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Use cases for stationary battery technologies: A review of the literature and existing projects

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ABSTRACT

In electricity systems with a high penetration of wind and solar power generation, electricity storage can be employed to balance power supply and demand. In recent years, stationary batteries are receiving a particularly high degree of attention as they can be used to provide several services in modern electricity systems. However, while a rising number of such battery systems are deployed globally, academic literature has not addressed the trends in deployment of these battery technologies. Thus, this study strives to address this gap by identifying and describing the most attractive use cases for stationary battery technologies on mainland and island electricity systems in two steps. First, the existing literature on applications, profitability and use cases of battery technologies has been reviewed. Second, based on analyses of a database of battery installations and of 26 interviews with industry and academia experts, the six most prevalent use cases have been identified and are presented in this paper. We describe these use cases in detail, highlighting their drivers, sources of value creation and risks.

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1. Introduction

With increasing emphasis on reducing global carbon emissions and promoting universal energy access [1], and long-term concerns over fuel price volatility and energy security [2], renewable energy technologies, with their fast declining costs [3,4], are becoming an increasingly important part of the future energy system [5]. However, integrating high shares of variable renewable energy sources into power systems can prove to be a challenge [6–8]. Out of the several available flexibility measures [9–12], energy storage technologies are particularly promising response options because of their unique ability to decouple power generation and load over time [13].

Due to their favorable technological characteristics and potential for cost reduction, electrochemical batteries are receiving an increasing amount of attention within industry, politics, and academia in recent years. Their fast response time, scalability and modularity enables them to serve both power and energy applications and thus provide a wide range of services in on-, off-, and weak-grid situations [14]. As a result, significant activity is being seen in this sector, with a large number of battery installations being deployed across countries [15].

Nevertheless, to support investment in and deployment of stationary battery technologies, investors and policymakers need to have a thorough understanding of viable use cases applying these technologies [16]. Use cases have been defined as "groups of (or sometimes individual) services that are provided by a single energy storage system" [17]. As battery technologies become more mature, the question of how use cases (or combinations of applications) can maximize the value created by battery installations to make them economically viable in real contexts is gaining more emphasis [18–20]. While the academic literature describes the technical characteristics of battery technologies, the various applications that can be served using them, as well as the theoretical profitability of the applications in different contexts, it does not systematically identify viable use cases for stationary battery technologies and the factors influencing them. Hence, there is a need for a review of use cases for stationary battery technologies based on empirical evidence. To address this gap, in this paper, we strive to identify and describe the most attractive use cases for stationary battery technologies on mainland and island electricity systems across different applications and geographies.

As the first step towards identification of viable use cases, we review the literature on profitability of energy storage applications for stationary battery technologies (Section 2). It is found that the studies are inconsistent in terms of the definition and nomenclature of different energy storage applications. To address this, we review different classification schemes and studies reviewing energy storage applications on mainland and island electricity systems, and adopt a mutually exclusive and collectively exhaustive classification scheme [21]. Further, we present the difficulties in identifying viable use cases from the existing literature, due to their limited geographical focus, the segregation between studies on mainland and island contexts, and scarcity of empirical evidence in existing studies. Second, we develop a database of energy storage projects deployed globally and pursue expert interviews to get a perspective on trends, and to identify viable use cases across different geographies (Section 3). The database is used to observe trends in applications, their combinations and the geographies in which they occur. This information is enriched using expert interviews in which the underlying drivers and risks for the use cases are identified. The obtained results are presented and discussed in Section 4. Section 5 concludes by stating possible avenues for future research while summarizing the paper's principle contributions.

2. Literature review

For the purpose of identification of use cases for stationary battery technologies, we reviewed peer-reviewed academic publications as well as the grey literature (technical reports and white papers by research laboratories, agencies, consultancy, and industry analysts), primarily because storage is a fast-moving industry, and a lot of up-to-date information regarding developments in energy storage applications can be found only in the grey literature. As a starting point for the identification of use cases for stationary battery technologies, we reviewed studies evaluating the profitability of energy storage technologies. An overview of the results of recent studies performing a comparative analysis of energy storage applications and use cases is provided in Table 1, followed by some key observations from these studies.

There are certain common observations which can be made from the studies presented in Table 1. One of the common conclusions across the studies is that the profitability of wholesale electricity arbitrage is lower as compared to other applications, and might need to be combined with other benefits to improve the economic viability of energy storage. Frequency regulation is found to be the application leading to the highest profits, especially in markets where it is valued highly (e.g. PJM Interconnection in the US). However, while the studies analyze a number of applications for different geographies and technologies, it is seen that there is no consensus on the nomenclature of energy storage applications, leading to difficulties in comparison across studies and ensuring exhaustiveness in terms of applications considered.

To arrive at a consistent and comprehensive definition and nomenclature of storage applications, we examine existing studies which qualitatively review and classify energy storage applications. Several studies such as Masiello et al. [31], Dunn et al. [32], Poullikkas [33], Koohi-Kamali et al. [34], Divya and Østergaard [35] and Beaudin et al. [36] provide overviews of stationary battery technologies, their performance and applications, often illustrated by examples from real world projects. Masiello et al. [31] discuss existing and hypothetical business models for energy storage, along with the complexities involved in their deployment and operation from a regulatory and business perspective. Poullikkas [33] provides an overview of energy storage applications with a list of 50 operational and planned large scale battery systems. Looking specifically at applications on small islands and microgrids, Koohi-Kamali et al. [34] describe "applications in micro-intelligent power grids" as a separate category of applications, focusing on grid-connected microgrids for power reliability. Additionally, there are several studies which provide an overview of applications of energy storage technologies specifically on island and remote microgrid systems: IRENA [37] provides a theoretical qualitative overview of the capabilities of energy storage