Plug-in vehicles for Smart Grids: What can and cannot be done with existing technology

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***Abstract*--There is much interest regarding the future possibilities – and risks – arising from integrating increasing numbers of plug-in vehicles with power system network operations, in particular demand-side management. There has been comparatively less enthusiasm directed towards addressing the question of what can and cannot be done with existing technology. This paper discusses what could be achieved and implemented using present technology only and a little innovative thinking – 'recharging regimes' – and discusses the limitations of these approaches.**

***Index Terms*--Electric vehicles, smart grids, energy management.**

I. Nomenclature

BEV: Battery Electric Vehicle.

PHEV: Plug-in Hybrid Electric Vehicle.

Plug-in vehicle: Any vehicle that can or must connect to an existing electricity network to source its energy for storage and subsequent use once disconnected (includes both BEV and PHEV).

NTS: National Travel Survey conducted by the Department for Transport (DfT). Full data available on request through the Economic and Social Data Service (ESDS) [1]. The NTS information is supplemented with national Census data and DVLA licensing information.

V2G: Vehicle-to-grid power, the use of plug-in vehicle batteries for short-term temporary storage and small-scale supply of electricity [2], [3].

II. Introduction

IN the UK, electricity supply has become flexible, responsive to inflexible electricity demand. A move towards intermittent renewable energy resources will change this: in future it is demand that must become flexible, responsive to inflexible supply. As the electricity supply mix evolves, so too must demand-side management.

There is much interest regarding the future possibilities – and risks – arising from increasing numbers of plug-in vehicles in terms of implications for electricity generation, network infrastructure reinforcement and system protection. Of particular interest has been the potential for plug-in vehicles to play a role in demand-side management, including the potential for plug-in vehicle batteries to function as temporary energy storage facilities.

Table 1 lists potential benefits from exploiting the grid-vehicle relationship. Not all of the benefits listed in Table 1 can be achieved today but the potential for existing technology to provide new services should be investigated. This can then be incorporated into the design of new technology to better provide those services. What could be achieved using existing technology has been the basis of this research project [4]-[6].

TABLE 1
BENEFITS ARISING FROM THE DEVELOPMENT OF THE RELATIONSHIP BETWEEN PLUG-IN VEHICLE AND ELECTRICITY SUPPLY SYSTEM

Potential benefit	How achieved
Load limitation for network infrastructure and conservation of electricity generation capacity.	Scheduling recharging of plug-in vehicles to avoid existing demand peaks.
Increased electricity generation efficiency for fuel-based generators.	Providing fuel-based generators with greater operational stability by targeting recharging to coincide with predicted lulls in demand so as to level overall demand.
Increased renewable electricity dependence.	A) By making plug-in vehicle recharging load adjustable according to the availability of supply of renewable electricity. B) By use of vehicle batteries as flexible energy storage (V2G).
Reduced necessity for fuel-dependent fast-dispatch flexible generators that handle ancillary services such as the provision of spinning reserves.	Allowing plug-in vehicle batteries to perform some of these functions through V2G.

III. Technology Presently Available

Many plug-in vehicle manufacturers are enabling plug-in vehicle drivers to set a timer for recharging their vehicles, the intention being to enable drivers to take advantage of cheaper off-peak tariffs such as Economy 7. Some Battery Electric

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Vehicles (BEV) like the Nissan LEAF and some Plug-in Hybrid Electric Vehicles (PHEV) like General Motors' Chevrolet Volt can control recharging using a timer that can also be set remotely using smart phone applications [7], [8].

Renault's Zero Emission series of BEV including the Fluence and upcoming ZOE will have an accompanying wall-box that has a timer for recharging. Although at time of writing the Mitsubishi iMiEV did not have a recharge timer, Mitsubishi intends to provide a timer in future for newer models, in line with other manufacturers of plug-in vehicles.

Existing electricity demand is moderated by the application of tariffs by energy suppliers. There are already plans to use variable tariffs to encourage consumers to make better use of electrical energy and to schedule usage to the advantage of the power industry. Lower tariffs will be offered when generation is available and therefore cheap, and higher tariffs when energy is in short supply and therefore expensive.

