The Potential of Domestic Electric Vehicles to Contribute to Power System Operation through Vehicle to Grid Technology

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Abstract- **The domestic use of electric vehicles (EVs) is expected to grow significantly over the next two decades. Wide scale use of EVs will have a significant impact on electricity loads and could risk of overstretching the power system if steps are not taken to prevent this. On the positive side, the charging of vehicle batteries could be regarded as an excellent opportunity to create responsive load as part of a demand side management (DSM) approach to network operation. DSM has been regarded as one of the most effective and efficient ways to solve problems associated with renewable energy integration. For the purposes of quantifying the potential impact of widespread electric vehicles use on the power system it is essential to understand how and when conventional vehicles are used at the present time. The Time of Use UK Survey 2000 contains valuable information relating to privately owned car use. Analysis of data shows that privately owned vehicles are utilised for only 5.2% of the time, in principal making them available for the remaining 94.8% of time for load control purposes. EV batteries could even be discharged briefly at times of peak system demand through vehicle-to-grid (V2G) technology. This article quantifies the potential for responsive load from EVs and outlines an appropriate control system to maximize the value of this. Overall, there were 28 million licensed cars registered in Great Britain at the end of 2008 with 89% of them being privately owned [1], indicating the considerable scope for responsive load and V2G.**

***Index Terms*—Demand Side Management, Responsive Load, Electric Vehicle, Power System Operation, Vehicle-to-Grid.**

I. Introduction

A. Energy Demand Growth

Reducing greenhouse gas emission, dealing with energy security risks and reducing pollution more generally are the current global challenges associated with the energy sector. In the transport sector, these challenges are even more serious, and energy for transport in developing and developed countries is growing faster than for other sectors. UK network operator National Grid (NG) said it planned to cut carbon emissions by 45 percent by 2020, and called on the government and industry to develop a route map for a low carbon economy. European Union countries aim to source 20 percent of their energy from renewable sources by 2020, the UK target being 15%. In addition, Britain has set a target of reducing carbon emissions by 80 percent by 2050 from the 1990 level, [2]. Wind energy in particular will grow significantly in next decades to help meet the wider sustainable energy production targets. The challenge of integrating such high penetrations of renewable sources creates the opportunity for domestic electric vehicles and in particular, those fitted with vehicle-to-grid (V2G) technology to provide the required flexibility for the power system.

B. UK Vehicle Statistics

Overall, there were 34.2 million licensed vehicles registered in Great Britain at the end of 2008 including motor cycle, cars and light vans. There are approximately 28 million cars licensed, with 89% of them privately owned, [1]. Most of the time these cars are parked; they are on average being driven for only about 5% of the time. These parked cars could thus provide a valuable second function as responsive load, or even as a generation source as with V2G.

C. Electric Vehicles

The increasing popularity of the hybrid electric vehicle and the overall rise in the price of oil is motivating the development and marketing of the next generation of plug-in hybrid electric vehicles. Major car manufacturers such as General Motors, Vauxhall, Chrysler, and Toyota have recently announced new Plug-in Electric vehicles (PHEVs) models. However, there are some other car manufacturers already producing excellent EV models, such as the Tesla Roadster, G-Wiz and others. PHEVs can also be used as energy storage for the power system. Most domestic vehicles sit parked most of the day, during which time, if they have significant battery capacity, they can be utilised as responsive load, or even for brief periods, as a generation source through V2G technology, rather than simply being an idle asset. On a daily basis, the battery energy could provide backup power generation during peak demand periods, and also provide spinning reserve and other regulation services whenever connected to the network. The batteries installed in the new vehicles are increasingly using Lithium-ion technology, with the most common being Lithium Nickel Cobalt Aluminium, Lithium Manage Spinel, Lithium Titanate and Lithium Iron Phosphate, [3].

