

Bucks for balancing:

Can plug-in vehicles of the future extract cash – and carbon – from the power grid?





Bucks for balancing:

Can plug-in vehicles of the future extract cash – and carbon – from the power grid?

1. INTRODUCTION

As governments around the world seek to reduce carbon dioxide emissions in order to combat climate change, there is a strong drive to achieve reductions in two of the largest contributors: energy supply and transport.

Aggressive EU targets for CO₂ emissions reductions in passenger cars will require a broad portfolio of technology solutions. Plug-in hybrid and electric vehicles are regarded as an important element in this portfolio, and have the potential to play a major role if deployed in significant numbers. The widespread adoption of these vehicles thus forms an important element of many national governments' strategies for a future low carbon economy. The high cost of energy storage is likely to remain critical for some time, however, and solutions are sought to reduce overall cost of ownership in order to improve rates of uptake in the market.

Within the energy supply industry, similarly dramatic moves are being made to decarbonize grid power supplies through increasing use of low or zero CO₂ generation sources. This will result in large numbers of variable sources of power, such as wind and wave, being connected to the electricity network. The connection of these types of generator, allied with an increase in the size of the largest generation plants, tends to increase the requirement for grid balancing services, which are of fundamental importance to the grid operator. New opportunities to help meet future needs for balancing services are essential in order to ensure the continued quality and reliability of grid power supplies.

In this research report we investigate whether a future fleet of plug-in vehicles (PIVs) could help to support an electricity grid that will require an increasing level of balancing services, and to what extent the market for these

services is likely to make it financially attractive for PIV owners or operators to provide such support.

This study is focussed on the UK, several aspects of which make it an especially relevant arena for the grid balancing opportunities to be investigated. As a country, the UK is committed through EU legislation to cut its CO₂ emissions by 34%¹ by 2020. In order to help achieve this, the UK Government intends to establish a significant amount of renewable generation capacity, primarily wind, and is playing a leading role within Europe in terms of policy incentives for encouraging consumer take-up of plug-in vehicles.

Moreover, within the UK the island of Great Britain represents one of the most open energy marketplaces in the world. The nature of this market enables the costs and benefits of active participation in grid management functions to be ascribed an accurate current financial market value, and facilitates reliable future predictions. Great Britain's geographic isolation means that regulation of supply and demand via international links is more challenging than in continental Europe, and provides an additional driver for effective power grid balancing.

Despite this report's particular focus on the UK, many of the principles covered are nonetheless generally applicable to other grid systems. It is expected that the grid balancing opportunities explored here for Great Britain (GB) can be seen as a useful template for comparison with other industrialized nations seeking to make similar changes to their generating mix and transport systems.

¹ Based on 1990 levels

2. BACKGROUND: MATCHING GRID SUPPLY AND DEMAND

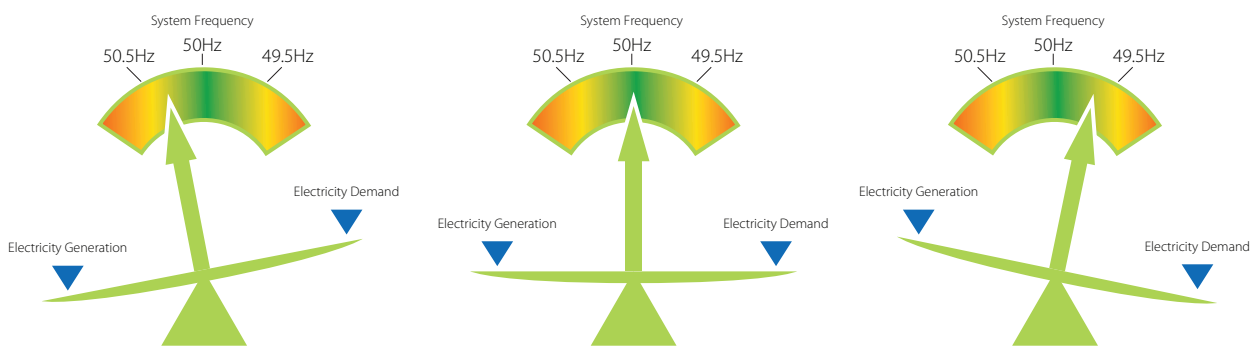
Great Britain's electricity grid is a highly meshed network, through which generating capacity and user loads can be pooled and balanced at a national level. In addition to enabling the pooling of generating capacity, such a grid enables the sharing of control systems and the various back-up resources required for the management of unexpected peaks or troughs in demand or disturbances – such as outages of major generating units. The overriding principle of operation of the GB electricity network (and any other large scale network) is to match electricity supply precisely to consumer demand on a second-by-second basis. Failure to do so within tight limits will result in shutdown of the network.

Grid operators have a high level of expertise in demand forecasting and use this knowledge to plan their operations from a seasonal to a minute by minute basis (see box on *Supply and Demand Balancing* below). In

addition to adding or removing generating capacity at any instant, they have additional tools that can be used to help smooth peaks and troughs in demand, including energy storage systems and energy exchanges with neighbouring networks via interconnectors.

