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Feasibility study: investigation of car park-based V2G services in the UK central hub

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Abstract: The increasing uptake of electric vehicles, and the established practice of long-term parking at stations and airports, offers an opportunity to develop a flexible approach to help with the energy storage dilemma. This paper investigates the feasibility of using a number of EV batteries as an energy storage and grid balancing solution within the UK Central Hub area. Here, the capital cost of the vehicle is a sunk cost to the EV owner. The potential income generated, or discount on long-term parking, is an additional benefit of ownership. This paper considers the income available to a small and large size car park from the different market mechanisms to offer grid support in the UK and contrasts this with the complexity and costs of the EV charging infrastructure required within these types of scheme.

1 Background

As the number of plug in vehicles (PIV) grows, there is an increasing interest in using these vehicles as loads or a distributed energy resource through vehicle to grid (V2G) schemes [1]. Key benefits quoted include backup for renewable sources, reactive power support, load balancing and ancillary services such as frequency regulation. There have been a number of vehicle-based trials of PIV's with the purpose of providing grid-based support [2]. These include trials in USA, Germany, and the UK looking across a range of activities such as smart scheduling of domestic EVs [3, 4], domestic smart charging based on time of use tariff [5, 6], active network management to reduce potential overloads on distribution equipment [3]. These trials have primarily focused on demand reduction and controlling PIV charging. Trials where PIVs are used as both a load and a distributed generator have been more limited to-date although examples of commercial equipment-based small-scale schemes exist [6, 7]. It has been suggested within literature that regulation-based services offer a higher value income stream albeit at potential for increased battery degradation. Academic estimates of anything from £0 to £300 have been suggested as an income per vehicle per annum. However, these figures are subjective and highly dependent on underlying assumptions [8–12]. Mostly, it has been assumed that the estimated revenue is offset against the cost of the vehicle to the owner rather than as revenue to offset the charging infrastructure provision.

Although the hardware for full V2G functionality now exists in small schemes, there has been an explosion of academic-based papers in recent years looking into many theoretical aspects of large-scale V2G. These include papers specifically looking at estimates of available energy [13–17] and aggregation dispatch [18–23] including fairness [24]. This paper builds on the work undertaken in literature but focuses on a large-scale hardware setup within a long-term car park and what this would involve in practice.

Long-term car parks are a major contributor to the global economy, with airport car parking income alone estimated to be worth $12.5 billion annually. Gatwick airport for example makes an estimated £51.7 m annually from car parking [25]. This offers significant opportunity for commercialisation over the long term. For every 1,000 EVs parked in a long-stay car park, this represents circa 10 MW of flexible electricity storage capacity. V2G appeal to long-term car park operators and the domestic customer is likely to increase as electrical network configurations, battery technology, and charging points become more sophisticated, and as the percentage of renewably generated grid electricity increases.

The basic building block for such a scheme is a set of electrically connected V2G chargers. V2G chargers exist in a variety of sizes from 3 kW (single phase 13A) through 7 kW and upwards of 22 kW towards 150 kW [26–28]. Many of these are uni-directional. However, there are a number of commercial bi-directional chargers published [7]. Currently, most existing EV parking schemes offer small numbers of uni-directional charging with no central control mechanism. This paper is based on work by an academic-industrial consortium as part of an innovate UK-funded project: Net-form. The paper looks more closely at the infrastructure requirements to charge/discharge large numbers of EV's in a car park–based environment. Previous work [29] in this area includes investigations into demand-side management and charging of commercial car parks located in non-residential areas near to the city centre. In these car parks, a high proportion of the drivers stay for work or leisure-related activities resulting in many vehicles being available for V2G between 8am and 4pm with statistical data of vehicle availability compared to that from the Singaporean Land Transport Authority. The objective of this work was to find the least cost solution for charging the EV's subject to the output of the car park model, electricity prices, reserve prices, individual EV constrains, and car park operator constraints. However, this paper did not consider infrastructure requirements and only considered charging services against costs. Other work in this area [30] looked at the impact of up to 4500 vehicles (450 MW) within a large shopping centre on the electrical grid system at HV. Two different connections to the 220 kV Network were considered and the car park was aggregated as a fixed load on recharge only. Additional work considering the parking lot as an additional interface has also been considered [31], based on a car park of 250 vehicles located within an IEEE standard power Network. This primarily focused on the balance between aggregator profit and car park operator profit (no mechanism for infrastructure cost consideration) with the vehicles acting as a flexible load. This paper is primarily different from previous published papers as it looks more closely at the infrastructure in a large car park. Not previously considered.

