Energy Strategy Reviews 9 (2016) 8–17

Contents lists available at ScienceDirect

Energy Strategy Reviews

journal homepage: www.ees.elsevier.com/esr

CASE STUDY

Development of the methodology for the evaluation of a hydro-pumped storage power plant: Swiss case study

N.A. Iliadis*, E. Gnansounou

Ecole Polytechnique Fédéral de Lausanne (EPFL), ENAC, Bioenergy and Energy Planning (BPE), Ecublens 1015, VD, Switzerland

ARTICLE INFO

Article history:
Received 20 October 2014
Received in revised form
19 October 2015
Accepted 21 October 2015
Available online 14 December 2015

Keywords:
Power plant operation policy
Long term valuation
Day ahead spot market
Intraday spot market

ABSTRACT

During the last two decades, an evolving market structure is recognised starting from the spot market and its derivatives, resulting to several other markets such as the Intraday Market (IM), the Balancing Market (BM) and the Reserve Capacity Market (RCM). The participation in these markets has changed significantly the operation policy of the plants and, consequently, their value in the market. The current paper deals with the problem of the long-term valuation of a Hydroelectric Pump Storage (HPS) plant participating in the DAM and IM. For this purpose, an appropriate methodology has been developed while it is demonstrated on a real case study concerning the operation of a Swiss based HPS plant that participates in the DAM and IM of the German electricity market, for a horizon of thirty-five (35) years.

1. Introduction

Since the launching of the first think-tanks and international forums on the impact of the power sector emissions on the environment, the generation mixes within countries started going through a significant change. There has been several studies analysing the effects of the fossil fuels on the environment and climate change speed [1] as well as the impact of cleaner generation technologies [2] such hydroelectric power [3], natural gas [4] and other technologies [5]. The latter studies are divided between these calculating the carbon emissions based on energy [6], and these having identified the mechanism of environmental effects and developed the relevant mathematical models [7, 8]. The common obvious result of these studies is the positive contribution of the renewable energy sources and low polluting technologies to the environmental health and climate change prevention. However, the important increase of renewable energy sources into the generation mix has raised a number of issues on the system reliability and marginal operating cost.

The last two decades have been characterised by the shifting from a cost minimisation objective to the revenue maximisation of power plants. More specifically, under the context of deregulated electricity markets, generation companies have abandoned the traditional minimum cost operation optimisation schemes and have moved to an operational policy where daily decisions are taken determining the amount of power, along with the type of ancillary services, they are willing to provide in order to maximise their profits [9].

An electricity spot market may be organised as a sequence of different market mechanisms including Day-Ahead Market (DAM) and the Intraday Market (IM) (during the delivery day). Given this marketplace's structure, every typical generation company tries to determine its optimal operation strategy in order to maximise the respective revenues and thus calculate the value of the plant in the long term. To achieve this target, there is an increased need of an appropriate methodological framework to be adopted that simultaneously considers these multiple markets and addresses the problem of deciding in which market mechanisms the owner agent should participate and in which volumes will maximise its profits [10] while considering a long horizon.

Furthermore, the increasingly growing penetration of wind and solar energy in all European countries has made forecast horizon shorter, emphasising thus, the importance of IM both for the demand and supply. Especially in countries like Germany, due to the high penetration levels of solar photovoltaics along with their generation profile particularities (production only in peak daytime), the difference between peak prices and off peak prices has been significantly reduced. Moreover, the highly possible lack of base load capacity, as a consequence of the nuclear plants decommissioning adopted by Switzerland and Germany, augmented further

* Corresponding author.
E-mail address: niko.iliadis@alumni.epfl.ch (N.A. Iliadis).

http://dx.doi.org/10.1016/j.esr.2015.10.001
2211-467X/

the off-peak DAM prices reducing thus the peak to off-peak spread. Further to the structural changes above, the crisis that hit the world and Europe the last six (6) years, had as a result the important decrease of the demand and hence the continuous fall of the prices to a level as low as 50% of their 2009 value. All these changes clearly denote the difficulty of a high flexibility plant belonging to the so-called Energy Storage Technologies (EST), to collect sufficient revenues from participating only in the DAM and highlight the increased need to participate in the IM as well.

The most representative and widespread known case of EST is the hydro pumped-storage (HPS) power plants, which can adopt diversified bidding strategies acting in multiple electricity market segments and therefore being in a potential privileged position compared to the thermal power generating plants. Their advantage comes from the storage capability of HPS power stations allowing them to be involved in both generating and pumping, and buying and selling energy depending on the price profile and their flexibility. For this reason, an HPS utility can buy and sell electricity on the DAM as well as on the IM, by following an appropriate strategy that can result to revenues' maximisation. The conventional way of estimating the future revenues of a HPS power plant considers simulating its activity in the DAM. Other revenues are then calculated as a fixed percentage on top of the latter amount. As pumping implies energy consumption, the economic efficiency of the operation can be achieved only if the electricity selling price is higher than the purchased price beyond a certain target, depending on the technical efficiency of the HPS plant. However, due to all the previously mentioned factors, the difference between peak and off-peak electricity prices is decreased, affecting thus the economics of HPS plants. All these aspects concur for the use of new instruments such as the IM, while the importance of potential revenues from the IM leads to the need of a more accurate consideration of them in the long term valuation of the HPS plants.

