Energy Policy 39 (2011) 1575–1585

Contents lists available at ScienceDirect

Energy Policy

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

A novel business model for aggregating the values of electricity storage

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ARTICLE INFO

Article history:
Received 20 August 2010
Accepted 14 December 2010
Available online 8 January 2011

Keywords:
Electricity storage
Business model
Optimization

ABSTRACT

Electricity storage is considered as a valuable source of flexibility with applications covering the whole electricity value chain. Most of the existing evaluation methods for electricity storage are conceived for one specific use of the storage, which often leads to the conclusion that the investment on storage does not pay off. However, the value of storage cannot be properly estimated without taking into account the possibility of aggregating the services that storage can offer to different actors. This paper proposes a new business model that allows aggregating multiple revenue streams of electricity storage in a systematic way. The model consists in coordinating a series of auctions in which the right to utilize the storage unit is auctioned upon different time horizons. In the mean time, non-conflicting usage of storage by the actors in these different auctions is ensured. The functioning of the model is demonstrated by a case study. The results show that a storage unit can achieve higher return on investment in the manner proposed in the business model.

1. Introduction

Electricity storage technologies can provide multiple services in generation, transmission and distribution, as well as in end-user activities. The function of electricity storage lies in a bi-directional transformation process: first, electricity is transformed into a storable form of energy at certain efficiency, and second, the stored energy is recovered rapidly into electric energy with certain losses in case of need. Therefore, the electricity storage technology is not an electricity generation means in strict sense, but a valuable flexibility resource adjunctive to all the resources in the power system, which can help achieving a higher asset utilization rate and contributing to the reliability of the power system, especially in the scenarios of massive intermittent renewable energy penetration.

Many studies have been undertaken to evaluate the benefits of electricity storage. Some focus on the arbitrage value of electricity storage in the spot market of electricity (Lund et al., 2009; Muche, 2009; Sioshansi et al., 2009; Sioshansi, 2010; Walawalkar et al., 2007). Walawalkar et al. (2007) also estimate the value of electricity storage to provide regulation services in the market environment. Other studies look into the use of electricity storage at transmission or distribution level (EPRI, 2007; EPRI and US Department of Energy, 2003; Sandia National Laboratories, 2005, 2007). The end-user applications are often studied in the scope of distributed energy storage system. The economics of coupling electricity storage to wind farms is investigated in the literatures (Black and Strbac, 2006; Dufo-López et al., 2009; Korpaas et al., 2003; Kapsali and Kaldelli, 2010). An overlap of the two former categories of studies is discussed by Denholm and Sioshansi (2009) and by EPRI and US Department of Energy (2004), which deal with the transmission-related benefits of combining wind and storage. However, by focusing on only one specific application of electricity storage, most of the analyses mentioned above do not show profitability of investment on storage in the current context. As indicated (Electricity Advisory Committee, 2008; Sandia National Laboratories, 2004; Walawalkar and Apt, 2008), in most cases one sole benefit does not allow the cost recovery of storage facilities. These references point out that the combination of services could lead to a better perspective for the development of storage. Indeed, the societal value of storage should be properly recognized and accounted for the cost recovery of the storage facilities. While engineers continue to make effort to decrease the capital cost and to reduce the cycle losses of electricity storage technologies, economists have began to search for ways to increase the revenue of electricity storage, through the aggregation of the benefits of storage.

To date, relatively little work has been carried out towards that aim. In Sandia National Laboratories (2005), the idea of combination of services is set out, together with the principles of combination, being the operational and technical compatibilities.

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doi:10.1016/j.enpol.2010.12.033

EPRI and US Department of Energy (2004) and Walawalkar and Apt (2008) test several combination options for case studies. Although these studies provide valuable insight of combined benefit of storage, they feature several weaknesses. First, the combination options are case-specific and therefore hard to generalize. This would create difficulty to establish general and non-discriminatory regulation on storage. Second, for a certain combination option, the allocation of storage resource for different services is defined beforehand instead of being the result of an optimization. The common approach for such allocation is to designate a certain period of time during which the storage is dedicated only to one service. As a result, the use of storage at a certain time is still exclusive, which implies in fact a ''division'' of the storage resource for different services along the time. Third, the combination options studied in these analyses might be specific to the electricity landscape in the US, where the integrated actors can quite easily merge several applications of storage that fall in different spheres of activities. However, the viability of some combination options would be questioned in Europe, where the electricity sector is unbundled and deregulated. In Europe, the challenge of aggregating the values of storage is more related to the questions: (1) how the regulated actors and deregulated actors can share the use of one storage unit, and (2) how the decentralized use of storage by different actors can be effectively coordinated. As an answer to these questions, we propose a business model that allows systematically aggregating the values of storage in deregulated electricity sectors.