Two-way communication between electricity users and their suppliers is limited. Real-time monitoring and control of electricity use by third parties is not possible at present. There is no option for an external operator to negotiate or schedule recharging or discharging of plug-in vehicle batteries on the plug-in vehicle driver's behalf in real-time, although development of the necessary technology is underway as exampled by Opel's MeRegioMobil project [9].

IV. What Can Be Done Using Existing Technology

Monitoring and data collection help to balance energy supply and demand via two pathways: prediction, and response to circumstances. Real-time data is crucial for improving response. However, improving prediction reduces the necessity for improving response. Real-time data is not yet available to make plug-in vehicle recharging loads responsive to unpredicted fluctuations in general electricity demand and supply. Nonetheless other kinds of data are accessible that could facilitate the prediction of known patterns in general electricity demand and vehicle energy use, and thus facilitate planning for recharge scheduling.

National Grid compiles annual records of half-hourly national electricity demand data for Great Britain, and these are available online [10]. To date, numbers of plug-in vehicles that are in use across the UK are small enough to have an insignificant impact upon national demand profiles. This is assumed a temporary situation but one that offers timely advantages: the data from National Grid shows existing patterns in human behavior towards electricity and therefore indicates when – and when not – new loads could be accommodated.

The National Travel Survey [1] run by the Department for Transport (DfT) provides a means to investigate the energy use of private vehicles. The NTS is supplemented with national Census data and DVLA licensing information and includes detailed information on UK travel and about the people travelling. This includes income and number of licensed vehicles per household, journey departure/arrival times, journey durations and purposes, modes of transport used, specifications for household vehicles and more. This data provides the basis for which plug-in vehicle ownership and likely travel behavior can be determined, and thus potential vehicle energy usage and likely plug-in times.

Estimating when drivers are likely to recharge their plug-in vehicles, and determining to what extent those vehicles are depleting their batteries prior to recharging, is essential for planning a schedule for their recharging demand. If these can be predicted then ideal recharging regimes can be identified, planned, and adopted. It is on this basis, that a project [6] was set up to investigate what could be accomplished using the technology and data presently available.

A. What are recharging regimes?

A Recharging regime is a schedule for recharging times that is imposed upon a plug-in vehicle by its driver according to some agreement made between the driver and or bill-payer and their electricity supplier. The scheduling of recharging for these regimes depends upon patterns in electricity supply and demand. The recharging regime project [6] considered that for the UK that there are – at least at the national level – three primary niches to target: nighttime, weekends, and summers, but has so far focused on taking advantage of only the nightly and weekend niches of electricity availability.

Recharging regimes are designed to be consumer-suited schedules that give drivers recharging time slots for each day of the week. Just as different tariffs are available to energy consumers in the UK, plug-in drivers will be able to choose between tariffs with different recharging regimes. Regimes that provide the best match to ideal load management patterns would offer the best incentives in order to encourage the largest proportion of customers/plug-in vehicle drivers. In the UK utilities companies have adopted a portfolio of incentives that could be applied, ranging from cheaper tariffs to reward schemes like Nectar [19].

B. Designing recharging regimes

Greater detail for how the project used the NTS and National Grid half-hourly annual electricity demand data for Great Britain to determine possible recharging regimes can be found in [6], but a summary is provided here.

Specifications were set for a generic BEV based upon the Nissan LEAF as follows: battery capacity of 24 kWh, flat-to-full recharge time of 10 h, range of 109 miles and priced at £25,990 after applying the UK Plug-In Car Grant [11]-[13], with an assumed recharging rate of 2.4 kW/h. Similarly specifications were set for a generic PHEV based upon the Vauxhall-Opel Ampera as follows: battery capacity of 16 kWh, flat-to-full recharge time of 4 h, an AER of 25-50 miles

and a combined range of 310 miles, priced at £28,995 after applying the UK Plug-In Car Grant [14]-[16], with an assumed rate of recharge of 4 kW/h.

