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Impact of the penetration of renewables on flexibility needs

Nikolaos E. Koltsaklis[a,c], Athanasios S. Dagoumas[a,*], Ioannis P. Panapakidis[a,b]

[a] Energy & Environmental Policy Laboratory, School of Economics, Business and International Studies, University of Piraeus, PC 18532 Piraeus, Greece
[b] Department of Electrical Engineering, Technological Education Institute of Thessaly, 41110 Larisa, Greece
[c] Department of Chemical Engineering, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece

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ABSTRACT

The paper aims to quantify the impact of the penetration of renewables on the flexibility needs and their price signal. It uses a generic Mixed Integer Linear Programming (MILP) model that integrates long-term power system planning with a Unit Commitment (UC) model, which performs the simulation of the Day-Ahead Electricity Market (DAEM). The integrated model evaluates the need of flexibility services, under different conditions of renewable penetration. A case study of the Greek interconnected electric system is examined. Results show that the main flexibility needs concern photovoltaics causing the sunset effect, while the needs from stochastic wind are alleviated from the fact that wind output is de-linked from the demand evolution and that wind installations' positions are diversified. The identification of flexibility needs from the Transmission System Operators (TSOs) require detailed data to depict the spatial and technical characteristics of each power system, which can reveal that ramping rates, and not just the magnitude of ramping capacity, can be an important flexibility requirement, due to large single-hour ramp contribution in some months. Such an analysis can also reveal the options for increasing flexibility, which are power system specific.

1. Introduction

The penetration of Renewable Energy Sources (RES) imposes additional challenged to electricity markets and power systems. It strongly depends on the capability of the Transmission System Operators (TSOs) to evolve towards tackling critical reliability issues, such as voltage dip and power balance management, dedicated predictability for electricity generation from RES as well as advanced flexibility services (Lannoye et al., 2012). Advanced electricity markets are considering the introduction of flexibility services towards enhancing the stability of the system (Cochran et al., 2014). Those flexibility services are supplementary to the ancillary services, such as frequency control, reactive power and voltage control, load regulation, replacement reserve, spinning and non-spinning reserve. The intermittent and variable generation from RES creates new challenges to balancing authorities, particularly to ramping capability. The capability of a power plant to start and stop on command as well as the request for high rates at which a power plant increases or decreases its output, namely its ramping up or down capability, is very crucial for a system with high penetration of RES. The identification of the flexibility services needed, depending on the penetration level of renewables as well as the topology of the electric systems, is of high priority. The identification of flexibility needs is very crucial for the TSOs, aiming at the enhancement of reliable and efficient electric systems, especially considering the fact that a considerable number of electricity markets are de-linked from central dispatch design towards self-dispatch design, either portfolio of unit based.

The incorporation of flexible products has already been implemented in advanced electricity markets, such as the approval of the California ISO Board of a flexible ramping product as well of its compensation methodology (CAISO, 2015). This product created a new short-term energy market that serves to shift energy supply or demand within minutes. However, this type of ramp capability differs from traditional ancillary services markets such as spinning reserves, which are aimed at minimizing the effects of a generator tripping or regulation, which is aimed at maintaining frequency. Instead, this ramp market attempts to send generators sufficient price signals for upward and downward flexible ramping capability, towards accounting for uncertainty due to demand and renewable forecasting errors. The incorporation of similar flexible products is being considered in European electricity markets, aiming to tackle such reliability issues but as well to provide a fair compensation for power plants.

Abbreviations: IPTO, Independent Power Transmission Operator; HEMO, Hellenic Electricity Market Operator; GAMS, General Algebraic Modelling System; MILP, Mixed Integer Linear Programming; RES, Renewable Energy Sources; DAEM, Day-Ahead Electricity Market; SMP, System Marginal Price; UCP, Unit Commitment Problem; ANN, Artificial Neural Network

* Corresponding author.
E-mail address: dagoumas@unipi.gr (A.S. Dagoumas).

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Nomenclature

Sets

$s \in S$ set of subsystems
$t \in T$ set of hours
$b \in B$ set of blocks of the energy offer function (bids) of each hydrothermal unit
$e \in E^z$ set of pumped storage units $e \in E$ interconnected with zone $z \in Z$
$g \in G^{hth}$ set of hydrothermal units
$g \in G^z$ set of units $g \in G$ that are (or can be) installed in zone $z \in Z$
$z \in Z$ set of zones
$n \in N^z$ set of interconnected power systems $n \in N$ with zone $z \in Z$
$n \in N$ set of interconnected power systems

