# Plug-In Electric Vehicle Integration into Smart Grids: An Overview of a Mixed-Integer Linear Programming Optimization Model

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***Abstract*** *— Plug-in electric vehicles have seen a rise in popularity for reasons such as efficiency and reduction in greenhouse gas emissions compared to internal combustion engine vehicles. Battery and fast charging technology are improving and getting less expensive, which means that plug-in electric vehicles will become increasingly cost competitive with internal combustion engine vehicles. Due to the potential for high penetration of plug-in electric vehicles, there is a need to design effective mechanisms for the integration of these vehicles into the power grid to avoid adverse effects. This paper describes vehicle-to-grid optimization and explores* approaches for solving *vehicle-to-grid* optimization problems. *Furthermore, this paper describes a multi-objective mixed-integer linear programming model for vehicle-to-grid optimization.*

**Keywords** — Plug-in electric vehicles, Vehicle-to-grid, Smart Grid, Optimization

## Introduction

Due to the advantages of plug-in electric vehicle (PEV), there is a potential for large-scale PEV integration into the power grid. This integration can have drastic consequences such as high energy costs, power peaks or shutdowns. However, if coordinated intelligently, these issues can be overcome (Egbue & Uko, 2019). This is where the concept of vehicle-to-grid (V2G) comes into play for the optimal coordination of PEV charging and discharging. V2G is generally classified into unidirectional V2G and bidirectional V2G. Where unidirectional means there is only controlled charging, and no discharging occurs from the vehicle to the power grid. An example of unidirectional V2G was implemented in a study by Wang et al. (2018), where they used a mixed-integer programming methodology to solve for an optimal schedule that maximized the revenues in a real-world demand response market in California. In the case of bidirectional charging, the flow of energy from between the grid and PEVs occurs in both directions. Therefore, in a bidirectional case, PEVs can be charged but they can also discharge energy to the power grid. Examples of studies on bidirectional V2G were conducted by Huang et al. (2020) and Li et al. (2020). The authors implemented a multi-objective strategy to coordinate the charging of PEVs. Their model carried out both charging and discharging to reduce the gap between the load peak and the valley. The results of their study show that the use of V2G can reduce the active power loss and power supply pressure.

Vehicle-to-grid optimization can be carried out for a single objective or multiple objectives depending on the goals of the designer and system planner. For single objective methods, the purpose of the problem is to either maximize or minimize a chosen objective while for multi-objective methods, more than one objective is considered in solving for the optimum charging schedule of the participating PEVs. Studies conducted by Hosseinpour and Egbue (2015) and Egbue and Hosseinpour (2014), address bidirectional V2G optimization with single objective functions. However, to satisfy all the participating stakeholders in a V2G system, the multi-objective optimization may be used instead of a single objective. Several studies have implemented multi-objective optimization of V2G. An example of such implementation is a model by Tong et al. (2014). The authors used NSGA-II to solve a multi-objective problem that minimized the charging cost and minimized the load variance in the system. These objectives were solved while considering constraints such as the power limit and the charging efficiency. The results of their study showed that their proposed strategy was effective in reducing the charging cost of participating vehicles compared to an uncontrolled scenario. In the next section, an overview of a multi-objective optimization by Egbue and Uko (2019) is presented.

## Multi-Objective Mixed-Integer Linear Programming Model for V2G System Optimization

Egbue and Uko (2019) developed a mixed-integer linear programming optimization model for a V2G system. The methodology for modeling the V2G system is shown figure 1 below. The authors argue that to carry out the optimization of the V2G system, certain factors including the requirements of participants in the system should be taken into consideration. This consideration is essential to develop objectives that meet the needs of all participants where possible. Three key participants are considered in the study by Egbue & Uko (2019), namely the electric utility, PEV owners, and the charging station agent also known as the PEV aggregator. As illustrated in figure 1, the study considered two objective functions that focused on minimizing the PEV drivers' cost of participating in V2G and maximizing the aggregator's profit. The study was subject to several constraints such as a constraint that the state of charge (SOC) of the participating vehicles must remain within the range of their given battery capacity. Another constraint considered was setting the charging power not to exceed 6.6 kW. There were also constraints related to PEV arrival times and departure times to ensure that vehicles only charge during periods when they are in the charging station. The information that was used to generate realistic travel behavior and characteristics for the vehicles in the simulation were obtained from National Household Travel Survey (2018) and U.S. Department of Energy (2020). The results of the optimization include a Pareto front that presents the conflicting relationship between the different objectives and the best trade-off points where neither objective outperforms the others.