These specifications were used to determine the likelihood of BEV or PHEV ownership for the participants of the NTS based upon household incomes and household vehicle daily mileages per day of the week. Average times for first departure and last return home journeys per day of the week were taken for the two groups of vehicles – BEV and PHEV – along with averages for the daily mileages. The proportion of vehicles deemed interchangeable with BEV or PHEV out of the total vehicles in the survey was used to scale up an estimate for the total number of BEV and PHEV rolling stock on UK roads.

With the numbers of BEV and PHEV set, vehicle specifications were used to estimate potential national recharging demands for each over a standard week. The project focused on testing the impact of adding plug-in vehicle recharging demands on the week of highest demand occurring in the year 2009: Monday 5th to Sunday 12th January [10] with an arbitrary limit of 60,000 MW. Several scenarios were tested, with full details described in [6].

Scenario 1 assumed drivers plugged in their vehicles upon arrival home. The first variation – '1a' – assumed all vehicles fully depleted their batteries every day. '1b' instead assumed that vehicles would have a magnitude and duration for recharging demand based upon their average mileages for each day of the week. PHEV were assumed to always fully deplete their batteries every day, but it was assumed for BEV that 50% travelled the average mileage for each day, 40% travelled the average mileage plus the standard deviation, and 10% assumed

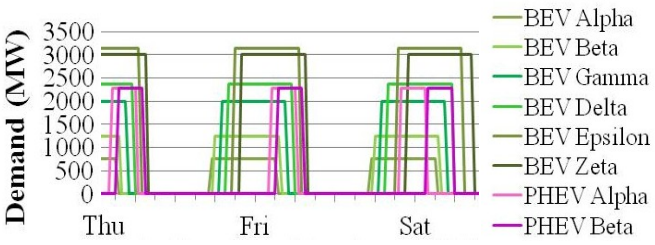

Fig. 2. Extract from recharging regimes for Scenario 2a adapted from [6] demonstrating how recharging demand can be spread more evenly over Friday night than over Thursday night.

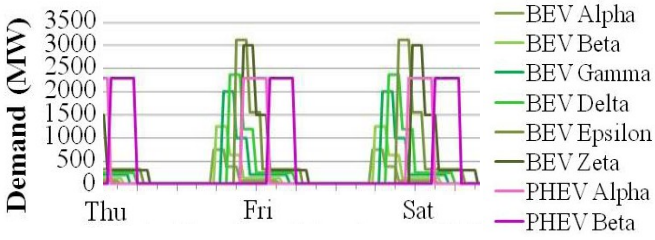

Fig. 3. Extract from recharging regimes for Scenario 2b adapted from [6] demonstrating how recharging demand can be spread more evenly over Friday night than over Thursday night but also the impact of assuming that not all vehicles are fully depleting their batteries.

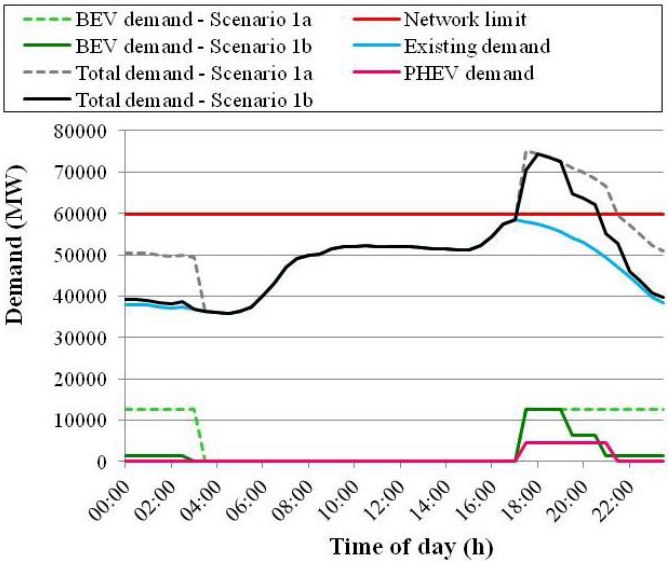

Fig. 1. Results from Scenario 1 comparing the impact of variations 'a' and 'b' for the day of highest recorded demand in 2009 – Tuesday 6th January – taken from [6].

to have fully depleted their batteries. The comparative results for Scenario 1a and 1b taken from [6] are shown in Fig. 1.

