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Optimum community energy storage for renewable energy and demand load management

David Parra [a,*], Stuart A. Norman [b], Gavin S. Walker [a], Mark Gillott [a]

[a] Energy Technologies Research Institute, Faculty of Engineering, University of Nottingham, University Park, Nottingham NG7 2RD, UK
[b] E.ON UK plc, Newstead Court, Little Oak drive, Annesley, Nottingham NG15 0DR, UK

HIGHLIGHTS

- Analysis of the complementarity of PV energy time-shift and demand load-shifting.
- A 4-period real-time pricing and Economy 7 (2-period time-of-use) are compared.
- Pb-acid and Li-ion batteries are optimised up to a 100-home community.
- Li-ion is better than Pb-acid for communities with large PV generation and vice versa.
- Batteries are more attractive for communities than individual homes for all scenarios.

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ABSTRACT

While the management of PV generation is the prime application of residential batteries, they can deliver additional services in order to help systems to become cost-competitive. They can level-out the demand and potentially reduce the cost and emissions of the energy system by reducing demand peaks. In this study, community energy storage (CES) is optimised to perform both PV energy time-shift and demand load shifting (using retail tariffs with varying prices blocks) simultaneously. The optimisation method obtains the techno-economic benefits of CES systems as a function of the size of the community ranging from a single home to a 100-home community in two different scenarios for the United Kingdom: the year 2020 and a hypothetical zero emissions target. It is demonstrated that the levelised cost and levelised value of CES systems reach intermediate values to those achieved when both applications are performed independently. For the optimal performance of a battery system being charged from both local PV plants and the grid, our results suggest that the battery should be sized suitable to ensure it can fully discharge during the peak period.

1. Introduction and literature review

PV self-consumption by residential batteries has become one of the key business applications for battery energy storage (ES) within the last few years. Although batteries for single dwellings across several countries such as Germany, Australia and California are the niche market at the moment [1,2], residential batteries for communities, referred to as community energy storage (CES) in this study, are attracting the attention of researchers [3], utility companies [4] and policy makers [5]. CES is being investigated in various research projects, many of them involving pilot plants [6] and/or product development and deployment [7]. Utility companies are so far one of the key promoters with several programmes worldwide addressing various services such as PV integration and management [4], demand peak shaving [8] and other applications for facilitating the proper performance of distribution networks [9].

Roberts and Sandberg argued that CES will be an important asset for managing distributed loads and renewable energy (RE) plants with stochastic generation outputs, facilitating the transition to the “smart grid” [10]. Some key advantages of CES systems over single-home ES systems highlighted by the previous literature are: (a) enhanced performance of battery systems due to the smoother electricity demand profiles of communities [11]; (b) relative reduction of the required energy and power ratings of residential batteries for communities in terms of kW h/home and kW/home [12]; (c) potential economies of scale across various components of the battery system (particularly, savings can be

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* Corresponding author at: Energy efficiency Group, Institute for Environmental Sciences and Forel Institute, University of Geneva, Switzerland.

E-mail address: David.Parra@unige.ch (D. Parra).

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Nomenclature

C	battery capacity, kW h
CF	cash flow, £
D_{ES}	community's demand proportion met by a CES system
E_{char}	seasonal CES charge, kW h
$E_{charDLS}$	seasonal CES charge from the grid, kW h
E_{charPV}	seasonal CES charge from PV plants, kW h
E_d	seasonal demand of a community, kW h
E_{dis}	seasonal CES discharge, kW h
E_{disDLS}	demand load-shifting seasonal CES discharge, kW h
E_{disPV}	seasonal CES discharge associated with PVts, kW h
IRR	internal rate of return, %
$LCOES$	levelised cost of energy storage, £/kW h
$LVOES$	levelised value of energy storage, £/kW h
n	mumber of years the battery lasts
P	price of the electricity, £/kW h
PV_{ES}	PV generation's proportion supplied to a CES system
Rev_{DLS}	demand load-shifting revenue, £
Rev_{PVts}	PVts revenue, £
$TLCC$	total levelised cost, £
η	round trip efficiency