Parameters

$CB_{g,b,t}$ 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)
$CPM_{e,b,t}$ Marginal bid of block $b \in B$ of pumped storage unit $h \in H$ in hour $t \in T$ (€/MW)
$L_{z,t}$ Injection losses coefficient in zone $z \in Z$ and hour $t \in T$ (p.u.)
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)
$RC1_{g,t}$ Price of the primary energy offer of each unit $g \in G^{hth}$, in hour $t \in T$ (€/MW)
$RC2_{g,t}$ Price of the secondary range energy offer of each unit $g \in G^{hth}$, in hour $t \in T$ (€/MW)
SDC_g Shut-down cost of each unit $g \in G^{hth}$ (€)
$CAP_{s,t}$ Maximum allowed price for priced energy offers in subsystem $s \in S$ and hour $t \in T$
$SMP_{s,t}$ System Marginal Price in subsystem $s \in S$ and hour $t \in T$ (Euro/MWh)
$SMP_{n,t}$ System Marginal Price in interconnected system $n \in N$ and hour $t \in T$ (Euro/MWh)

Continuous Variables

$exb_{n,b,t}$ Cleared quantity of power capacity block $b \in B$ exported to interconnected system $n \in N$ in hour $t \in T$ (MW)
$imb_{n,b,t}$ Cleared quantity of power capacity block $b \in B$ imported from interconnected system $n \in N$ in hour $t \in T$ (MW)
$pb_{g,b,t}$ Quantity of power capacity block $b \in B$ of unit $g \in G^{hth}$, dispatched in hour $t \in T$ (MW)
$pmb_{e,b,t}^{pum}$ Cleared quantity of block $b \in B$ of pumping unit $h \in H$ in hour $t \in T$ (MW)
$r1_{g,t}^{up}$ Contribution of unit $g \in G^{hth}$ in primary-up reserve in hour $t \in T$ (MW)
$r2_{g,t}^{down}$ Contribution of unit $g \in G^{hth}$ in secondary-down reserve in hour $t \in T$ (MW)
$r2_{g,t}^{up}$ Contribution of unit $g \in G^{hth}$ in secondary-up reserve in hour $t \in T$ (MW)

Binary Variables

$x_{g,t}^{sd}$ 1, if unit $g \in G^{hth}$ is shut-down in hour $t \in T$

Considering that several power plants are facing financial viability problems, as long as they don't get the appropriate price signals for their ramping capability, they are considering of preferring the cold-reserve status or even the decommissioning of the units. Besides the depreciation of new power plants, this would accelerate the need for the introduction of energy security compensation schemes, which could increase significantly the total energy cost. Therefore, the introduction of flexibility products provides several supplementary gains for the energy system and the overall energy cost.

Therefore, it is crucial to develop robust methodologies aiming to identify the flexibility needs, as well as their pricing. A recent research paper examines market solutions for managing ramp flexibility (Navid and Rosenwald, 2012). Milligan et al. (2016) explore both traditional and evolving electricity market designs in the United States that aim to ensure resource adequacy and sufficient revenues to recover costs when those resources are needed for long-term reliability (Milligan et al., 2016). It also investigates how reliability needs evolve as the renewables penetrate in the market. A continuation of this work Ela et al. (2016) examines the market design with high penetration of renewables, aiming to offset the inefficient utilization of existing flexibility or unwillingness of resources to provide flexibility, which lead to higher energy system costs (Ela et al., 2016). It explores some of these existing market designs, as well as new market mechanisms, such as pay-for-performance regulating reserve and primary frequency response markets, explicit products for flexible ramping provision and the allowance for non-traditional resources, such as demand response, energy storage, and even variable generation itself. Such market schemes aim to explicitly incentivize the provision of more flexibility to the system, particularly as a result of increasing variable generation penetration levels.

A recent paper reviews different approaches, technologies, and strategies to manage variable electricity generation from RES, considering both supply and demand side measures (Lund et al., 2015). Moreover, it focuses on presenting energy system flexibility measures, ranging from traditional ones such as grid extension or pumped hydro storage to more advanced strategies such as demand-side approaches. Kondziella and Bruckner (2016) provide a review of research results and methodologies on the flexibility requirements deriving from the penetration of renewables. It classifies the results into technical, economic, and market potential categories to enhance their comparability. Moreover, the paper conducts a methodological evaluation of the literature findings, discussing a conceptual framework to quantify the market potential of flexible technologies.

Frew et al. (2016) present a cost optimization planning model of the power system of USA, aiming at evaluating the trade-offs and relative benefits of four flexibility mechanisms as well as comparing pathways to a fully renewable power system. The paper concludes that geographic aggregation is the optimum mechanism among the four flexibility mechanisms considered. Mikkola and Lund (2012) present a fast and easy-to-use optimization model to find cost-optimal ways to manage the energy system with large-scale variable renewable energy, aiming to identify the optimal use of energy system flexibility. Moreover, the model handles both electric and thermal loads, allowing the identification of penetration capability of power-to-heat conversion systems.

Denholm and Hand (2011) examine the changes to the electric power system required to absorb high penetration of variable wind and solar electricity generation in a transmission constrained grid. It concludes that a highly flexible system allows for penetration of electricity generation from RES up to 80% of the system's electricity demand. However, this requires a combination of load shifting and