Applied Energy 188 (2017) 226–236

Contents lists available at ScienceDirect

Applied Energy

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

Cloud energy storage for residential and small commercial consumers: A business case study

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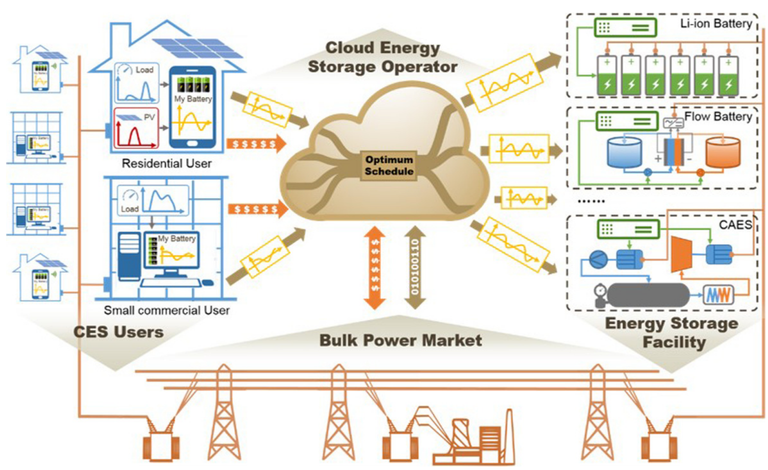
HIGHLIGHTS

- A virtual distributed energy storage service using centralized storage facilities.
- Architecture and business model of Cloud Energy Storage.
- Operation mechanism of consumer and operator for Cloud Energy Storage.
- Profitability analysis of Cloud Energy Storage using actual power system data.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 25 July 2016
Received in revised form 5 November 2016
Accepted 28 November 2016

Keywords:
Energy storage
Energy internet
Cloud
Business model
Distributed energy storage
Sharing economy
Economies of scale

ABSTRACT

Energy storage is extensively recognized as a significant potential resource for balancing generation and load in future power systems. Although small residential and commercial consumers of electrical energy can now purchase energy storage systems, many factors, such as cost, policy and control efficiency, limit the spread of distributed energy storage (DES). This paper proposes a new type of DES—cloud energy storage (CES)—that is capable of providing energy storage services at a substantially lower cost. This grid-based storage service enables ubiquitous and on-demand access to a shared pool of grid-scale energy storage resources. It provides users the ability to store and withdraw electrical energy to and from centralized batteries. This paper describes the concept of CES and the control and communication technologies that are required for its implementation and its operating mechanism, as well as its business model. Simulation results that are based on actual power system operating data demonstrate the feasibility and economic benefit of CES.

1. Introduction

Power systems around the world are transitioning from fossil fuels to renewable energy sources, with variable renewable energy (VRE) sources, such as wind and photovoltaic (PV), increasing from 181.57 GW of worldwide installed capacity in 2009 to 549.24 GW in 2014 [1], and generating 2.7% of the electrical energy consumed globally [2]. By 2050, wind power and PV are estimated to provide more than half of the electricity demand in China and more than 40% of the electricity demand in the U.S. [3,4]. However, statistics

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http://dx.doi.org/10.1016/j.apenergy.2016.11.120
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about installed capacity and energy production do not reveal the entire story. Maintaining the stability of the power system requires real-time balancing of the energy that is consumed and produced. The integration of VRE replaces controllable power-generating plants with an uncertain and intermittent energy source that complicates the task of satisfying the demand at all times [5]. In countries where electrical energy is traded on a competitive market, the intermittency and variability of renewable energy sources will also increase the volatility of electricity prices [6].

Energy storage can significantly facilitate VRE integration [7] because it can store electrical energy when VRE sources produce more power than can be used and release this energy when needed. Energy storage can smooth the intermittency of VRE sources to better follow the variation of the load demand [8]. Several energy storage technologies are in various stages of development: pumped hydro, compressed air (CAES), super capacitor, flywheel, and various types of flow batteries or solid batteries [9]. Although the cost of these energy storage technologies remains high compared with the price of electricity [10,11], recent advances in battery technologies, especially in lithium-ion chemistries, suggest that their cost may be substantially declining [12]. In parallel, electricity markets are evolving toward a model in which a larger number of consumers will be exposed to real-time prices [13]. As VRE sources cause the volatility of real-time prices to increase, these consumers will want to control their instantaneous demand using an individual energy storage system [14]. Consumers who have installed solar panels may also want to use this storage to reduce their dependence on electricity purchased from the grid. These factors are likely to lead to the development and deployment of distributed energy storage (DES) [15]. Commercial products aimed at this market are already available [16].