Balancing services for the GB network are procured by National Grid on a commercial basis from both power station operators and large scale energy consumers. Power station operators may enter contracts with National Grid, for example, to hold spare capacity at varying levels of readiness. Similarly on the demand side, contracts are placed with large industrial consumers who are able to reduce their consumption as required within a defined response period, and maintain this reduction for contract 'call-off' periods. Provision of these services is particularly commercially attractive to consumers such as steel works, where process inertia is such that effective operation will

Supply and Demand Balancing



The vast majority of power plants connected to the grid generate electricity by using a turbine to drive a generator. The speed at which the generator rotates dictates the frequency of the alternating electric current (AC) produced, measured in units of Hertz (cycles per second). With the exception of some renewable generators, all power station turbines are electrically 'locked together' (synchronized) and rotate at the same speed, all giving the same frequency of output. In the UK the nominal frequency is 50 Hz, corresponding to 3000 turbine revolutions per minute.

In a single power generator, the energy input to drive the turbine must be matched with the energy output of the generator, i.e. the electrical demand connected to it. Any mismatch between the two will cause the turbine to gradually speed up or slow down. In extreme cases this will result in either destructive over-speed or stalling of the turbine

respectively. For a network of power generators, the same basic concept applies on a much larger scale, with generators synchronized to each other by the shared frequency of the whole grid.

Large frequency variations can be very damaging to electrical equipment connected to the network. National Grid has a transmission licence obligation to control the system frequency within the limits specified in the 'Electricity Supply Regulations', i.e. $\pm 1\%$ of nominal system frequency save in abnormal or exceptional circumstances. National Grid must therefore ensure that sufficient generation and/or demand is held in automatic readiness to manage all credible circumstances that might result in frequency variations. It does this through a number of different actions depending on the different timescales required for managing the system.

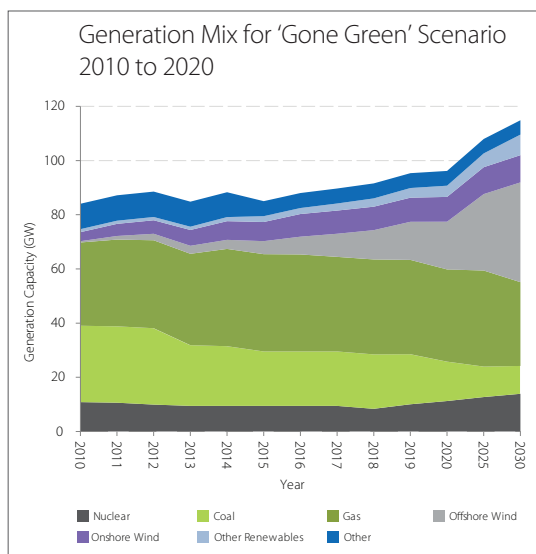
not be affected by short term connection interruption. Participation in commercial grid balancing services is currently restricted to consumers in excess of 3 MW. However this does not preclude provision of service on the basis of aggregated loads from multiple grid-connected sites nationally that collectively add up to or exceed 3 MW. (For a summary of the balancing services procured by National Grid see box right).

Grid balancing represents a significant commercial market. In 2009/10 National Grid spent £270m on procuring reserve services, including £70m and £90m on Fast Reserve and Short Term Operating Reserve (STOR) respectively. In the same year £170m was spent on Frequency Response services. The UK government's stated renewable energy and CO₂ emission reduction targets mean that the type and size of generation units (known as the generation mix) connected to the grid will be very different in the coming decades, with a potentially large impact on the demand for and provision of balancing services.

Implications of future changes in the generating mix

This study assumes a 2020 generation mix based on a scenario that was produced by National Grid and ratified

Figure 1



2 http://www.ensg.gov.uk/assets/ensg_transmission_pwg_full_report_final_issue_1.pdf

by the Electricity Network Strategy Group for the report titled *Our Electricity Transmission Network: a Vision for 2020 (March 2009)*². The report identified potential transmission network solutions that would facilitate the

Balancing Services

There are three main types of balancing services, covering both demand and generation, all of which help National Grid to maintain the supply and demand balance on a second-by-second basis:

- Frequency Response
- Fast Reserve
- Short Term Operating Reserve (STOR)

As such, balancing services are essentially divided into two main types:

- Those that can be applied quickly and automatically, termed "response" services
- Those that can be dispatched and sustained for longer periods, termed "reserve" services.

Reserve services are required in order to cater for variations in electricity demand and actual out-turn of variable generation output against forecasts, as well as to cover unplanned events such as generating plant failures.

Of the reserve services, Fast Reserve acts as a conduit between Frequency Response and STOR. This can be required in order to aid system recovery or to cover predictable but dramatic changes in demand, such as 'TV pick-up' – where electricity use increases rapidly at the end of a popular film or sporting event, for example.

