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Peak shaving algorithm with dynamic minimum voltage tracking for battery storage systems in microgrid applications

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ABSTRACT

This paper proposes a new Peak Shaving algorithm in combination with a continuous battery peak power estimation algorithm for a battery energy storage system (BESS).

The objective of the proposed Peak Shaving algorithm is to avoid energy exchanges when the output power is considered to be too high. Therefore, the algorithm allows configuring the power limits for the system operation. However, in extreme situations, the BESS might no longer be able to follow the algorithm commands and the power will surpass this limit. In these situations, the proposed dynamic minimum voltage tracking algorithm ensures that the maximum available power is extracted from the BESS, thus reducing the total output power.

The proposed control system has been experimentally tested on a real-time microgrid. Results show that the proposed Peak Shaving algorithm allows to easily limit power exchanges between the microgrid and the main grid. Moreover, combining it with the dynamic minimum voltage tracking algorithm ensures that the power surplus, with reference to the defined limit, is minimized.

1. Introduction

In microgrid applications, it is possible to have undesired peaks of active power during short periods. These power peaks can happen in both consumer and generation systems, although problems related to consumer peaks are studied more often.

Transmission and distribution lines must consequently be sized accordingly to these power peaks, despite this power capacity not being used for most of the operating time. This infrastructure oversizing means that the consumer must pay a higher price for their energy [1]. Usually, electrical companies charge their clients for both the consumed energy and the maximum power demand. Savings of 10%–30% can be achieved just by reducing the peak power demand [2–4]. Economic analysis vary between countries but the increased costs related to peak power demand are always present [4,5].

In renewable energy generation systems, such as photovoltaic (PV) or wind energy systems, power peaks can cause them to operate outside of their maximum power point as they may not be able to deliver all of the available power to the grid. This is undesired since these systems should try to extract as much energy as possible. For instance, the Spanish transmission system operator (TSO) imposes limits for power generation in certain situations which are considered to be hazardous as defined in the Operating Procedure (P.O. 3.7).

Therefore, reasons for peak power reduction include infrastructure limits, TSO requirements and economic considerations. Most studies in the literature are related to economic considerations.

Solutions for reducing this peak power include load shedding of non-critical loads, activation of generation systems dedicated for this application and peak-shaving algorithms implemented in energy storage systems, such as Battery Energy Storage Systems (BESS) [6–13]. A review of the specific implications for each implementation is given in [6], where it is concluded that integrating ESSs to the grid is the most potential strategy of peak shaving. In [12] ESS applications for wind energy generation systems are reviewed, highlighting the benefits of implementing peak-shaving strategies.

Consumer peak shaving services have usually been provided by diesel generators. However, these systems have high operation and maintenance (O&M) costs [14]. Nowadays it is possible to install energy storage systems which can deliver the power required to avoid these power peaks [3]. Peak shaving applications through energy storage systems are a growing topic with test projects being developed across several countries. This is further inspired by the increasing installed capacity of non-controllable elements such as renewable energy systems [15]. Even moderate sized ESS can provide a significant reduction in peak demand power [16].

Peak shaving through energy storage systems is based on providing

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the power surplus, thus effectively "shaving" the total exchanged power in order to avoid surpassing the programmed set-point. When the peak shaving service is not needed, the energy storage system is prepared for the next peak situation through a state of charge (SOC) regulation. The SOC must be regulated to a value that allows for the energy exchange required by the peak-shaving algorithm [5,15].

To study the economic implication of using BESS for peak-shaving applications, both the daily variation in the cost of electricity and the variation on the electricity tariff depending on the reduction in power peaks should be taken into account. The BESS energy efficiency and state of health (SOH) are usually considered as well. Sometimes, a BESS model is included for the SOH estimation [4,5,15,17]. One-year results on a real-time test-bench show the influence of the SOH on the economic performance of peak-shaving algorithms [4]. In [15] the life time of a BESS dedicated to peak-shaving is estimated to be around 10–20 years. Algorithms to maximize the BESS SOH have been proposed in [5] and [17].

Several authors have proposed methods for the estimation of the economic benefit using these parameters [1,3,17]. A practical benefit estimation case-study is presented in [1]. In [3] the model is used to compare the financial benefit of different BESS applications, showing that peak-shaving is one of the most viable options although an oversizing of battery might be required depending on the expected power profile. Therefore, a good estimation of the load profile to be reduced is critical for these studies. The effect of this estimation of the BESS sizing is further analyzed in [18,19]. Hybrid systems, including both ESS and renewable energy generation, might also improve the economic feasibility [20].