Although the technology to support DES is available and the economics of DES are evolving favorably, some regulatory barriers and technical limitations may hinder its development. In particular, in many countries, customers receive little or no compensation for electrical energy that they inject back into the power grid. This lack of compensation provides little incentive for DES to react to variations in electricity prices [17]. DESs, particularly those installed at the residential level, are unlikely to be equipped with the smart control and communication systems that enable them to optimally self-schedule based on price forecasts and the total need for system real-time balancing. To circumvent these problems, centralized management approaches have been proposed to better utilize DES resources [18,19]. There are also emerging commercial attempt of DES. Green2store is a project which uses the energy storage units in a local network together as one large storage facility [20]. Sonnenbatterie, a Germany based company, aims at providing an energy storage solution to residential users, including software and energy storage units [21]. SENEC.IES utilizes DES to provide users a lower electricity price [22]. Some other companies aggregate users' DES to participate ancillary services market [23,24].

In this paper, we describe an alternative technique that we refer to as cloud energy storage (CES). This technique supports both the needs of residential DES and the optimal operation of storage resources. The CES concept is inspired by cloud services [25] and the sharing economy [26–28]. As locating shared computing resources in "the cloud" enhances their utilization and cost-effectiveness, CES is dependent on the power grid to optimize the use of energy storage resources [29]. In the remainder of this paper, we describe how the cloud energy storage concept can be realized using state-of-art technology. We also demonstrate how CES can provide the same quality of service as DES at a substantially lower cost via sharing storage resources and taking advantage of the economies of scale. The gains in social welfare and profitability are illustrated using actual residential load data and electricity prices.

The contribution of this paper mainly lies in three aspects: (1) proposing the concept of Cloud Energy Storage which would utilize centralized energy storage facilities to provide distributed storage services for residential and small commercial users; (2) describing the architecture and enabling technologies, operation mechanism that facilitate CES; (3) designing the business model of CES and demonstrating its profitability using real-life residential load and electricity data.

The rest of the paper is organized as follows. Section 2 describes the concept of CES and the associated technology framework and business model. Section 3 proposes an economic analysis model which can be used to calculate the benefits of CES. Section 4 presents the case study. Section 5 concludes.

2. Concept and business model

2.1. Concept of cloud energy storage

The demand for DES has very similar characteristics to the demand for distributed computing services [30]. (1) Uniformity: electrical energy is a homogeneous commodity that is similar to computing services, which facilitates the extensive sharing of resources. (2) Transportability: electrical energy can be rapidly and efficiently transmitted through the power grid as data are communicated via the Internet, which enables the use of a real-time remote service that is comparable to a local service. CES can be defined as a grid-based storage service that enables ubiquitous and on-demand access to a shared pool of grid-scale energy storage resources. CES provides users the ability to store and withdraw electrical energy to and from centralized batteries. It relies on the sharing of resources to achieve economies of scale [31]. Fig. 1 illustrates the structure of CES, which consists of three main parts: the CES users, the energy storage facilities and the CES operator.

The users of CES can be residential consumers or businesses who want to use energy storage to optimize the profile of their demand for electrical energy or reduce their electricity bill by storing energy when the price of energy is low and releasing the energy that have been stored when the price of energy is high. Instead of purchasing batteries and battery management systems, they rely on energy storage services from the CES, where they can rent a customized amount of both power and energy capacity. CES users can charge or discharge their cloud batteries in the same manner as they would control an actual battery that they would buy, install, operate and maintain.

The energy storage facility of CES is large-scale and centrally controlled by the CES operator to achieve optimal operation. Because of its size and centralized nature, CES facilities can combine different storage technologies, such as Li-ion batteries, flow batteries or compressed air energy storage, and use each technology as appropriate for current needs.

The CES operator controls the energy storage devices to satisfy the charging and discharging demands of CES users while maximizing the utilization of the storage resources. The available storage facilities are not only shared by multiple CES users but are also dynamically reallocated based on the demand for charging and discharging. By optimizing schedules and coordinating the control of the energy storage facility, the CES operator can reduce the total investment cost, the cycling losses, the battery space, and the maintenance cost.

Fig. 1 also illustrates the flows of information, energy and money among the various participants. The CES operator bidirectionally communicates with the CES users and the energy storage facilities. CES users do not directly communicate with the energy