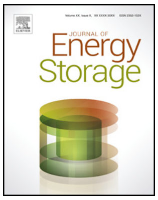
Journal of Energy Storage 17 (2018) 357–366

Contents lists available at ScienceDirect

Journal of Energy Storage

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



Assessing Electric Vehicle storage, flexibility, and Distributed Energy Resource potential

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ARTICLE INFO

Article history:
Received 6 January 2017
Received in revised form 26 January 2018
Accepted 26 January 2018
Available online xxx

Keywords:
Electric Vehicle
Storage
Distributed Energy Potential
Sydney Australia

ABSTRACT

The emergence of Plug in Battery Electric Vehicles (BEV) is a process which will bring a large aggregate source of distributed energy storage into the electricity industry. The potential exists for this storage to bring benefits from the ability to shift net BEV demand (both charging and vehicle to the grid export) in response to electricity industry needs. The potential for BEV flexibility to act as a Distributed Energy Resource (DER) is however constrained by a range of factors including their mobility, need to serve transport energy requirements, and the locational/temporal availability of physical charging opportunity.

This paper addresses the challenge of characterizing the availability of this new storage resource and aims to be of use to policy makers and electricity industry planners in developing strategies for maximizing the value of BEV integration for the electricity industry. In particular it: presents a general discussion of, and framework for understanding the manner in which BEV storage gives rise to charging/discharging flexibility, presents a method for simply characterizing the factors which constrain this flexible resource, introduces a method for empirically establishing a benchmark DER potential which fully accounts for relevant constraints, and applies these methods to a case study of vehicle use in the Sydney Greater Metropolitan area.

Results show that, in respect of vehicle transport in Sydney, charging speed and the need to reserve energy in respect of transport needs is a lesser constraint than the impact of charging infrastructure availability. While the DER potential declines during the day in all cases, access to additional charging infrastructure minimizes this decline. Investment in additional non-residential charging infrastructure may therefore be particularly important in maximizing the DER potential arising from BEV storage flexibility, in particular for the opportunity to manage the integration of high future PV generation levels.

1. Introduction

The emergence of Plug in Battery Electric Vehicles (BEV) is a process of historic significance. BEV emergence will not only see transport energy demand satisfied by the electricity industry but also bring a large aggregate source of distributed energy storage into the industry. The potential exists for this storage to be harnessed in such a way as to bring benefits in respect of the ability to shift net BEV demand (both charging and vehicle to the grid export) in response to electricity industry needs. This paper addresses the challenge of characterizing this new resource and aims to be of use to policy makers and electricity industry planners in developing strategies for maximizing the value of BEV integration for the electricity industry.

The power system requires flexible resources which it can deploy on a dynamic basis as demand not served by variable generation [1]. While the need for power system flexibility is not new, it is a challenge which will to grow in future given the manner in which higher levels of intermittent renewable generation will increase the variability of net system load. While sources of flexibility presently exist on both the demand and supply side of the electricity industry, BEV battery electric storage creates the potential to use vehicles themselves as a new source of flexibility in managing the challenge of renewable energy integration.

The potential for BEV storage to enable a flexible Distributed Energy Resource (DER), is however constrained by a range of factors. Unlike stationary batteries, BEVs are mobile devices with vehicle investment costs justified by their end use transport function. This situation therefore makes the interests of the

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https://doi.org/10.1016/j.est.2018.01.016
2352-152X/

Nomenclature

Variable, index, and parameter list

k	Variable to reference the number of expeditions taken by a modelled vehicle (index)
t	Variable to reference the simulation time step utilized in modelling (index)
t_{dep_k}, t_{arr_k}	The departure are arrival times corresponding to vehicle expedition k
$TER_{k,t}$	The transport energy requirement constraint associated with vehicle k at time step t (fraction of effective battery capacity)
$TSOC_{k,t}$	The translated fractional state of charge profile forming the TER in respect of expedition k (fraction of effective battery capacity)
ERR_k	The energy reservation requirement at the start of expedition k to satisfy future transport needs (fraction of effective battery capacity)
MCO_k	The unbounded maximum charging opportunity during the dwell time immediately prior to expedition k (fraction of effective battery capacity)
$TMCO_k$	MCO profile in respect of expedition k translated so as to equal the ERR at the point of departure (fraction of effective battery capacity)
SF_k	Shortfall in charging opportunity in respect of expedition k which needs to be carried forward into the TER in respect of coming expeditions (fraction of effective battery capacity)
DER_i	Benchmark Distributed Energy Resource potential in respect of vehicle i (fraction of battery capacity)
t_{comm}	Time of DER export potential evaluation
t_{int}	Time of intersection between the DER export profile and TER constraint
τ	Duration of travel time between expeditions k and k +1 (min)
P_{drv}	Rate of battery discharge during travel (kWh/min)

