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Vehicle to Grid regulation services of electric delivery trucks: Economic and environmental benefit analysis

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HIGHLIGHTS

- Potential net present revenues of electric truck based V2G regulation services are investigated.
- GHG emission mitigation of V2G regulation services provided by electric trucks are quantified.
- The total cost of ownership and the life-cycle GHG emissions of electric trucks are also analyzed.
- V2G regulation services for electric trucks could yield considerable revenues and GHG emission savings.

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ABSTRACT

Concerns regarding the fuel costs and climate change impacts associated with petroleum combustion are among the main driving factors for the adoption of electric vehicles. Future commercial delivery truck fleets may include Battery Electric Vehicles (BEVs) and Extended Range Electric Vehicles (EREVs); in addition to savings on fuel and maintenance costs, the introduction of these grid accessible electric vehicles will also provide fleet owners with possible Vehicle to Grid (V2G) opportunities. This study investigates the potential net present revenues and greenhouse gas (GHG) emission mitigation of V2G regulation services provided by electric trucks in a typical fleet. The total cost of ownership and the life-cycle GHG emissions of electric trucks are also analyzed and compared to those of traditional diesel trucks. To account for uncertainties, possible ranges for key parameters are considered instead of only considering fixed single data values for each parameter. The results of this research indicate that providing V2G regulation services for electric trucks could yield considerable additional revenues ($20,000–50,000) and significant GHG emission savings (approximately 300 ton CO_2) compared to conventional diesel trucks.

1. Introduction

The U.S. electricity and transportation sectors are, respectively, the largest and second largest contributors to greenhouse gas (GHG) emissions in the U.S., altogether accounting for almost 60% of the total U.S. GHG emissions [1]. As industrial and residential energy/fuel needs continue to grow over time, the resulting increase in the consumption of petroleum fuels have led to growing climate change and energy dependency concerns. As a result, although fossil fuels are still the dominant energy source today, concepts such as clean energy and green transportation have received a great deal of attention in research and industry [2].

The electrification of vehicles is a widely accepted and effective green transportation practice [3,4], and Electric Vehicles (EVs) – including Hybrid Electric Vehicles (HEVs), Battery Electric Vehicles (BEVs) and recently introduced Electric Range Extended Vehicles (EREVs) – have thus been strongly promoted by federal and state governments. The electric drive system is especially suitable for driving in congested traffic, and from a life cycle perspective, EVs have proven to have significant environmental impact mitigation potential if the local electricity sources are renewable (esp. hydropower or wind power) [5]. More importantly, Vehicle to Grid (V2G) systems, a further integration of electric power grids and EVs, utilize the battery capacity of idled EVs as grid storage, allowing them to improve the reliability of the power grid, reduce GHG emission impacts as opposed to the low-efficiency operation of traditional power plants, provide additional revenue for vehicle/fleet owners, and help to promote the implementation of clean energy and to further increase the market penetration of EVs. However, despite the benefits that V2G technologies provide, the implementation of this relatively new concept may face economic or sociological