The second scenario split vehicles unequally into 6 subsets, each subset named using the Greek alphabet and given a recharging start time for each day of the week. In the first variation – '2a' – it was assumed first that all vehicles required full recharges upon returning home every day of the week. The second variation of this scenario – '2b' – followed the same assumptions as 1b for vehicle energy usage: PHEV would fully deplete their batteries but not all BEV would require a full recharge every night.

The numbers of vehicles per subset and the timing of each subset's demand were adjusted manually to give the smoothest profile that did not exceed network capacity limit, and to take advantage where possible of lulls in electricity demand. Vehicle arrival and departure times differ per day of the week, so this permitted the recharging load to be more evenly spread on weekend evenings than weekday evenings. This is demonstrated in Fig.2. and Fig. 3. This is not simply nightly recharging: it is a weekly regime where recharging start times can differ per day of the week. The impact of applying recharging regimes is shown in Fig. 4.

A final scenario tested the possibility for shifting weekly recharging needs to weekends by partial recharging for BEV that were not requiring full recharges on weekdays. The recharging regime subsets were further split into groups, firstly by recharging slot and then by recharging need i.e. by their expected mileage. 'Standard' groups for subsets contained vehicles expected to have travelled the full mileage permitted by their vehicles batteries and therefore required full recharging every night. Groups within subsets labeled 'Extra'

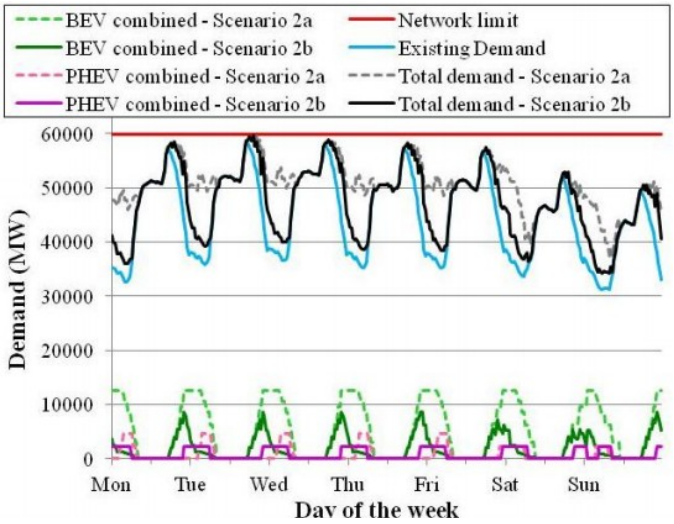

Fig. 4. Results from Scenario 2 comparing the impact of applying recharging regimes taken from [6]. Variation 'a' assumes all vehicles have completely depleted their batteries, variation 'b' assumes some but not all vehicles have completely depleted batteries.

were expected to be travelling the average plus the standard deviation mileage for each day of the week, whilst groups labeled 'Ultimate' within subsets were assumed to be travelling only the average daily mileages for each day of the week.

10% of vehicles for each subset were assumed 'Standard', 40% assumed 'Extra', and 50% were assumed 'Ultimate'. Those vehicles belonging to groups within subsets labeled 'Extra' and 'Ultimate' were permitted a deteriorating battery SOC through the week with their SOC being fully restored at the weekend. Like the previous scenario, the regimes for each were manually adjusted to give the smoothest profile that did not exceed network capacity and took advantage where possible of lulls in electricity demand over the whole week as well as per night. The difference between recharging regimes for Scenarios 2b and 3 are illustrated in Fig. 5. Results for both are provided for comparison in Fig. 6.