electricity industry subordinate to those of the end user with respect their transport needs. As a result, a fundamental constraint to the flexibility of a BEV is imposed by the need to ensure that battery capacity is reserved for the primary purpose of the vehicle which is to satisfy transport requirements. In addition, BEV flexibility is also constrained by the locational/temporal availability of physical charging opportunity.

There has been significant academic interest in the potential to utilize BEV storage as a flexible DER to advance the objectives of the electricity industry. BEV flexibility is at least implicitly considered by studies that assess outcomes given different approaches to BEV load control. These include scheduling BEV charging during the overnight load valley [2–4] providing system services such as short time scale Ancillary Services [5–8] and longer time scale ramping services and load following [9–12].

Instead of considering outcomes associated with specific use and load control cases, this paper presents a method for establishing a benchmark BEV DER potential. A smaller number of studies also have had related goals [6,13,14,11]. In particular, [6] quantified the potential for PHEV's to meet operating reserve requirements for up and down regulation services by delaying and advancing vehicle charging. [13] presented a general relationship for quantifying flexibility and applied this relationship to characterizing how average vehicle flexibility changed given different qualifying dwell time thresholds. Bei Zhang and Mladen Kezunovic, 2015 took a stochastic view of BEV mobility in evaluating the potential for participation in real time markets for flexible resources. Apart from [14] however, there hasn't yet been a general empirical method presented for assessing the extent to which BEV storage could act as a flexible DER, particularly one which is constrained by transport energy requirements and physical interface parameter settings. This paper addresses this challenge by:

- Presenting a general discussion of, and framework for understanding, the manner in which BEV storage gives rise to flexibility and the factors which constrain it from the perspective of the electricity industry;
- Presenting a method for simply characterizing a Transport Energy Resource (TER) constraint thereby allowing easy identification of the flexible decision space available to a vehicle;
- Introducing a method for empirically establishing a benchmark DER potential in a way which fully accounts for relevant constraints; and
- Applying these methods to a case study of vehicle use in the Sydney Greater Metropolitan area to explore outcomes.

2. A framework for BEV flexibility

BEV flexibility, which can act as a DER, may be conceptualized as a 'flexible region' bounded by two specific charging trajectory cases [13]. The first of these boundary cases involves the vehicle Battery State of Charge (SOC) trajectory arising from earliest possible charging upon arrival at a location with charging infrastructure. The second boundary case represents the SOC profile arising from latest possible charging so as to achieve the minimum SOC required to meet upcoming transport energy needs, an Energy Reservation Requirement (ERR). An example flexible region is presented in Fig. 1 which shows a hypothetical SOC trajectory, bounded by these two boundary charging trajectories, as one specific outcome possible in respect of BEV participation over a dwell window [t_a, t_d].

If a BEV has charging opportunity which exceeds the requirement, that BEV represents an un-constrained and therefore flexible resource. A BEV may therefore be considered 'flexible' as charging isn't restricted to a specific trajectory and the vehicle driver has the discretion to choose whether to charge/discharge at any point in time without compromising the ERR at the point of departure [13]. Within this flexible region an infinitely large set of specific trajectories can arise depending on end user decisions, potentially in response to commands or other signals applied by the electricity industry. The relationship between specific outcomes, BEV flexibility, coordinating signals, vehicle travel patterns, and physical interface (charging infrastructure) characteristics are illustrated in the flowchart presented in Fig. 2.

Fig. 2 indicates that BEV flexibility, the size of the flexible region, is a function of the alignment of physical infrastructure availability/characteristics and vehicle travel patterns. The importance of these factors is in respect of the need for a physical connection with the power system and the rate constraints imposed on charging/discharging by that connection. The extent to which vehicle travel patterns align with charging infrastructure also determines the energy reservation requirement and, by extension, the size of the flexible region.

In order to establish a DER potential from vehicle flexibility, these constraints will need to be characterized alongside the TER in the context of vehicle characteristics and travel patterns. Modelling the DER potential from BEV flexibility, as seen by the electricity industry, will therefore require explicit consideration of: