Electric Power Systems Research 148 (2017) 303–310

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Value of perfect information of spot prices in the joint energy and reserve hourly scheduling of pumped storage plants

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ARTICLE INFO

Article history:
Received 8 July 2016
Received in revised form 13 January 2017
Accepted 18 March 2017

Keywords:
Pumped-storage plant
Secondary regulation service
Price forecasting
Value of perfect information

ABSTRACT

The value of perfect information of the day-ahead energy prices is studied in the context of the operation of a closed-loop and daily-cycle pumped-storage hydropower plant, participating in the spot market as a price-taker and in the secondary regulation reserve market as a price-maker. The impact of the real-time use of the regulation reserves is also taken into account. Results show that the value of perfect information of the spot prices in the Iberian electricity market decreases if the plant also participates in the secondary regulation service. Several novel indicators to better explain the value of perfect information are presented and evaluated. Finally, several regression models to roughly estimate the value of perfect information of any price forecasting model are obtained. These might help to evaluate the investment in pumped-storage hydropower plants.

1. Introduction

Competition has been introduced in many electricity power systems worldwide in order to, among others, improve the economic efficiency. An agent that participates in liberalised electricity markets must deal with several sources of uncertainty before submitting the bids, for instance the uncertainty of the spot and reserve prices which are not known in advance. The value of perfect information of the spot prices (VPI, also called profit loss due to the uncertainty) depends on the quality of the forecasting tool that is used to forecast the prices but also depends on the technology of the power producer [1].

In this paper, the VPI is studied in the context of a PSHP that participates not only in the spot market, but also in the secondary regulation service, with the aim of enlarging the expected income and reducing the payback period of the investment. In order to analyse the VPI, a day-ahead energy and reserve scheduling model is proposed. The model is based on mixed integer quadratic programming. The objective function of the model consists in maximizing the income of a PSHP participating in the spot market as a price-taker and in the secondary regulation reserve market as a price-maker, in the framework of the Iberian electric power system (MIBEL [2,3]). The upward and downward secondary regulation energy due to the real-time use of the committed reserves is also considered in the model formulation. In the Spanish electric power system, there is a single day-ahead reserve market where the available upward and downward secondary regulation reserves are determined and remunerated by the same marginal price. In addition, the upward and downward secondary regulation energy is also remunerated[1] according to the marginal price of the upward and downward tertiary regulation energy prices, respectively. In order to participate in the secondary regulation service, the PSHP has to participate in the spot market previously. Note that the procedure for the procurement of secondary regulation is not exclusive of the Spanish system. For instance, a similar procedure is implemented in Norway, Sweden, Finland, Slovenia, Czech Republic and Romania in the short-term (less than a week) and in Denmark, Netherlands, Belgium, Germany, Austria and Switzerland in the long-term (more than a week) [4].

The proposed model is based on the one proposed in [5], which has been revised in order to consider the PSHP as a price-maker in the secondary regulation reserve market. The PSHP under study is closed-loop and daily-cycle, as in [5], and is equipped with a single reversible Francis pump-turbine unit. In order to obtain representative enough as well as useful results, the VPI is calculated running

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[1] The upward (resp. downward) secondary regulation energy represents an income (resp. cost).

http://dx.doi.org/10.1016/j.epsr.2017.03.015
0378-7796/

Nomenclature

Superscripts

d indicates that the magnitude is related to generation/discharge

p indicates that the magnitude is related to consumption/pumping

sec indicates that the magnitude is related to the secondary regulation service (reserve or energy)

Sets

t hourly period, running from 1 to T

Parameters

cSU^d start-up cost in generating mode, €

cSU^p start-up cost in pumping mode, €

δ^d energy coefficient in generating mode, MW/Mm^3/h

fv target water volume in the last hour of the time horizon (in this study, the last hour of the day), Mm^3

$\bar{g}^d$, $\underline{g}^d$ maximum and minimum technical power generation, MW

$\bar{g}^p$ maximum technical power consumption (there is no minimum power consumption as this study considers a pump-turbine unit with fixed speed in pumping mode), MW

l_t time length of period t, 1 h

$\lambda_{D,t}$ day-ahead electricity market price, €/MWh

$\lambda^o_{S,t}$ the intercept of the linear approximation of a residual demand curve of the secondary regulation reserve market, i.e. the secondary regulation reserve price when the residual reserve quantity of the system is zero, €/MW

