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A mid-term, market-based power systems planning model

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HIGHLIGHTS

- A mid-term Energy Planning along with a Unit Commitment model is developed.
- The model identifies the optimum interconnection capacity.
- Electricity interconnections affect the power mix and the day-ahead spot price.
- Renewables' penetration has impacts on the power reserves and the CO_2 emissions.
- Energy policy and fuel pricing can have significant impacts on the power mix.

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ABSTRACT

This paper presents a generic Mixed Integer Linear Programming (MILP) model that integrates a Mid-term Energy Planning (MEP) model, which implements generation and transmission system planning at a yearly level, with a Unit Commitment (UC) model, which performs the simulation of the Day-Ahead Electricity Market. The applicability of the proposed model is illustrated in a case study of the Greek interconnected power system. The aim is to evaluate a critical project in the Ten Year Network Development Plan (TYNDP) of the Independent Power Transmission System Operator S.A. (ADMIE), namely the electric interconnection of the Crete Island with the mainland electric system. The proposed modeling framework identifies the implementation (or not) of the interconnection of the Crete Island with the mainland electric system, as well as the optimum interconnection capacity. It also quantifies the effects on the Day-Ahead electricity market and on the energy mix. The paper demonstrates that the model can provide useful insights into the strategic and challenging decisions to be determined by investors and/or policy makers at a national and/or regional level, by providing the optimal energy road-map and management, as well as clear price signals on critical energy projects under real operating and design constraints.

1. Introduction

The integration of all European national electricity markets into a single one is of high priority on the political agenda of the European Commission. The security of the supply is one of the key drivers of the electricity market integration in Europe, as the implementation of interconnections among neighboring countries eliminate the effect of emergency situations. Integration of electricity markets can diversify the power generation mix, lower the electricity prices by creating more competitive and transparent markets, and give access to additional power generation capacity in case of a shortage in any one country [1]. Moreover, the expansion of grid interconnections is of utmost importance in order to facilitate the transition toward a power generation mix with very high levels of renewables penetration, by enabling full use of the flexibility of the power plants fleet and by increasing the flexibility to balance the variable wind output. [2–4]. Not surprisingly, the deployment of renewable energy at regions without extensive grid interconnections and far from the main load consuming centers could result in overloading of transmission lines [5].

The assessment of the value of the transmission capacity is a very complex task since it includes a large variety of issues such as power networks physics, power systems economics and reliability aspects. However, evolving supply and demand dynamics set a

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Nomenclature

Acronyms

ADMIE Independent Power Transmission System Operator S.A.
ETMEAR special duty for the reduction of gas emissions
GAMS General Algebraic Modeling System
LOLP Loss of Load Probability
MEP Mid-term Energy Planning
MILP Mixed Integer Linear Programming
RAE Regulatory Authority of Energy
RES Renewable Energy Sources
SMP system marginal price
TYNDP Ten Year Network Development Plan

Sets

$(s,s') \in S$ set of subsystems
$(s,s') \in S^{IS}$ set of subsystems of the interconnected power system
$(s,s') \in S^{CR}$ set of subsystems of the autonomous power system
$(t,t') \in T$ set of hours
$e \in E$ set of pumped storage units
$b \in B$ set of blocks of the energy offer function (bids) of each hydrothermal and pumper storage unit as well as of each interconnection
$e \in E^s$ set of pumped storage units $e \in E$ interconnected with subsystem $s \in S$
$e \in E^z$ set of pumped storage units $e \in E$ interconnected with zone $z \in Z$
$f \in F$ set of transmission capacity range blocks between the mainland and the autonomous power system
$g \in G^h$ set of hydroelectric units
$g \in G^{hth}$ set of hydrothermal units
$g \in G^{res}$ 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
$m \in M$ set of months
$n \in N^s$ 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
$s \in S^{s'}$ set of subsystems $s \in S$ interconnected with subsystem $s' \neq s \in S$
$w \in W$ set of start-up types {hot, warm, cold}
$z \in Z$ set of zones

