Journal of Power Sources 336 (2016) 63–74

Contents lists available at ScienceDirect

Journal of Power Sources

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

Charging a renewable future: The impact of electric vehicle charging intelligence on energy storage requirements to meet renewable portfolio standards

Kate E. Forrest [a], Brian Tarroja [a, *], Li Zhang [a], Brendan Shaffer [a], Scott Samuelsen [a, b]

[a] Advanced Power and Energy Program, University of California Irvine, Engineering Laboratory Facility, Irvine, CA 92697-3550, USA
[b] Department of Mechanical and Aerospace Engineering, University of California Irvine, Engineering Gateway Building, Suite E4230, Irvine, CA 92697-2175, USA

HIGHLIGHTS

- Energy storage provides little benefit when excess renewable generation is small.
- Uncoordinated EV charging requires large energy storage capacities to reach 80% RE.
- Intelligent EV charging reduces energy storage capacity requirements to reach 80% RE.
- V2G charging can potentially eliminate the need for stationary energy storage.

ARTICLE INFO

Article history:
Received 28 May 2016
Received in revised form
2 September 2016
Accepted 15 October 2016

Keywords:
Battery electric vehicle
Vehicle-to-grid
Renewable energy
Energy storage
Smart charging

ABSTRACT

Increased usage of renewable energy resources is key for energy system evolution to address environmental concerns. Capturing variable renewable power requires the use of energy storage to shift generation and load demand. The integration of plug-in electric vehicles, however, impacts the load demand profile and therefore the capacity of energy storage required to meet renewable utilization targets. This study examines how the intelligence of plug-in electric vehicle (PEV) integration impacts the required capacity of energy storage systems to meet renewable utilization targets for a large-scale energy system, using California as an example for meeting a 50% and 80% renewable portfolio standard (RPS) in 2030 and 2050. For an 80% RPS in 2050, immediate charging of PEVs requires the installation of an aggregate energy storage system with a power capacity of 60% of the installed renewable capacity and an energy capacity of 2.3% of annual renewable generation. With smart charging of PEVs, required power capacity drops to 16% and required energy capacity drops to 0.6%, and with vehicle-to-grid (V2G) charging, non-vehicle energy storage systems are no longer required. Overall, this study highlights the importance of intelligent PEV charging for minimizing the scale of infrastructure required to meet renewable utilization targets.

1. Introduction

Climate change spurred by anthropogenic greenhouse gas emissions has been identified as a threat to human health, the natural environment, and the economy. Arid regions such as California are at risk of higher temperatures, degraded air quality, and shifts in water availability leading to more severe, prolonged droughts due to climate change impacts [1,2]. To prevent or reduce the extent of these effects, policies for reducing greenhouse gas (GHG) emissions or related measures such as increased renewable energy utilization are being implemented. Achieving goals for deep decarbonization will require near-zero GHG electricity generation [3]. Addressing both electricity and transportation-related emissions is crucial given their dominant role in total emissions.

Through renewable portfolio standards (RPS) mandates (SB 1058, SB 107, SB 2, SB 350) and emission-related legislation (AB 32), California has supported the large-scale deployment of renewable energy technologies as the preferred means of decarbonizing electricity generation. This paradigm shift, however, presents

* Corresponding author.
E-mail address: bjt@apep.uci.edu (B. Tarroja).

http://dx.doi.org/10.1016/j.jpowsour.2016.10.048

Nomenclature

BEV	Battery Electric Vehicle
CAISO	California Independent System Operator
EVSE	Electric Vehicle Supply Equipment
FASTSim	Future Automotive Systems Technology Simulator
FCV	Fuel Cell Vehicle
FERC	Federal Energy Regulatory Commission
HiGRID	Holistic Grid Resource Integration and Deployment tool
LandGEM	EPA Landfill Gas Emissions
LDV	Light-Duty Vehicle
NHTS	National Household Travel Survey
NREL	National Renewable Energy Laboratory
NSRDB	National Solar Radiation Database
OASIS	Open-Access Same-Time Information System
PEV	Plug-in Electric Vehicle
PV	Photovoltaics
RPS	Renewable Portfolio Standard
SES	Stationary Energy Storage
TOU	Time-of-Use
V2G	Vehicle-to-Grid
VFB	Vanadium Redox Flow Battery
VMT	Vehicle Miles Traveled
WWSI	Western Wind and Solar Integration project
ZEV	Zero-Emission Vehicle

unique challenges. Most types of renewable electricity generation fluctuate in response to natural shifts in resource availability (solar, wind, etc.) independent of demand. Traditionally, this variability has been managed dynamically by ramping up or down fossil fuel burning power plants in order to balance total generation and electricity load demand. However, as the portion of electricity coming from renewable resources grows, temporal fluctuations in electricity generation will outstrip the capacity of existing power plants to respond effectively. Periods of over-generation will force renewable curtailment, while periods of low generation will require greater reliance on dispatchable generation, such as natural gas power plants or discharge of energy storage systems, to compensate.

