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Synergy of smart grids and hybrid distributed generation on the value of energy storage

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HIGHLIGHTS

- We propose a valuation model for end-user energy storage in smart grids.
- A hybrid energy system (electricity-heat) integration via storage units is analyzed.
- Battery and thermal storage provide flexibility to CHP operations and wind surplus.
- Storage units produces interesting cost savings (around 10%).
- Demand response programs are crucial to the value of electricity storage.

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ABSTRACT

In smart grids, demand response and distributed energy systems aim to provide a higher degree of flexibility for load-shifting operations and the leverage to control intermittent wind supply. In this more dynamic energy system, deployment of energy storage at the site of consumption is envisioned to create synergies with the local distributed generation (DG) system. From a large end-user perspective, this paper contributes to the practical understanding of smart grids by modelling the impact of real-time pricing schemes (smart grids) on a hybrid DG system (mixed generation for heating and electricity loads) coupled with storage units. Specifically, we address: How does the portfolio of DG units affect the value of energy storage? and, what is the value of energy storage when assessing different designs of demand response for the end-user? To this end, we formulate a dynamic optimization model to represent a real-life urban community's energy system composed of a co-generation unit, gas boilers, electrical heaters and a wind turbine. We discuss the techno-economic benefits of complementing this end-user's energy system with storage units (thermal storage and battery devices). The paper analyses the storages policy strategies to simultaneously satisfy heat and electricity demand through the efficient use of DG units under demand response mechanisms. Results indicate that the storage units reduce energy costs by 7–10% in electricity and 3% in gas charges. In cases with a large DG capacity, the supply–demand mismatch increases, making storage more valuable.

1. Introduction

The UK government has committed to increase the share of electricity generated from renewable energy to 20–40% by 2020–2030 [1]. As renewable intermittency creates uncertainty in power supply, the national grid will need to raise a higher amount of balancing power (e.g. reserves) than today. For instance, a recent warning coming from UK energy regulators has noted a potential shortage of energy spare capacity for the 2015–16 winter [2,3]. This warning reinforces previously raised concerns about the feasibility of ambitious EU environmental policies, which so far have predominately focused on increasing the share of renewable energy rather than upgrading stand-by capacity for electricity generation. As a result of these developments, the national grid is

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facing an unprecedented challenge of modernizing the grid infrastructure, keeping the lights on and integrating large quantities of renewables.

As part of the overall strategy to address this energy system transition, the UK National Grid is currently installing smart meters nationwide [4]. In smart grids, knowing and influencing consumer demand patterns, close to real-time, is setting the scene to use distributed energy systems (small/medium sized generation units) as part of the grid balancing services. Through smart demand response systems, a shortfall of electricity supply can be counter-balanced with changes in consumption patterns. Indeed, in the last years, the UK National Grid has introduced incentives for large energy users to control demand during peak hours in winter [5]. In this context, energy storage has been promoted as the key synergy catalyst to balance the inflexibility in local supply (e.g. renewable) and to actively control demand in a smart grid [6]. In the last year, for instance, Japan and Germany have launched subsidy programs to support the installation of battery systems to complement end-user distributed generation systems [7]. Distributed energy storage increases demand elasticity, which in turn, through smart meters, enhances grid balancing services. Locally, energy storage improves energy supply strategies (energy efficiency) and hence increasing the revenue stream from distributed generation (DG). At the policy level, local energy storage provides the necessary flexibility to support further deployment of renewables via DGs systems located on site of consumption.