The new business model distinguishes itself from the existing methods in that it does not predefine the service that the storage is supposed to offer, nor does it reserve the capacities of the storage in advance for a certain service. The model consists in arranging a series of auctions in which the right to utilize the storage unit is auctioned in different time horizons. The aggregation of values of storage is achieved by superposing the utilization profiles of storage resulting from the auctions chain. A non-conflicting usage of the storage unit is ensured by communicating the utilization profiles resulting from the previous auctions to the actors in the next auction, who are required to respect the utilization profiles previously established when elaborating their own strategy on the use of storage.

The paper is structured as follows. Section 2 introduces the concept of the business model. The mathematic formulation of the model is presented in Section 3. In Section 4, we demonstrate the functioning of the model by a case study, together with a discussion of the key results. Section 5 concludes the paper.

2. Concept of the business model

The core of the business model lies in organizing a series of auctions to sell the available power and energy capacities of the storage unit among different actors. The auctions are taking place in sequential time horizons. For example, we can first introduce a week-ahead auction, which is followed by a day-ahead auction, after which finally an hour-ahead auction can be carried out. In each auction, the underlying product is the right to utilize the remaining ''capacities of storage''[2] during the auctioned period. Different actors will decide upon their strategy to use the storage according to their own objective function, be it maximizing the profit, minimizing the cost, or minimizing the risk, etc. In principle, all actors are asked to keep the energy balance over the auctioned period, which means that the sum of power injected into the storage should be equal to the sum of the power withdrawn from the storage unit by the end of the auction period (cycle losses included). This energy balance requirement demonstrates the principle that the storage facility is auctioned as a flexibility resource, but not as an electricity generation resource. This way, each actor will use the electric energy that he himself feeds into the storage unit, so there will be no conflict of interest between actors in different auctions.

The energy balance requirement is also critical for the conduct of the auction chaining. As the auctions are taking place in order of descending length of horizons, a non-zero energy balance resulting from a subordinate auction might make the previously established profiles infeasible in future periods. Furthermore, as energy has value in itself, a net energy deviation will influence on the value that the bidders attach to their submitted profile. An illustrative example can be considered in which bidder A submits a profile with zero energy balance for the price of 100, while bidder B submits a profile with an energy deficit (discharging more energy than what it has injected into the storage) for the price of 120. Then the winner of the auction will depend on whether the energy deficit is worth more than 20 or not. This information, however, will not necessarily be revealed before the gate closure of the underlined auction, but most probably only a posterior. In this case, the bid selection could become difficult. In addition, it raises another question that the value of energy deficit (or surplus) should ascribe to the storage operator or to the bidders in the next auction. Taking into account these factors, the energy balance constraint is imposed in each auction, so that the linkage of the auction chain as well as the bid selection can be facilitated. Therefore, it is stressed that in this work only storage is offered in the strict sense, i.e., not allowing for any resulting net injection or withdrawal (which might however be focus of future research).

The bid the actors submit consists of two parts: a utilization profile of the storage unit over the underlying period and one sole price for the desired utilization profile. The bidder who offers the highest price (thus who attaches the most value to use the storage unit upon that time horizon) will win the auction.[3] Note that the utilization profile submitted will imply real energy charging and discharging at the delivery time and does not stand for the reservation of the charge and discharge capacity. The utilization profile defined as such presents the property of being able to be aggregated. As illustrated by the formula below, the final charging or discharging of the storage unit at a certain time is the result of several charging or discharging actions that different actors (actors A, B, and C) have decided upon in different time horizon:

$$charge_t = charge_t^A - discharge_t^B + charge_t^C$$

This way, the use of the storage unit by different actors will result in only one final physical charging or discharging action, while the value of the storage unit will be the sum of the values that each actor attaches to the desired utilization profile. Hence, the aggregation of values of storage is achieved.

As a storage unit has limited charge, discharge and energy storage capacities, a coordination mechanism is needed to ensure the feasibility of aggregating several utilization profiles. This coordination is done by the organizer of the auction who communicates the retained utilization profiles of the previous

[2] The notion of ''capacities of storage'' refers to the charge/discharge capacities (MW) and energy storage capacity (MWh) of an electricity storage unit.

[3] The bidder who participates in the auction can be one single actor or be an aggregator who aggregates the desired utilization profiles of several actors. Therefore, the joint optimization of the use of storage by several actors within one auction is allowed in the presented model, as long as they submit one profile and one price. But as the optimization of utilization profile is an external part of the business model, for the sake of simplicity, we will only simulate simple optimization process for single actors in the case study in order to put more emphasis on the auction chaining process.