D. Vehicle-to-grid Technology

Vehicle-to-grid (V2G) technology represents a means by which power generation capacity available from parked EVs

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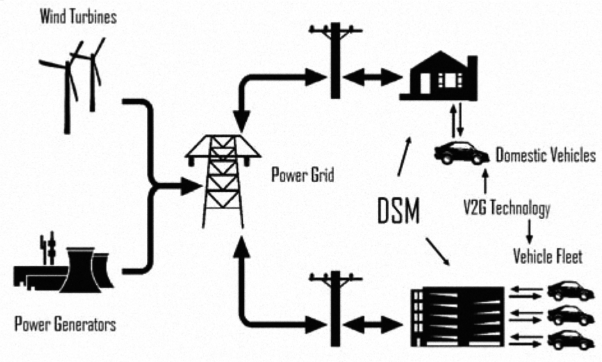

Fig. 1. Illustrative schematic of proposed system with vehicle fleet and wind farm. [4]

can be used to supply electricity to the power grid. In technical terms, there are no barriers to V2G technology. For each electric vehicle, three elements are required: a connection to the grid for electrical energy flow; suitable communication with the power network operator (perhaps via real time price signals), power flow controls and metering either off or on-board the vehicle, [4]. In the early stages of V2G implementation, systems are expected to focus on power delivery of time-critical power market services due to the associated high value/rewards. In effect, such V2G technology makes available bi-directional energy storage that can be used to ease the integration of wind energy. V2G implementation is of value only if the appropriate match occurs between electric vehicle availability and times of high electricity cost within the power market. There is a cost associated with V2G resulting from the increased cycling of the battery and consequent reduced lifetime, but this cost is expected to be more than covered by the high value of electricity at peak times. Simple using the batteries as responsive load (i.e. no discharging for power generation purposes) is not anticipated to reduce the battery lifetime.

E. *Demand Side Management*

The charging of on-board batteries of EVs and plug in hybrids (PHEVs) will form an additional, potentially significant, domestic electricity load. If not properly managed this may result in large increases in the total load at specific times of the day and if this coincides with times of existing peak demand, there will be increasing strain on the network, perhaps to the extent of overload. Demand Side Management (DSM) needs to be implemented with all battery charging for EVs in order to minimise the impact on the power system, and if designed correctly there is potential to control charging so as to in fact improve system operation. The latter could be especially important in the case of high wind penetration. For instance, if the charging of electric vehicles can be accomplished mainly at night, as would be consistent with driving use patterns, EVs could provide significant value to the power system and network operators. There would of course be advantages to the domestic consumer in terms of reduced charging costs (assuming the existence of some suitable cost reflecting tariff), resulting in cheaper transport and making EVs even more attractive. Combined with peak lopping using V2G, EVs have much to offer the power system. The proposed system is illustrated in Fig. 1. As already noted, with V2G, electricity can flow bi-directionally between the power grid and the vehicle fleet batteries, [4].

II. UK Vehicle Use Analysis

For the purposes of quantifying the potential impact of widespread electric vehicle use on the power system, it is essential to understand how and when conventional vehicles are currently used. The Time of Use UK Survey 2000 contains valuable information relative to privately owned car use. This database has been analysis to obtain detailed car use statistics. The longer term aim of the research is to build up a Monte Carlo simulation of a power system including the use and charging of electric vehicles.

A. *Time of Use Data Overview*

The Time of Use UK Survey (UKTUS) 2000, [5] provides detailed data on domestic vehicle use. These are predominantly conventionally fuelled, but usage patterns are not expected to change dramatically with the shift to EVs, and certainly as far as medium range commuting and the "school run" are concerned. Probabilistic characterizations of domestic vehicle usage cover time of use, duration of use and distance covered. The results presented here illustrate the driving behaviour of the survey sample. After extracting the relevant data from the UKTUS database, a new database of conventional car use data has been created. This new database has been characterised and analysed as outlined below.

B. *Data Characterisation and Format*

Several pre-requisite procedures are needed in order to process the database before more detailed analysis is undertaken. The first step is to extract the relevant data from the original UKTUS database. A C# code has been developed to extract the location, mode of transport and purpose for travel from the original UKTUS database. The function of the C#

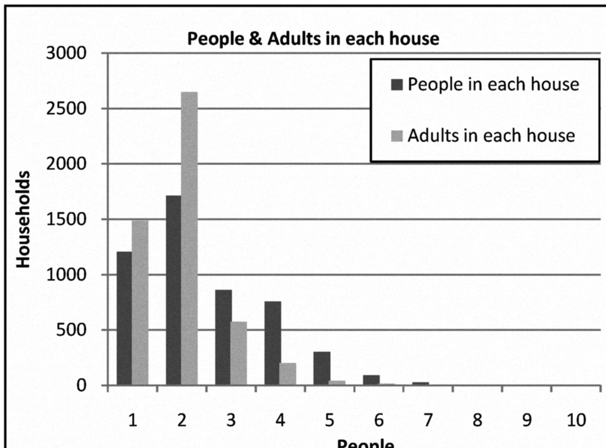

Fig. 2. Contrast between people and adults in each house.