This paper investigates the feasibility of using a number of EV batteries as an energy storage and grid balancing solution within the UK Central Hub area. Section 2 looks at an overview of the

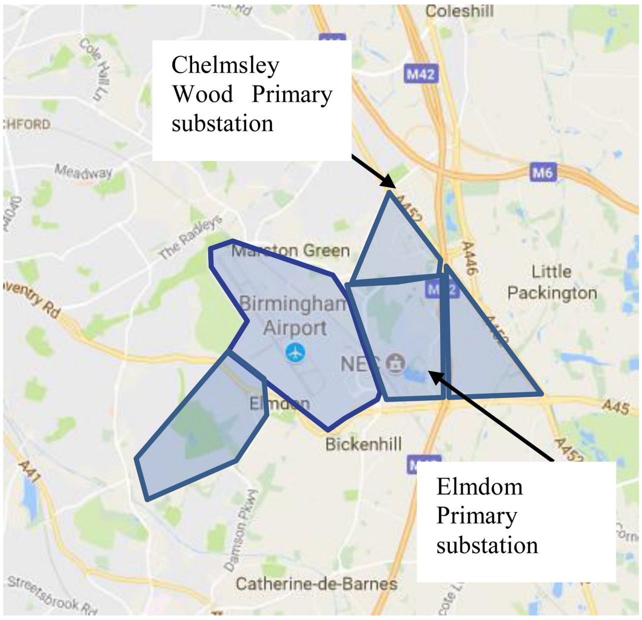

Fig. 1 *UK Central Hub Region showing supply points*

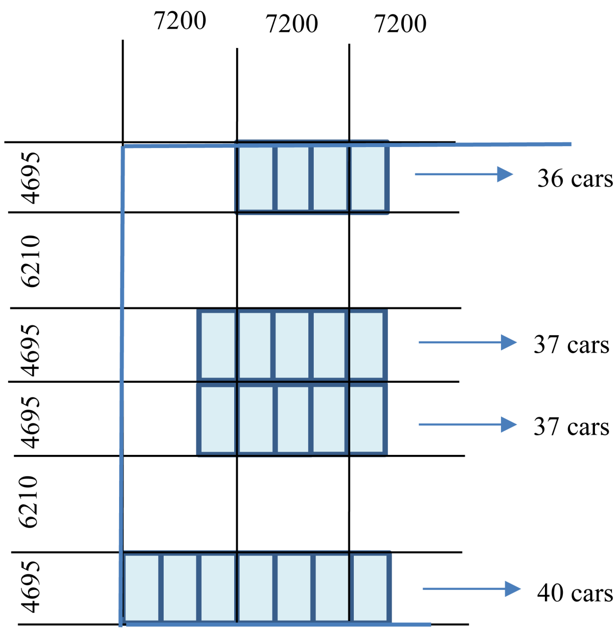

Fig. 2 *Car park layout and dimensions (mm)*

case study area in the UK Central Hub region. Section 3 looks at the operation and hardware related to such a scheme. Section 4 looks at the income this scheme may generate to offset the hardware costs in Section 3.

2 Central hub region car park

The feasibility study focuses on modelling the parking facilities in the area around the planned HS2 Birmingham Interchange Station/UK Central site in the West Midlands. UK Central is the location for a unique combination of economic assets including: Birmingham Airport, The National Exhibition Centre (the 'NEC'), Jaguar Land Rover manufacturing plant, Birmingham and Blythe Valley Business Parks and Solihull Town Centre as shown in Fig. 1. The feasibility study will focus on modelling the deployment of parking facilities at Birmingham International station and on the planned HS2 Birmingham Interchange Station/UK Central site in the West Midlands. This location will provide 7,000 parking spaces, of which 3,000 are claimed to become available in 2026, and the remainder by 2033. In addition, there are 12,000 spaces at the nearby National Exhibition Centre, and numerous on- and off-site car parks which serve Birmingham International Airport and station.

There are two primary substations close by with an estimated spare capacity as follows; Elmdom- 60 MVA demand and 40 MVA generation and Chelmsley – 22 MVA demand and 19 MVA generation [32]. Modelling undertaken on the new H2S link indicates that the power consumption pattern for a 4 train, 3 stop system with 70% load from Euston – Birmingham, and for Birmingham – Euston would be about 12 MW. The regenerative capacity looks to be about 7.4 MW based on 100 s and 200 kWh [33].

