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ScienceDirect

Energy Procedia 87 (2016) 45 – 52

Energy Procedia

5th International Workshop on Hydro Scheduling in Competitive Electricity Markets

Intraday Optimization of Pumped Hydro Power Plants in the German Electricity Market

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Abstract

Historically, the optimal production of hydro power plants was determined once day ahead. Today, many regulatory requirements in the German electricity market make this process much more complex: Power plant operators are committed to report information on planned production and even on provision of balancing energy of each single generator to transmission system operators. As soon as a deviation in the schedule occurs, the information hast to be updated and reported again. These requirements lead to the point where optimization of pumped hydro power plants can no longer be done manually.
In order to fulfil these requirements, EnBW has developed its own optimization model and established a system-based day ahead and intraday asset optimization process. The optimization problem is formulated as a mixed integer problem which determines the minimum operating cost subject to all technical constraints of a hydrothermal portfolio and covering load.
As a post-optimization of this new intraday optimization system we set up an effective multistage looping optimization algorithm for daily pumped hydro power plants considering e. g. reservoir limits, quarter-hourly prices, grid charges and availabilities. A real world case study is presented and discussed.

Peer-review under responsibility of SINTEF Energi AS

Keywords: continuous intraday trading; intraday optimization; mixed integer programming; pumped hydro power plants;

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Peer-review under responsibility of SINTEF Energi AS
doi:10.1016/j.egypro.2015.12.356

1. Introduction

With the so called “Energiewende” the conditions on the German energy market have changed fundamentally. A lower price level but most notably the flattened regular price spread between peak and off-peak have influenced the profitability of pumped hydro power plants. A lot of optimization methods for daily hydro power plants struggle to address the new challenges on the energy markets in Germany. Furthermore, new regulatory requirements of the German Federal Network Agency were introduced. Since 2014 energy producers are dedicated to frequently transfer the latest production plan to the transmission system operator.

After giving a short overview on the literature in 1.1, challenges of the energy market and the new regulatory requirements are discussed in 1.2 and 1.3. In 2.1 the implemented intraday optimization model to fulfill the regulatory requirements is introduced. The implementation of hydro plants is explicitly explained in 2.2. Using the model outputs such as accurate reservoir filling levels and price forecasts, we outline in 3.1, 3.2 and 3.3 adopted versions of the algorithm from Lu et al. 2004 and conclude with real world examples in 4.

1.1. Literature review (on pumped hydro storage optimization)

The literature on solving pumped hydro power storage scheduling problems can be separated into two general categories. On the one hand, the literature follows a system economic approach: e.g. Oliviera et al. (1993) solve a mixed integer linear program in a system context and integrate cost-efficient storage capacity. On the other hand, several papers focus on the individual plants and on how to operate a singular or a portfolio of hydro storages. These approaches are mainly based on using whole sale electricity prices and calculating an optimal control strategy.

The latter approach usually separates the optimization between daily pumped hydro power storages with small reservoirs and seasonal hydro power storages with large reservoirs and relatively small machines in comparison to their reservoir size. Literature that deals, among others things, with the daily pumped hydro storage scheduling problem are e. g. Thompson et al. (2004). They present a real option approach for pumped hydro storage operation inspired by financial mathematics. Horsley and Wrobel (2002) use a deterministic continuous price curve and derive valuation methods using duality methods. Lu et al. (2004) suggest an algorithm to determine a bidding strategy for pumped hydro power plants considering reservoir limits. Kanakasabapathy and Swarup (2010) and Zhao and Davidson (2009a and 2009b) expand this idea considering additional aspects such as spinning and non-spinning reserve, storage level-dependent efficiency and random inflows.

1.2. Market environment for pumped hydro power plants

The characteristics of the German electricity market have changed significantly over the past decade. The renewable energy act fostered the exploit of significant amounts of renewable energy resources (RES) that have entered the market in the last years and replaced power generation by fossil fuel power plants. As a consequence, the price at the EPEX Spot Auction decreased since 2012 by 10 % per year on average. This does not only influence the utilization of fossil fueled power plants but also pumped hydro plants.

The renewable generation is not equally distributed in time and space. Further, due to limited storage and a lack of sufficient transmission, generation capacity is not leaving the market. Less price fluctuation can be seen than expected with such amounts of RES in the market. In particular, this effect has reduced the average price spread and thereby the profitability of daily pumped hydro power plants that were constructed to balance production and demand.

This effect is depicted in Fig.1. The exemplary calculation is made for a daily pumped hydro power plant with 500 MW turbine/pump power, an efficiency of 80 % and grid charges of 4 €/MWh for the consumption of energy. In part (a) the historic average spot price and the water values for pumping and water release are plotted. On average a pumped hydro power plant in 2005 could be operated 9 hours a day in pumping and 7 hours in generating mode with an average spread of 32.21 €. In the year 2014 the plant is operated 6 hours in pumping and 5 hours in generating mode taking advantage of an average spread of 21.34 €.