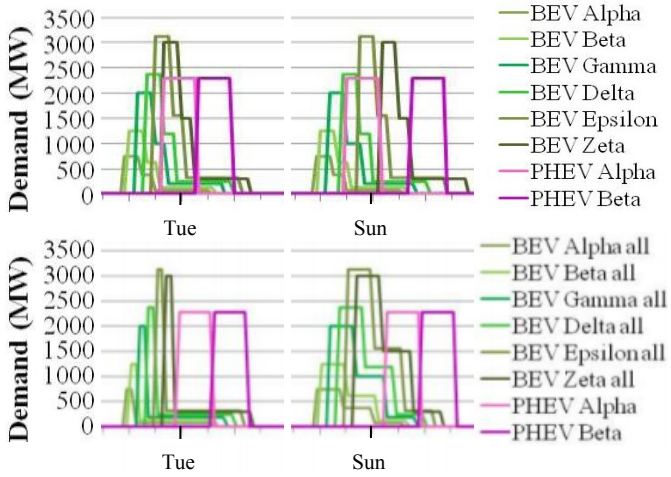

Fig. 5. Adapted from [6] compares recharging demands from regimes set for Scenario 2b (top) to recharging demands from regimes set for Scenario 3 (bottom) to show how in Scenario 3 a portion of the load for Monday night has been shifted to Saturday night.

C. *Importance of recharging regimes*

The concept of recharging regimes that can be implemented without need for a smart control system is particularly important under the following conditions:

1) When recharge timers are not available.
2) When recharge timers although available are ignored (no incentive for use).
3) When remote access to timers by an external recharge scheduler is not available – either because it is physically impossible or because it is denied by vehicle owners.

Not all plug-in vehicles entering the UK market have recharge timer capability, and there is presently no vehicle designed with the capability for real-time recharge scheduling by a third party in the UK, nor is there network infrastructure in place. The average lifespan of a vehicle in the UK is 13yrs [18] – whatever capability vehicles entering the market have this year and in coming years with regards to recharging, those vehicles and their technological limitations could endure for a decade. Will plug-in vehicle owners take advantage of recharge timers if they have them? If available, will plug-in vehicle drivers use timers to schedule recharging away from existing peaks in electricity demand? Plug-in vehicle trials e.g CABLED trials in Coventry and Birmingham [17] may provide answers about this kind of human behavior.

D. *What benefits could recharging regimes offer?*

The selection of recharging regimes offered to plug-in vehicle drivers can be refined to enable the matching of known human travel behavior to the primary needs of the electricity

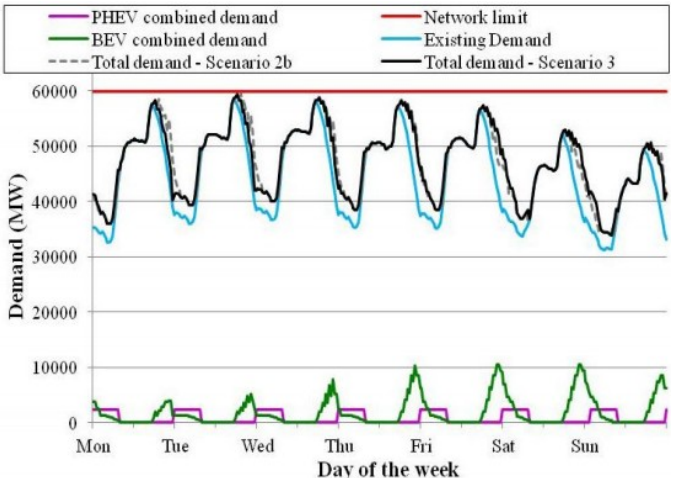

Fig. 6. Results from [6] for Scenario 3 and for comparison, Scenario 2b.

supply industry [6]:

- To limit loads on the network infrastructure and therefore limit the necessity for infrastructure reinforcement,
- To conserve electricity generation capacity and therefore minimize the need for increasing that capacity, and,
- To reduce dependency upon fossil fuels, subsequently reducing emission of greenhouse gases (GHG) along with other pollutants.

Meeting these needs will be facilitated by providing a rudimentary method for scheduling recharging to avoid existing demand peaks. Recharging regimes in this respect is two-fold. Firstly they provide generators greater operational stability by targeting recharging to coincide with predicted lulls in demand – load leveling. Secondly they force recharging demands upon electricity generation to be more predictable and avoid exacerbating existing peak demand.

