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An integrated model for assessing electricity retailer's profitability with demand response

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HIGHLIGHTS

- Integration of Unit-Commitment problem with econometric models.
- Quantification of demand response' effect on the fluctuations of spot prices, based on their short-term price elasticities.
- Identification of periods with high price margins for electricity retailers.
- Provision of price signals on the profitability of electricity retailers and.
- Provision of useful insights into the risk of electricity retailers with price-responsive consumers.

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ABSTRACT

This paper introduces a model that integrates a Unit Commitment (UC) model, which performs the simulation of the day-ahead electricity market, combined with an econometric model that estimates the income and price elasticities of electricity demand. The integrated model is further extended to estimate the retailers' profitability with demand responsive consumers. The applicability of the proposed model is illustrated in the Greek day-ahead electricity market. The model is designed to identify the effects of demand responsiveness to the fluctuations of spot prices, based on their short-term price elasticities. It provides price signals on the profitability of retailers/demand aggregators, when forming their tariffs. We argue that the non-linearity between demand response and evolution of wholesale price, inherits risk for retailers. This finding could lead even to losses for some time periods, affecting strongly their viability. The model provides useful insights into the risk of retailers from their price responsive customers and therefore acts as a pivotal study to policy makers and government officials (i.e. regulators, transmission and distribution system operators) active in the electricity market.

1. Introduction

The evolution of smart networks is expected to be radical over the next years [1]. Integration of metering, sensing and actuation systems, is likely to optimize the whole energy consumption, by eliminating the needs for new infrastructure, as the efficiency, reliability and economics of the power systems can be improved. We are not far away from a period with consumers reshape their consumption patterns, especially for energy, based on real-time price signals. The price responsiveness of final consumers has been extensively examined in the past, mainly through econometric studies that estimated the income and price elasticities on energy demand. A review paper [2] aggregated a number of econometric studies, for countries of different geographical and economic backgrounds, aiming at identifying the relationship of electricity consumption with its determinants. The empirical evidence in a study over 100 countries [3] estimated their correlation. However, the variation in the results, concerning the magnitude of the elasticities, but as well as the causality among them may be attributed to variable selection, model specifications, time periods of the studies, different institutional, structural frameworks in the countries examined, and the econometric approaches undertaken [4,5]. However, those studies have investigated the price responsiveness of electricity consumers, based on non-dynamic electricity prices and neglecting demand response to real-time market prices.

In real electricity markets, the price responsiveness might be more dynamic. Therefore, the demand aggregators who act as demand representatives in the wholesale market of large industrial firms, residential and commercial customers are in high risk in case their customers respond to the fluctuations of real-time market prices. This paper aims to assess how the profitability and the risk

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Nomenclature

Acronyms
ADMIE Independent Power Transmission System Operator
LAGIE Hellenic Electricity Market Operator
GAMS General Algebraic Modelling System
MILP Mixed Integer Linear Programming
RAE Regulatory Authority of Energy
RES Renewable Energy Sources
SMP System Marginal Price
IMP Imbalance Marginal Price
UCP Unit Commitment Problem

Sets
$g \in G^{res}$ set of renewable units (not including hydro units)
$g \in G^{s}$ set of units $g \in G$ that are installed in subsystem $s \in S$
$g \in G^{th}$ set of thermal units
$g \in G^{z}$ set of units $g \in G$ that are (or can be) installed in zone $z \in Z$
$g \in G$ set of all units
$c \in C$ set of all customer types (industrial, residential, commercial)
$r \in R$ set of all retailers participating in the electricity market
$n \in N^{s}$ set of interconnected power systems $n \in N$ with subsystem $s \in S$
$n \in N^{z}$ set of interconnected power systems $n \in N$ with zone $z \in Z$
$n \in N$ set of interconnected power systems
$w \in W$ set of start-up types {hot, warm, cold}
$z \in Z$ set of zones