Usually, BESS that are designed for other applications, such as uninterruptible power supply (UPS) in data centers [5] or PV power smoothing [21], are used for the peak shaving service. Nevertheless, sizing of BESS used for peak-shaving application must be selected according to each specific demand pattern. In [22] it is reported that power to energy ratios of Lithium-Ion batteries used in peak-shaving applications vary between 4:1 and 1:4 depending on the application scenario.

There are two main peak-shaving methods. The first is based on shaving the power above the defined limit by fixing the consumed power to the maximum [15,17]. The second is based on providing a fixed power through the BESS thus reducing the total consumed power and keeping it below the defined limit [1,5].

In the second method, the BESS accumulates or provides, for consumer or generation peaks respectively, a pre-calculated power value for a specific time period. It is based on a daily planning obtained from historical data of the system. This method does not require a control algorithm for calculating the BESS power depending on power measurements. Therefore, this method is recommended for systems where the power profile can be easily forecasted, such as data centers [1,5].

The first method is better for the BESS SOH but requires a more complex control system and is worse for SOC estimation. Besides, the second method is common in BESS where the peak-shaving algorithm is provided together with other applications.

Considerations regarding the optimum economic performance including the energy price and BESS utilization are also included by some authors in the operation algorithm [21,23], showing that shaving the peak power might not be profitable in all situations [23]. Since this paper is focused on technical aspects, it is considered that shaving the peak power is always preferred over reducing the use of the BESS.

The main contributions of this paper are:

1) A new algorithm for the Peak-Shaving service by BESSs is proposed by categorizing the states of a microgrid power balance.
2) This algorithm has been implemented on a real time test-bench. The analysis for all the possible scenarios in a given peak-shaving case study is included.
3) A Dynamic Minimum Voltage Tracking for Power Capability algorithm is implemented together with the proposed Peak-Shaving algorithm, showing the benefits of its implementation in microgrid systems.

The paper is divided in six sections. Section 2 describes the case study where the proposed Peak-Shaving algorithm is implemented. Section 3 describes the algorithm and in Section 4 it is evaluated through empirical tests. Section 5 summarizes the main conclusions extracted from the article. An Appendix A section is also included to describe the real-time test-bench.

2. Case study: peak shaving in a hybrid system

The studied system is composed of a PV generator, a load and a BESS which is responsible of providing the Peak Shaving service.

The test bench used for the real time implementation is described in the Appendix A. The BESS is made of 210 Ni-Cd cells. The control system includes an ampere-hour counting electrical model of the battery in order to estimate the SOC, which is considered sufficient for this application [13,24,25]. The efficiency is fixed to a value of 0.98 in the process of charge (ηloss = 0.98 for i > 0, where i represents the BESS current entering the battery) and 1 in discharge (ηloss = 1 for i < 0) [26,27,28].

A schematic of the complete system is depicted in Fig. 1. The power exchanged with the PV system and the load, represented by the dashed section in Fig. 1 titled "Photovoltaic source and load balance emulator", is emulated through a DC/AC power converter connected to the main grid. The DC/DC converters, the load and the PV panel are not present

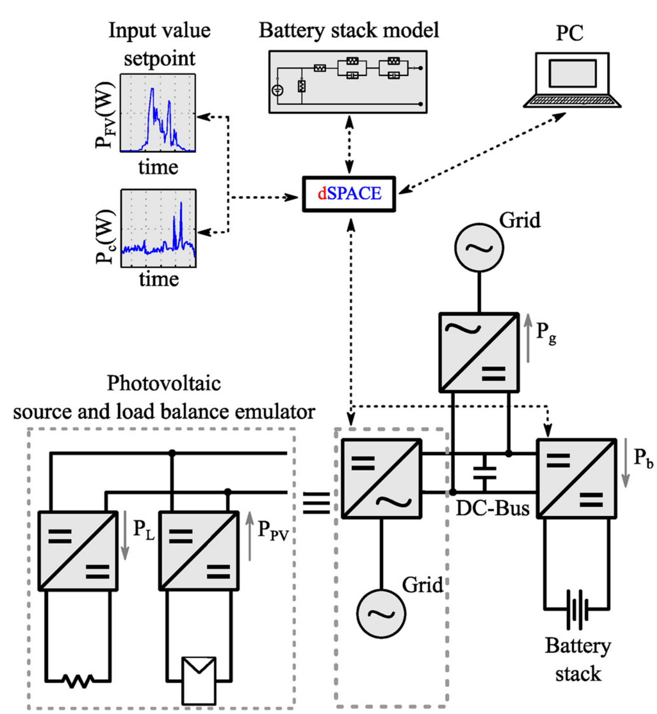

Fig. 1. Scheme of the hybrid system for the Peak Shaving service implementation through a BESS.