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European day-ahead electricity market clearing model

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ABSTRACT

Following the latest directives, the European Union promoted the integration of local/national electricity markets into one multi-area market, thus allowing the optimal exploitation of the scarce interconnection transmission capacity. In this paper, the authors present a mathematical formulation that explicitly incorporates nearly all market products and transmission constraints currently appearing in the European Power Exchanges (PXs). The proposed clearing model incorporates an optimization problem, formulated as a mixed integer linear programming model, and is solved within an iterative algorithm for the handling of paradoxically accepted block and minimum income orders.

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1. Introduction

1.1. Background and aim

European power exchanges (PXs) constitute marketplaces where two-sided supply (portfolio- or unit-based) and demand orders are effectively cleared in the presence of critical line congestion constraints, and settled in a uniform, marginal price per bidding area. During the last decade, the European Commission has prioritized the creation of a single internal electricity market, aiming at the effective trading of electricity products in different bidding areas and time periods [1].

In this direction, important steps have been achieved lately with the creation of a pan-European day-ahead electricity market. In June 2012 and following the publication of the Network Codes on capacity allocation and congestion management [2] by ENTSO-E (European Network of Transmission System Operators for electricity), seven PXs of the European region launched the Price Coupling of Regions (PCR) initiative [3], which aimed at the integration of the European day-ahead electricity markets. The successful launching of the PCR market clearing took place on February 4th 2014 [4], effectively coupling in this way the CWE (Central-Western European) region and the Nord Pool Spot market. Further important steps in the creation of the pan-European day-ahead electricity market were accomplished with the implicit auctioning of the Spain–France border (13th May 2014 [5]) and the successful coupling of the Italian market with the other European markets on February 24th 2015 [6]. In this way, the integrated European electricity market currently clears on average daily basis more than 4 TWh of electric power. Finally, on May 20th 2015, another important step towards the efficient European electricity market integration was achieved, since the Flow-Based (FB) approach was confirmed to go-live in the CWE region [7].

1.2. Literature review

The explicit modeling of European PXs has been an extremely timely and interesting topic. In this direction, various researchers have presented formulations that model and handle most of the trading products that are available in European PXs.

One basic characteristic of most European day-ahead electricity markets lies in the inherent non-convex character of such markets. Most PXs allow the submission of multi-period energy products, which emulate some of the unit technical and operational characteristics and allow market participants to internalize all different costs (variable and fixed costs) in the same offer. The most common types of such orders are the block, linked block and flexible hourly orders; due to their “fill-or-kill” nature they require the use of binary variables for their explicit modeling. The explicit modeling of indivisible block (regular, linked and convertible) and flexible hourly orders, which constitute the basic multi-period products traded in European PXs, has been presented in

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Nomenclature

Indices and Sets

$t(T)$ index (set) of trading periods within the trading day (typically, the period is 1 h)
$a(A)$ index (set) of bidding areas
$b(B)$ index (set) of supply offers' and demand bids' steps
$d(D)$ index (set) of demand bids, $D_a \subseteq D$ is the subset of demand bids submitted to bidding area a
$eg(EG)$ index (set) of exclusive groups
$l(L)$ index (set) of interconnections, where $L_{ac} \cup L_{dc} = L$ are the subsets of AC and DC interconnections and $L_{ls} \subseteq L$ is the subset of interconnections belonging to the same line set
$s(S)$ Index (set) of supply, $S_a \subseteq S$ is the subset of supply offers submitted to bidding area a, $S_{lg} \subseteq S$ the subset of supply offers that are subject to a Load Gradient Condition, $S_{mic} \subseteq S$ the subset of supply offers that are subject to a Minimum Income Condition and $S_{ss} \subseteq S$ the subset of supply offers that are subject to a Scheduled Stop Condition
$bo(BO)$ index (set) of block orders (profile or regular block orders), $BO_a \subseteq BO$ is the subset of block orders submitted to bidding area a
$lbo(LBO)$ index (set) of linked block orders, $LBO_a \subseteq LBO$ is the subset of linked block orders submitted to bidding area a
$fho(FHO)$ index (set) of flexible hourly orders, $FHO_a \subseteq FHO$ is the subset of flexible hourly orders submitted to bidding area a
$ls(LS)$ index (set) of line sets