Parameters
$AF_{g,z,t}$ availability factor of each unit $g \in G^{res}$ in zone $z \in Z$ and hour $t \in T$ (p.u.)
$CB_{g,b,t}$ marginal cost of block $b \in B$ of the energy offer function of each unit $g \in G^{hth}$ in hour $t \in T$ (€/MW)
$CEP_{n,b,t}$ marginal export bid of block $b \in B$ to interconnection $n \in N$ in hour $t \in T$ (€/MW)
$CIP_{n,b,t}$ marginal cost of block $b \in B$ of the imported energy offer function from interconnection $n \in N$, in hour $t \in T$ (€/MW)
CL_f capacity range- f of the proposed interconnector between the mainland (interconnected) and the autonomous power system
$CPM_{e,b,t}$ marginal bid of block $b \in B$ of pumped storage unit $h \in H$ in hour $t \in T$ (€/MW)
$D_{s,t}$ power load of subsystem $s \in S$, in hour $t \in T$ (MW)
$EP_{n,b,t}$ quantity of capacity block $b \in B$ of each energy export interconnection $n \in N$ in hour $t \in T$ (MW)
$FL_{s,s',t}$ Upper bound of the flow from subsystem $s \in S$ to subsystem $s' \neq s \in S$ in hour $t \in T$ (MW)
FSR_t^{down} system requirements in fast secondary-down reserve in hour $t \in T$ (MW)
FSR_t^{up} system requirements in fast secondary-up reserve in hour $t \in T$ (MW)
IC_{res}^{int} installed capacity of renewables in the mainland (interconnected) power system
$IP_{n,b,t}$ quantity of capacity block $b \in B$ of each power import interconnection $n \in N$ in hour $t \in T$ (MW)
$L_{z,t}$ injection losses coefficient in zone $z \in Z$ and hour $t \in T$ (p.u.)
$NP_{g,t}$ fixed (non-priced) component of the energy offer function of each unit $g \in G$ in hour $t \in T$ (MW)
$PCB_{g,b,t}$ Power capacity block $b \in B$ of the energy offer function of unit $g \in G^{hth}$ in hour $t \in T$ (MW)
$PC_{g,t}$ available power capacity of unit $g \in G$ in hour $t \in T$ (MW)
$PMB_{e,b,t}$ quantity of capacity block $b \in B$ of pumped storage unit $h \in H$ in hour $t \in T$ (MW)
P_g^{min} technical minimum of each unit $g \in G^{hth}$ (MW)
P_g^{max} Maximum power output of each unit $g \in G^{hth}$ (MW)
$P_g^{max,sc}$ maximum power output (when providing secondary reserve) of each unit $g \in G^{hth}$ (MW)
P_g^{max} maximum power output (dispatchable phase) of each unit $g \in G^{hth}$ (MW)
$P_g^{min,sc}$ minimum power output (when providing secondary reserve) of each unit $g \in G^{hth}$ (MW)
P_g^{min} minimum power output (dispatchable phase) of each unit $g \in G^{hth}$ (MW)
P_g^{soak} power output of each unit $g \in G^{hth}$ when operating in soak phase (MW)
PR_g maximum contribution of unit $g \in G^{hth}$ in primary reserve (MW)
PR_t^{up} system requirements in primary-up reserve in hour $t \in T$ (MW)
SR_i maximum contribution of unit $g \in G^{hth}$ in secondary reserve (MW)
SR_t^{down} system requirements in secondary-down reserve in hour $t \in T$ (MW)
SR_t^{up} system requirements in secondary-up reserve in hour $t \in T$ (MW)
TR_g^{nsp} maximum contribution of unit $g \in G^{hth}$ in non-spinning tertiary reserve (MW)
TR_g^{sp} maximum contribution of unit $g \in G^{hth}$ in spinning tertiary reserve (MW)
TR_t system requirements in tertiary reserve in hour $t \in T$ (MW)
$PRO_{g,t}$ price of the primary energy offer of each unit $g \in G^{hth}$, in hour $t \in T$ (€/MW)
$SRO_{g,t}$ Price of the secondary range energy offer of each unit $g \in G^{hth}$, in hour $t \in T$ (€/MW)
R_g^{down} ramp-down rate of unit $g \in G^{hth}$ (MW)
R_g^{sc} ramp rate of unit $g \in G^{hth}$ when providing secondary reserve (MW)
R_g^{up} ramp-up rate of unit $g \in G^{hth}$ (MW)
SDC_g shut-down cost of each unit $g \in G^{hth}$ (€)
T_g^{htw} non-operational time of unit $g \in G^{hth}$ before going from hot to warm standby condition (h)
T_g^{desyn} desynchronization time of unit $g \in G^{hth}$ (h)
T_g^{down} minimum down time of unit $g \in G^{hth}$ (h)
T_g^{past} extended time period in the past (greater than the higher cold reservation time of all thermal units) (h)
T_g^{rdn} non-operational time (after being shut-down) of unit $g \in G^{hth}$ (h)
$T_g^{soak,w}$ type-w soak time of unit $g \in G^{hth}$ (h)
$T_g^{sync,w}$ type-w synchronization time of unit $g \in G^{hth}$ (h)
T_g^{up} minimum up time of unit $g \in G^{hth}$ (h)
T_g^{wtc} non-operational time of unit $g \in G^{hth}$ before going from warm to cold standby condition (h)
CAP maximum allowed price for priced energy offers
$MARGIN_{s,r,c,t}$ margin of the retailer $r \in R$, from the tariffs he provides to customer type $c \in C$ in subsystem $s \in S$ and hour $t \in T$
$TOL_{s,c,t}$ tolerance for the responsive customers to respond to price differences among the SMP and the tariff provided by the retailers, for customer type $c \in C$ in subsystem $s \in S$ and hour $t \in T$