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Distributed energy storage in Australia: Quantifying potential benefits, exposing institutional challenges

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ABSTRACT

The rapid development of distributed renewable energy systems and the pressures associated with increasingly variable energy demand in electricity industries worldwide have highlighted the importance of more efficiently managing temporal and locational supply and demand balance throughout the electricity network. At the same time, progress in a range of distributed energy storage technologies offers new opportunities to assist in this regard. This paper presents findings from a study investigating the potential applications for distributed energy storage (DES) in the Australian National Electricity Market (NEM). It first identifies and then provides estimates of the potential value of some key applications of DES in the NEM. These highlight particular opportunities in improving customer reliability and avoiding network expenditure. The paper then presents a framework developed to assess the extent to which the current institutional environment of the NEM enables, or constrains access to those applications. The findings suggest that a raft of institutional arrangements currently restrict access to DES applications and that aggregation and integration of DES benefits associated with these applications, across both spatial and temporal scales is particularly problematic.

1. Introduction

Recent rapid developments with distributed renewable energy systems (RES) and the pressures associated with increasingly peaky energy demand within electricity industries around the world have highlighted the importance of more efficiently managing the temporal and locational match of supply and demand across power systems. The electricity industry poses interesting challenges in this regard – electricity flows instantaneously from operating generating plants to end-use equipment through a dedicated, shared, electrical transmission and distribution network. Load is highly variable and only somewhat predictable both temporally and spatially. It is, at present, also generally unresponsive to changing supply and network conditions [1–3]. Consequently, a considerable proportion of generation and network capacity are only required for short and irregular periods of time. The economics of supply–demand balance within electricity industry operation are also challenging. Generation and network assets are capital intensive and historically large, lumpy, non-reversible and long-lived. This complexity, electricity's role as an essential public good, and its many externalities means that current market arrangements in the electricity industry do not closely reflect all of the underlying economics. The growing deployment of highly variable and somewhat unpredictable renewable generation – both large-scale (wind) and small-scale (photovoltaic within the distribution system) – with their own particular technical and economic characteristics has added to these challenges.

The potential value of energy storage to assist in managing supply–demand balance has been long appreciated.[1] Until recently, however, there have been only very limited cost-effective energy storage options available at the distribution network level.[2] Now, there is a growing range of distributed energy storage (DES) options that might assist in the more effective and efficient management of supply–demand balance in the electricity industry. These include a range of battery storage systems, energy management systems

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[1] The use of distributed battery (accumulator) storage to manage peaky electrical lighting loads was discussed in an 1888 paper in the Journal of the Society of Telegraph Engineers and Electricians [4].

[2] One early example in Australia has been Utility control of residential electric storage hot water systems.

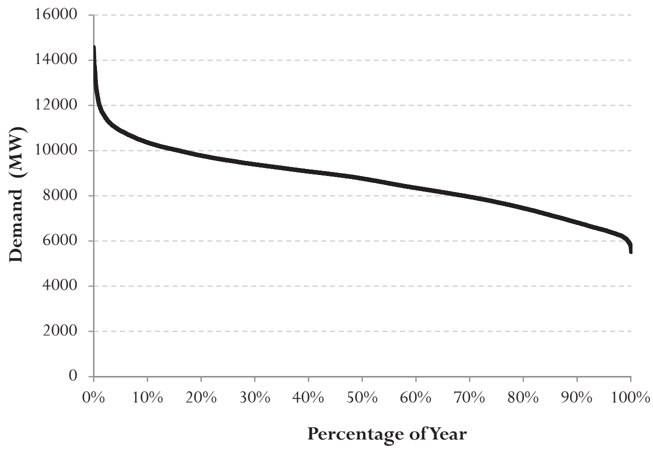

Fig. 1. Australian Energy Market Operator 30-min demand data for NSW region in 2011 plotted as demand duration curve. In this case, the top 17.25% of demand occurs for less than 1% of the year or 88 h.

with controllable loads and emerging technologies such as electric vehicles. The confluence of growing supply–demand balance challenges, and the development of new energy storage technologies, appears to present a valuable opportunity for the greater deployment of DES. Nevertheless there are considerable uncertainties for such deployment. Some arise, perhaps surprisingly, from the wide range of potential benefits storage can bring to the electricity industry. Other uncertainties arise from the disruptive nature of these technologies and the challenges this poses for traditional industry arrangements. In the first instance, what are the highest value applications of storage likely to be? Does, for example, improving customer reliability, deferring network augmentation, shifting energy from low to high-cost periods, or providing ancillary services represent the best value? Secondly, do current market arrangements actually facilitate the integration of storage technologies so that different industry participants can appropriately exploit these benefits? If not, what might be done to facilitate its more effective integration into the electricity networks?

