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Evaluation of the uncertainty in the scheduling of a wind and storage power plant participating in day-ahead and reserve markets

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Abstract

Increase the participation of wind energy in the power market is of paramount importance to increase the penetration of wind energy in the power systems. To adress this issue, we propose a system consisting on a wind farm and a generic energy storage system and develop a deterministic model of such a plant participating in day-ahead and reserve markets used to decide the operation strategy of the system and to evaluate the cost of the uncertainty linked to several parameters of the model. The resulting model is a deterministic Mixed Integer Convex Program and is used to analyze a real-world case of a wind farm located in northwestern Spain.

Keywords: Data uncertainty; integration renewable energy; mixed-integer convex program; reserve market; scheduling; storage; wind energy

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1. Introduction

One way to overcome the drawbacks associated with the use of renewable energy resources is to use energy storage systems (ESS) to be able to manage the generation from renewable energy resources appropriately. In this framework, this work considers a wind farm (WF) as renewable energy source and a generic ESS. The resulting system will be a Wind and Storage Power Plant (W&SPP).

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The traditional way to operate a system of this kind is to consider such a system participating in the day-ahead energy market (DAM) following the simplified strategy of buying energy during low price periods to be sold during peak hours. Several authors have reported the lack of economic feasibility for such a strategy[1], proposing a more comprehensive participation in the electrical markets instead. In particular, [2] shows that the participation of a pump-hydro energy system (PHES), which is a particular case of ESS, in the reserve market (RM) is critical to get economic feasibility. The advantages of operating jointly a wind farm and a pump hydro plant as ESS in the DAM are shown in [3]. Just a few papers have considered the modeling of RM in the short term scheduling problem of a wind farm[4]. For example, [5] models the participation of a hydro-pump power system in the RM without considering the uncertainty effects in the results. Several papers have studied the impact of the uncertainty of wind power availability in different kind of problems. [6] assesses the impact of the wind uncertainty on ESSs and thermal units schedule in Unit Commitment problem. Thus, the main contributioins of this paper are the following:

- Develop a deterministic model of a W&SPP participating in both DAM and RM. Imbalances and regulation capabilities both upwards and downwards are allowed in both modes of operation and in both markets.
- Evaluate the increase in the net income that a W&SPP can get by participating in the RM.
- Evaluate the cost of the uncertainty linked to several parameters in the model, mainly the wind power available and the requirements of regulation by the SO in the RM.

Nomenclature

T	Number of periods under consideration
l_t	Duration of each period.
$\hat{P}_t^{wind}$	Wind power available in time t (MW)
E_0^{ess}	Initial energy stored in the ESS (MWh)
η_{in}	Charging efficiency of the ESS.
η_{out}	Discharging efficiency of the ESS.
$\bar{E}^{ess}$	Maximum energy stored in the ESS (MWh)
$\bar{P}^{ess}$	Maximum power to/from ESS (MWh)
$SOC_t^{\min}$	Minimun state of charge allowed for the ESS
β_t^{dam}	Energy price in the DAM (€/MWh)
$\lambda_t^{dam,up}$	Energy price of deviation up (€/MWh)
$\lambda_t^{dam,dw}$	Energy price of deviation down (€/MWh)
γ_t^{sm}	Price of power reserve (€/MW)
$\beta_t^{sm,up}$	Energy price of energy under regulation up(€/MWh)
$\beta_t^{sm,dw}$	Energy price of energy under regulation down(€/MWh)
$\beta_{desvt}^{sm,up}$	Energy price of energy if deviating under regulation up(€/MWh)
$\beta_{desv,t}^{sm,dw}$	Energy price of energy if deviating under regulation down(€/MWh)
$\pi_t^{sm,up}$	Percentage of reserves up required by SO.
$\pi_t^{sm,dw}$	Percentage of reserves down required by SO.
$R_t^{sm,up}$	Ratio between reserves up and total reserves
$\varphi_t^{dam}, \gamma_t^{dam}$	Parameters for convex model.

Continuous Variables

P_t^{wind}	Wind power actually used in time t (MW)
E_t^{ess}	Energy stored in the ESS in time t (MWh)
$P_t^{ess,in}$	Power entering the ESS in time t (MW)
$P_t^{ess,out}$	Power delivered by the ESS in time t (MW)
SOC_t	State of charge of ESS in time t
P_t	Power to/from W&SPP in time t (MW)
$\hat{P}_t^{dam}$	Power offered in the DAM (MW)
P_t^{dam}	Power actually delivered/taken in time t in the DAM (MW)
Δ_t^{dam}	Unbalance in DAM (MW)
$\Delta_t^{dam,up}$	Deviation up in DAM (MW)
$\Delta_t^{dam,dw}$	Deviation down in DAM (MW)
$\hat{P}_t^{sm}$	Power committed for RM (MW)
$\hat{P}_t^{sm,up}$	Power committed for regulation up (MW)
$\hat{P}_t^{sm,dw}$	Power committed for regulation down (MW)
$\hat{E}_{t,reg}^{sm,up}$	Energy required by SO for reg. up (MWh)
$\hat{E}_{t,reg}^{sm,dw}$	Energy required by SO for reg. down(MWh)
$E_t^{sm,up}$	Energy actually offered for reg. up (MWh)
$E_t^{sm,dw}$	Energy actually offered for reg. down (MWh)
$D_t^{sm,up}$	Deviation in regulation up in RM
$D_t^{sm,dw}$	Deviation in regulation down in RM

Binary Variables

u_t	1 if ESS is charging. 0 otherwise