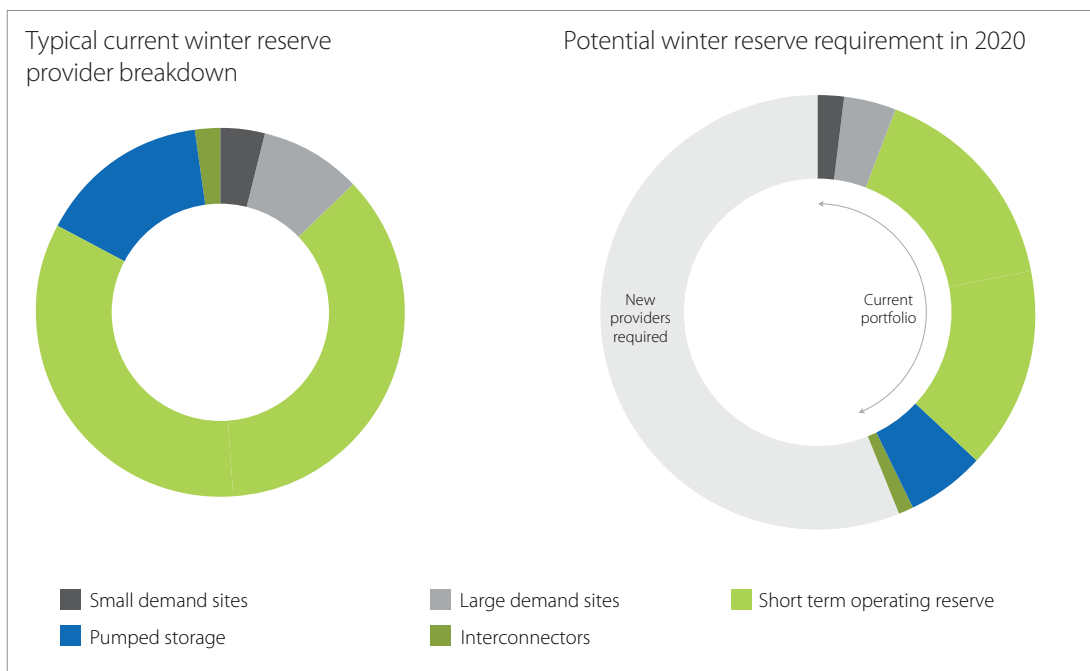
Balancing services must be made available and delivered in the minimum quantities and timescales indicated in the table below.

	Speed of Response	Minimum Capacity	Minimum Delivery Period
Frequency Response	< 30sec	10MW 3MW	30 min
Fast Reserve	< 2sec	50MW	15 min
Short-Term Operating Reserve (STOR)	< 20 min (ideal) (up to 4 hours)	3MW	120 min

These balancing services are procured in volumes just sufficient to ensure that the National Grid's frequency control obligations can be met.

As with generation sources, reserve and response balancing services can be located at any point on the network (subject to system constraints) i.e. a reduction in generation at one point in the grid can be balanced by a reduction of demand at a completely different one.

Figure 2: Current and future reserve requirements



achievement of Government climate change policy targets (e.g. renewable generation connection targets). A potential development of generating capacity is represented by the 'Gone Green' scenario, as illustrated in Figure 1.

Over the period to 2020 and beyond, the change in generation mix will have a marked effect on the level of balancing services that will need to be procured in order to maintain the required levels of system reliability and security of supply. Two changes that impact upon the volume of frequency related balancing service requirement are:

- The connection of large volumes of variable renewable generation
- The connection of potentially less flexible conventional plant

The primary energy sources for renewable generation are natural. The output from such generators is therefore variable and while it can be predicted to some degree of accuracy it cannot always be externally controlled e.g. a wind turbine operating below its maximum potential output cannot increase generation if the wind speed does

not permit. Similarly the larger contribution from new technology 'conventional' generating plant, for example new nuclear and carbon capture and storage, may reduce the overall flexibility of the total generation capacity connected to the network at any one point in time.

As it is not possible to forecast variable generation output precisely, increasing levels of this type of generation connecting to the network will lead to a requirement for additional balancing reserve provision, as illustrated in the pie charts presented in Figure 2 above. The reserve requirements vary according to time of day and season; the current winter figure is typically 3 GW, with the potential for this to double by 2020 (primarily driven by level of wind output).

Thus there is a need to identify alternative methods of providing balancing services to National Grid, which may result in opportunities for involvement by new market players.

3. THE USE OF PLUG-IN VEHICLES (PIVS) FOR GRID BALANCING

Plug-in vehicles of all kinds – whether pure battery electric vehicles, range extended electric vehicles or plug-in hybrid vehicles – all represent a potential opportunity for grid balancing on account of their relatively high energy draw and power levels. With appropriate control of a large pool of vehicles, the net power flow within the grid can be influenced with a similar effect to that of conventional balancing measures. For plug-in vehicles, there are two possible modes of operation.

The principle of Demand-Side Management (DSM) in the context of plug-in vehicles is simply the interruption or reduction of recharging when required to ease grid imbalances, and the resumption and completion of recharging at a later time. Clearly, once fully charged each vehicle can no longer participate in the balancing service as it has no further load available for disconnection from the grid. Similarly, once a vehicle with a depleted battery comes within the time period required for recharging prior to its next road use, it too can no longer provide a demand management balancing service as it needs to remain connected to fulfil its primary purpose as a road going vehicle. An alternative DSM approach – albeit one not included in this modelling exercise – is for vehicle charging to take place at a power level below the charger’s maximum, allowing some headroom to increase as well as decrease power in response to dynamic high and low system frequency grid balancing needs.

With the second mode, known as Vehicle-To-Grid (V2G) operation, “reverse charging” can also take place, in which there is a transfer of energy from the battery to the grid. Subject to the availability of the hardware required to allow bi-directional power flows, and appropriate control mechanisms, the vehicle’s battery could be made available whilst connected to the grid as an energy buffer for balancing services, rather in the same manner as pumped storage hydro. Clearly it would be necessary to restrict the authority of the grid’s control over the vehicle battery in order to ensure a sufficient charge level when the car is next required for use on the road.