This reduces the need for additional flexible, fast response electricity generators to be built to cope with the added demands of plug-in vehicles. Such generators are invariably gas powered. If probability studies can provide rough annual estimation of renewable electricity availability at different times of day across the year, then this too could be factored into recharging regimes to increase renewable electricity dependence.

The recharging regime concept enables the intelligent use of existing technology. It relies upon plug-in vehicles having recharge timers which the vast majority marketed in the UK have although vehicles without recharging regimes can still participate. It relies upon plug-in vehicle owners having a context and incentive to select an appropriate recharging regime for their needs, and this could be achieved through existing electricity supplier/consumer relationships. The electricity industry need not involve itself in actively controlling the recharging of vehicles or monitor recharging needs through smart technology.

Recharging regimes can be chosen and enforced by plug-in vehicle owners themselves, leaving owners reassured by the continuing familiarity of being in control of their vehicle's recharging. However the plug-in vehicle owner will no longer be the sole party influencing the scheduling of their vehicle's recharging. This signifies an important step towards developing more sophisticated systems.

V. Limitations Of Recharging Regimes And To Further Development

There are significant limitations to these recharging regimes, primarily because of the limitations of the information used to design them, and the limitations of the technology that might be used to implement them.

A. Determining recharging location

Discussions with Distribution Network Operation (DNO) engineers have highlighted the fact that the location of demand in relation to the geographical and topological specifications of local distribution networks could be crucial to their ability to:

1) Assess the potential impact of recharging vehicles,
2) Assess the best times for those vehicles to recharge, and, if necessary,
3) Design the implementation of any required modifications and upgrades to the network.

It is the overall increase in electricity demand over a given segment of the distribution network that would be of interest to DNOs. This requires the summation of recharging demands of vehicles connected within a specific area. This would likely involve assessing the demands placed upon different network branches that have different profiles e.g. domestic, commercial or industrial. Koyanagi and Uriu [20] modeled the importance and benefits of introducing a regional time shift in the recharging of electric vehicles to ensure that demands are leveled across areas of a distribution network according to existing patterns in local demand. However, predicting exactly when and where vehicles will be recharging is difficult.

The recharging regime project concentrated on national electricity demand acquired from National Grid [10]. In consequence the specific location of vehicle recharging was not required. A more detailed analysis of NTS data may enable placement of households on a specific transmission system branch. The NTS data can be geographically divided as follows:

- North East
- North West and Merseyside
- Yorkshire and Humberside
- East Midlands
- West Midlands
- Eastern
- Greater London
- South East
- South West
- Wales
- Scotland

The NTS data is coded so as to protect the identity of participants which includes hiding their actual address location. Access to data that may compromise anonymity of survey participants is heavily restricted by the ESDS. However it may be possible if permission were granted to access data allowing sufficient resolution, to place households upon a

given segment of the distribution network branch.

The recharging regime assumed vehicles were meeting all their recharging needs at home. In reality recharging regimes expected to be applied to home recharging may require modification because vehicles may be meeting some of their recharging needs elsewhere. Public recharging points are expected to be more numerous in future, promoted by the government's initiative 'Plugged In Places' [21]. It is also expected that institutions and commercial organizations will be interested in the provision of recharging facilities for car parks on their premises, for example research has examined the impact of a high level of electric vehicles on the University of Bath network [22].

Unfortunately it is difficult to assess the likelihood or recharging away from home, and even more difficult to assess where that recharging might take place using data from the NTS. Whilst the NTS collects address details for households, it does not collect address details for any of the other destinations participants are travelling to and from. The survey collects estimated distances from the household to the nearest of a selection of nine services e.g. nearest hospital, grocers, and primary school. Coupled with the household's postcode, it might be possible to discern the location of e.g. the nearest hospital. However these are not necessarily the hospitals, grocers, schools etc. that the household members use.

In the survey a journey is defined by its purpose, not just its location e.g. 'food shopping', 'work', 'home'. It might be possible to assess to some extent the potential likelihood of recharging to occur away from home, given the destination of travel. Journeys for 'Escort education' i.e. where a child is being dropped off at school will be unlikely to involve a stop long enough to involve recharging. The labeling of journeys with purposes is however subject to the discretion of the survey participant.

