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Vehicle-to-grid feasibility: A techno-economic analysis of EV-based energy storage

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HIGHLIGHTS

- A V2G economic feasibility analysis environment was built.
- Manchester Science Park was used as a case study for review of 50 vehicles for V2G.
- Vehicle savings of up to £400,000 could be made over a 10-year period.

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ABSTRACT

The potential for electric vehicles to obtain income from energy supplied to a commercial building together with revenue accruing from specific ancillary service markets in the UK is evaluated in this work. A hybrid time-series/probabilistic simulation environment using real-world data is described, which is applied in the analysis of electricity trading with vehicle-to-grid to vehicles, buildings and markets. Key parameters are found to be the electric vehicle electricity sale price, battery degradation cost and infrastructure costs. Three vehicle-to-grid scenarios are evaluated using pool vehicle trip data, market pricing index data and half-hourly electricity demand for a commercial building. Results show that provision of energy to the wholesale electricity market with additional income from the capacity market results in the greatest projected return on investment, producing an individual vehicle net present value of ~£8400. This is over 10 years for a vehicle supplying energy three times per week to the half-hour day-ahead market and includes the cost of installing the vehicle-to-grid infrastructure. The analysis also shows that net income generation is strongly dependent upon battery degradation costs associated with vehicle-to-grid cycling.

1. Introduction

In common with many other nations, the transition to a future energy system largely based on low or zero-carbon electricity for services such as heating and transport, is predicted to result in significant risks in terms of energy security of supply and cost for the UK [1]. In this context, electric Vehicles (EVs) are projected to contribute up to 60% of total new car sales in the UK by 2030 [2], thus creating significant extra demand on electricity networks, including during peak demand hours. One potential opportunity to manage increasing electricity costs and demand spikes is the utilisation of EVs to act as an aggregated energy store, providing peak shaving or demand shifting to both local buildings and to the power system when demand is high. This is facilitated through vehicle-to-grid (V2G) technology, which allows energy to flow both to and from the vehicle, facilitated by a bi-directional power converter. In recent years, an increase in the number of V2G systems in Japan occurred as a result of grid insecurity after the Fukushima disaster in 2011 [3–5]. As such, V2G can help provide a means of powering buildings from a portable battery store, which can be re-charged at a different location on a regular basis [5]. Such concerns are of lesser relevance in the UK however, where research indicates V2G uptake will predominantly be related to system economics and CO_2 emissions as opposed to grid security [6–10].

Abbreviations: CM, Capacity Market; DSM, Demand Side Management; DUoS, Distribution Use of System; EV, Electric vehicle; ICE, Internal Combustion Engine; MSP, Manchester Science Park; NG, National Grid; PiM, Plugged-in Midlands; PS, Pumped Hydro Storage; PV, Photovoltaic; SoC, State of Charge; TOUT, Time of Use Tariff; UK, United Kingdom; V2G, Vehicle to Grid; VPP, Virtual Power Plant.

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Management of fixed (as opposed to mobile) storage assets is relatively straightforward. However, EVs inject additional complex considerations in comparison to static systems, such as vehicle usage, journey requirements and location. One solution to the management of these disparate assets is through aggregation services, a relatively well-established industry in the UK, with commercial service providers aggregating small generation assets to address a range of balancing services [11]. Current aggregation of assets includes generators and uninterruptible power supplies being used to reduce peaks in electrical demand [12]. The term "Virtual Power Plant (VPP)" is used to describe geographically dispersed generation and storage assets being exploited via web services, designed to provide connection and control for all distributed energy resources available to the VPP operator [13]. This allows greater opportunity for trading within the wholesale energy, capacity and ancillary markets with generators that would otherwise be too small and dispersed to have any significant impact [14]. Aggregators also dictate where the energy available within the vehicles should be used, for building self-consumption or exported for markets. It is this management system that facilitates the possibility of energy use for multiple activities.

Crucial to the implementation of EVs as battery storage assets is the evaluation of UK energy markets suitable for aggregated EV storage assets. There are several markets that are potentially appropriate, including reserve services such as Short Term Operating Reserve (STOR), wholesale day-ahead market and the capacity market, with STOR requirements specifying the minimum generation limit at 3 MW [15]. Being a pre-contracted balancing service, the provider delivers to a contracted level of power when instructed to do so by the System Operator [15]. Another market potentially suitable for V2G buy-in is the Capacity Market. This enables National Grid to buy energy capacity in advance, ahead of delivery to guarantee investment in developing generation [16]. A limit of 2 MW de-Minimis has been set, under which any generation must be taken into an aggregation service [17]. The bidding and delivery requirements are set by National Grid for each individual participant in the Capacity Market depending upon their availability and National Grid requirements [17]. Thus, uptake through the Capacity Market means that battery storage for arbitrage is more feasible than has been the case in previous years.

