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Cloud energy storage for grid scale applications in the UK

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ABSTRACT

In this paper, the UK's electricity market and battery technologies were researched to determine the economics of aggregating domestic batteries for grid-scale services. A feasibility study was conducted under three scenarios in order to estimate the value of Advanced Lead-Acid (ALA) and Lithium-Ion (LI) batteries for domestic households in the UK. A profit optimization model was built using historical market data, and technical parameters of the batteries. An aggregated system of 5000 batteries was simulated and used to compare and stack value streams of seven different grid-scale services in the UK, including energy arbitrage, reserve and frequency regulation services.

The results showed that using a battery system for domestic services is currently not economically viable, however grid-scale provision of dynamic frequency response and fast reserve services yield sufficient annual revenue to compensate for these losses. The annual profit margin per household obtained was £ 532/692 for ALA and LI batteries respectively, allowing a shared margin of £ 230–300 after accounting for household costs.

The promotion of an aggregated storage system is hindered by current regulatory barriers in the UK, such as a double payment structure for storage operators, lack of subsidy and lack of separate definition for storage devices.

1. Introduction

Rising concerns in recent years over anthropogenic climate change have spurred academic and industrial efforts in mitigating its effects, which include changes in energy consumption and generation patterns around the world. The advantages of promoting clean electricity generation and transportation technologies are accompanied by major challenges for the operation of current electricity grid systems. The change in generation mix from conventional base-load to intermittent renewable power supply creates a need for flexible generation capacity and demand-side management (Georgilakis, 2008).

Energy storage technologies are well placed for providing valuable services due to their ability to shift generation and load patterns, and many technologies have been researched for both domestic and grid-scale applications (Akhil et al., 2013; Eyer and Cory, 2010).

Among different energy storage technologies, electrochemical batteries hold several advantages for grid-scale services including a fast response time, scalability and an ability to provide both power and energy applications (Battke et al., 2013). However, these advantages are hindered by high capital costs, thereby promoting many techno-economic research projects looking at different technologies, markets and potential services, such as in (Zucker et al., 2013; Malhotra et al., 2016) and many others.

Because domestic batteries are of limited size compared to bulk storage devices (kWh capacities, compared to MWh), they have been mostly researched and used to date for increasing self-consumption from a domestic power plant. However, a 'cloud' network (coined from 'cloud computing') of many distributed domestic batteries, higher capacities could be achieved, with several operational advantages compared to bulk energy systems for grid scale services.

First, using an aggregated system could provide flexibility in capacity and performance required for supplying different services

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Abbreviations: ALA, Advanced Lead-Acid; BAU, Business as Usual; BMU, Balancing Mechanism Unit; BSUoS, Balancing Services Use of System; CFD, Contracts for Difference; Cr, Charge rate; Dem, annual domestic demand; DFFR, Dynamic Firm Frequency Response; DG, Distributed Generators; DoD, Depth of Discharge; DNO, Distribution Network Operator; Dr, Discharge rate; Drmax/Crmax, maximum discharge/charge power rates of the battery (kW); *DrService*, Discharge rate allocated for ancillary service;; Ds, Discount rate; ECOd/n, Economy 7 day/night tariff; EFR, Enhanced Frequency Response; EMR, Energy Market Reform; Erp, Electricity retail price; FFR, Firm Frequency Response; FiT, Feed in Tariff; FiTg, Generation Feed in Tariff; FiTe, Export Feed in Tariff; FR, Fast Reserve; *Ft, Correction factor*; HR_d*Service*, Energy headroom needed for the contracted service; LI, Lithium-Ion; LTO, Lithium Titanium Oxide; NG, National Grid; NGET, National Grid Electricity Transmission; NPV, Net Present Value; Ofgem, Office of Gas and Electricity Markets; OTC, Over the Counter; Pr, System price at a given settlement period;; PV, Photo-Voltaic; SBR, Supplemental Balancing Reserve; SFFR, Static Firm Frequency Response; SHETL, Scottish Hydro Electric Transmission Limited; SNS, Smarter Networks Storage; SoC, State of Charge; S_t, State of charge at a given t; $S_t$min, Minimum storage level defined by the maximum DoD allowed; $S_t$max, storage energy capacity; STOR, Short Term Operating Reserve; TSO, Transmission System Operator; TNUoS, Transmission Network Use of System; UK, United Kingdom; μ_D/μ_c, Discharge and charge efficiencies of the device

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simultaneously, at different locations. In addition, by connecting many battery systems, existing and new services that require high energy or power capacities could become accessible.

Moreover, by controlling energy at the centres of demand, consumption patterns can be changed according to electricity generation, thereby alleviating renewable integration constraints, and reducing transmission and distribution losses.

Finally, installing batteries in households can provide a means to stack benefits of utilizing a shared system for both the household owner and the grid. Land-area and power-electronic costs could be shared by mutual use of the system, which could also lead to the propagation of distributed renewable technologies.

Lithium-ion and advanced lead-acid batteries are currently regarded as the most suitable commercially available technologies for domestic use (Fathima and Palanisamy, 2015; Dufo-López and Bernal-Agustín, 2015; Diorio et al., 2015), while other technologies (such as NaS, vanadium redox, ZEBRA and NiMH) pose commercial, safety and economic problems for wide scale adoption (Dunn et al., 2011; Lott and Kim, 2014; Boicea, 2014).