B. Determining the timing of recharging

The NTS is a socially-focused survey, not a vehicle focused survey. 'Journeys' are defined as 'stages' made by individuals numbered and associated to households. Journeys made by passengers must be separated from journeys made by drivers and journeys may consist of multiple stages. A journey may include a stage travelled by car followed by a stage travelled by the identified person walking from a car park to their final destination. Start and end time is recorded for each journey, not each stage, so some car journey records have missing start and end data.

The first part of the recharging regime project considered whether particular journeys would be suitable for PHEV or BEV vehicles based on daily mileages travelled by vehicles. After discerning which vehicles might be replaced by which type of plug-in vehicle, home recharging times for each type of plug-in vehicle were investigated by assessing earliest departure from and latest return to home times. 0.2% of the departure and 0.1% of return times for the PHEV group were missing. 1.3% of departure and 1.0% of return times for the BEV group were missing. When these journeys with missing times were attributed to individual vehicles, the following figures applied. 5.9% of the vehicles belonging to the PHEV group, and 4.2% of the vehicles belonging to the BEV group had missing times either for departure, return, or both.

In reality it is the household's demand – not their individual vehicles – that is of interest for load management on the distribution network. When vehicles were matched to their households, 6.6% of households that had a PHEV and 6.3% of households that had a BEV had incomplete travel data. Some households had more than one plug-in vehicle, sometimes one of each type. Overall, 7.0% of the households whose travel indicated they could have one or more plug-in vehicles had incomplete travel for one or more of the household vehicles of interest. In addition to this there is no guarantee that all houses on a distribution network branch would have participated in the survey.

C. NTS design constraints – time period surveyed

The NTS is designed to ensure that no previously consulted household is asked to do the survey again the following year. Care is taken to distribute the survey across geographic and socioeconomic areas. The survey is distributed at different times of year so that some assessment of annual patterns in travel can be made.

However, travel information is only collected from respondents for a single week. Accumulated daily mileage is subject to errors in correlating journeys from home with those returning – they may not necessarily occur on the same day. The one week survey period further introduces margins for error when estimating energy usage for any identified vehicle over longer periods of time, such as over a month or year.

The fact that the NTS covers only one week of travel has another drawback. Of the 57,069 households that fully complete their surveys, 36.3% recorded no travel during the survey week. This was not by omission or mistake on the part of the survey participants; it was due to legitimate reasons such as family holidays. For recharging regime project only households earning annual incomes of £35,000 or over were considered prospective plug-in vehicle owners. They accounted for 29.2% of the households who fully completed their surveys. Unfortunately 40.1% of them had no recorded travel data, and therefore could not be included in any further assessment for likely PHEV or BEV ownership.

D. Other NTS constraints

There is always the potential for inaccurate answers arising from errors in the human interpretation. The DfT employs interviewers who will attempt to carefully explain the survey and its questions. Although guidance is provided on how to

properly complete the NTS, not all respondents manage to do so. 11.2% of households with vehicles did not fully complete their surveys.

Over the years the NTS has been modified to include data collection on new variables. In recent years details on overnight parking location is requested, but the information collected from respondents is sketchy. Over 38% of vehicles belonging to households earning above the threshold annual income of £35,000 lacked appropriate information for this variable to be used for analysis. Whether responses were poor for this question because the question was designed badly, or because of some reluctance on the part of participants to give answers, is unknown. The NTS team does not have the resources to query each reported journey to determine whether guidelines have been followed precisely.

Once response rates, survey design limitations and uncorrectable errors like missing journey start and end times are accounted for, only 7816 households – that's 41.9% of a potential 18,672 surveyed households earning annual incomes at or above the threshold of £35,000 – could be considered for a more rigorous study, one that incorporates the requirements of DNOs to consider local network constraints. The number of vehicles belonging to those households is 12,188. To put this in perspective: in 2008 there were 27,021,000 private cars registered for use on UK roads [23].