This paper looks at two car park schemes, a 300-vehicle scheme typified by the car parking around Birmingham International Station dimensioned as two floors of 150 vehicles as shown in Fig. 2 and a larger scheme of up to 3000 vehicles to represent a large proportion of the parking that could be made available for such services at the new HS2 station in the first tranche of development. This layout and the dimensions are based on details of a typical car park scheme for non-electric vehicles.

The top left of the car park is assumed to house the distribution panel for connecting each vehicle charger. The chargers themselves are assumed to be connected to the vehicles using a suspended system to reduce the requirement to lose car parking spaces due to hardware provision. There it is assumed to be 3000 mm between storeys and 2780 mm clearance between floor and ceiling.

For the purposes of this study, it is assumed that different charging/discharging scenarios will be considered for sizing and costing the wiring scheme. A value of 80% battery efficiency is used as representative. Three different size chargers are considered: single-phase 3 kW charger (13 A), three-phase 7 kW charger (13 A), and three-phase 22 kW phase (32 A).

Three different car park sizes are also considered: 300 cars, 1000 cars, and 3000 cars made up in modular form so that the V2G costs are considered to scale based on 300 vehicles. An additional two different conditions are considered; a diversity factor of 100% (very long term car parks where vehicles are left for up to a week and plugged in during this time.) and 60% (based on the response of 212 vehicles from 300 car parking spaces at peak demand for a 22 kW system).

3 Car park V2G scheme

It is necessary to design the car park to not only have the infrastructure but also to have operational functionality. Costs around providing the operational requirements have not been included here.

3.1 Operational requirements

To control the V2G services to the grid, it is necessary to have the following information;

To declare advanced availability of service (day ahead)

(i). An estimated prediction of the occupation of the car park with time

(ii). An estimated prediction of the size the energy storage available for use with timeTo undertake real-time operation

(iii). Active online opt in of vehicles

(iv). Knowledge of the opt-in vehicle including plugged in status, knowledge of battery capacity, and SOC

(v). An estimate from the vehicle owner on duration of stay

(vi). A requirement from the vehicle owner of required battery capacity at end of stay

(vii). Any ongoing changes to vehicle owner requirements

(viii). Time-dependent requirements of grid response characteristic (STOR, FFR, EFR for example)

It is anticipated that individual customers would control access to their batteries via a secure mobile web app. The operation underpinning this activity will be all but invisible to the EV owner, whose main interest will be in knowing their vehicle battery will be appropriately charged upon their return to the car park. Data security and billing could be provided using block chain