$\lambda^m_{S,t}$ the slope of the linear approximation of a residual demand curve of the secondary regulation reserve market, €/MW/MW

$\lambda_{up,t}$ upward secondary regulation energy price, €/MWh

$\lambda_{dw,t}$ downward secondary regulation energy price, €/MWh

N a big number, 10^6

$\bar{\eta}^d$, $\underline{\eta}^d$ efficiency in generating mode at maximum and minimum water discharge, %

η^p efficiency in pumping mode (only at maximum pumped water as this study considers a pump-turbine unit with fixed speed in the said mode), %

$\bar{q}^d$, $\underline{q}^d$ maximum and minimum technical water discharge, Mm^3/h

$\bar{q}^p$ maximum technical pumped water (there is no minimum pumped water as this study considers a pump-turbine unit with fixed speed in pumping mode), Mm^3/h

ρ^{up}_t, ρ^{dw}_t percentage of the offered upward and downward secondary regulation reserves that will be used by the TSO

R^{SM}_t ratio between the required upward and the total secondary regulation reserve, set by the TSO in advance

$\bar{v}$, $\underline{v}$ maximum and minimum water storage limits of the upper reservoir due to design characteristics, Mm^3

Positive variables

g^d_t, g^p_t power generation and consumption, MW

q^d_t total water discharge, which includes water for the real-time use of reserves, Mm^3/h

q^p_t pumped water, which does not include water for the real-time use of reserves as this study considers a pump-turbine unit with fixed speed in pumping mode, Mm^3/h

qs^d_t water discharge above the minimum technical limit, Mm^3/h

$g^{sec,up}_t$ upward secondary regulation reserve, MW

$g^{sec,dw}_t$ downward secondary regulation reserve, MW

$\lambda_{S,t}$ clearing price in the secondary regulation reserve market, dependent on the price-maker agent activity, €/MW

$e^{sec,up}_t$ upward secondary regulation reserve requested in real-time by the TSO, MWh

$e^{sec,dw}_t$ downward secondary regulation reserve requested in real-time by the TSO, MWh

v_t water volume of the upper reservoir at the end of time period t, Mm^3

Binary variables

u^d_t On/off state in generating mode

u^p_t On/off state in pumping mode

y^d_t 1 if the pump-turbine unit is started-up in generating mode, 0 otherwise

y^p_t 1 if the pump-turbine unit is started-up in pumping mode, 0 otherwise

ϕ_t 1 if there is more upward than downward secondary regulation reserve requested in real-time during time period t, 0 otherwise

the model, day by day, with a similar methodology as in [1] or [6], for a period of one year (the selected year is 2014) and for thirteen forecasting tools of the spot prices.

The goals and contributions of this paper are twofold: 1) to study the extent to which the VPI of the spot prices in the operation of conventional PSHPs participating in the spot market and in the secondary regulation service can be reduced in comparison to PSHPs participating only in the spot market and 2) to propose and evaluate novel indicators to better explain the VPI in comparison to others proposed in the literature such as MAPE and Rank Correlation.

In the literature, the VPI of the spot prices has been studied in the context of load-shifting industrial plants [6], demand-side market customers [7], distributed storage systems (batteries) [8], and thermal and hydro power produces [9–11]. As far as we know, [1] is the only work published so far where the VPI of the spot prices has been studied in the context of PSHPs. The results presented in that paper show that the profit loss due to the errors in forecasting the spot prices is higher for PSHPs than for hydro or thermal power plants. In the paper here presented, we take a step ahead of [1] by considering the participation of the PSHP in the secondary regulation service. As demonstrated in [12], the traditional PSHP operation strategy based on the well-known price arbitrage does not allow justifying the investment. The said operation strategy is therefore evolving to an "ancillary services driven" one [13], in which the PSHP diversifies its sources of revenue among the different energy and ancillary services markets.

In order to evaluate the profitability of a PSHP, it is necessary to simulate its operation over a long time horizon within the context of the electricity market where the PSHP is planned to operate. Such simulation is often done by means of a deterministic approach, using either historical prices or synthetically generated future prices, and assuming a perfect price forecast. The regression models presented in this paper can be used to obtain a rough estimate of the VPI of any price forecasting model, as a function