A number of papers have analysed the potential of domestic batteries in providing large quantities of energy required for grid services (Telaretti et al., 2016; Dufo-López, 2015) however they have neglected regulatory analysis, required in order to identify the most suitable aggregator for such a system, and the potential of stacking several value streams. Therefore, in this paper, regulatory, economic and technological aspects have been assembled together in order to analyse the profitability of aggregating domestic batteries for providing multiple grid-scale services in the UK.

In Section 2, a background on the UK's electricity market relevant for the analysis is presented. Section 3 presents the methodology of the analysis, beginning with a domestic feasibility analysis looking at the potential value for household owners, followed by an assessment of aggregated batteries for grid-scale arbitrage and ancillary services. In Section 4, the results of the analysis are presented, followed by a discussion in Section 5.

2. Background

2.1. UK electricity market framework

In order to conduct a comprehensive economic analysis for the use of storage devices in grid scale applications, a general understanding of the electricity system and market in the UK is necessary.

The identity of potential operators and owners of an aggregated storage system could be explored by listing the existing stakeholders in the UK's electricity market. Since 1989, the British electricity system is segmented and decentralized (Green and Newbery, 1992). The emerging private companies in this new system have different functions, under separate licences and regulations: Generation, Transmission, Distribution, Interconnection and Supply. The main distinction for the purpose of this paper is between grid operators, which are strictly regulated with limited access to different activities, and unregulated supply and generation companies that have the possibility of supplying several services in a vertically integrated business. Fig. 1 presents a schematic structure of the electricity grid and its different participants.

Transmission System Operators (TSOs) and Distribution Network Operators (DNOs) are companies in charge of infrastructure, and the secure supply of electricity. This is assured through several mechanisms, which include the matching of supply and demand, and maintaining the grid's frequency and voltage levels.

Generators are private electricity generation companies, connected either to the transmission system or directly to the distribution system as Distributed Generators (DGs). Generators sell electricity to suppliers in the wholesale market. Generators are divided into small (under 10 MW capacity), medium (under 100 MW in England and Wales) and large (above 30/50 MW in Scotland and above 100 MW in England and Wales). Small and medium generators can apply for a generation license exemption, which releases them from providing mandatory services required by the grid code – a relevant restriction for smaller generators, such as aggregated battery operators.

Electricity suppliers buy electricity in the wholesale market from generators and sell it to customers in retail prices. Suppliers can participate in demand balancing services (Cluzel and Standen, 2013). The main supply companies in the UK (also called ‘The big six’) hold generation assets as well, making them vertically integrated businesses.

2.2. The electricity market

The economic value of providing grid-scale services is dependent on the electricity market structure, and the different mechanisms involved in generation, supply and balancing of the system.

Electricity trades are made over 30 min electricity delivery ‘settlement periods’, and conducted on different time-scale auctions (future contracts/spot trades) in exchange markets, or according to Over the Counter (OTC) bilateral contracts (Ofgem, 2016).

The exchange markets account for the majority of near-term trading, with day-ahead trading dominated by the six largest vertically integrated companies (82% of overall day-ahead volumes in 2016 (Ofgem, 2015a)). The three electricity exchanges operating in the UK are ‘APX Power Spot Exchange’, ‘N2EX Nord Pool Spot’ and the Intercontinental Exchange (ICE).

Trading in the wholesale market is conducted up to ‘gate closure’ in order to allow enough time for the TSO to match any imbalances in supply and demand. This is done through the different mechanisms of the balancing market, which include the Balancing Mechanism (a ‘bid-offer’ market between registered Balancing Mechanism Units (or BMUs)), the penalties of supply and demand imbalance and ancillary services, which are contracted in advance to ensure system integrity.

In recent years, there has been a decline in electricity capacity margins due to closure/mothballing of conventional power plants (Marr, 2015), therefore additional ancillary services have been introduced lately.

2.3. Regulatory barriers and potential value streams for aggregated batteries

The current regulatory framework in the UK holds several barriers for the implementation of storage technologies for grid-scale use. First, storage devices are considered as generation devices, which limits the ability of network operators to operate storage devices in the market due to license restrictions (Anaya and Pollitt, 2015). This also means that their users are subject to both consumption and generation charges, under no separate license definition such as interconnectors hold.

Domestic batteries can be aggregated to provide any necessary amount of power or energy, at different locations, making them attractive for providing different services simultaneously. However, the potential value of the storage device depends on the aggregator's identity, as different services hold different drivers of value. Table 1 presents possible revenue streams for storage devices. While several value streams can be stacked together directly, others have secondary value. For example, by shaving peak-demand, reinforcement needs are mitigated and network charges are reduced.

In the current market structure, there are several advantages for energy suppliers, over other parties, to own and operate aggregated domestic batteries. This is because network operators do not have access to the wholesale market and commercial ancillary services, making an additional contract with a third party necessary. In contrast, large suppliers already hold trading and generating licences, giving them access to these value streams without regulation on their margins. Moreover, the existing customer base of suppliers could be used for market penetration, and allow shared value streams between customer and supplier.