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Modeling the Real-Time Use of Reserves in the Joint Energy and Reserve Hourly Scheduling of a Pumped Storage Plant

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Abstract

This paper studies the impact that different approaches of modeling the real-time use of the secondary regulation reserves have in the joint energy and reserve hourly scheduling of a price-taker pumped-storage hydropower plant. The unexpected imbalance costs due to the error between the forecasted real-time use of the reserves and the actual value are also studied and evaluated for the different approaches. The proposed methodology is applied to a daily-cycle and closed-loop pumped-storage hydropower plant. Preliminary results show that the deviations in the water volume at the end of the day are important when the percentage of the real-time use of reserves is unknown in advance, and also that the total income in all approaches after correcting these deviations is significantly lower than the maximum theoretical income.

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Keywords: Pumped-Storage Plant; Secondary Regulation Reserve Market; Real-Time Use of Reserves;

1. Introduction

The secondary regulation service, also called secondary control or load-frequency control service, is defined as a centralised automatic function to restore frequency deviations in a control area and to maintain the interchange power flow with all other control areas, according to the European Network of Transmission System Operators of Electricity (ENTSO-E) [1]. This service generally comprises two payments: one for the available power capacity and one for the real-time use of the said capacity [2]. The former is related to the remuneration of the amount of power that has been reserved for the provision of the service. The latter refers to the remuneration/charge of the real-time use of the upward/downward reserves by the Transmission System Operator (TSO) [3].

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In the context of the co-optimization of the energy and reserve hourly scheduling of a daily-cycle, price-taker and closed-loop pumped-storage hydropower plant (hereinafter referred to as PSHP), a hydropower producer must decide, depending on the water availability, which quantity of power is sold and/or bought in the spot market and which quantity of the power is reserved for the secondary regulation service. Here, closed-loop PSHP refers to a plant without natural inflows. However, as the real-time use of reserves (RTURs) is uncertain when bids are submitted, a deviation from the expected secondary regulation energy and, therefore, from the target volume at the end of the day may be expected. The deviation may have an impact in the real-time management of the PSHP as well as a cost due to the corrective actions that might be necessary to exert in order to meet the power and reserve schedule and to minimize the said deviation.

Nomenclature

Sets

c	hydropower unit, running from 1 to *C*
t	time period, running from 1 to *T*

Parameters

cSU_c^d	start-up cost of the turbine, €
cSU_c^p	start-up cost of the pump, €
δ^d	energy coefficient in generating mode, MW/hm^3
fv	target water volume in the last hour, hm^3
$\bar{g}_c^d$	maximum technical power generation, MW
$\underline{g}_c^d$	minimum technical power generation, MW
$\bar{g}_c^p$	maximum technical power consumption, MW
λ_t^{DM}	spot market price, €/MWh
λ_t^{SM}	secondary regulation reserve market price, €/MW
$\lambda_t^{UEM}, \lambda_t^{DEM}$	upward and downward secondary regulation energy market price, respectively, €/MWh
$\lambda_t^{UDES}, \lambda_t^{DDES}$	upward and downward imbalance price, respectively, €/MWh
$\bar{\eta}_c^d, \underline{\eta}_c^d$	turbine efficiency at maximum and minimum flow, respectively, %
$\bar{\eta}_c^p$	pump efficiency at maximum flow, %
$\bar{q}_c^d$	maximum technical water discharged, hm^3
$\underline{q}_c^d$	minimum technical water discharged, hm^3
$\bar{q}_c^p$	maximum technical water pumped, hm^3
ρ_t^{up}, ρ_t^{dw}	percentage of the real-time use of upward and downward secondary regulation reserves, respectively, %
R_t^{SM}	relationship between upward and total secondary regulation reserve, %
$\bar{v}, \underline{v}$	maximum and minimum technical water storage limits of upper reservoir, hm^3

Positive Variables

$g_{c,t}^d, g_{c,t}^p$	power generation and consumption, respectively, MW
$q_{c,t}^d, q_{c,t}^p$	water discharged and pumped, respectively, hm^3
$qs_{c,t}^d$	water discharged above the minimum technical limit, respectively, hm^3
$g_t^{DM,d}, g_t^{DM,p}$	power that is sold and bought in the spot market, respectively, MW
$g_t^{des,up}, g_t^{des,dw}$	upward and downward scheduled imbalance power, respectively, MW
$g_t^{sec,up}, g_t^{sec,dw}$	upward and downward secondary regulation reserve, respectively, MW
$E_t^{sec,up}, E_t^{sec,dw}, E_t^{sec}$	upward, downward and net secondary regulation energy, respectively, MWh
v_t	water volume of the upper reservoir, hm^3

Binary Variables

$u_{c,t}, y_{c,t}$	on/off state in generating and consumption mode, respectively
$SU_{c,t}^d, SU_{c,t}^p$	start-up decision of the turbine and pump in the hydro unit *c*, respectively
ϕ_t	1 if there is more upward than downward secondary regulation energy, 0 otherwise

The aim of this paper is twofold: 1) to preliminary study the impact that several approaches to model the RTURs have in the joint energy and reserve hourly scheduling of a PSHP; and 2) to preliminary evaluate the economic impact of the RTUR forecasting error when deviations in the committed reserve schedule and in the secondary regulation energy are corrected, following the criteria used in the Spanish electricity market: being charged due to deviations in the committed reserve schedule, receiving an extra payment due to an unexpected upward imbalance (at a price lower or equal to the spot price) and finally, being charged due to an unexpected downward imbalance (at a price greater or equal to the spot price). The conclusions of this study are preliminary as they are obtained from a case study of one day, being expected to carry out a more advanced study in the future.

This paper uses a mixed integer linear programming model to obtain the optimal joint energy and reserve schedules of a PSHP participating in the spot and secondary regulation reserve markets of the Spanish electricity