Journal of Energy Storage 8 (2016) 320–338

Contents lists available at ScienceDirect

Journal of Energy Storage

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

Impact analysis of different operation strategies for battery energy storage systems providing primary control reserve

Johannes Fleer*, Peter Stenzel

Forschungszentrum Jülich, Institute of Energy and Climate Research, Systems Analysis and Technology Evaluation (IEK-STE), Germany

ARTICLE INFO

Article history:
Received 26 November 2015
Received in revised form 3 February 2016
Accepted 3 February 2016
Available online 18 February 2016

Keywords:
Battery energy storage systems
Primary control reserve
Frequency regulation
Ancillary services

ABSTRACT

Regarding the supply of primary control reserve (PCR), stationary battery energy storage systems (BESS) are a promising alternative to fossil fuel power plants. They offer the ability to respond fast and precisely to grid frequency deviations and may contribute to reducing the must-run capacity of fossil fueled power plants.

In Germany, primary control reserve is traded on a separate auction market with specific regulations, which enable the BESS to use a number of measures to balance its charge level and preserve operability. However, little is known about how the requirements from primary control deployment and the measures to keep the BESS operational during PCR contract periods affect operational parameters of the system. This study investigates the impact of operation strategies on different parameters including energy exchange through schedule transactions, total energy turnover, full cycle equivalents (FCE), and state-of-charge (SOC) distributions in a case study for a 2 MWh BESS under the German regulatory framework.

The results of this study are key to the economic assessment of BESS providing PCR, to an optimization of BESS operation, and to an estimate of battery aging in this specific application field.

Based on battery operation simulations, individual elements of operation strategies are identified and their influence on BESS operational parameters is analyzed in a parameter variation. These elements include the chosen measures for charge level management, the SOC ranges, within which these measures are used, parameters defining the schedule transactions, and the prequalified power rating of the BESS.

The results show that the choice of the measures for charge level management, the choice of schedule transaction parameters and the prequalified power rating of the BESS have a major impact on energy exchange through schedule transactions. The choice of the measures for charge level management and the choice of schedule transaction parameters have limited influence on the total energy turnover and the resulting number of FCE. These values are mainly influenced by the system design.

1. Introduction

The electric grid, in contrast to other supply networks like the gas grid, does not have the capability of storing energy. Hence, the feed-in of power to the grid and the use of power from the grid need to be balanced at all times. The grid frequency is the main indicator for grid stability. Its nominal value in the ENTSO-E[1] grid is 50 Hz. When the power feed-in exceeds the electricity use, the grid frequency increases. In contrary, when the electricity use exceeds the feed-in, the frequency decreases. Primary control reserve (PCR) for frequency regulation is required to compensate occurring imbalances.

On a worldwide level, PCR is currently mainly supplied by conventional power plants and pumped hydro power plants. However, the discussion about the possibilities of using BESS for PCR supply came up during the 1980s [1]. A 17 MW/14 MWh BESS for frequency regulation based on lead-acid batteries was successfully operated by the utility BEWAG in Berlin between 1986 and 1993 [2]. In the following years the application of BESS for frequency regulation has been limited to only a number of applications [3] due to limited battery lifetimes and relatively high battery prices. Over the last few years, the situation has changed

* Corresponding author at: Forschungszentrum Jülich, Institute of Energy and Climate Research, Systems Analysis and Technology Evaluation (IEK-STE), D-52425 Jülich, Germany.
E-mail address: j.fleer@fz-juelich.de (J. Fleer).

[1] The ENTSO-E (European Network of Transmission System Operators for Electricity) is an association of European transmission system operators which covers virtually all of Europe.

http://dx.doi.org/10.1016/j.est.2016.02.003
2352-152X/

Nomenclature

BESS	Battery energy storage system
C	Battery capacity (MWh)
E	BESS charge level (MWh)
f	Current grid frequency (Hz)
f_n	Nominal grid frequency (Hz)
FCE	Full cycle equivalents
P_{grid}	Grid-side power demand (MW)
P_{PC}	BESS's response to the grid-side power demand (MW)
P_{PQ}	Power output prequalified for primary control provision (MW)
P_{ST}	Charging/discharging power in schedule transactions (MW)
PCR	Primary control reserve
SOC	BESS state of charge (%)
t,t_k	Time (s)
TSO	Transmission system operator
ΔE_{DU}	Energy exchanged through deadband utilization (MWh)
ΔE_{OF}	Energy exchanged through overfulfillment (MWh)
ΔE_{PC}	Energy exchanged through primary control provision (MWh)
ΔE_{SC}	Self-consumption of the BESS (MWh)
ΔE_{ST}	Energy exchanged through schedule transactions (MWh)
$\Delta E_{transaction}$	Energy exchanged in a schedule transaction (MWh)
Δf	Frequency deviation (Hz)
$\Delta t_{contract}$	Contract period for a schedule transaction (h)
Δt_{lead}	Lead time for a schedule transaction (h)
η_{ch}	Charging efficiency (–)
η_{dis}	Discharging efficiency (–)