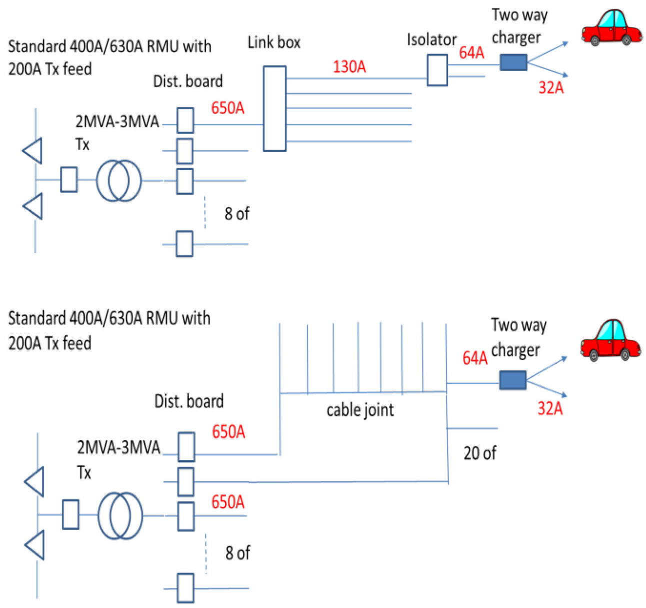

Fig. 3 *Wiring schemes – radial and ring based*

Table 1 300 size car park with 22 kW @60% diversity factor

Equipment	Size	Total no.	Length of cable, m	Unit cost	Total cost £k
RMU	400/630 A	2	—	3000	£6
11 kV/400 V transformer	2.5 MVA	2	—	20,000	£40
earth cable rod	—	2	—	1000	£2
earth busbar	—	2	—	£500	£1
transformer tails	3000 A total per tx per phase	30	360	120	£4
distribution board with 8 breakers	650 A CB	2	—	£4,000	£8
4 core cable dist board to link box	650 A	32	192	120	£4
link box – 5 way	650 A/130 A	16	—	£4,000	£64
link box to isolator, 4 core cable	130 A	80	11,904 5 different lengths	40	£476
isolators	130 A	80	—	£100	£8
cable isolator to 2 way charger	64 A	160	1152	20	£23
chargers	2 way 32 A 3 phase charger	160	—	£8,000	£1,280
charger installation	—	160	—	£8,000	£1,280
ducting & Tray	—	—	13,608	£10	£136
ducting & Tray Installation	—	—	11,340	£30	£340
	total				£3,672

technology, not yet deployed on this scale in the energy sector in the UK.

This information on large populations of grid-connected electric vehicle batteries then needs to be collected, aggregated, and dynamically optimised to provide a managed service to the electricity system. EV vehicles act as both producers and consumers of electricity, as they respond to demand signals from the electricity network to meet grid-side response. It is, therefore, necessary to have clear and visible process which show the energy data from producers (electric vehicle batteries) and consumers (National Grid and Distribution Network Operators). These energy (and data) flows fluctuate constantly as electrical demand within the local area responds to a variety of external circumstances including weather conditions and time of day.

3.2 Infrastructure requirements

The infrastructure requirements can be divided into two sections:

(i). The hardware related to the charging and wiring
(ii). Additional reinforcement costs of the building due to additional weight

The wiring costs can be split into those costs relating to connection to the local distribution system and those costs inherent in the wiring. Two different wiring schemes were considered as shown in Fig. 3, but only the radial scheme was costed to keep the weight of the wiring as low as possible.

The wiring was sized using IET wiring regulations (with de-rating factors calculated on a clipped direct method of installation). An extra earth bar and rod were included to ensure that the potential earth loop impedance was kept sufficiently low for protection to operate. Protection would need to be properly sized for bi-directional control. An isolator was used for each four cars to maintain a good level of availability and to provide a local point of isolation. The cable run lengths were taken from the car park dimensions in Fig. 2.

The wiring components and approximate 2018 costs of the scheme for the 22 kW system are shown in Table 1. Similar tables were drawn up for the other charger sizes. To give an estimate of total cost and total cost per vehicle. This results in around £17 k for a 22 kW system per vehicle, £16.7 k for a 7 kW system/vehicle, and £12.5 k for a 3 kW system/vehicle cost.

The wiring connection costs were estimated by WPD as follows (See Table 2)

The infrastructure costs relating to the increased weight also need to be included. There are two different weights that need to be counted; the extra weight of the electric vehicle and the weight of the charging infrastructure.

Table 2 WPD Connection Cost

Car park size	Cost	Cost per vehicle
300	£negligible.	£negligible
1000	£ 564 k	£ 564
3000	£ 45,5 M	£ 15 k

Table 3 Vehicle kerb weights

Conventional vehicle	Mass, kg	EV equivalent	Mass, kg
Ford Fiesta	1,011–980	BMWi3	1195–1365
Ford Focus	1,163–1,505	Renault Zoe	1468–1480
Vauxhall Corsa	1,004–999	Tesla model S	1999–2267
Vauxhall Astra	1,088–1,731	VW e-Golf	1549–1585
Volkswagen Golf	1,090–1,576	Nissan Leaf	1474–1535
Volkswagen Polo	1,005–995	Hyundai Ioniq	1420
Nissan Qashqai	1,297–1,614	Volkswagen e- up	1214
Nissan Juke	1,162–1,446	Smart ForTwo ED	1085–975
Mercedes-Benz A class	1,105–1,555	Nissan e-NV200 Combi	1571–1677
Mercedes-Benz C class	1,450–1,925	Kia Soul EV	1565–1580
Suzuki Celerio	835–845	Peugeot iOn Electric	1120
Suzuki Swift	1,020–945	Citreon C-Zero	1120
Hyundai i10	1,008–996	Renault Fluence ZE	1605
Fiat 500	1,020–980	Smart forfour electric drive	1200
Toyota AYGO	790–860	Ford focus electric	1700
Skoda Superb Estate	1,340–1,706	Mitsubishi Outlander PHEV	1810
BMW 3 Series	1,300–1,765	Volvo XC90 T8	2256
Audi SERIES	1,050–2,095	Porsche Panamera S E-Hybrid	2095
Seat Leon	1,114–1,527	Mitsubishi I MiEV	1110
Mazda CX-5 SUV	1,350–1,671	BMW 225xe	1660
Peugeot 308	1,075–1,850	Volkswagen Passat GTE	1647–1690
MINI Clubman	1,140–1,490	The Mia	765–815
Renault Megane	1,125–1,625	Mercedes-Benz Vito E-Cell	2255
Jaguar XF	1,545–1,987	Mercedes- Benz S500 PHEV	2015
Jaguar XJ	1,755–1,915	Volvo V60 Plug-in Hybrid	1995
Jaguar XE	1,475–1,665	BMW 330e iPerformance	1660
Approximate average	**1300**	—	**1560**