Work on these questions is underway. A large body of research reviewing the broad scope, specific operation, and costs of specific particular energy storage technologies has been conducted, both for stationary storage technologies [5–8] and vehicle-to-grid storage [9–11]. Likewise, the technical challenges for DES integration, such as the requirement for intelligent control and advanced power systems have been discussed [12]. Rather than engage with such literature, this paper aims to align the general applications of DES with the institutional regimes fundamental to electricity industries, so as to conduct an initial analysis of its wider integration opportunities. The focal market, in this instance, is the Australian National Electricity Market (NEM), however, the underlying framework is designed for relevance across a broad spectrum of electricity industries.

To date, researchers have investigated the potential for integrating energy storage with RES both within the electricity industry generally [13–16], and specifically into the NEM [17,18]. However, the potential breadth of distributed storage applications, beyond RES integration, has received less attention. This paper is intended to assist in addressing this deficit. Specifically, we aim to: (i) investigate the potential applications for DES in the NEM, (ii) develop methodologies for assessing the potential economic value of these applications in electricity markets, (iii) provide preliminary estimates of those benefits for the NEM, and (iv) propose a general framework to assess the extent to which current institutional and regulatory frameworks which present barriers to implementing the most valuable applications.

While we specifically focus on DES in the NEM in this instance, this research aims to improve our understanding of the challenges faced by emerging technologies at a more general level. The broader purpose of this paper to highlight that existing regulatory and institutional structures may affect the deployment of new innovations due to path dependency. This aims aligns with broader themes surrounding institutions and energy governance, innovation, and the sociology of technology which have been identified as key areas for energy research [19].

The structure of this paper is as follows. Section 2 outlines the Australian NEM with a focus on its demand characteristics to provide context for the case study. Section 3 will then outline the key applications for DES in the NEM and present indicative benefit values for applications where possible. Finally in Section 4, we develop an institutional framework through which institutional constraints to the integration and exploitation of DES can be identified. We then apply this framework to high-value DES applications and discuss the outcomes.

2. The National Electricity Market

The Australian NEM is, by some measures, one of the largest interconnected power systems in the world. It covers the five Eastern and Southern Australian States of Queensland, New South Wales (NSW), Victoria, Tasmania and South Australia and the Australian Capital Territory, and serves around 90% of the Australian population (almost 10 million customers). It extends some 4500 km and has approximately 750,000 km of distribution network [20].

Significant temporal variability exists within the NEM, both on an intra-day basis and over longer seasonal time scales. These periodic variations combined with significant demand spikes (generally driven by heating and cooling loads in response to extreme weather) create annual regional demand curves characterised by the sizable percentage of demand occurring for relatively small periods of the year. This is evident in the demand duration curve for the NSW1 region in 2011 (Fig. 1). In this case, the top 17.25% of demand occurs for less than 1% of the year, or 88 h. Within the distribution network, of course, more ‘peaky’ demand curves are experienced, particularly in residential and commercial regions which typically serve considerable air-conditioning loads.

A range of drivers including major recent increases in retail electricity tariffs (primarily as a result of increased network expenditure) and environmental concerns have seen growing public, industry and government attention on the sustainability of the Australian electricity industry [21,22]. The literature surrounding the NEM has become increasingly focused on renewable energy systems (RES) pathways [23–25], distributed generation [1], and the more effective management of demand [26,27]. Supportive government policy and public interest have seen over 2 GW of wind and 2 GW of distributed photovoltaic generation installed in the NEM over the past decade, approaching 10% of conventional generation capacity. Concerns over the network effects of supply variability of RES, in particular distributed PV systems [28], have resulted in an articulated niche for energy storage to better couple RES resource availability with demand in the NEM [29].

Although well suited to RES integration and peak demand management, energy storage has had little penetration in the NEM to date. Commercialised energy storage has so far been restricted to 1.5 GW of pumped hydro storage typically operating in a peak shaving role [30] and a recently announced project to construct the first large-scale integrated PV-energy storage facility to be registered on the NEM [31]. While innovation and development of