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Value of combining energy storage and wind in short-term energy and balancing markets

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Abstract

An algorithm is described that calculates the optimum dispatch of an electrical energy storage (EES) facility taking into account the short-term power exchange and the expected imbalance penalties of a wind farm. The effect of daily price variation, imbalance price spread, market closure lead-times, and wind contracting errors on the added value (AV) of an EES is shown for a range of different EES configurations. Finally, it is demonstrated that significant AV with more than one wind farm is possible where the combined rated power of wind is much greater than that of EES.

Keywords: Energy storage; Wind generation; Energy markets

1. Introduction

Utility-scale electrical energy storage (EES) in forms other than pumped-hydro is rapidly becoming a commercial reality. Demonstration and production plants are now being produced at feasible prices in sizes ranging from hundreds of kilowatts through to tens of megawatts, with capacities ranging from minutes through to tens of hours [1].

A well-recognised value stream for utility-scale EES is inter-temporal energy arbitrage in short-term energy markets. A key factor in the value of arbitrage is the daily price variation, which is a function of the generation mix and daily demand variation. As the energy price flattens, the arbitrage value reduces to the point where profitable arbitrage can no longer be achieved. Correspondingly, the value of arbitrage increases proportionally with the daily price variation, to the point where arbitrage is favoured over all other possible EES functions. As most EES technologies are very flexible, they have an additional value in providing real-time balancing services to other market participants. Balancing is an important function in advance contracting energy markets such as new electricity trading arrangements (NETA) and Nordpool [2,3]. In these markets, a participant may have contract commitments that it cannot meet due to plant failure or natural output variation. Any real-time energy imbalances are then cleared at one of the two current market-based imbalance prices depending upon whether the participant's position is long or short. The impact of these prices can be either trivial or severely punitive depending upon the current market situation. However, the spread of these two imbalance prices is of little relevance to EES because other than plant failure, it has complete control over its output.

Wind farm is one of the participants that may benefit from a balancing service due to the significant difficulty in accurately predicting their output. For wind, as a stochastic generator with little or no control over its generation, the average daily price and the imbalance price spread are the key factors in the value of its generation. In an advance contracting market, the difficulties associated with accurate prediction of wind generation will inevitably result in a substantial imbalance error for the wind farm. Therefore, as the imbalance price spread around, the contract price increases and the average value of the wind energy generated decreases dramatically. The value of wind energy then becomes a complex function of the average

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energy price, imbalance price spread, and the forecasting error.

Given the flexibility of EES, it may be possible to balance the wind farm's position at the same time as performing other functions such as energy arbitrage. Although EES can provide these balancing services, this may constrain its ability to perform arbitrage. Therefore, the value of balancing to the group must be weighed-off against the individual cost to EES in terms of lost arbitrage revenues. If the benefit or added value (AV) of the balancing service is greater than zero then all participants will gain from this form of participation. A negative result however infers that one party may be free riding at the expense of the others. AV of the balancing service comes from the avoided cost of wind farm imbalance penalties. This initial cost then provides an upper limit on the potential AV of EES.

Previous papers investigating the optimal dispatch of storage facilities have mainly taken the approach of optimising the interaction of energy storage with the economic dispatch of hydrothermal systems [6–8]. Another paper investigated the application of energy storage with wind power but again the energy storage dispatch was part of an economic dispatch algorithm [9]. The approach that this paper takes is different in the sense that the interaction with the main system generation units is solely through the energy markets using cleared and estimated market prices. It is assumed that the storage plant is small relative to the rest of the system and so the prices are inelastic for this analysis.

This paper describes a combined optimal dispatch algorithm that calculates the AV of EES taking into account both the short-term power exchange (STPX) and the expected imbalance position of the wind farm in the balancing market. The effect of market and energy storage design parameters on AV is also investigated. Historical STPX pricing and wind data are used along with assumptions about imbalance price behaviour.

In real operation, STPX and/or balancing prices may not be known in advance and so the dispatch must be formulated using forecasted prices. It was assumed in this paper that the arbitrage prices were known 24 h in advance in a rolling window and the balancing prices known at market closure. These authors' prior experience has shown that in certain market conditions, up to 80% of the full-knowledge value can be obtained using primitive statistical price forecasting techniques.

2. Energy market overview

The energy market used in this analysis is representative of advance contracting markets such as NETA and Nordpool. There is an STPX with half-hour energy prices available in a day-ahead rolling window. This market closes a certain time ahead of the physical delivery so that the system operator can adjust the system to ensure safe and secure operation. At the close of STPX, all participants must submit their final positions to the system operator, which become their contract obligations. Flexible generators can then bid into the balancing market, which the system operator uses to physically balance the electrical system. These balancing costs then form the two imbalance prices that must be paid by participants for any differences between their actual and contractual positions.

At real-time, there is likely to be some deviation from participants' contracted positions. This is mainly due to natural variations in generation output and consumption forecasting errors. These differences in volumes for each half-hour period are cashed-out at the system buy price (SBP) for short positions and system sell price (SSP) for long positions. A short position corresponds to the difference in contracted and physical positions leaving a short fall in energy on the system. A long position results in an excess of energy on the system.

To avoid potentially punitive charges, a participant could have a balancing contract with another party within its trading group. This balancing contract would mean that if one party were short on its contract position, the second party would increase output to keep the group position in balance.

2.1. Base market model

The base system for this analysis uses a 4-h market closure delay with a 24-h STPX ex-ante-rolling window for the energy prices. The markets trade in half-hour periods for both the energy and the balancing markets, with no ex-post trading. The energy balancing prices in the balancing market are symmetrically spread around the STPX price. They are assumed to be known ex-ante and there is sufficient liquidity in STPX that the energy can be traded as required. Trading costs are neglected. The energy prices use half-hourly data from UK and Wales Pool from 1999; this is the same year as generation data for the 10 MW UK wind farm. Fig. 1 shows the structure of the balancing and energy markets, and the timings of the decisions.

The 24-h price data during STPX window is used for planning EES arbitrage dispatch, but the contracts for both EES and the wind farm are only fixed in the contracting interval. While the imbalance prices and the expected wind contracting error are known during the balancing window, they are only used as planning guides for managing the delivery interval where the costs would be incurred.

2.2. Wind energy contracting policy

In this analysis, the wind farm uses a persistence forecasting policy for selling its energy on STPX. As