Despite of these synergistic potentials, in the literature, relatively limited attention has been paid to the pragmatic role of *end-user* energy storage in enhancing demand flexibility that is complimentary to grid requirements. This paper provides a bottom-up perspective – the end-user – on investigating the value of storage units have on the end-user's energy system in smart grids. Through analyzing a practical example of a large end-user (community, industrial site or building complex, see Fig. 1), we discuss the conditions under which energy storage is valuable for a mix of local generation units that satisfy heating and electricity loads (hybrid energy system). To this end, the paper explicitly focuses on analyzing how dynamics of local demand, energy prices and the hybrid DG profile impact the value of energy storage to answer the following research questions:

– What is the value of end-user energy storage, in the form of a battery and a thermal water tank, for heating and electricity systems?
– How does a hybrid[1] DG structure impact the value of storage units?
– As the UK National Grid is introducing demand response schemes (e.g. price signals) to enhance its electricity supply operations, we analyze: what is the value of end-user electricity storage from load-shifting operations in smart grids?

To address these questions, we study a real-life community's energy system considering energy storages for demand response and energy efficiency purposes. Lancaster University campus serves as our case study, where the hybrid DG system is composed of a wind turbine, a combined heat and power unit (CHP), gas boilers, and electrical heaters (Fig. 1). The community collects the necessary energy from the grid at prevailing prices (i.e. under a price driven demand response mechanism), but does not deliver energy to the grid. Through a dynamic optimization model we consider the inter-temporal dynamics of price, demand and renewable generation. The model's objective is to provide procurement and storage strategies that minimize the community energy costs for electricity and gas consumption over a finite planning horizon of one day. Results examines how local DG units work together to satisfy demand for comparable cases with/without storage units exposed to demand response mechanisms. We describe energy storage benefits to enhance the integration of the heating and electricity systems by focusing on:

- Synergies of the hybrid DG units portfolio and load profiles (electricity and heat) on the value of energy storage. We quantify how energy storages smooth peak demands through a more efficient utilization of the CHP and possible wind power surplus. For example, thermal storage enhances the efficient usage and operation of the boilers and the CHP.
- Energy arbitrage decisions and load-shifting operations under a demand response mechanism. Specifically, the value of electricity storage on procuring electricity at low prices and using the battery to avoid high prices.

In a nutshell, the paper reports on the value of end-user energy storage and its reciprocal effects on a hybrid DG system under a demand response mechanism (smart grid setting). In the next section, literature on energy storage valuation is reviewed. In Section 3, a description of demand response in relation to DG is presented. This is followed by a description of the case study and the modelling methodology (Section 4). Section 5 discusses the results from different DG case configurations. Then, conclusions and directions for future research are summarized in Section 6.

2. Related literature

Valuating energy storage has predominantly focused either on its application feature or ownership setting (see review by [8]). Most studies are devoted to a supplier perspective, that is to medium or large-scale energy providers or utility at grid level. These studies predominately examine the supplier's optimal control strategies for energy storage to a mix of energy generators so as to maximize profits from its energy commitments to electricity markets (see review by [9]). In contrast, this paper explores decentralized storage benefits from an end-user perspective for a micro grid that integrates renewables and district heating operations.

Recently, the assessment of end-user energy storage has gained attention due to the promising prospects of smart grids [10,11]. Research in this area analyses the value of storage under uncertain wind supply [12], its contribution to micro grid operation and stability [13] and its technical benefits for power and network management [14]. However, the storage literature from an end-user perspective is limited, particularly when considering integrated energy systems for electricity and heating, which – depending on the problem context – are modelled as separate structures and studied as such (see review by [15]). Some literature studies, for instance, analyze thermal storage systems complemented with CHPs [16,17] or storages role when heating/cooling requirements are electricity driven [18]. In Stadler et al. [19] both thermal and electricity storage are considered with emphasis on the value of solar PV systems. This is extended in a second paper [20] in which they examine the cost-benefits of electricity storage and the impact on CO_2 emissions. Though both storage units are taken into account, the study gives little analysis on the energy unit interactions within the system. In contrast, this paper extents the analysis by including a more detailed assessment of the heating system. We highlight the heating-electricity interactions of wind power as most of the studies have only researched the effects to the electrical system or addressed engineering aspects of the technology (see [21]).

[1] An energy system composed of more than one energy carrier is refereed as hybrid (electricity and heat mix).

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