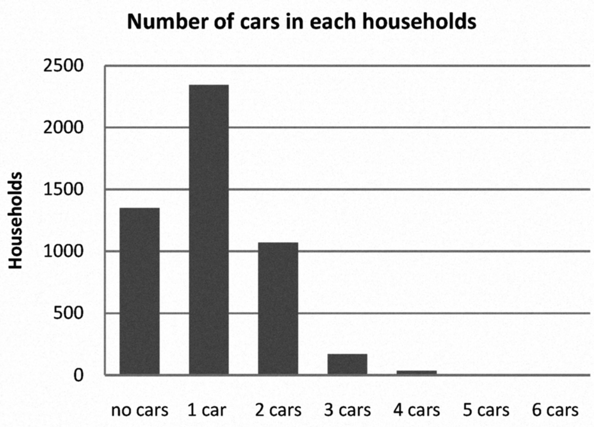

Fig. 3. Car ownership in each households.

code is to locate the required variable label and extract the whole variable value for each diary entry. These diaries record every household's daily activities. Each diary contains the specific code denoting people actually driving their car (there are separate codes for passengers in transit). The extracted data is saved as a new Excel readable file for further data analysis.

The resulting new database contains other information, such as household number, day of the week, etc. It results from 18,469 daily diaries and includes 5,158 cars owned by the sample population in question. Comparison between the number of people in each household and number of adults in the house shows the proportion of occupants capable of driving (ie the adults), as illustrated in Fig. 2. The population of adults whose household has at least one car in this study is 7,565. Non-car owning households are of course excluded from the analysis of actual car use, but the proportion of such households will of course be important for future electricity distribution system modelling.

Fig. 2 shows that the majority of households have just two adults. The number of cars per household is also analysed and classified by car ownership as shown in Fig. 3. The bulk of households in the survey have just one car. Just over one-fourth of total households have two cars. 25% of households in the original data base do not have a car, as shown in Fig. 3. The average car ownership per household is just over one for the entire sample population.

C. *Data Analysis and Results Discussion*

For the population outlined above, the task is now to calculate the exact patterns of vehicle use. After filtering out the child diaries, the remaining adult's diaries, which are recorded for each ten-minute period throughout the day, were arranged into two sub-databases, depending on whether weekdays or weekends are being considered. This was done as driving habits are self-evidently different at weekends. Both databases contain a specific code that indicates that the diary owner is travelling in a car as the driver (inherited from the initial UKTUS data base). These diaries are also distinguished the purpose and mode of travelling. By searching for this specific driving code for each 10 minute interval, the probability of cars being driven on the road at any time can be calculated, as illustrated in Fig. 4. The figure presents the probability that a car is being driven, and shows that the expected peaks occurring in the weekday morning and evening, and in contrast that driving over the weekend is more widely spread over the day. Specifically the results confirm that the peak driving time for weekdays is over the period 7:30 to 9:20 in the morning and 16:45 to 18:40 in the evening as might be expected from known commuting behaviour, and that the pattern over the weekend is very different, justifying the disaggregation of the data. If a significant proportion of cars are assumed to be electric at some time in the future, it will be essential to ensure provision of adequate electricity supply capability (both generation, transmission and local distribution) to charge these electric vehicles whilst of course supplying the remainder of the demand. Without further analysis, including other system loads, it is not possible to identify when the most critical time periods will be. This work will be undertaken at a later stage of the project.

Most importantly though of the purposes of this research, calculation shows that on average privately owned vehicles are utilised for only 5.2% of the time for transportation, making them potentially available for the remaining 94.8% as responsive load.

D. *Data Analysis for Mondays*

Since electricity use profiles have a distinct diurnal characteristic, it is important to capture the daily pattern of vehicle use, and in particular the probability of journeys commencing at particular times of the day, and their expected duration. By extracting and analysis the data for Mondays* the probabilities of travel to/from work and the parking location of cars at different times of the day has been determined.