Pricing for the balancing service types under consideration here is quantified in terms of a value per kW, per hour of service availability – regardless of whether the service is activated or not – and follows the wholesale prices for these services within the UK market. In the case of grid balancing by plug-in vehicles, charger power can be varied relatively rapidly compared with typical generation plant, making participation in (currently highly-priced) “response” balancing services appear to be particularly

attractive for PIVs. Conversely, the likely limitations of charger power, flexibility over timing and energy storage capacity would appear to make “reserve” balancing services less appropriate for plug-in vehicles, although participation could be possible to some extent.

Irrespective of the details of the balancing services provided, it would be necessary to establish appropriate commercial arrangements for the management of contracts between vehicle owners and the grid operator. The details of such mechanisms, which might include the pooling of individual vehicle contracts by service intermediaries, are beyond the scope of this work. Instead, the study seeks to identify potential future business opportunities that could be developed and exploited by market actors in general.

4. ASSUMPTIONS AND METHODOLOGY OF ANALYSIS OF THE PIV PARC AND GRID IN 2020

Ricardo has developed a comprehensive model that simulates interaction between PIVs and the electricity grid in order to evaluate the potential for a future ‘parc’³ of plug-in vehicles to enter the balancing services market. The model incorporates Ricardo’s extensive research knowledge of PIVs and user behaviour patterns and combines this with technical and balancing market economic data provided by National Grid. The model simulates the impact on the electricity network of electric vehicle charging based on a five minute time step throughout the day. By carrying out these simulations the value of balancing service provision per vehicle can be assessed at each time step.

National Grid projections based on the Gone Green scenario were used as a basis to evaluate the 2020 requirement for balancing services by time of day. Balancing services encompass a wide range of service providers operating according to differing power ratings, call-off durations and availability requirements, so the values associated with different contracts are correspondingly diverse. For this study, National Grid has derived a set of assumptions that represents a reasonable value for the nature of balancing services that PIVs could provide, based on current market rates. As the services are procured in an open market in competition with this diversity of contract types,

and as the market is likely to change so as to accommodate the anticipated increases in balancing services requirements, a full economic analysis of likely future prices was not included in the scope of the study. It was assumed that plug-in vehicles would participate in both reserve and response balancing services.

Vehicle modelling assumptions

This work does not attempt to make predictions regarding the future uptake of plug-in vehicles, and the analysis performed investigated a range of scenarios for the number of vehicles in circulation in the UK. For the sake of clarity, this report includes results for a single scenario of ca. 600,000 vehicles, which lies within the range of PIV uptake scenarios developed by the EC FP7 MERGE project⁴.

The baseline charger power rating was set as 3 kW, this being the capacity universally available from typical UK domestic power sockets. However, to enable a full range of charging options and also to be able to capture fully the potential of vehicle to grid power transfers, a range of charging options were considered from 3 kW up to 50 kW, which is comparable to the power available from the CHAdeMO and Mennekes charging connectors. The key assumptions made regarding individual PIVs is summarized in Table 1.

Table 1: Plug-in vehicle assumptions

Description	Value	Source
Plug-in vehicle parc size in 2020	Range from 100,000 to 2 million	Figures used were derived from PIV uptake scenarios developed by EC FP7 MERGE project ⁴
Vehicle energy usage (battery to wheels)	0.14 kWh/km	Ricardo V-SIM vehicle simulation results, C-segment vehicle, NEDC, with regenerative braking
Battery nominal capacity	19.6 kWh start of life 16.8 kWh average 14 kWh end of life	Assumption derived from likely typical EV & PHEV specifications
Allowable battery depth of discharge (DoD)	80%	Assumption based on anticipated PIV battery specifications
Battery usable capacity	13.4 kWh average	Calculation (average nominal capacity times allowable DoD)
Charging efficiency (charger to battery)	93.5%	Assumption based on specifications of existing charging systems
Charging frequency	One charge per day	Assumption based on results of EC FP7 MERGE project assessment of human behaviours ⁵
Average distance travelled per day	38.2 km	Sourced from DfT data (all private passenger cars for all journey purposes) ⁶
Cost of battery in 2020	\$500/kWh	Assumption based on current automotive battery prices and targeted 2020 cost improvements
Battery life	5,000 cycles	Sourced from US Advanced Battery Consortium

³ ‘Parc’ is the term used to denote a population of vehicles in service

⁴ For more information, see www.ev-merge.eu

⁵ http://www.ev-merge.eu/images/stories/uploads/MERGE_WP1_D1.1.pdf

⁶ Department for Transport (2002) ‘Trends in Personal Travel’ National travel survey: revised data for urban and rural areas: 1996-2001, London: Department for Transport

Ricardo performed two distinct modelling activities in order to analyse the opportunity for grid balancing from two different viewpoints:

- That of a grid operator or service provider, covering the macro-level effects of a large number of vehicles in use with an assumed variation in recharging patterns across the entire PIV parc: *the grid-level model*
- That of an individual vehicle user or owner, covering specific recharging patterns in order to investigate how revenue could be maximized: *the individual vehicle model*.

