Applied Energy 183 (2016) 1142–1156

Contents lists available at ScienceDirect

Applied Energy

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

Impacts of plug-in electric vehicles in a balancing area

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HIGHLIGHTS

- Unit commitment methodology is used to determine BEV impact on electricity market.
- Roles of charging profile, dispatch strategy and interconnecting area are assessed.
- Results show that impact of BEV on cost of electricity generation is small.
- Controlled BEV charging can lower emissions intensity of the grid and MCP.
- BEV deployment helps reduce overall criteria pollutant emissions.

ARTICLE INFO

Article history:
Received 6 July 2016
Received in revised form 9 September 2016
Accepted 24 September 2016

Keywords:
Plug-in electric vehicles
Grid modeling
Cost of electricity
Emissions
Unit commitment
Economic impacts

ABSTRACT

High contributions of the electricity generation and transportation sectors to criteria pollutant and greenhouse gas emissions have resulted in an increased interest and shift towards low to non-carbon generation options such as renewable wind and solar, and alternative transportation options including plug-in electric vehicles. Since plug-in electric vehicles transfer the tailpipe emissions to the electric grid, it is important to study the interaction between the two sectors. In this paper, a previously developed spatially and temporally resolved unit commitment model is used to determine the dispatch schedule of resources with and without battery electric vehicles for 2050 in a fictitious balancing area located within the South Coast Air Basin of California. Cases studied include various charging profiles, penetration in light-duty fleet, imports mix, and grid dispatch strategies. Results of the analysis include average cost of electricity production, market clearing price, temporal production of individual generators, and emissions from electricity generation and the transportation sectors.

The results show that deploying battery electric vehicles (1) has little impact on the average cost of electricity generation-maximum of \$2.5 per MW h for the cases studied with 40% penetration in the light-duty fleet, (2) reduces the overall criteria pollutant emissions except for one case, and (3) results in a smoother load profile, reduces the use of peaking units, and reduces the average emission intensity of the grid through controlled off-peak charging.

1. Introduction

Concerns about air quality, energy security, and global climate change have led to more stringent energy and environmental regulations to reduce energy consumption and emissions from both mobile and stationary sources. In 2014, the transportation sector accounted for 28 percent of energy consumption in the United States [1] and it is estimated that the transportation energy use and greenhouse gas (GHG) emissions have increased 28 percent worldwide since 2000 [2].

In the state of California, the electricity generation and transportation sectors are the main contributors to both criteria pollutants and GHG emissions [3] with the transportation sector accounting for 37 percent of GHG emissions in 2013 [4], and 49 percent of NO_x emissions in 2012 [5]. Thus, the transportation sector is a major contributor to air pollution, a major contributing factor to chronic diseases and mortality impacting public health. Several pathways are available to address this issue: (1) increasing the efficiency and thereby reducing tailpipe emissions of conventional vehicles, (2) reducing the transportation demand by changing life style through public transit, a reduction in commute time by living closer to workplace, and consuming local produce, and (3) implementing regulations to reduce emissions (such as California Assembly Bill 32 that requires a reduction to 1990 levels by 2020 in GHG emissions), and encourage alternative low and non-carbon transportation options (such as Assembly Bill 118 that supports alternative and renewable fuel and vehicle technologies [6]).

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http://dx.doi.org/10.1016/j.apenergy.2016.09.063
0306-2619/

Nomenclature

BEV	Battery Electric Vehicle
CAISO	California Independent System Operator
GHG	Greenhouse Gas
LCOE	Levelized Cost of Energy
MCP	Market Clearing Price
NERC	North American Electric Reliability Corporation
PEV	Plug-in Electric Vehicle
PHEV	Plug-in Hybrid Electric Vehicle
SoCAB	South Coast Air Basin
V2G	Vehicle to Grid
VMT	Vehicle Miles Traveled

All these factors have resulted in regulatory initiatives to replace internal combustion engine vehicles with alternative, lower emitting options. One of the options considered is plug-in electric vehicles (PEVs) as a feasible, near-term option [7] that will prepare consumers for a future that includes fuel cell vehicles, public transit, and shared autonomous vehicles [8]. PEVs, which include plug-in hybrid electric vehicles (PHEV) and purely battery electric vehicles (BEV), have the benefits of reduced liquid fuel usage [9], lower overall criteria pollutant emissions [10,11], improved air quality [12,13], utilization of idle and stranded resources, reduced GHG emissions [14], and a less expensive source of mobility than gasoline on a per mile basis.