If it is assumed that as the NTS suggests, 47.1% of these vehicles belonged to households earning £35,000 or more, then that leaves us with a theoretical population size of around 12,717,000 vehicles that may or may not be substituted with plug-in vehicles depending on their daily mileages. The 12,188 vehicles belonging to households for which sufficient data exists for a more rigorous study, represent a sample size of less than 0.1% of that theoretical population.

E. Implementation issues relating to recharging regimes

The UK does not yet have smart metering in place, so recharging regimes could instead be arranged in contract. Complexity in contractual arrangements must be minimized to avoid customer confusion and stress regarding implementation of recharging regimes. It is thus unlikely that recharging regimes implemented manually by drivers will be responsive to renewable electricity availability. Likely they will instead be able only to incorporate long-term predictions in supply.

The roll-out of smart meters would ideally provide suppliers with sufficient daily electricity meter readings for them to assess whether customers with plug-in vehicles are recharging their vehicles as per their specified recharging regime. Readings could be transmitted directly when taken or through some delayed data collection process. Regime-specific tariffs could then set patterns in electricity cost to encourage recharging to occur during a regime's prescribed recharging time.

As with domestic meters there could be enforcement issues when relying upon present technology: the supplier would have no idea when or if the agreement is being kept or broken. There are, however, more subtle psychological methods for ensuring honest customer behavior. TV licensing is a good example [24]. If customers believe that suppliers know their electricity demand patterns and can detect if they are breaking their agreement, this can be as good as enforcing the agreement through use of actual means.

VI. Conclusions

Monitoring and data collection together balance energy supply and demand via two pathways: prediction, and response to circumstances. Recharging regimes are designed to match anticipated patterns in recharging needs to the anticipated lulls in electricity demand, they rely on prediction of both. Their effectiveness is dependent upon the quality of the data available to predict both recharging needs and lulls in other electricity usage. The NTS provides invaluable insight into travel behavior and the possibilities of being able to predict, not just react to, plug-in vehicle recharging.

Recharging regimes can deliver immediate benefits but their design is limited by the sample size, accuracy, and by the type of information gathered by the NTS. The NTS is a socially-focused survey. It is not a vehicle-focused survey, nor is sampling focused according to the design of the electricity supply network. To get the best out of existing technology using recharging regimes, prediction of vehicle energy use must improve. This provides an incentive to improve data collection on vehicle energy use – a prerequisite also for more complex vehicle-grid relationships to develop.

Active data collection has significant drawbacks. Needs for privacy and anonymity constrain surveys like the NTS that look in detail at human behavior. Passive data collection regarding the location and timing of recharging demands would allow recharging regimes to be tailored more carefully to match supply and demand. Use of recharging regimes could also then be monitored. Location-related information may yet prove a grey area for privacy, although car manufacturers are already finding ways to turn collection of such information into a tool for drivers to use. The Nissan LEAF's 'Information Technology to Support the New Values of the EV' [7] already collects information to support the services provided.

Recharging regimes are not the final solution. Instead they are a precursor to the smart technology that is expected to follow, laying foundations for trust in third parties to control interactions between vehicles and grid and providing a framework for building desirable patterns in recharging behavior. Providing information that better allows the assessment of vehicle energy use and therefore recharging needs is the "next step for smart grid development".

The development of two-way communication and remote

recharging capability that will enable true 'smart recharging' and V2G services will follow. In the meantime instead of waiting upon the development of smart technology, recharging regimes can enable the smarter use of existing technology.

VII. Acknowledgment

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IX. Biographies

Emily L. Parry was born in the UK in 1983. She graduated from the University of Wales, Aberystwyth with BSc Environmental Science. She is studying at the University of Bath for a PhD in Electronic and Electrical Engineering titled "Electricity as the Prime Energy Vector". She is investigating the possibilities of shifting UK road transport energy use towards electricity dependency. Her interests include plug-in vehicles, sustainability and international development.

Miles Redfern (M' 1979) received his BSc degree from Nottingham University and PhD degree from Cambridge University in 1970 and 1976 respectively. In 1970, he joined British Railway Research, and in 1975, moved to GEC Measurements where he held various posts including Head of Research and Long Term Development and Overseas Sales Manager. In 1986, he joined Bath University with interests in Power Systems Protection and Management.