Table 4 Estimated costs

Car park size	Total cost	Cost per vehicle
300	£14 M	£47 k
1000	£33 M	£33 k
3000	£125 M	£41 k

Table 3 shows the increase in vehicle weight that can be expected of an EV compared to conventional vehicles. The kerb weight (No passengers or luggage) has been used as it is assumed that the car will be empty in the car park.

This gives an estimated weight increase of around 260 kg per vehicle – an extra 78 tonnes per 300 space car park. The weight of the wiring and charging equipment can be estimated to be 273 tonnes in total. Adding these two numbers gives a combined increase in floor weight of 175.5 tonnes per floor. The extra weight of the vehicle plus the weight of the charging equipment and wiring will result in the need for reinforcement. At present, this is factored in using an approximate weighting factor of $1.2x$, the cost of a car parking space in a typical car park of that size. However, detailed structural analysis would be needed to determine an accurate cost. The combined costs of wiring, connection and reinforcement per vehicle are shown in Table 4

4 Income stream

National grid operates various schemes which pay MW-scale storage facilities to provide balancing and short-term operating reserve services to the national electricity system. There is, therefore, an opportunity to generate operating revenue by managing long-stay car parks as energy storage facilities (with active opt-in participation from individual drivers). The day ahead price varies with settlement period and is around £44/MWh. If it is assumed that each car parking space is available 100% of the time and at full power rating, then the following income can be estimated as a yearly income (See Table 5)

The conclusion behind this is that even without the vehicle owner making money by allowing their vehicle to be used, the cost of the infrastructure would take over 20 years to pay back based on possible income from services delivered. Smaller charging schemes (3 and 7 kW) offer no additional benefit as the income is proportionally reduced but is not completely offset by the cheaper wiring costs.

5 Conclusions

There are several points to note in this work. First, some electric vehicles have dimensions which mean they will not fit into the car parking spaces easily, for example; the Mercedes-Benz S500 PHEV which has a length of 5246 mm and the Tesla model *X* which has a width of 2271 mm, which makes it very tight, and the

Table 5 Potential sources of income (2018 prices)

	STOR [34]	FFR [34]	EFR [34]
operating regime	06:00–13:00 week day 16:30–20:30 week day	triggered on a frequency event	dynamically adjusting to frequency
typical utilisation price	around £100/MWh	—	—
typical availability (utilisation price above)	around £5 /MW/h	Around £150/hr (about 20 MW)	around £9.50/MW/hr
approximate income 300 cars @22 kW	£267	£256 k	£323 k
approximate income 1000 cars @22 kW	£886 k	£850 k	£1086 k
approximate income 3000 cars @22 kW	£2670 k	£2560 k	£3326 k

Nissan e-NV200 Combi which has a height of 1858 mm. At present, it has been assumed that the chargers do not take up any car parking space. However, a combination of larger vehicles and charger places mean traditional dimensions may need to be reconsidered resulting in a loss of car parking spaces per volume.

The extra weight of the vehicle and charging infrastructure will result in the need for reinforcement of existing car parks. This needs to be calculated in more detail than presented here by more rigorous analysis. The push for faster charging (>50 kW) will further increase the weight as auto-docking is likely to be needed because of the weight of the cable to the user. This will act to further reduce car parking spaces. It is unlikely that the income from a large-scale V2G scheme will allow the costs of implementing such a scheme to be offset quickly and provide a profitable revenue scheme. Even without detailed costing – it is difficult to make the costs add up.

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