The probabilities of travel to/from work and driving in total provide information relevant to that the amount of electricity needed for charging the EVs, whether overnight at home or at the work place. These probabilities will be used in future work to calculate the amount of energy used for moving the car and thus energy left in the on-board vehicle energy storage device (batteries in this study, but this analysis could later be extended to hydrogen vehicles).Fig. 5 presents the probability of cars being driven on the road with regard to different specified driving purposes.

* Monday data has been selected in this provisional data analysis to save time; in future all weekdays will be analysed together unless significant and persistent weekday variations are identified.

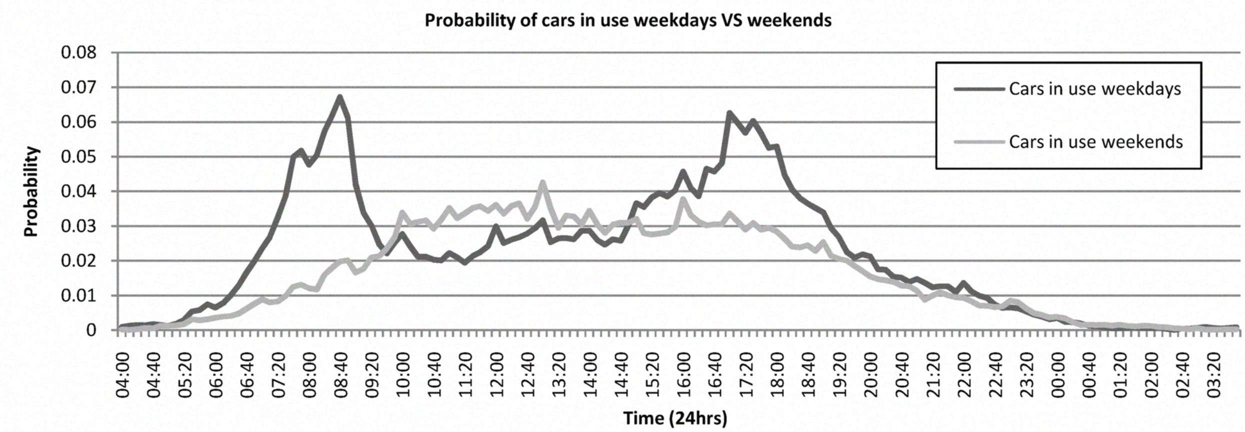

Fig. 4. Probability of cars being driven during weekdays and weekends..

The large proportion of Monday driving is for commuting to work in the morning rush hours, with most of the remaining cars being parked at that time. At 7:30 in the morning on a Monday, the probability of cars on the road travelling to (or from) work is around 18% less than the probability of driving for all purposes. In other words, during the morning peak, 78% of cars on the road are being used for commuting. During the evening peak however, the reasons for driving are a little more diverse with 90% of cars being used to access the workplace. The key conclusion, perhaps not unexpected, is that most cars on the road at peak times are commuting to and from work; most other drivers endeavour to avoid these times. One point to note though is that the design of the survey, and in particular the 10 minute resolution, makes it difficult to distinguish when cars are being driven to drop off children at school en route to work.

The implementation of V2G technology could be deployed widely in next decade or so. Both home and the work place are the most obvious locations for EVs to be grid connected and able to deliver responsive load or V2G services to the power network. The statistics show that more than half of all cars are parked at home during night time and early evening when they could play an important role in easing the integration of renewable and offsetting other loads on the system. In addition, as shown in Fig. 6, following the morning commute to work, almost all cars are subsequently parked there.

III. Conclusions

This paper has presented an analysis of domestic cars use based on data from Time of Use UK 2000 survey. It shows that privately owned cars are utilised only 5.2% of the time of transportation, thus making them in principal available for the remaining 94.8% of time as responsive loads. Detailed analysis allows the calculation of key probabilities directly relevant to electricity system analysis. This is very much work in progress, but some interesting provisional results showing vehicle use patterns have been presented on a high resolution, 10 minutes, basis.