significantly with the fast development of lithium-ion based batteries for electromobile applications and their rapidly falling costs [4].

With the transformation of energy systems in various countries towards more sustainable systems, the shares of fluctuating renewable electricity generation will rise significantly. It is expected that, consequently, the quantity of required grid services to secure system stability will increase likewise [5]. This trend opens various opportunities for energy storage technologies. Together with the technological and cost development of batteries, BESS for stationary applications have become more and more interesting. In this context, several projects for PCR/frequency regulation have been realized recently [6,7]. Although BESS operation has been successfully demonstrated in a number of research and commercial projects, BESS for grid applications are still in focus of ongoing research activities.

1.1. Literature review

The state of the art of large-scale stationary battery systems, including technical and economic parameters, is reviewed by Poullikkas [8] and Hamidi et al. [9]. In stationary applications, especially on grid level, storage systems are always in competition with alternative flexibility measures [10]. In this context, Pearre et al. [11] introduce a general methodology for initial feasibility assessment of energy storage technologies for grid services. Oudalov et al. [12] present an overview of different energy storage technologies and their possible applications in electric power systems. It is shown that frequency regulation and the integration of renewables are the grid services that will most likely be asked for by utilities in the future and that BESS are the most suitable technology for PCR applications. A monetary value analysis identified PCR supply currently as the application with the highest financial benefit for the BESS owner and operator [13].

Regarding frequency regulation applications, different model-based approaches exist for analyzing the techno-economic performance, and optimal system sizing and operation of stand-alone BESS [14–19] and hybrid systems consisting e.g., of a wind power plant in combination with a BESS [20]. Another focus is put on lifetime and aging characterization for BESS in PCR applications [21,22]. Based on simulation results, Ding et al. [23] point out the improved frequency regulation performance of BESS compared to coal-fired power plants in terms of fast response, precise tracking and reliability. Hollinger et al. [24] compare cost structures of BESS and fossil fueled power plants providing PCR finding BESS to be competitive in the German PCR market. Environmental impacts of BESS for PCR supply are assessed by Stenzel et al. [25].

Results from BESS operation of a realized 1 MW BESS for grid applications show an outstanding performance of the BESS for PCR supply. The system has been prequalified by the responsible transmission system operator (TSO) and different recharge strategies have been investigated [26]. Comparable field test results of a 1.6 MW BESS for PCR together with BESSs lifetime considerations are reported by Swierczynski et al. [27,28].

Furthermore, several studies investigated the possibility of applying BESS for PCR/frequency regulation in small isolated power systems (island grids) in combination with high shares of renewable electricity generation. The range of subjects includes studies dealing with economic assessments [29], system design [30,31], and technical aspects including the development of control strategies [32]. It is shown that BESS in small isolated power systems with low grid inertia completely fulfill the frequency control requirements and that BESS can significantly increase the power system stability, the grid security, and the planning flexibility [31].

1.2. Research objectives

Here we show, in a model-based approach, how different parameters of a grid-connected BESS used for providing primary control are affected by the operation profile resulting from this specific application. Based on the German regulatory framework, this study focuses on operation strategies which take into consideration the scopes and degrees of freedom which have recently been published the German TSOs [33]. It analyses the impact of different parameters, which are part of the operations strategy, and points out the influence of system design. The energy flows between the battery and the grid are identified and assigned to their cause (primary control deployment vs. schedule transactions to balance the charge level). Results cover the energy turnover of the battery, the amount of energy exchanged in schedule transactions and battery parameters, which are particularly relevant for battery aging. This investigation is a case study for the German control area and uses high-resolution frequency data of the Continental European ENTSO-E grid. It is beyond the scope of this study to examine the impact on battery lifetimes and the resulting economic feasibility.

The first section of this paper gives a detailed description of the legal framework of the German primary control reserve market. In the remaining part of the paper, the simulation model is described and the results obtained from the simulations are presented.