Grid-level model

The grid load simulation model was created to represent the macro-level effects of the full plug-in vehicle parc on the GB electricity grid (see Figure 3). The model accounted for a range of usage patterns, represented by assumed “charging profiles” that specify the proportion of vehicles that are plugged in at each point in time over a period of 24 hours. Also modelled were participation in smart grid management and vehicle-to-grid energy flow.

A range of charging scenarios was considered in order to define the proportion of the plug-in vehicle parc that has commenced charging at each simulation time step. This enabled an analysis of the effects of three different modes of vehicle charging:

- **Uncontrolled (or “dumb”) charging:** vehicle users simply plug in and charge the vehicle according to their daily usage requirements without regard to energy supply considerations.
- **Delayed charging:** vehicle owners take advantage of price incentives on the use of off-peak electricity by charging at night, but in doing so create a large instantaneous step in demand at the start of the off-peak period.
- **Smart charging mode:** the power grid is able to control charging of an aggregated pool of vehicles within a set period in order to limit the maximum load on the grid at any instant.

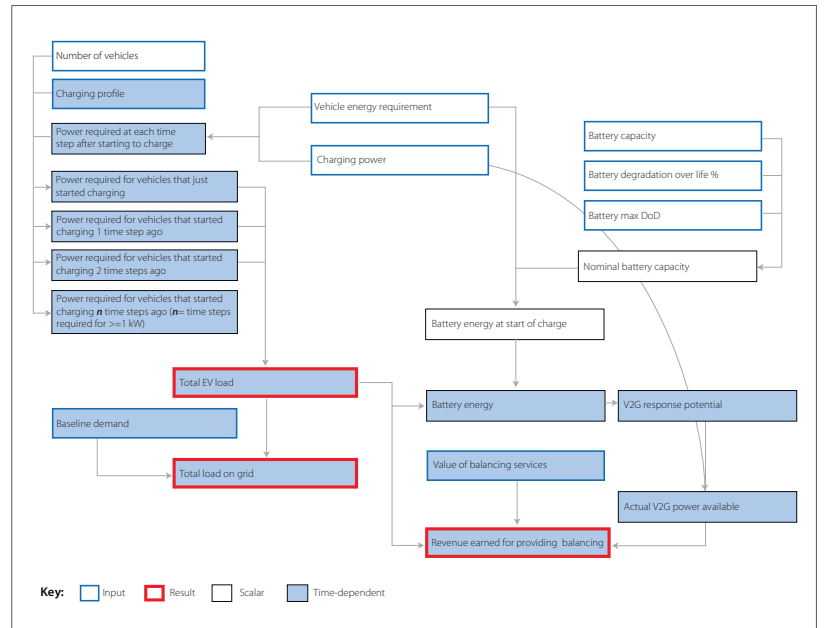


Figure 3: The Ricardo grid-level simulation model

The uncontrolled and delayed charging scenarios use assumed charging profiles, representing the numbers of vehicles plugging in to charge at each time of day⁷, while the charging profile under the smart charging scenario can be altered according to the needs of the grid. For all scenarios, the total value of the balancing services provided to the grid is averaged across a range of users whose individual contributions vary according to the charging profile assumed. The results of this analysis give an indication of the potential total balancing service contribution by PIVs to the grid as a whole. However, the average grid balancing revenue per vehicle is less than would be paid to an individual contributing the maximum response possible.

Individual vehicle model

The individual vehicle model enables the evaluation of grid balancing revenue for a single vehicle according to different specific charging regimes and includes V2G capability. For this study it was assumed that the vehicle would remain plugged in for two periods during the day. The first of these was a nominal ‘office hours’ connection period from 09:00 to 17:00 (8 hours), while the second was overnight from 19:00 to 07:00 (12 hours). A third period was also defined as combining these two periods, representing a vehicle plugged in for the full 20 hours per day, thereby maximizing its grid connectivity when not being used for its daily commute.

Results from the individual vehicle model are useful to gain insight into the maximum potential value to a single plugged-in vehicle owner for a best-case charging pattern. Of course, in some scenarios it may not be possible for a particular single-vehicle return to be realized across the entire parc. A key example is market saturation: with increasing numbers of participating vehicles, the total value of balancing services provided by the vehicle parc cannot exceed the quantity required by the system operator.

⁷ Charging profiles used were based on those presented in Parks, K., Denholm, P. and Markel, T. (2007) ‘Costs and Emissions Associated with Plug-In Hybrid Electric Vehicle Charging in the Xcel Energy Colorado Service Territory’, Golden: National Renewable Energy Laboratory

5. RESULTS AND IMPLICATIONS OF THE ANALYSIS

Demand-Side Management (DSM) – a modest financial benefit but at zero cost

Simulations were carried out to evaluate the total availability of PIVs to provide balancing services. For Demand-Side Management, it was found that a standard domestic 3 kW charger could provide approximately the same level of balancing as higher-rated chargers. The reason for this is that the value of the grid balancing service provided by reducing demand is proportional to the total energy drawn from the grid; in effect, that a larger charger power could cut a higher power level from demand, but it operates for a shorter period of time.

The simulations showed that an aggregated DSM service based on the PIV parc of 2020 would be able to provide an average of 6 percent of the GB grid’s daily averaged balancing service requirement. This average value comprises balancing contributions from PIVs of greater than 10 percent during the evening peak period, offset by smaller contributions during the day (see Figure 4).

