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Finding Equilibria in the Pool-Based Electric Market with Strategic Wind Power Produce and Network Constraints

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***Abstract*—This paper proposes a model to find the equilibria in the short-term electricity market with large-scale wind power penetration. The behavior of each strategic player is modeled through a two-stage mathematical problem with equilibrium constraints (MPEC) where the upper-level problem maximizes the profit of the strategic player and the lower-level problem describes the clearing processes of the day-ahead and real-time markets while considering the network constraints. The joint solution of all the MPECs constitutes an equilibrium problem with equilibrium constraints (EPEC). The uncertain wind power production and demand are represented by a set of plausible scenarios. By using the duality theory and Karush-Kuhn-Tucker (KKT) condition, each MPEC is transferred into a mixed-integer linear programming problem. The Nash equilibria of the electricity market are obtained by solving the EPEC using Game theory and the diagonalization algorithm. Case studies are performed to show the effectiveness of the proposed model.**

***Index Terms*—Electricity market, equilibrium problem with equilibrium constraints (EPEC), game theory, Nash Equilibrium, stochastic programming, strategic player, wind power.**

NOMENCLATURE

Indices and Sets:

t	Index for time periods, $t \in \{1,\cdots,T\}$.
i	Index for strategic players (i.e., power producers), $i \in \{1,\cdots,I\}$.
j	Index for nonstrategic players, $j \in \{1,\cdots,J\}$.
g	Index of conventional units, $g \in \{1,\cdots,G\}$.
w	Index of wind generating units, $w \in \{1,\cdots,W\}$.
d	Index for demands, $d \in \{1,\cdots,D\}$.
ω	Index of scenarios, $\omega \in \{1,\cdots,\Omega\}$.
b	Index of energy blocks offered by a power producer, $b \in \{1,\cdots,B\}$.
l	Index of demand blocks, $l \in \{1,\cdots,L\}$.
m, n	Indices of system buses, $m, n \in \{1,\cdots,M\}$.
Γ_i^W / Γ_j^W	Set of indices of wind units belonging to the player *i*/*j*.
Γ_i^G / Γ_j^G	Set of indices of conventional units belonging to the player *i*/*j*.
Ψ_m^W	Set of indices of wind units locat
Ψ_m^G	Set of indices of conventional bus *m*.
Ψ_m^D	Set of indices of the demand loca
Φ_m	Set of indices of the buses connec

Decision Variables:

$\lambda_{b(w\in\Gamma_i^W)t}^{\mathrm{WDA}}$	Offering price of block *b* of th which belongs to the strategic pl period *t* in the day-ahead market.
$\lambda_{b(w\in\Gamma_i^W)t}^{\mathrm{WRT}}$	Offering price of the wind unit *w* to the strategic player *i* in a time real-time market.
p_{bwt}^{WDA}	Produced power of wind unit *w* i *t* in the day-ahead market.
p_{wt}^{WRT}	Rescheduled power of wind un period *t* in the real-time market.
$\lambda_{b(g\in\Gamma_i^G)t}^{\mathrm{CDA}}$	Offering price of block *b* of th unit *g* which belongs to the strat a time period *t* in the day-ahead n
$\lambda_{g\in\Gamma_i^G t}^{\mathrm{CRT+}} / \lambda_{g\in\Gamma_i^G t}^{\mathrm{CRT-}}$	Offering price of the increased/de of the conventional unit *g* which strategic player *i* in a time perio time market.
p_{bgt}^{CDA}	Power produced by the convent block *b* in a time period *t* in market.
$P_{gt}^{\mathrm{CRT+}} / P_{gt}^{\mathrm{CRT-}}$	Increased/decreased power of th unit *g* in a time period *t* in the rea
p_{ldt}^{LDA}	Power bought by the demand *d* time period *t* in the day-ahead ma
P_{dt}^{LRT}	Accepted power deviation of the time period *t* in the real-time marl
$\lambda_{mt}^{\mathrm{DA}} / \lambda_{mt}^{\mathrm{RT}}$	Day-ahead/real-time locational