Parameters

P^t_{db}, Q^t_{db} price-quantity pair of step b of the hourly priced demand bid d in trading period t, in €/MWh and MWh, respectively
P^t_{sb}, Q^t_{sb} price-quantity pair of step b of the hourly priced energy offer s in trading period t, in €/MWh and MWh, respectively
P_{bo}, Q^t_{bo} price-quantity pair of block order bo, in €/MWh and MWh, respectively; in the case of a profile block order, the quantity may be different in each trading period t
P_{fho}, Q_{fho} price-quantity pair of flexible hourly order fho, in €/MWh and MWh, respectively
$F^{\min}_{lt}(F^{\max}_{lt})$ minimum (maximum) available capacity (also called Remaining Available Margin in the flow-based model) of interconnection l in trading period t, in MW
$R^{\min}_{bo}$ Minimum Acceptance Ratio of block order bo, in p.u.
$PTDF^{lt}_{aa'}$ power transfer distribution factor (PTDF) of AC interconnection l for an energy transfer (exchange) between bidding areas a and a' in trading period t, in p.u.
A^{lbo}_{bo} linked block order lbo to block order bo incidence matrix
A^{eg}_{bo} block order bo to exclusive group eg incidence matrix
τ_{lt} flow tariff for the utilization of DC interconnection l in trading period t, in €/MW h
$G^{dn}_s(G^{up}_s)$ decrease (increase) gradient of the supply order s, which is subject to the Load Gradient Condition, in MW/min
B^{ss}_{sbt} ancillary parameter denoting the activation of the Scheduled Stop Condition, if equal to 1
B^{mic}_s ancillary parameter denoting the number of available opportunities a supply offer s has, in order to fulfil its Minimum Income Condition
$\chi^a_l(\varphi^a_l)$ parameter denoting that DC interconnection l begins (ends) from (to) bidding area a, if equal to 1; otherwise it is equal to 0
λ^a_l loss factor of DC interconnection l when power is transferred to bidding area a, in %
$R^{H,dn}_{at}(R^{H,up}_{at})$ hourly ramp-down (ramp-up) limit of bidding area's a net position, in trading period t, in MW/h; the term "net position ramping" refers to the hourly difference in the net position of a bidding area between two consecutive trading periods of the trading day.
$P^{H,ini}_{at}$ parameter denoting the initial net position of bidding area a in trading period t; it is equal to the net position of bidding area a during the last hour of the previous trading day for the first trading period ($t = 1$) and zero for all other trading periods ($t \in \{2-24\}$), in MW
$R^{D,dn}_a(R^{D,up}_a)$ daily ramp-down (ramp-up) limit of bidding area's a net position, in MW (per day)
$P^{D,ini}_a$ total net position of bidding area a during the previous trading day, in MW
$R^{H,dn}_{lt}(R^{H,up}_{lt})$ hourly ramp-down (ramp-up) limit of interconnection l power flow, in trading period t, in MW/h
$F^{H,ini}_{lt}$ parameter denoting the initial power flow in interconnection l in trading period t; it is equal to the power flow of interconnection l during the last hour of the previous trading day for the first trading period ($t = 1$), and zero for all other trading periods ($t \in \{2-24\}$), in MW
$R^{LS,dn}_{ls}(R^{LS,up}_{ls})$ ramp-down (ramp-up) limit of line set ls total power flow, in MW/h
$F^{LS,ini}_{ls,t}$ parameter denoting the initial total power flow in line set ls in trading period t; it is equal to the total power flow of line set ls during the last hour of the previous trading day for the first trading period ($t = 1$) and zero for all other trading periods ($t \in \{2-24\}$), in MW

Variables
(i) Positive Variables

p_{at} net position of bidding area a in trading period t, in MWh; the term "net position" refers to the net injection of a bidding area, namely total cleared production minus total cleared demand.
f_{lt} power flow in interconnection l in trading period t, in MW
$e^t_{aa'}$ bilateral exchange between bidding area a and bidding area a', in trading period t, in MWh
$x^t_{sb}(x^t_{db})$ acceptance ratio of step b of supply (demand) entity's s priced offer (bid) in trading period t
x_{bo} acceptance ratio of block order bo
f^+_{lt}, f^-_{lt} positive variables utilized in the power flow variable decomposition schema for DC inter-connection l in trading period t, in MW

(ii) Binary Variables

u_{bo} clearing status of block order bo
u^t_{fho} clearing status of flexible hourly order fho in trading period t

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