Energy Policy 37 (2009) 4851–4862

Contents lists available at ScienceDirect

Energy Policy

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

A real option-based simulation model to evaluate investments in pump storage plants

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ARTICLE INFO

Article history:
Received 10 March 2009
Accepted 13 June 2009
Available online 23 July 2009

Keywords:
Real option
Simulation
Pump storage plant

ABSTRACT

Investments in pump storage plants are expected to grow especially due to their ability to store an excess of supply from wind power plants. In order to evaluate these investments correctly the peculiarities of pump storage plants and the characteristics of liberalized power markets have to be considered. The main characteristics of power markets are the strong power price volatility and the occurrence of prices spikes. In this article a valuation model is developed capturing these aspects using power price simulation, optimization of unit commitment and capital market theory. This valuation model is able to value a future price-based unit commitment planning that corresponds to future scope of actions also called real options. The resulting real option value for the pump storage plant is compared with the traditional net present value approach. Because this approach is not able to evaluate scope of actions correctly it results in strongly smaller investment values and forces wrong investment decisions.

1. Introduction

The expansion of power generation from renewable energy sources includes especially the power generation from wind power plants (Benitez et al., 2008). Since the supply of wind fluctuates strongly, the power generation from wind power plants underlies massive fluctuations, too. In order to compensate this strongly fluctuating power generation, pump storage plants are suitable in particular (Benitez et al., 2008), so that increasing investments in pump storage plants are to be assumed. For assessing the investments in pump storage plants an investment appraisal is necessary that covers the peculiarities of this type of power plant.

The common approach for the appraisal of capital budgeting, and thus of power plants represents the net present value method. Within the scope of the net present value method the expected cash flows of the investment are discounted with risk-adjusted cost of capital. This method results in incorrect valuations, if future scope of actions should be considered in the valuation. These future scope of actions within investments are also referred to as real options (Muche, 2007, with further proofs).

In this article a valuation approach will be developed that will consider the real options in the valuation of a pump storage plant. These real options particularly arise from a price-based unit commitment planning that has been necessary or possible since the liberalization of the power markets.

For the valuation of pump storage plants on the liberalized market and with consideration of price-based unit commitment planning different articles have been published (Bregar, 2007; Kanamura and Ōhashi, 2007; Lu et al., 2004; Thompson, 2004; Vieira and Ramos, 2008). This article differs from these articles by its explicit reference to a power price simulation and a unit commitment planning being based on a binary optimization model. During the planning of a unit commitment, price models for the day-ahead and the intra-day market at the European Energy Exchange (EEX) for Germany are taken as a basis. At the same time, the price model for the day-ahead market serves as a forecast basis for the intra-day market. By an unit commitment on the intra-day market, this approach makes it possible to make use of price jumps which are otherwise difficult to forecast. The valuation model, developed with regard to these aspects, requires the application of methods of statistics, operations research and capital market theory.

The structure of the article is as follows. In Section 2 it is illustrated how a price process for power can be determined, basing on historical data, and simulated and predicted for future years. A model for unit commitment planning on basis of this price process is introduced in Section 3. In Section 4 the simulation model is described, which enables the valuation of a pump storage plant using the results from Sections 2 and 3.

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doi:10.1016/j.enpol.2009.06.041

Sections 5 and 6 evaluate and summarize the major results of the article.

2. Electricity price model

On principle, the power generated by the unit commitment can be traded on wholesale markets and on reserve markets. The trading on wholesale markets includes the delivery contractually fixed in height and time between supplier and buyer. The trading on reserve markets is to balance unplanned deviations between power input and power output. The conclusion of a contract in trading on wholesale markets can be made bilaterally or through trade exchanges. The most important trade exchange for scheduled power in Germany is the EEX in Leipzig. Trading at the EEX is possible on the spot market with delivery at (or shortly after) the conclusion of a contract and on derivative markets with delivery at a (longer term) time in the future. Trade in reserve power takes place through the common trading platform of the transmission system operators E.ON Netz GmbH, EnBW Transportnetze AG, RWE Transportnetz Strom GmbH and Vattenfall Europe Transmission GmbH (Hartmann, 2007; Hinüber, 2007).

In this article, only the trade with scheduled power on the spot market is looked at. The derivative market for scheduled power is not taken into consideration, since the hourly optimization of unit commitment, which would be interesting for a pump storage plant, cannot be realised due to the time pattern of the derivative market. Although on principle, pump storage plants allow a participation on the reserve market due to their technical properties as well, this market is not looked at too, because the consideration of one market is sufficient for the intended valuation of scope of actions. The spot market is favoured to the reserve market since the spot market is more suitable because of its several years of existence, its trade volume (liquidity) and its transparency for the applied modelling approach in the article than the reserve markets which are still in development.[1] The presented modelling approach, however, is transferable to reserve markets, too.