Analysis of the range of possible DSM scenarios showed that the financial benefit of this service to the individual vehicle owner is relatively modest, representing only in the region of £50 per year or £30.8 million in total for the vehicle fleet.

However, while the potential revenue for each vehicle is relatively low, this should be seen in the context of there being no requirement for additional hardware investment by the vehicle owner over and above that of smart metering technology, which is already mandated for future roll-out within the UK. Moreover, since no extra energy is transferred to or from the battery, participation in such a demand management balancing service incurs no degradation of vehicle batteries over and above that resulting from their daily use in propelling the vehicle. Finally, despite the limited financial reward to each vehicle owner, the value returned represents a significant 18 percent of the estimated £287 annual electricity bill for charging an average electric vehicle as modelled in this study (based on the average UK domestic electricity rate for December 2010 of 13.2 pence/kWh⁸).

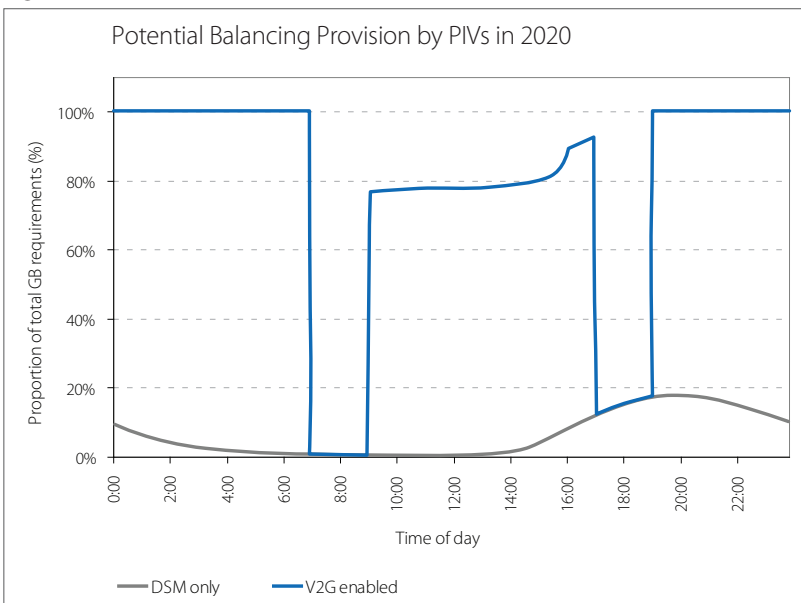
It is also worth noting that, while the provision of DSM balancing services does not yield sizeable financial benefits to the consumer, the significant benefit to the grid operator represents an additional justification for the establishment of “smart grid” infrastructure, which is already broadly regarded as a pre-requisite for widespread plug-in vehicle usage.

Vehicle-to-Grid balancing services – potentially attractive returns but with likelihood of high investment costs and limited market size

The balancing service that can be provided by a plug-in vehicle equipped for vehicle-to-grid energy flow comprises the value of demand-side management – as described in the previous section – plus the value of providing power to the grid for a fixed contract period and call-off period. V2G technology also enables each vehicle to provide response over a much longer period than is the case for DSM alone, as it can remain on stand-by beyond the point at which its battery is fully charged.

The level of balancing response that a plugged-in vehicle providing V2G energy flow can provide is proportional to the energy available in its battery at the start of a given call-off period. For the average vehicle and daily duty modelled within this study, a total of 8.1 kWh of battery capacity remains unused at the end of each day.

Figure 4



8 <http://www.decc.gov.uk/assets/decc/Statistics/publications/prices/1085-gepdec10.pdf>

Assuming a contractual obligation to provide balancing response subject to a call-off duration of 30 minutes, for example, a typical vehicle would be able to provide a maximum of 16.2 kW of response on connection to the grid following completion of its daily use. This limit avoids depletion of the battery before the end of the call-off period. However, if the charging hardware has a maximum power that is less than the maximum potential response power, the response will be limited to this value.

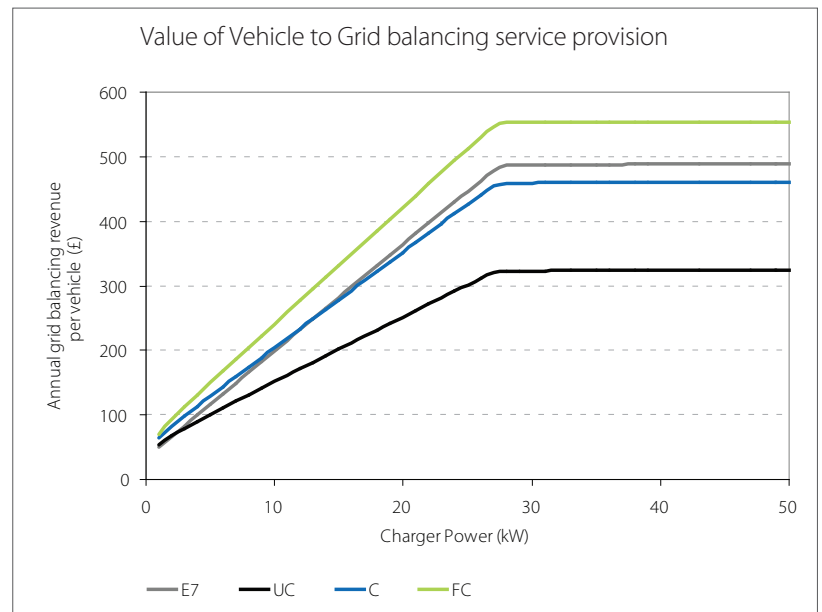
Analysis was performed for a range of vehicle charger power levels between 3 kW and 50 kW. Results from the grid-level model show that, for a parc-wide implementation in 2020 of V2G charging capability, a 22 kW charger power is theoretically just sufficient to provide a peak level of 100 percent of Great Britain’s balancing service requirements, between the hours of 19.00 and 06.55. This corresponds to an average across the day of 79 percent (see Figure 4), which is clearly much more significant than in the case of DSM alone.

