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Light-duty electric vehicles to improve the integrity of the electricity grid through Vehicle-to-Grid technology: Analysis of regional net revenue and emissions savings

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HIGHLIGHTS

- Vehicle to Grid (V2G) technology for use in ancillary services is studied.
- A regional net revenue and life cycle emissions savings of V2G system is conducted.
- The future market share of electric vehicles is predicted using an Agent-Based Model.
- For a single vehicle, net revenue of V2G service is highest for the New York region.
- However, PJM region has an approximately $97 million overall net revenue potential.

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ABSTRACT

Vehicle to Grid technologies utilize idle EV battery power as a grid storage tool to meet fluctuating electric power demands. Vehicle to Grid systems are promising substitutes for traditional gas turbine generators, which are relatively inefficient and have high emissions impacts. The purpose of this study is to predict the future net revenue and life cycle emissions savings of Vehicle to Grid technologies for use in ancillary (regulation) services on a regional basis in the United States. In this paper, the emissions savings and net revenue calculations are conducted with respect to five different Independent System Operator/Regional Transmission Organization regions, after which future EV market penetration rates are predicted using an Agent-Based Model designed to account for various uncertainties, including regulation service payments, regulation signal features, and battery degradation. Finally, the concept of Exploratory Modeling and Analysis is used to estimate the future net revenue and emissions savings of integrating Vehicle to Grid technology into the grid, considering the inherent uncertainties of the system. The results indicate that, for a single vehicle, the net revenue of Vehicle to Grid services is highest for the New York region, which is approximately $42,000 per vehicle on average. However, the PJM region has an approximately $97 million overall net revenue potential, given the 38,200 Vehicle to Grid-service-available electric vehicles estimated to be on the road in the future in the PJM region, which is the highest among the studied regions.

1. Introduction

1.1. Background and problem statement

The U.S. electricity generation and transportation sectors are, respectively, the largest and second largest Greenhouse Gas (GHG) contributors in the U.S., together accounting for almost 60% of total national GHG emissions [1]. Due to concerns associated with global warming, rising energy prices, and energy supply security, developing alternative ways to efficiently manage resources has become critically important. Given the increasing demand for passenger vehicles in the U.S., increasing the proportion of alternative fuel vehicles on today's roads will help to mitigate transportation sector emissions and increase energy security [2,3].

Alternative vehicle technologies, such as Battery Electric Vehicles (BEVs), have the potential to minimize the negative

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List of Acronyms

ABM	Agent-Based Model
AER	All-Electric Range
AFLEET	Alternative Fuel Life-Cycle Environmental and Economic Transportation
AGC	Automatic Generation Control
BEV	Battery Electric Vehicle
CAISO	California ISO
DoD	Depth of Discharge
EMA	Exploratory Modeling and Analysis
ERCOT	Electric Reliability Council of Texas
EREV	Extended Range Electric Vehicle
EVReMP	Electric Vehicle Regional Market Penetration
FCV	Fuel Cell Vehicle
GHG	Greenhouse Gas
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation
HEV	Hybrid Electric Vehicle
ICEV	Internal Combustion Engine Vehicle
ISO	Independent System Operator
ISONE	ISO New England
LCA	Life Cycle Assessment
LCOE	Levelized Cost of Electricity
MPG	Miles per Gallon
NYISO	New York Independent System Operator
PHEV	Plug-in Hybrid Vehicle
PJM	PJM Interconnection
RTO	Regional Transmission Organization
SOC	State of Charge
V2G	Vehicle-to-Grid
VMT	Vehicle Miles Traveled
WTP	Well to Pump

environmental impacts of the transportation sector, but there are several barriers to their widespread adoption [4]. These include an aging electrical distribution system unequipped to handle neither additional load nor smart grid technologies; lack of a public charging infrastructure network; apprehension about the limited range of EVs; and the long charging times of EVs [5]. One potential benefit that could drive adoption in spite of these challenges, is the potential for an electrified vehicle fleet to generate new revenue streams for the businesses and individuals who own alternative fuel vehicles [6]. Modeling customer behavior is an important step towards identifying the barriers to widespread adoption of BEVs and developing strategies to harness this technology efficiently. BEVs can serve as a storage system for the electric power grid, termed Vehicle to Grid (V2G) system, and may create monetary saving opportunities, help widespread adoption of BEVs, and minimize negative environmental impacts of both the energy and transportation sector. In this study, the regional life cycle emissions savings and net revenue of V2G ancillary service (regulation) are explored from a customer perspective.

Currently in the U.S. there are several stationary battery facilities that provide grid stabilizing services, with capacities ranging from 1 MW to 20 MW [7]. These high-capacity battery packs usually require an enormous capital investment and are thus far used only for energy storage. However, if the existing U.S. light vehicle fleet were electrified, the resultant total power capacity would be about 24 times more than that of the entire electricity generation system [8]. EV battery capacity is already routinely plugged into the grid for charging, and has significant potential to serve as grid storage and capacity to be used for grid stabilization services. Furthermore, with the introduction of government incentives and reductions in manufacturing costs due to large-scale battery production, EVs are expected to have greater market penetration levels over the next 15 years [4]. In fact, every major car manufacturer today has already manufactured one or more electric vehicle models with significantly higher fuel economy levels than Internal Combustion Engine Vehicles (ICEVs). Passenger cars are parked for most of the time in any given day, and even during rush hours in California, only 10% of vehicles are on the road, while the remaining 90% of vehicles are potentially available to the grid [9]. For Plug-in Electric Vehicles (PHEVs) and Battery Electric Vehicles (BEVs), given certain upgrades, existing systems are technologically capable of supporting the grid. Therefore, with limited onboard meter and home wiring upgrades, EVs can be used as an ideal grid electricity storage solution.

The current electricity market consists of four different types of electricity services:

- *Baseload power*, a.k.a. *"bulk" power*, is generated most commonly by large coal or nuclear power plants on a round-the-clock basis. It has the lowest electricity unit cost, but the generators commonly take days to start up or shut down, making it practically impossible for them to respond to rapid system fluctuations.
- *Peak load power* is typically generated by natural gas turbines when high electricity usage is predicted, such as during summer afternoons. Peak power has higher prices in the electricity market and, due to the peak power market's relatively predictable demand pattern, generators can be adjusted in advance to accommodate the additional demands.
- In addition to generating baseload and peak power, the grid also needs *ancillary services* to maintain grid reliability and stability. Two types of ancillary services are spinning reserves and regulation services.
  - *Spinning reserves* mainly provide backup capacity to the grid and stabilize system frequencies in the event of a generator failure or other such emergency.
  - *Regulation services*, namely Automatic Generation Control (AGC) services, serve as grid stabilizers, maintaining system voltages and grid frequencies as needed, which is currently accomplished by ramping up/down the output of the generator in question, in accordance with an ISO's regulation up/down signals.

Regulation services are mainly controlled by Independent System Operators (ISOs) and/or Regional Transmission Organizations (RTOs). These entities are responsible for non-discriminatory access to electricity transmission within a region, monitoring transmission, and maintaining reliability of the grid. Although they do not own transmission, they help coordinate transmission as well as plan for future transmission needs. They accomplish these objectives through the use of energy, capacity and ancillary services markets. Due to rapid but short demand periods and high electricity unit prices, the ancillary services market requires flexible power supply methods and sources. V2G technology utilizes the existing battery capacity of idle EVs as a means to store electricity and then respond to grid operator request signals on a minute-by-minute basis, making it a great ancillary service option. However, since spinning reserves would require this battery