Since PEVs are directly connected to the grid, understanding the interaction between the transportation and electricity sectors is important to correctly characterize the impacts of deploying these vehicles. One group of studies, focused on the generation side of the electricity grid, suggest that large-scale deployment of PEVs will have limited negative impacts on the electric power system in terms of additional generation requirements [15,16], and that they will have positive impacts on emissions, the extent of which depends on the charging profile, charging level, and the grid mix [17]. Other groups of studies address the interaction of the PEVs with the distribution system [18], distribution transformer [19], and distribution substations [20], as well as the implications of vehicle-to-grid (V2G) [21,22] and using V2G to increase penetration of intermittent resources [23,24].

Studies have also explored the impacts of PEVs on regional electricity markets and ISOs, and focus on the appropriate regulations that need to be implemented to facilitate the integration of PEVs [25,26]. However, there are few studies that assess the impact of PEVs on electricity market prices [27,28]. As a result, a need exists to determine the interaction between the electricity generation and transportation sectors in a manner that represents real-life electricity market operations and captures the many physical constraints in order to (1) assess the impacts on the cost of generation and operation of the grid, and (2) impact on overall emissions.

A comprehensive spatially and temporally resolved dispatch model, based on unit commitment with market operations and associated physical constraints [29], is used in this paper. Various cases with different BEV charging profiles, and dispatch strategies are studied. Three dispatch strategies are assessed, one with an *economic* dispatch strategy and two with *environmental* strategies in which minimizing the overall emissions from generating units is the objective instead of cost of the system. The environmental dispatch strategies (1) provide an opportunity to reduce the environmental impacts with neither investment nor change to the grid, and (2) indicate the maximum achievable reduction in a specific species associated with the grid mix and design under study, thereby facilitating realistic roadmaps in the future.

Role of imports in the overall results is also explored. The economic metrics of each case-including average cost of generation, and market clearing price (MCP) are determined and compared. The dispatch schedules are then used to determine the emissions associated with generating units including part-load, start-up, and ramping emissions.

2. Approach

2.1. Dispatch model

A detailed market model including a dispatch model and multiple modules was developed for the South Coast Air Basin (SoCAB) as a balancing area to mimic the operations of the electricity market and business in the state of California while taking into account the physical constraints of the system. In this methodology renewable resources are treated as must-take, and imports are dispatched ahead of in-basin units to mimic actual market operations. Note that in practice, imports are settled ahead of time and the negotiated price is usually lower than the spot market price (similar to bilateral contracts). This is simulated in this study by dispatching them first.

Studying historical data from the state of Californian and SoCAB [30,31], it is concluded that the imports, more or less, follow the same profile as the demand [29]. Moreover, for the following reasons it is assumed that transmission capacity for imports to SoCAB remains unchanged: (1) Obtaining licenses required for building transmission lines takes a long time, (2) environmental concerns, and (3) assessing an air quality episode in the basin requires a high generation inside the basin. This capacity is determined by assessing historical data [10].

During off-peak hours, it is assumed that the imports are provided by load-following units with capacity factor projected for the year under study [32,33], and during peak hours, the extra import is assumed to be provided by peaking (and more expensive) units. In all cases, a 5% transmission loss in assumed for the imports [34]. When the amount of imports is less than 10% of the total import capacity, it is assumed that the generators providing the imports are operating at minimum allowable capacity factor, resulting in increase in the price of imports per MW h.

After dispatching must-take units and imports, conventional in-basin units are dispatched using a unit commitment dispatch model. The objective of the economic dispatch is to minimize the social cost of the market as shown in Eq. (1).

$$Minimize \sum_{i=1}^{N_g} [C_i(P(i,t))I(i,t) + S(i)I(i,t)\{I(i,t) - I(i,t-1)\}] \quad (1)$$

In this equation, N_g is the number of generators participating in the market, C_i is the cost function of generating unit i which is equal to the Levelized Cost of Energy (LCOE) associated with that unit which is itself a function of the capacity factor. $P(i,t)$ is the production (generation) of unit i at time t, $S(i)$ is the start-up cost of unit i, and finally $I(i,t)$ is the commitment status of unit i at time t.

Constraints of the system include matching demand and generation, minimum and maximum capacity factor of each generating unit, ramping up and down limits, minimum on/off time and transmission line constraints. A detailed description of the dispatch