In the same way, V2G capability can potentially enable a much more significant return to the vehicle owner than DSM alone. Maximizing the opportunity for the provision of balancing services over the range of charger/inverter powers considered showed that the potential revenue for the vehicle owner varies from approximately £600 per year for a 3 kW system to in the region of £8000 per year for a 50 kW three phase installation. The variation in revenue with charger/inverter power levels is shown in Figure 5. This chart also demonstrates how the maximum value of response is achieved at the precise charger/inverter power level required to completely discharge the available battery capacity within one call-off period (in this case assumed to be 30 minutes); further increases in charger power do not increase the return to the vehicle owner.

In the case of V2G grid balancing, unlike for DSM, additional energy may be transferred to and from the battery beyond the quantity required simply to recharge for driving. This has the potential to accelerate the process of battery degradation, with associated cost implications to the PIV owner.

In order to estimate the likely level of battery degradation resulting from participation in V2G balancing services, a simple analysis was performed. It was assumed that battery degradation is in proportion to the total amount of energy transferred between battery and grid. Historic data recording the variation in grid frequency over many months was analysed to determine how much energy is likely to be transferred in total over a year of

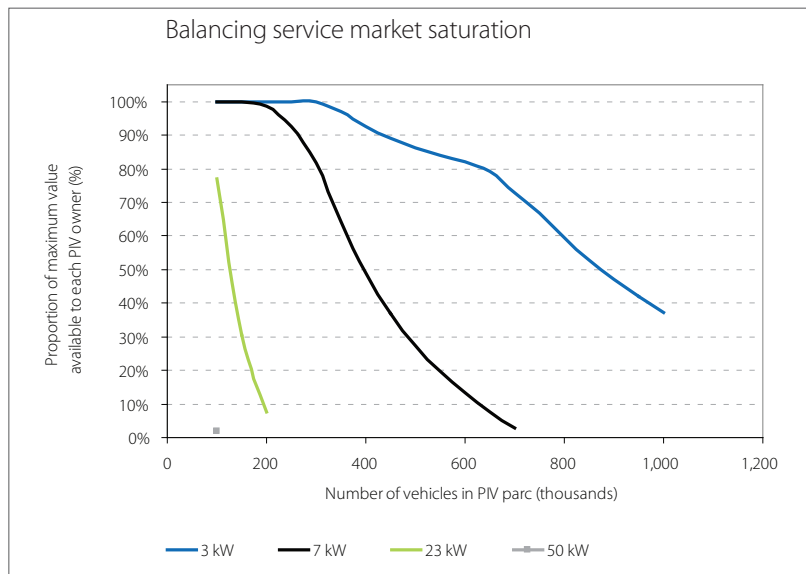
Figure 5



operation. This depends on the way in which the vehicle charger responds to frequency deviations. For an assumed progressive response (from zero at 50.0 Hz to full power at 49.5 Hz), the analysis indicated that the additional energy transferred to and from the battery for grid balancing amounts to considerably less than 1% of that associated with charging for normal vehicle use. Thus the degradation cost associated with the expected additional battery “cycling” is likely to be very low. A more thorough analysis of the trade-off between utilization rates and value of balancing provided could be performed to optimize the ‘response function’ for a maximum net rate of return to the vehicle owner, taking account of battery depreciation.

Although revenue values for V2G balancing are attractive, and battery degradation does not appear to be a significant concern, it seems likely that investment costs for the bi-directional charging infrastructure required to enable V2G implementation will significantly reduce the net profit to an individual vehicle owner. Based on currently available technology, Ricardo estimates that the cost of the additional equipment required to enable bi-directional energy transfer would involve an incremental capital cost to the consumer of several hundred pounds for each kilowatt of charger rated power. Any required upgrades to domestic wiring and local distribution networks would raise

Figure 6



this overall cost further still, significantly offsetting or even exceeding the income from balancing service provision.

As mentioned above, another limit on the potential revenue to EV users from V2G grid balancing services is likely to be saturation of the balancing market. If a large proportion of the vehicle fleet were to participate in the provision of high-power V2G balancing services, the resulting increase in supply into this market could be expected to drive down the price of balancing services, making an overall return on the investment in charging equipment still harder to achieve. An economic analysis of market price effects is beyond the scope of this study; instead, a simple assumption has been made that the total value of balancing services provided by vehicles remains constant at 100% of the national requirement, while each vehicle owner contributes a smaller proportion (and generates less revenue) as the vehicle parc grows. For the 23 kW V2G case shown in Figure 4, this implies that access to the market for new entrants beyond 2020 could only take place under conditions of reduced participation by some or all grid balancing providers. Further examples of market saturation limits for different charger power ratings are shown in Figure 6.