IV. Further Topics for Research and Discussion

The next stage of the research involves calculating the probabilities of car use and parking status for both weekday and weekends. Probabilistic characterisation of domestic vehicle usage will then be extended to cover time of use, and

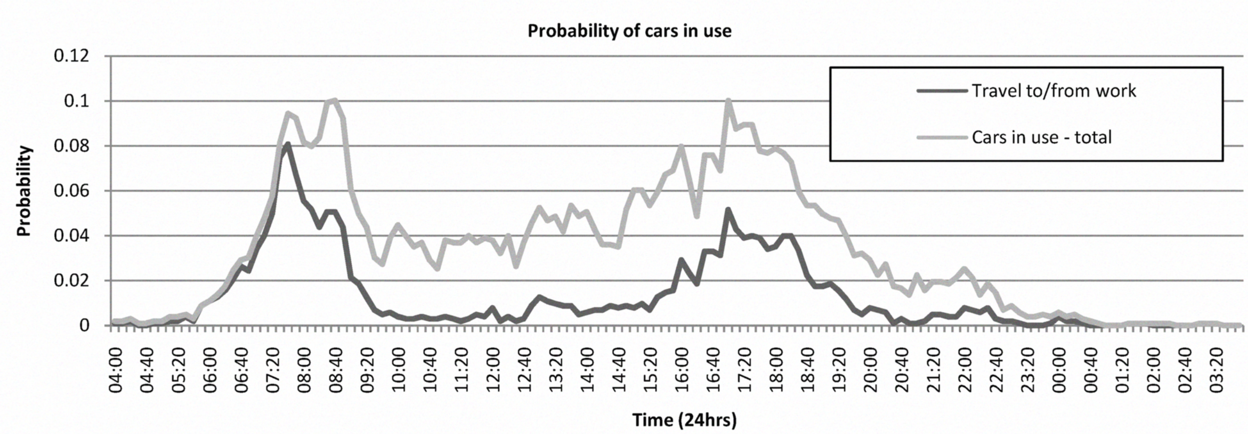

Fig. 5. Probability of cars being driven by different purpose of Monday.

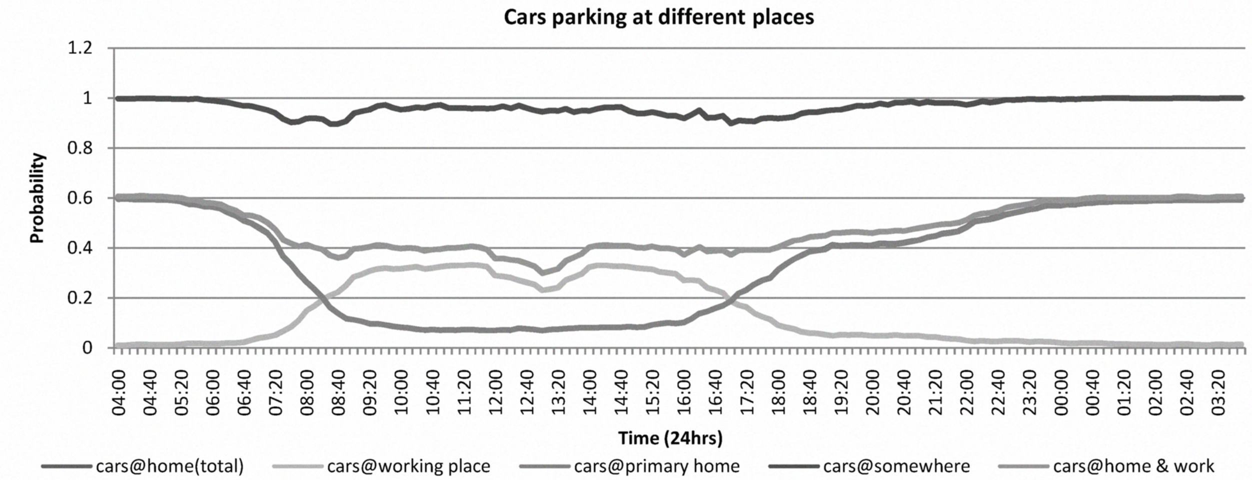

Fig. 6. Probability of cars being driven during weekdays and weekends.

duration of use and distance covered (needed for estimating energy consumption). These probabilities will then be used as the basis for Monte Carlo simulations of vehicle use and EV availability to feed into studies to quantify the potential for responsive demand as a function of time of day. The Monte Carlo simulations will be extended in due course to model the complete UK power system to assess the role of responsive demand, and V2G, in the integration of wide scale wind power generation.

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