The deployment of large-scale stationary energy storage has the potential to increase renewable integration without added emissions [4]. Energy storage technologies, which range from pumped hydro to batteries, can charge during periods of over-generation, storing energy to be used when renewable power is unavailable. So far, few studies have attempted to quantify the scale of energy storage needed to reach high renewable utilization. Recent legislation in California, such as AB 2514, supports an energy storage adoption target but does not necessarily correspond with a quantified need to support RPS targets. Rather it focuses on reducing peak demand and the need for peaker plants, acknowledging recent research suggesting that high renewable utilization will require a significant investment in dispatchable, clean resources.

In addition to the increased utilization of renewable resources, the electrification of the transportation sector is also being pursued as a parallel measure for reducing societal greenhouse gas emissions. Around the world, plug-in electric vehicles (PEVs) exist in relatively low percentages of the total light-duty vehicle fleet stock. In California, Governor Brown's Executive Order B-16-2012 sets a target of 1.5 million zero-emission vehicles (ZEVs) in California by 2025. This has drawn greater attention to the potential management of PEVs to interface with the grid in the near future, however, 1.5 million ZEVs will only comprise 6.5% of the light-duty vehicle fleet. To meet carbon reduction goals for the state for 2050, between 3.9 million and 34.3 million PEVs need to be on-road depending on the evolution of other elements of the energy system [5]. The rapid adoption of PEVs requires a better understanding of how mass PEV charging will affect renewable integration.

The electrification of the light-duty vehicle fleet through PEV deployment will increase the electric load demand and alter the shape of the demand profile. The first effect poses an obstacle for meeting renewable energy utilization targets, since more renewable generation will be needed to meet a targeted percentage of the total electricity load demand with renewable energy. The second effect, however, can potentially provide a benefit for reaching renewable utilization targets depending on the intelligence of vehicle charging management. If vehicle charging loads can be shifted to more closely align with renewable generation, it can allow the system to capture otherwise curtailed renewable generation. Additionally, intelligent charging can reduce the amount of renewable generation that needs to be shifted to meet electricity demand, which can reduce the required capacity of energy storage systems need to meet a renewable energy utilization target.

Depending on charging strategies (immediate, smart, or vehicle to grid, "V2G") and charging locations (at home, work, and/or public spaces), the degree to which PEV loads align with renewable generation can vary [6]. Currently, almost all public and private charging in the U.S. is immediate, the exception being select pilot projects for smart and V2G [7–9]. However, the coordinated charging of electric vehicles through smart or V2G charging has the potential to increase renewable utilization, by optimizing the timing and intensity of vehicle charging to maximize capture of otherwise curtailed renewable energy [10–12]. Smart charging allows for planned charging based on load and time of use (TOU) market signals, and can, therefore, be applied to improve renewable integration. Vehicle to grid (V2G) charging incorporates the functionality of smart charging with the added ability to discharge to the grid.

Widespread deployment of PEVs would provide a dual service of reducing transportation emissions, while helping to manage load dynamics, potentially delaying the need for large-scale, stationary energy storage installations. EV batteries acting as mobile energy storage have a lower available capacity for grid services compared to stationary storage devices of the same capacity, due to travel constraints [13]. Nevertheless, intelligent charging takes advantage of an already available resource, providing the opportunity to manage both renewable integration and the new load associated with the electrification of the transportation sector.

To date, the benefits of installing energy storage to meet renewable energy utilization targets and the benefits of intelligent PEV charging to help meet those targets has only been studied independently. Specifically, the impact of charging intelligence on required energy storage capacities has not been examined. Exploring this question is important for the design of renewable energy systems and for determining the scale of energy storage infrastructure and investment required to meet renewable utilization targets.

Few studies exploring the deployment of PEVs to help integrate renewable energy consider additional stationary energy storage to reach high renewable penetration into the grid [14,15]. These select studies do not consider, and by extension do not quantify, the impact of increased charging intelligence on decreasing additional stationary energy storage capacity.

In this context, the aim of this paper is to evaluate the ability of PEVs under immediate and intelligent (smart, V2G) charging