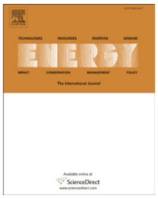
ARTICLE IN PRESS

Energy xxx (2016) 1–10

Contents lists available at ScienceDirect

Energy

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



Demand management to mitigate impacts of plug-in electric vehicle fast charge in buildings with renewables

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ARTICLE INFO

Article history:
Received 19 May 2016
Received in revised form
16 November 2016
Accepted 21 November 2016
Available online xxx

Keywords:
Plug-in electric vehicles
Photovoltaic
Retail building
Demand management
Direct current fast charging

ABSTRACT

Plug-in electric vehicle penetration is increasing due to technical advancements and environmental concerns. Along with residential plug-in electric vehicle charging, the public charging infrastructure is much needed to reduce plug-in electric vehicles' range anxiety and foster their adoption. Renewable energy and demand management programs are considered viable options that can reduce the impacts of widespread plug-in electric vehicle penetration on the electric grid. This research studies the impacts of plug-in electric vehicle direct current fast charging on a simulated standalone retail building's peak demand and energy consumption, and presents the ability of renewable energy and demand management options to reduce their impacts. Additionally, insights into a public charge station usage are presented by monitoring different types of plug-in electric vehicle charge behaviors at a retail site. Research findings indicate that demand management of building end-use loads along with the use of solar photovoltaic can contribute to absorbing plug-in electric vehicle penetration at the building level ranging from the average of 7% for the demand management option alone to an average of 38% for the combination of demand management and solar photovoltaic, and contributing to shifting building peak demand to late evening hours.

1. Introduction

Plug-in Electric Vehicles (PEVs) will play a key role in the U.S. transportation future as they reduce petroleum dependence and greenhouse gas emissions [1]. However, there are some barriers to PEV adoption, including PEV cost, range anxiety and availability of charging infrastructure [2]. With growing PEV penetration, public charging infrastructures coupled with fast charging would be needed. Depending on PEV penetration, PEV can result in negative impacts on an electrical grid [3]. As opposed to Level 1 charging (rated at 120 V [4]), Level 2 charging (rated at 208/240 V [4]) can quickly increase peak electrical demand [5]. Direct Current (DC) fast charge with a typical 208/480 V AC three-phase input [4] on the other hand can quickly overload the local distribution circuit. Additionally, PEV charging tends to increase transformer losses, voltage deviations, harmonic distortion, peak load and thermal loading on a distribution system [6]. Authors in Ref. [7] present impacts of fast charging represented by a 2-MW load, the equivalent of eight cars, and indicate that locations with a weak electrical infrastructure could not handle simultaneous fast PEV charging. Authors in Ref. [8] demonstrate that uncontrolled PEV charging leads to peak load in the early evening at residential sites, in the morning at the workplace and in the afternoon at commercial sites. An expensive way to manage such an impact is to reinforce the grid's infrastructure. However, instead of investing in the electricity infrastructure, impacts of PEV charging can be mitigated by exploiting the synergy among PEV charging, renewable generation and demand management (DM) [9].

With respect to the integration of solar photovoltaic (PV) into a PEV charging system, authors in Ref. [10] provide a review of PEV charging methods using PV-grid and standalone PV systems. Authors in Ref. [11] show a PV system with battery storage powering a residential PEV to reduce CO_2 emissions. Authors in Ref. [5] indicate that solar-assisted PEV charging could reduce the peak load, but it is not a cost effective solution. Authors in Ref. [12] indicate that installation of PV panels to supply daytime charging of PEVs could not meet PEV's driving needs in winter. Authors in Ref. [13] study a public charging infrastructure integrated with PV and their results show that in urban environment, the high variability of renewable generation causes charging waiting delays. There are studies which

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http://dx.doi.org/10.1016/j.energy.2016.11.118
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Please cite this article in press as: Sehar F, et al., Demand management to mitigate impacts of plug-in electric vehicle fast charge in buildings with renewables, Energy (2016), http://dx.doi.org/10.1016/j.energy.2016.11.118

discuss DM of PEV charging either by controlling or delaying PEV charging to reduce peak demand. Authors in Ref. [14] present different PEV charging scenarios including uncontrolled charging, delayed charging and off-peak charging to reduce grid impacts. Authors in Ref. [15] demonstrate DM of residential PEV charging, i.e., deferred charging, based on utility signals.

In addition to control of PEV charging, control of end-use loads in a building can effectively reduce peak load due to PEV integration. This study focuses on retail buildings, which include enclosed/strip malls and standalone outlets. Typically, lighting in U.S. retail (non-mall) buildings accounts for 26% and Heating Ventilation and Air-Conditioning (HVAC) 34% of total electricity consumption for non-mall buildings [16]. There are some studies which have demonstrated load control in retail buildings. Authors in Ref. [17] introduce daylighting, energy efficient lighting and HVAC system and a rooftop PV to a simulated hardware store and a visitor center to achieve electrical demand savings. Authors in Ref. [18] recommend the control of plug and process loads to reduce energy consumption. Authors in Ref. [19] show energy savings for two big box retail buildings. First store's cooling set point was raised by 2.9 °C and second store's cooling set point was raised by 1.83 °C to achieve annual cooling energy savings of 48% and 22% respectively. Authors in Ref. [20] show the reduction in annual electricity consumption in the range of 0.96%–1.84% for 1 °C indoor air temperature set point modification for retail stores located in seven U.S. climate zones. A 20% reduction in lighting power densities in the seven stores resulted in annual electricity savings in the range of 8.86%–10.09%. Authors in Ref. [21] have implemented temperature setback and main sales lighting control strategies in big box retail buildings during a demand response event - defined as a period during which an utility requests customers to reduce their peak demand. Temperature set point was raised by 1 °C and main sales lights were shut down by 50%, achieving 6% and 10% load reduction respectively.