The purpose of this paper is to describe the main aspects of a methodology that can be used for the long term valuation of a HPS power plant. That plant valuation consists in estimating the net expected present value of a plant taking into account investment and future revenues from operation in the various market that the plant participates in. A practical application of the developed methodology will be presented by addressing the main questions of calculating, developing and laying out the optimal simulation of the electricity generation policy of a Swiss HPS for its long term valuation (i.e. from 2015 until year 2050) through the optimal allocation of power output being dealt to the successive market mechanisms of DAM and IM in Germany. The selection of Germany has been based upon the high liquidity achieved in the energy market being calculated as the ratio of the traded volume of wholesale day-ahead power contracts and the annual gross inland electricity consumption in the respective region, among the possible markets that a Swiss operator can participate in. The solution to the assessed problem reveals the real value of an HPS plant in Switzerland, and consequently the assumed operation strategy, from a long-term perspective, required in order to lead to an expected revenue maximisation.

Thompson et al. in Ref. [11] present an algorithm that can be used for the valuation and optimal operation of hydroelectric and thermal power plants operating in the liberalised electricity market. Appropriate equations are derived by using real options theory that incorporate an increased variety of spot prices models for representing realistically the main characteristics of spot prices markets (e.g. price spikes). The operational constraints of the involved power plants are taken into consideration and the developed models lead to non-linear partial-integro-differential equations, when solved determine simultaneously the expected cash flows and the optimal strategy. The paper presents the obtained results for two case studies that concern a hydroelectric pumped-storage facility designed to take advantage of price spikes and a hypothetical thermal generator.

Pedram and Moff in Ref. [12] focus on the valuation of energy storage technologies in electric power markets by assessing the relative arbitrage revenues that may occur. For this purpose, appropriate models have been developed for optimising the operation of a storage facility over a 24-h period while the respective problem has been framed as a linear program, a multi-stage stochastic program and a dynamic program. These discrete optimisation frameworks have been separately used in order to analyse two specific storage technologies.

Botterud in Ref. [13] investigates the way that dynamic and stochastic optimisation can be used for improving the investment decisions concerning the power generation facilities in the competitive electric energy markets. An appropriate model has been developed for determining the optimal conditions for investing in a new power generation technology, when solving the respective problem using the dynamic and stochastic solution. Within this framework, a stochastic simulator is developed in order to realise the way that the investment strategy may differentiate through time, assuming that the investor changes the implementation of potential investment projects due to more updated and accurate information being gradually available. A case study that concerns a new base-load gas power plant in the Norwegian power system has been assessed in order to demonstrate the revenues gained from the developed methodology.

Weber and Woll in Ref. [14] present a methodology that has been developed for valuing the long-term operation of CHP portfolio by applying recursive stochastic optimisation. The main difference between the CHP power plants and the conventional power plants regarding their optimal operation in the liberalised market, concerns the additional operational constraint for the heat demand that needs to be satisfied. This constraint is appropriately modelled in the proposed method while a specific case study concerning a CHP system consisting of eight CHP power plants and two boilers with two main district heating grids is assessed.

Siddiqi in Ref. [15] concentrates on long-term project evaluation and power portfolio management issues in a competitive electric energy market that include decisions about various aspects such as building a power plant, entering into contracts for buying or selling energy over the short or long-term, etc. The developed method is based on Options Pricing Theory and Decision Analysis and is applied for implementing the long-term power portfolio management of an existing power utility in the U.S.

Deng in Ref. [16] addresses the problem of valuing electricity generation capacity as well as investing in new power generation facilities within the framework of the competitive electric energy market. An increased attention is given to the power price spikes that may occur and affect significantly the decision about investing in new generation capacity as well as the actual time to make this investment.

Proven by the literature review above, it is justified that the present research is occupied with a subject, where scarce scientific work has been published. Therefore, an opportunity is offered to develop a new methodology covering the relative research gap between long-term valuation, various markets participation and HPS plants valuation, thus promoting new ways of addressing and solving this specific combination of problems. Furthermore, having taken into account the current needs of Swiss electricity utilities, this study is also of entrepreneurial importance for the local HPS operators. The obtained results regarding the Swiss case study are expected to be of increased importance, not only from a theoretical point of view but also on the actual implementation to HPS facilities.

In recent years, increased research effort has been devoted in developing optimal policies for electricity utilities participating in