Parameters

$AF_{g,z,m,t}$ availability factor of each unit $g \in G^{res}$ in zone $z \in Z$, month $m \in M$ and hour $t \in T$ (p.u.)
$CB_{g,b,m,t}$ marginal cost of block $b \in B$ of the energy offer function of each unit $g \in G^{hth}$ in month $m \in M$ and hour $t \in T$ (€/MW)
$CEP_{n,b,m,t}$ marginal export bid of block $b \in B$ to interconnection $n \in N$ in month $m \in M$ and hour $t \in T$ (€/MW)
$CIP_{n,b,m,t}$ marginal cost of block $b \in B$ of the imported energy offer function from interconnection $n \in N$, in month $m \in M$ and hour $t \in T$ (€/MW)
CL_f capacity range-f of the proposed interconnector between the mainland (interconnected) and the autonomous power system (MW)
$CPM_{e,b,m,t}$ marginal bid of block $b \in B$ of pumped storage unit $e \in E$ in month $m \in M$ and hour $t \in T$ (€/MW)
$D_{s,m,t}$ power load of subsystem $s \in S$, in month $m \in M$ and hour $t \in T$ (MW)
Dur_m duration of each representative day of each month $m \in M$ (days)
$EP_{n,b,m,t}$ quantity of capacity block $b \in B$ of each energy export interconnection $n \in N$ in month $m \in M$ and hour $t \in T$ (MW)
$FL_{s,s',m,t}$ upper bound of the flow from subsystem $s \in S$ to subsystem $s' \neq s \in S$ in month $m \in M$ and hour $t \in T$ (MW)
$FR2^{down}_{m,t}$ system requirements in fast secondary-down reserve in month $m \in M$ and hour $t \in T$ (MW)
$FR2^{up}_{m,t}$ system requirements in fast secondary-up reserve in month $m \in M$ and hour $t \in T$ (MW)
IC^{int}_{res} installed capacity of renewables in the mainland (interconnected) power system (MW)
IC^{tot}_{res} installed capacity of renewables in both the mainland (interconnected) and autonomous power systems (MW)
INV_f investment cost of transmission capacity block $f \in F$ (€/MW)
$IP_{n,b,m,t}$ quantity of capacity block $b \in B$ of each power imports interconnection $n \in N$ in month $m \in M$ and hour $t \in T$ (MW)
$L_{z,m,t}$ injection losses coefficient in zone $z \in Z$, month $m \in M$ and hour $t \in T$ (p.u.)
$NP_{g,m,t}$ fixed (non-priced) component of the energy offer function of each unit $g \in G$ in month $m \in M$ and hour $t \in T$ (MW)
$PCB_{g,b,m,t}$ power capacity block $b \in B$ of the energy offer function of unit $g \in G^{hth}$ in month $m \in M$ and hour $t \in T$ (MW)
$PC_{g,m,t}$ available power capacity of unit $g \in G$ in month $m \in M$ and hour $t \in T$ (MW)
$PMB_{e,b,m,t}$ quantity of capacity block $b \in B$ of pumped storage unit $e \in E$ in month $m \in M$ and hour $t \in T$ (MW)
$P^{max,sc}_g$ maximum power output (when providing secondary reserve) of each unit $g \in G^{hth}$ (MW)
P^{max}_g maximum power output (dispatchable phase) of each unit $g \in G^{hth}$ (MW)
$P^{min,sc}_g$ minimum power output (when providing secondary reserve) of each unit $g \in G^{hth}$ (MW)
P^{min}_g minimum power output (dispatchable phase) of each unit $g \in G^{hth}$ (MW)
P^{soak}_g power output of each unit $g \in G^{hth}$ when operating in soak phase (MW)
$R1_g$ maximum contribution of unit $g \in G^{hth}$ in primary reserve (MW)
$R1^{up}_{m,t}$ system requirements in primary-up reserve in month $m \in M$ and hour $t \in T$ (MW)
$R2_g$ maximum contribution of unit $g \in G^{hth}$ in secondary reserve (MW)
$R2^{down}_{m,t}$ system requirements in secondary-down reserve in month $m \in M$ and hour $t \in T$ (MW)
$R2^{up}_{m,t}$ system requirements in secondary-up reserve in month $m \in M$ and hour $t \in T$ (MW)
$R3^{nsp}_g$ maximum contribution of unit $g \in G^{hth}$ in non-spinning tertiary reserve (MW)
$R3^{sp}_g$ maximum contribution of unit $g \in G^{hth}$ in spinning tertiary reserve (MW)
$R3_{m,t}$ system requirements in tertiary reserve in month $m \in M$ and hour $t \in T$ (MW)
$RC1_{g,m,t}$ price of the primary energy offer of each unit $g \in G^{hth}$, in month $m \in M$ and hour $t \in T$ (€/MW)
$RC2_{g,m,t}$ price of the secondary range energy offer of each unit $g \in G^{hth}$, in month $m \in M$ and hour $t \in T$ (€/MW)
R^{down}_g ramp-down rate of unit $g \in G^{hth}$ (MW)