non-convexities of production sets of the power plants.

* Corresponding author at: Louvain School of Management, Universite Catholique de Louvain, Belgium.
E-mail address: mehdi.madani@uclouvain.be (M. Madani).
1 CORE & Louvain School of Management, Universite Catholique de Louvain, Belgium.

https://doi.org/10.1016/j.ejor.2017.10.024
0377-2217/

Please cite this article as: M. Madani, M. Van Vyve, Revisiting minimum profit conditions in uniform price day-ahead electricity auctions, European Journal of Operational Research (2017), https://doi.org/10.1016/j.ejor.2017.10.024

When considering a market clearing problem with non-convexities such as indivisibilities (so-called block bids in the Pan-European PCR market (Euphemia, 2016)), or start-up cost recovery conditions (so-called complex bids with a minimum income condition also called MIC bids in PCR), most of the time no market equilibrium exists, see e.g., the toy example in Section 2.1 for an instance involving MIC bids, and in Madani and Van Vyve (2017) for an instance involving block bids.

Let us also mention that in coupled day-ahead electricity markets, representation of the network is a particularly important matter. Besides the potential issues due to the simplifications or approximations made to represent a whole network, it is of main importance for participants to understand clearly the reason for price differences occurring between different locations. Economically speaking, locational prices should ideally form a spatial equilibrium, as historically studied in Enke (1951); Samuelson (1952), which could equivalently be interpreted as requiring optimality conditions for TSOs, relating locational price differences to the scarcity and marginal prices of transmission resources.

Near-equilibrium under minimum profit conditions in uniform price day-ahead electricity auctions is the main topic of the present contribution, and is also considered in references (Euphemia, 2016; Gabriel, Conejo, Ruiz, & Siddiqui, 2013; Garcia-Bertrand, Conejo, & Gabriel, 2006; 2005; Ruiz, Conejo, & Gabriel, 2012), which are discussed in Section 3.1 below.

1.2. Contribution and structure of this article

The main contribution of the present paper is to show how to handle minimum profit (or maximum payment) conditions in a new way which turns out to generalize both block orders with a minimum acceptance ratio used in France, Germany or Belgium, and, mutatis mutandis, complex orders with a minimum income condition used in Spain and Portugal. The new approach consists in new bids, which we call MP bids (for minimum profit or maximum payment), and the corresponding mathematical programming formulation is a MILP modelling all the corresponding market clearing conditions without *any* auxiliary variables, similar to an efficient MIP formulation previously proposed for block orders (Madani & Van Vyve, 2015). An efficient Benders decomposition with sparse strengthened cuts similar to the one proposed in Madani and Van Vyve (2015) is also derived. These MP bids hence seem an appropriate tool to foster market design and bidding products convergence among the different regions which form the coupled European day-ahead electricity markets of the Pan-European PCR project.

We start by providing in Section 2.1 a toy example illustrating the key points dealt with in the reminder of the article. It illustrates the issues arising when considering minimum profit conditions, and alternatives to take them into account in the computation of market clearing solutions. We describe in Section 2.2 the notation used and a basic 'unrestricted' welfare maximization problem where such minimum profit conditions are first not enforced, also recalling the nice equilibrium properties which would hold in a convex market clearing setting.

Section 3 is devoted to modelling minimum profit conditions or more generally MP conditions, as with the approach proposed, the statement of a maximum payment condition for demand-side orders is formally identical. After reviewing previous contributions considering minimum profit conditions, we derive economic interpretations for optimal dual variables of a welfare maximization program where an *arbitrary* MP bids combination has been specified. We then develop the core result, showing how to consider MP bids in a computationally-efficient way, relying on previous results to provide a MILP formulation without complementarity constraints nor any auxiliary variable to model these MP conditions. Section 4 shows how to adapt all results when ramping constraints of power plants are considered.

Section 5 derives from the MILP formulation provided in Section 3 a Benders decomposition procedure with locally strengthened Benders cuts. These cuts are valid in subtrees of a branch-and-bound solving a primal welfare maximization program, rooted at nodes where an incumbent should be rejected because no uniform prices exist such that MP conditions are all satisfied. They complement the classical Benders cuts which we show to correspond indeed to 'no-good cuts' basically rejecting the current MP bids combination, and which are globally valid.

Numerical experiments are presented in Section 6. Implementations have been made in Julia/JuMP (Lubin & Dunning, 2015) and are provided together with sample datasets in an online Git repository (Madani & Van Vyve, 2016). They show the efficiency and merit of the new approach, in particular compared to the current practice in OMIE-PCR.

Table 1
Toy market clearing instance.

Bids	Power (MW)	Limit price (EUR/MW)	Start-up costs
D1: Demand bid 1	11	50	–
D2: Demand bid 2	14	10	–
MP1: Offer MP bid 1	10	10	100
MP2: Offer MP bid 2	10	10	200

2. Near-equilibrium and minimum profit conditions

2.1. Position of the problem: A toy example

In the following toy example whose data is provided in Table 1 and depicted on Fig. 1, a bid curve (in blue) represents some elastic demand, the first step of the curve corresponding to the bid

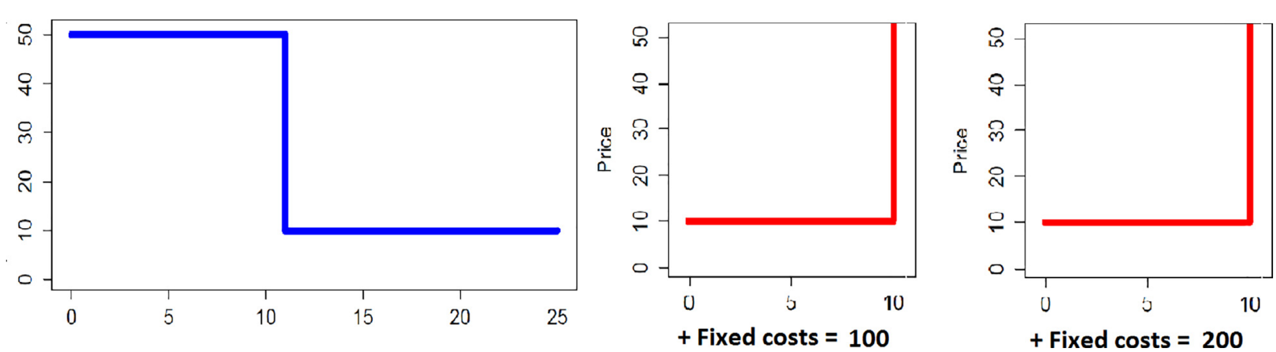

Fig. 1. Marginal cost/utility curves (see Table 1 for related start-up costs). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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