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Evaluation of Reactive Power Capability by Optimal Control of Wind-Vanadium Redox Battery Stations in Electricity Market

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Abstract. Battery energy storage systems (BESSs) integrated with renewable energy resources are considered as necessary solutions for economical, technical and quality aspects. A BESS requires a power conditioning system (PCS) which permits both active and reactive power to be generated. In this paper, a wind-vanadium redox battery (W-VRB) station is considered as an independent power producer. The profit of this producer is maximized by solving a constrained dynamic optimization problem in a day-ahead electricity market depending on real-time electricity prices. Then, the reactive power compensation capability of this station for fulfilling the recent technical guidelines is estimated. A numerical case study is presented to illustrate the proposed method. It can be concluded that a large amount of reactive power can be achieved by an optimal operating strategy for the W-VRB station.

Key words

Electricity market, optimization, wind-vanadium redox battery station, reactive power capability.

1. Introduction

Wind farms connected to distribution power systems are considered as "non-firm energy" (i.e. when they provide energy the generators in these wind farms are paid based on the output) and thus cannot be dispatched. Therefore, many studies have recently been carried out to make the wind farms at least hourly dispatchable. This can be achieved by integrating appropriate BESSs with these wind farms. However, in practice large-scale wind farms tend to maximize their profits in a day-ahead electricity market system. This can be made by optimizing the daily scheduling of their plants integrated with an appropriate energy storage system (ESS) such as pumped storage [1], [2], which can introduce both power and energy capabilities for dispatching power from wind farms. Another solution is to use a vanadium redox battery (VRB) [3] which will be developed for large capacity so that it could be used to substitute conventional pumped power storage stations [4].

In addition, a BESS to be connected to an AC power system requires a PCS [5] which provides a bidirectional power conversion between AC and DC systems. A PCS connected to the terminals of a BESS, as shown in Fig. 1, permits it to generate both active and reactive power in all four quadrants, as shown in Fig. 2. Reactive power is needed for operating a wind farm. This can be either absorbed from the network where the wind farm is connected to, or generated locally. However, the recent technical guidelines [6] obligate the wind farms' owners to provide both active and reactive power. Furthermore, the reactive power compensation capability of wind farms must fulfil the recent grid code requirements.

The most important issues related to the reactive power compensation capability of wind farms presented recently in the literature can be classified as follows [6]-[12]:

- Optimal reactive power flow
- Allocation of reactive power loss
- Optimal reactive power provision of wind farms
- Reactive power control and voltage regulation
- Reactive power support requirements during faults
- Low voltage ride through (LVRT) requirements

From the discussions above it is obvious that wind farms can be in the near future at least hourly dispatched for trading active power and fully controlled for reactive power.

In this paper, we consider the operation of W-VRB stations which are composed of two main substations, see Fig. 1. First, a wind farm substation which can hourly be dispatched. Second, a VRB substation in which its power and capacity are selected initially through simulation procedures and at the same time electricity market requirements can be satisfied. In addition, to maximize the profit of the W-VRB station for a day-ahead market system, a dynamic optimization problem depending on both a forecasted wind power profile and real-time electricity prices is formulated and solved where all operational constraints are satisfied. In this way, the reactive power compensation capability of this W-VRB station can be estimated. Solutions of this problem yield two active and reactive power bidding scenarios which are formulated hourly for one day-ahead. A case study is presented to evaluate the reactive power capability of the W-VRB station.