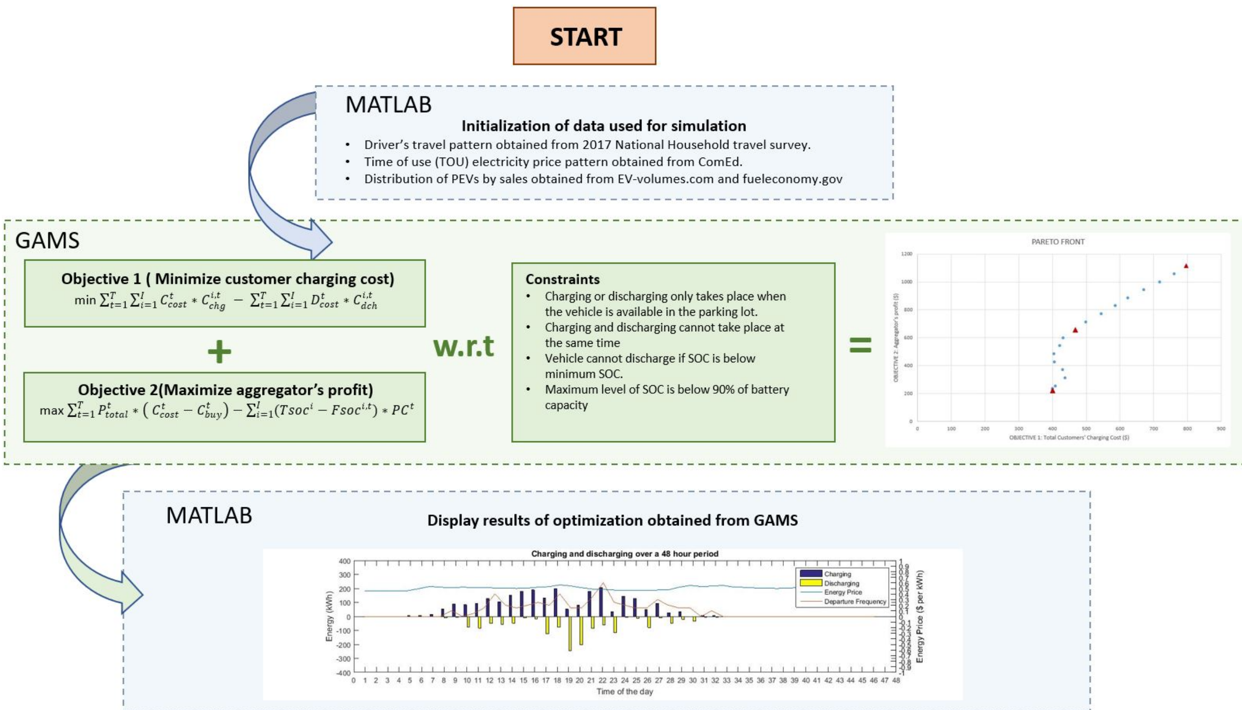


**Figure 1.** Vehicle to grid Optimization overview

The study can be expanded to account for more objectives of the various stakeholders in order to increase satisfaction of V2G participants. For instance, for the PEV owners, the objectives could include minimizing the charging cost, maximizing earnings from selling energy back to the grid, minimizing the degradation effect on the battery due to repetitive charging and discharging and receiving adequate charging to get to the next available charging opportunity. The aggregator's objective includes maximizing profit from operating the charging station, ensuring vehicles are charged to meet the customer's expectation on departure, and providing ancillary services such as frequency regulation. For the electric utility, objectives include the reduction of energy production cost, peak demand shaving and valley filling, frequency regulation, and reduction of emission cost.

## Conclusions

The topic of using V2G optimization to augment the performance of the power grid is very important given the potential for mass deployment of V2G and related impacts on the power grid. This paper provides an overview of V2G optimization and discusses some methods and approaches for solving V2G optimization problems. Furthermore, a multi-objective mixed-integer linear programming model developed by the authors is described. Finally, this study emphasizes the importance of considering objectives of V2G stakeholders when solving V2G optimization problems in order to meet stakeholder needs where possible.

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