Acronyms

BoP	balance of plant
CAPEX	capital expenditure
CES	community energy storage
DOD	depth of discharge
DSO	distribution system operator
EFC	equivalent full cycles
ES	energy storage
HP	heat pump
Li-ion	lithium ion
NETA	New Electricity Trading Arrangements
PbA	lead acid
PVts	PV energy time-shift
RE	renewable energy
SOC	state of charge

Subscripts

ex	export
i	import
i-op	import at off-peak time
i-o	import at peak time
k	generic year

made in terms of communications and control equipment) [2]; and (d) catalytic effect for implementation of various energy efficiency and RE initiatives in communities following a bottom-up approach [13].

Two important challenges for the further deployment of ES in general and CES in particular are the still high capital expenditure (CAPEX) of most ES technologies (and batteries in particular) and the need for integration several services and/or requirements in order to create attractive economic benefits (i.e. multi-objective use of ES systems) [14,15]. Various applications could potentially involve different stakeholders such as end users, utility companies and/or distribution system operators (DSOs). However, many previous studies have addressed ES applications independently without discussing the integration of various applications by the same ES system [16,17]. For example, Santos et al. compared four different roles of residential battery storage (PV self-consumption, demand peak shaving, reduction of PV injection into the grid and integration of wind power from the grid) from a techno-economic perspective (required battery capacity, system cost and power exchange with the grid) but these applications were considered as being mutually exclusive [18].

Alternatively, some attempts have made so far to analyse value propositions including several applications. Zucker and Hinchliffe concluded that the optimum ES system is dependent on the grid situation and its final application. Their study considered PV energy time-shift (PVts) in isolation as well as PVts and arbitrage, each application leading to different sizing in terms of hours of discharge and capacity [19]. Sundararagavan et al. included the combination of demand load shifting, frequency regulation and power quality in their analysis, but they only studied the cost of performing these applications assuming some ES properties such as durability and efficiency constant [20]. Wade et al. argued that the corresponding economic benefit should be identified in order to prioritise the events which add more value, identifying the stakeholder that can internalise the benefit [21]. From a DSO perspective, a strategy for optimal allocation of multiple CES systems including energy arbitrage, peaking power generation, energy loss reduction, system upgrade deferral, emission reduction and VAr support has been proposed [22]. However, the coordination of the ES asset could become a challenge if benefits accrue to different stakeholders. Technical issues such as the lack of engineering standards were also highlighted as key market failures which explain the marginal application of value propositions including several benefits according to a comprehensive report prepared by Sandia for the Department of Energy in USA, [23].

Two previous studies demonstrated for a scenario in 2020 that CES systems managing PV generation (in particular PVts was performed) offer more value than when they manage the community demand (demand load shifting) while the latter allow CES systems to further reduce the levelised cost [11,12]. The work presented here investigates the impact of managing both community PV generation and demand. CES systems performing both PVts and demand load-shifting simultaneously are investigated in order to understand how the combination of applications affect the performance, optimum battery capacities and economic benefits of CES systems. The analysis compares lead-acid (PbA) and lithium-ion (Li-ion) batteries as well as two different retail tariffs for demand load shifting: a time-of-use tariff (Economy 7) and a real-time-pricing tariff including four periods based on the electricity prices from the wholesale market in the United Kingdom (UK). Whether CES performing both applications makes economic sense is investigated as a function of the size of the community (ranging from a single home to a 100-home community) and under two different scenarios: year 2020 and a hypothetical zero carbon scenario. For the 2020 scenario, the battery parameters are based on the targets given by battery manufacturers and government technology agencies [2].

2. Methodology

Grid-scale ES systems tend to operate at the distribution level responding to different events on multiple networks with the occurrences of those events given by the network state. CES considered here in this work perform PVts and demand load-shifting on a daily basis. This study follows an end-user perspective and