In contrast, for the case of provision of electricity to buildings, the nature of the procurement and billing arrangements employed by the building owner or tenants is significant. Commercial buildings operate under several standard payment types including fixed rate tariffs, Time of Use Tariff (TOUT) and Triads. TOUT presents an opportunity for EVs to supply energy directly to the building during peak demand times when tariffs are highest, whilst triads avoidance (the three half hours in the year with the highest national demand [18,19]) offers another opportunity. This billing system enables large consumers to pay a lower fixed price for their electricity via the wholesale market [20]. Through using EVs to supply energy to a building, the energy consumed during these triad periods can be reduced, therefore reducing the energy bill of the commercial consumer during these high cost periods. As billing occurs post triad occurrence, consumers often employ a triad forecasting service that allows them to estimate when the triad period may occur and therefore respond accordingly.

Research suggests there is potential for V2G trading in electricity markets. However the relationship between vehicle use, building demand and market requirements is relatively unknown [21,22]. There is little known about the potential of aggregation of EVs for supply into STOR, the capacity market or local demand self-consumption. Utilisation of EVs for storage of excess PV generation to re-distribute into buildings during periods of high demand or high cost, such as TOUT or triad periods, also presents possibilities. Again, relevant research is sparse and little is known as to the impact electricity pricing will have on V2G suitability for the UK market.

This research paper evaluates the potential income generation from V2G services for three different V2G scenarios; building self-consumption and provision to two different markets – STOR and the Wholesale market. The overall aim is to identify key scenarios where income can be generated through the sale of electricity from EV batteries, either to buildings or to external markets. This is made possible through development of a data-driven Monte Carlo based modelling methodology. The modelling approach taken allows for multiple scenarios to be reviewed using real-world data input.

2. Methodology

This research uses a data-driven Monte Carlo-based analysis to evaluate the economic potential of EVs with V2G technology

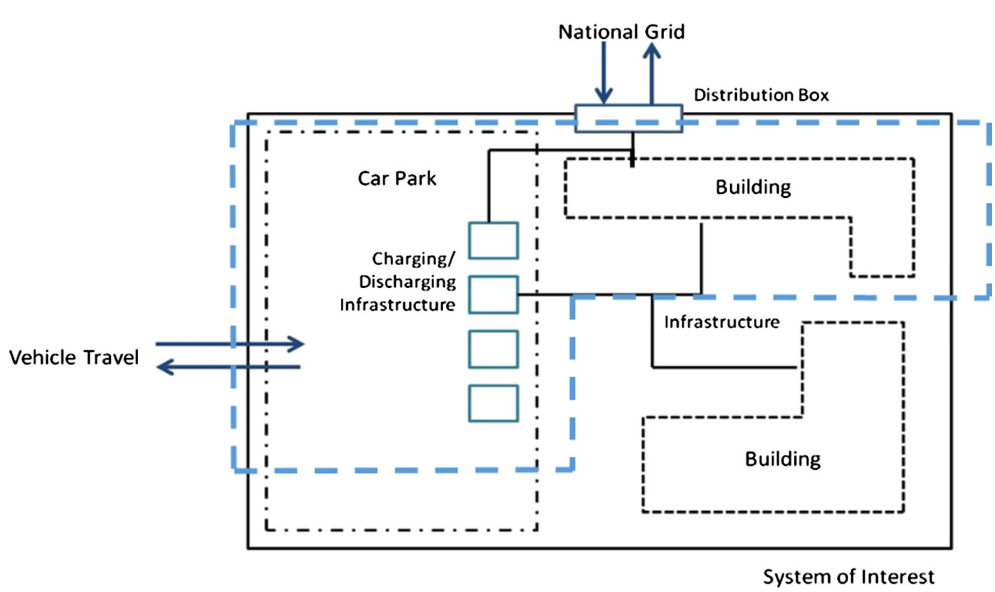

Fig. 1. System conceptual model, showing system boundary, key components and data flows.