The spot market for scheduled power at the EEX is carried out as day-ahead-trading and as intra-day-trading. On both markets, the trade in hour contracts and in block contracts is possible. By the unit commitment of pump storage plants especially the daily difference of hour prices for power is taken advantage of. During hours with low prices the pump mode takes place, during hours with high prices the power is generated in turbine mode. Against this background, the hourly optimization of a unit commitment applied in this article, only the hour contracts are looked at. For each trading day 24 different hour contracts with a smallest output unit of 0.1 MW can be traded.[2]

By intra-day-trading, hour contracts with delivery at the same or following day can be traded, although a trade at the same day can be made up to 75 min before delivery. On the day-ahead market the hour contracts are for the next day are traded. Each trading day at 12 o'clock an auction and price fixing takes place for each of the 24 hours of the following day. The day-ahead prices for an offer on the day-ahead market are not decision-relevant for a single valued pump storage plant and thus for a price-based unit commitment, because the offers have to be on hand already before the price fixing.[3]

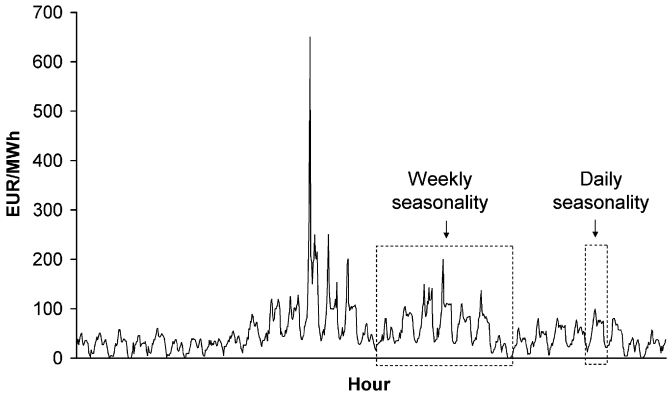

Fig. 1. Hour prices in EUR per MWh at the EEX in December 2007.

As it will be illustrated in this section more detailed, the hour prices show a high correlation on the day-ahead market and on the intra-day market, so that the pricing on the day-ahead market can be used as forecast basis for a price-based unit commitment and respective offers on the intra-day market. This procedure serves as basis for a price-based unit commitment in this article. For the implementation in the valuation model, at first, the development of a price model is required to describe and predict the hourly price course on the day-ahead market.

Starting point of the price model for the day-ahead market are the observed properties of the price. Fig. 1 shows the course of the hourly price for December 2007 at the EEX in Euro (EUR) per megawatt hour (MWh).[4]

According to various empirical studies and the course of the price shown in Fig. 1, the following characteristic properties of the price can be identified in particular (Swider and Weber, 2007, with further proofs):

- high volatility (i.e., strong price fluctuations),
- price jumps caused by price spikes,
- seasonality and
- mean reversion (i.e., the prices tend to fluctuate around an equilibrium mean).

For modelling the price considering the mentioned properties, most various approaches have been developed (Cuaresma et al., 2004; Garcia et al., 2005; Huisman et. al., 2007; Knittel and Roberts, 2005; Mugele, 2005; Nogales et al., 2002; Swider and Weber, 2007; Weber, 2005). Since the price model represents only a part of a valuation model, a modelling as simple as possible will be applied for the price model hereafter, nevertheless covering the stated properties in regard to the presented valuation of the pump storage plant.[5]

In order to determine the price model the hour prices of the EEX for the year 2007 are taken as a basis (8760 hours). Since the price model – to avoid negative hour prices – is to be created for logarithmized prices the prices from the year 2007 are transformed into logarithmized prices first (Cuaresma et al., 2004). Then, an additive model is used for the logarithmized price in the

[1] Cf. for Germany information on www.regelleistung.net.

[2] Cf. for current arrangement of day-ahead- and intra-day-trading here and hereafter information of EEX on www.eex.com and EEX, 2007.

[3] A daily optimization related to the prices on the day-ahead market would be possible, if there are already closed trades available for the respective day. This possibility exists especially with a portfolio of different power plants bringing their

(*footnote continued*)
power generation on the market for a longer term as well. In this consideration of an individual pump storage plant, this case is rather unrealistic. Cf. also Hinüber, 2007, p. 7.

[4] Hereafter data from the year 2007 are taken as a basis as well since only the whole hour values for the year 2007 were available when writing this article.

[5] It is assumed that the pump storage plant does not have any influence on the pricing on the market and can thus be considered as price taker. Cf. thereto also Fosso et al., 1999, p. 76.