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Nomenclature

$P_{vehicle}$	power output of vehicles (kW)
B_{cap}	capacity of batteries (kW h)
D_d	daily VMT (mile)
D_{buffer}	minimum backup range required for electric vehicles (mile)
F_e	fuel efficiency of electric vehicles (mile/kW h)
C_e	electricity conversion efficiency
T_{disp}	effective regulation provision time (min)
$Price_{cap}$	regulation capacity price ($/kW h)
$Price_{ele}$	electricity price ($/kWh)
T_{plug}	total vehicle plug-in time (h)
T_{cyc}	actual time of one regulation cycle (h)
P_{line}	power capacity of charging equipment (kW)
N_{disp}	number of accepted regulation requests
$Upstream_{kjy}$	upstream amount of air pollutant k in region j for year y (lb/kW h)
$eGrid_{kj}$	eGrid annual emission rate in region j for air pollutant k (lb/kW h)
GGL_j	eGrid grid loss factor for region j
WTP_{kp}	well to pump air pollutants of power plant p (lb/kW h)
E_{disp}	dispatched electricity (kW h)
Emi_{grid}	emission rate of the electricity generated by the grid mix (ton/kW h)
$Emi_{battery\ wear\ out}$	emissions due to the battery wear out from providing V2G services (ton)
P_{disp}	requested dispatched power in each regulation cycle (kW)
E_{disp}	total dispatched electricity (kW h)
R_1	total capacity payment revenue ($)
R_2	total energy payment revenue ($)
C	battery degradation cost ($)
C_{bat}	capital cost of battery ($)
L_{et}	lifetime throughput energy (kW h)
C_{ac}	annualized capital cost ($)
P_{bat}	battery unit price ($/kW h)
B_{cap}	battery capacity (kW h)
L_c	battery lifetime cycles (cycles)
DoD	battery depth of discharge (%)
d	discount rate
n	life cycle duration of the battery (year)
ACF	annual cash flow
Pur	vehicle purchasing cost
Equip	equipment upgrade cost
Ch	charging station cost
R	total V2G regulation service revenue
VM	vehicle maintenance cost
ChM	charging station maintenance cost
Brepl	battery replacement cost
Sal	vehicle salvage value
i	discount rate

Subscript

p	power plant index
k	air pollutant index for GHG
j	region index
y	year index
v	vehicle type index

Acronym

AFLEET	Alternative Fuel Life-Cycle Environmental and Economic Transportation
AGC	Automatic Generation Control
BAU	business as usual
BEV	Battery Electric Vehicle
CAISO	California ISO
DOD	depth of discharge
ERCOT	Electric Reliability Council of Texas
EREV	Extended Range Electric Vehicle
EVRO	Electric Vehicle Regional Optimizer
GHG	greenhouse gas
GREET	greenhouse gases, regulated emissions, and energy use in transportation
HEV	Hybrid Electric Vehicle
ICV	internal combustion vehicle
ISO	Independent System Operator
ISONE	ISO New England
LCA	Life Cycle Assessment
MPG	mile per gallon
NYISO	New York ISO
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

problems [6]. To explore the feasibility of the application of V2G systems, this article will evaluate the GHG emission savings and potential revenues for fleet operators using EREVs or BEVs as V2G regulation service providers. The system boundary will follow the most cited studies [7–10], including fuel/electricity production phase, battery manufacturing phase and V2G-related vehicle operation phase, which is the main focus of this study. Vehicle manufacturing and end-of-life disposal will not be involved considering that these two phases have no effect on V2G-related analysis. On the other hand, V2G regulation services may accelerate the degradation of batteries and battery manufacturing and disposal are emission intensive, hence, battery degradation scenarios will also be analyzed in detail. To address the spatial differences and uncertainties of the parameters, the research will be conducted in five Independent System Operator (ISO) and Regional Transmission Organization (RTO) regions, and the resulting revenues and life cycle emission savings will be projected for 15 years (2016–2030). The methods as well as calculations used in this study are shown in Fig. 1.

This article contains five additional sections. In Section 2, the current situation of ancillary service markets as well as the necessity and suitability of V2G technologies is discussed. Literature review is conducted in Section 3. Section 4 is devoted to illustrate the framework of the economic and environmental benefit projections. The total ownership cost and revenue of V2G regulation services as well as the life cycle GHG emission and savings are shown in Section 5. The conclusions and future works are summarized in Section 6.

2. Electricity grid fluctuation, V2G technologies and delivery truck fleets as grid storage providers

Electricity (as a “unique” commodity) has to be generated and consumed simultaneously; otherwise, if the real time demand for electric power is less than its generation, the unconsumed electricity generation is ultimately wasted due to the lack of adequate grid storage methods [11]. On the other hand, if the total electricity demand surges unexpectedly at a certain time and exceeds the