When the practical considerations of vehicle integration of the required systems are accounted for,

together with the costs of upgrading grid access points to enable higher power ratings, the commercial potential of this form of grid balancing on a large scale basis appears to be somewhat limited. As such, the required investment costs would tend to make vehicle-to-grid balancing uneconomic for individual users if implemented on an ad-hoc basis, while market size limitations would render it unattractive for implementation across the entire parc.

For vehicle manufacturers too, the limited size of the potential market would not appear to justify the development of the V2G battery management systems required to enable safe bi-directional power transfer with minimum impact on ease of use, battery life and vehicle warranty.

A potentially attractive opportunity for captive fleets

These issues, though serious for large numbers of individually-owned vehicles, may be less critical for fleets of vehicles operated by a single aggregator. Where vehicles are centrally managed and recharged, with ready access to high capacity electrical connections, it may well be possible to improve technology utilization, and therefore investment amortisation. Likewise, the scale benefits and availability of accurate usage data available to an operator of a large fleet of vehicles would tend to make the arrangement and management of a balancing service contract simpler and more commercially attractive. In addition, such an operator would be in a stronger position to support the development of the necessary vehicle-based battery management technology, whether in collaboration with the vehicle OEM itself or via a third-party system supplier.

Obvious examples of such fleet operators or vehicle aggregators include commercial logistics organizations, ports and airports, companies with large service vehicle pools, vehicle rental or car-sharing scheme operators, as well as battery-swap station networks.

6. CONCLUDING REMARKS

Balancing is a fundamental requirement of the operation of power grids the world over and in an open market such as that of Great Britain, the provision of these services is subject to a commercial rate of return. As efforts are made to reduce the carbon intensity of the UK energy supply, the resultant changes in the generation mix will increase the need for balancing services through increasingly variable generator availability and a potential reduction in the overall flexibility of the generating plant connected to the network. These changes will drive a requirement to assess how balancing services are specified and procured and whether additional and/or alternative methods of service provision will become available.

It is clear from this study that there may be an opportunity for the plug-in vehicle parc to provide a new source of balancing services. PIVs may be able to work in synergy with the electricity market to smooth the daily demand profile by providing services in a manner that is not currently available to the system operator, and thereby reducing the need to meet additional balancing requirements by simply running more 'conventional' generation and potentially incurring additional CO₂ emissions.

The research described in this paper has demonstrated a clear potential for the commercial exploitation of a future parc of electric plug-in vehicles in the provision of grid balancing services while they are connected for the purposes of daily recharging. Based on the simplest mode of service provision considered – that of demand-side management using a standard 3 kW domestic socket supply – the UK plug-in vehicle parc of 2020 would be capable of providing an average of 6 percent of the country's predicted daily grid balancing requirement for the same year. This would be realizable at zero investment cost and no inconvenience to the consumer, while providing a financial return that, while limited, represents the equivalent of 18 percent of vehicle electric 'fuel' costs at current prices.

This study has also identified the much higher returns possible from vehicle-to-grid balancing service provision, for which an attractive business case for the more significant investment costs involved may be possible in the context of captive vehicle fleets and other vehicle aggregators.

The realization of the opportunities presented by wide-scale use of vehicle charging demand management would require the implementation of smart metering technology as well as mechanisms for the effective fleet level aggregation of plug-in vehicles. However, smart metering roll-out is already mandated for introduction within the UK⁹, and the results of this research reinforce the value case for timely meter installation to support increasing plug-in vehicle use.

A key enabler for the success of V2G-based grid balancing is the development of an efficient charging infrastructure, appropriate to the needs of individual or fleet-based vehicles in order to maximize vehicles' availability for grid balancing throughout the day. Also worthy of further investigation are opportunities for lower cost inverter systems for bi-directional power flow, which could considerably improve the economic case for V2G-based grid balancing. Finally, while the limited size of the grid balancing market may make development of mainstream V2G-capable battery management systems difficult for OEMs to justify, the very significant potential revenue streams available from this mode of operation are likely to offer incentives for implementation on a smaller scale in collaboration with captive fleets or vehicle aggregators.

⁹ Smart Meter roll-out target completion is 2020, with 85% installed by 2017

NOTES ON THE RESEARCH TEAM

The research project described in this paper has been a collaboration between Ricardo and National Grid.

Ricardo is a leading global provider of product innovation, engineering solutions, clean technology and strategic consulting. With 10 years of experience in hybrid & electric vehicles, it has delivered hundreds of projects, from initial business-case and concept studies to multi-year turn-key out-sourcing of hybrid powertrain hardware, software and calibration.

National Grid is the owner of the electricity transmission network in England and Wales and the operator of the GB transmission network. In its role as GB System Operator, National Grid is responsible for the economic, efficient and non-discriminatory procurement of Balancing Services.

The analysis described in this report was conducted by Neil Downing, Simon Wrigley and Dave Greenwood of Ricardo, and Ben Smith and John Hyde of National Grid, drawing on additional expert input from both organisations. The report is published jointly by Ricardo and National Grid.

© Copyright Ricardo plc and National Grid plc







Delivering Value Through Innovation & Technology

www.ricardo.com