Literature review indicates that most studies have analyzed either PEV charge stations integrated with PV systems, DM of PEV charging, especially for PEV fleets in residential areas, or control of end-use loads for retail buildings to achieve demand savings. However, there are no studies which analyze the synergy between PV and DM of buildings' end-use loads to mitigate the impacts of PEV charging demand in retail buildings. This paper addresses this knowledge gap by analyzing the impacts of fast PEV charging on the retail building's load profile and quantify the benefit of PV and DM of building's end-use loads — mainly HVAC and lighting - in absorbing PEV penetration. The DM algorithm designed for the retail building can lower the building's demand without sacrificing its functionality, while satisfying customer comfort. Realistic driving and charging behaviors of different types (e.g., Nissan Leaf, Chevrolet Volt) and classes (e.g., Sedan, SUV) of PEVs are considered in this study. Real-world PEV data are derived from PEV DC fast charging stations located at a retail site's on-street parking area. Approximately 12 months of PEV charge data have been collected and analyzed to determine PEV charge patterns and associated power consumption. Different types of PEVs with random batteries' State of Charge (SOC) indicate random driving patterns arriving at different times of the day at the public charging site. As PEVs are being integrated to the electric grid, it is essential to understand their charging behavior so that the grid can be managed to accommodate higher PEV penetration.

2. Standalone retail building model in EnergyPlus

This section summarizes the simulated retail building model and its end-use loads. EnergyPlus version 8.3, a building energy simulation tool, is used for this simulation study. The simulated standalone retail building model is based on the prototype medium-sized retail building model available in Refs. [22,23] developed by National Renewable Energy Laboratory (NREL). According to the 2012 Commercial Buildings Energy Consumption Survey (CBECS) data, 96% of retail buildings (non-mall) have an area up to 4600 m^2 [24]. The retail building model represents a medium box store with average level of retail activity, such as a clothing store, has little plug loads and is located in Virginia, U.S. area. Weather data used are of Ronald Reagan Washington National airport, U.S. available from Ref. [25].

2.1. Building construction

The simulated standalone retail building for this study is a 3762.57 m^2 single-story building. The building is rectangular shaped with an aspect ratio of 1.25. Building envelope constructions include steel framed walls, flat roof with insulation above the deck and slab-on-grade floors. Windows are located on the south façade with a window-to-wall ratio of 22%. The different zones include sales area, vestibule, stockroom, office, meeting room, break room, restroom, corridor and mechanical room.

2.2. Building operation

A weekday is considered for simulation purposes – since on these days other commercial buildings such as office buildings are also operational and grid load is high. The occupancy, lighting, and electric equipment schedules as a fraction of peak densities on a typical weekday used in this study are shown in Fig. 1. As shown, the building follows typical occupancy patterns for a retail building with peak occupancy between 11am to 1pm and 5pm–7pm on weekdays. Lighting (general and accent) and equipment usage is high from 9am to 9pm. HVAC system operates all day. This information is necessary to analyze a building load profile when DM is performed to ensure customer comfort.

2.3. HVAC load

Each zone has a single packaged rooftop unit with constant air volume (CAV) distribution. Each packaged unit has a direct exchange (DX) cooling coil and a gas fired furnace. In addition, each zone has an electric baseboard heat to maintain comfort. For a summer weekday from 6am to 12am the normal operating cooling set point is 24 °C. From midnight to 6am the cooling temperature set point is 30 °C.

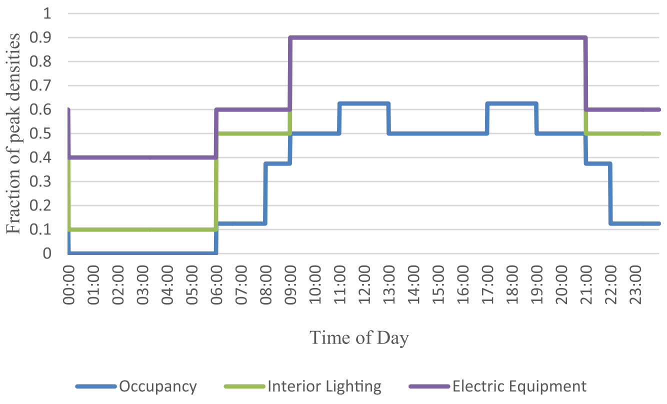

Fig. 1. Typical weekday schedules for occupancy, lighting and equipment of the standalone retail building.

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