POTENTIAL OF PLUG-IN ELECTRIC VEHICLES FOR SUPPORTING REGIONAL POWER DISTRIBUTION SYSTEM OPERATION WITH HIGH PENETRATION OF WIND GENERATION

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Abstract

With wider deployment of the plug-in electric vehicle (PEV), a power distribution network operator (DNO) would expect increasing domestic demand due to large numbers of vehicles charging. This could lead potentially to overloading of power system assets unless appropriate demand side management is in place. The UK coalition government has made a commitment to increase the amount of renewable generation capacity. To ensure 15% of energy demand is met from renewable sources by 2020, a massive amount of wind generation needs to be installed across the country. This paper presents the potential opportunities from using domestic owned electric vehicles to support the operation of regional power distribution networks in the context of a high penetration of wind generation.

1 Introduction

Since 1997 when the first commercial plug-in electric vehicle (EV) was marketed, in Japan, the market for plug-in electric vehicles has rapidly developed. Major automobile manufactures continue producing new models of electric vehicles from small two-seaters (e.g. G-Wiz) to medium four-seated cars such as the General Motor Chevy Volt and including sports models such as the Tesla Roadster, [1-4]. Battery technology has become more mature and cost-efficient with the shift from Nickel-Metal Hydride to Lithium-ion technology. The later type has a larger energy density and is relatively light-weight.

With larger battery capacity, range limits are expected to be longer for both full electric vehicle and plug-in hybrid electric vehicles. For example, the early version of plug-in hybrid EVs could only be driven approximately 3 miles on full electric supply and needed to recharge its battery through the internal engine powered charger. The typical range for full EVs nowadays is around 100 miles. These changes in terms of electric vehicle configuration offer opportunities to reduce both re-fuelling costs and carbon emissions from the tail pipe. In contrast, new plug-in hybrid EVs can be driven for 40 miles on a single charge without engine support. This option gives users more flexibility to choose their preferable time of charging. The number of the electric vehicle deployed in the UK up to 2050 has been forecast by John et al [5]; Figure 1 shows the predicted number of EVs up to 2050 under the 'Market Rules' scenario presented in that work. It is assumed in the scenario that there would be 1.1 million electric vehicles driven on the road by the year of 2020.

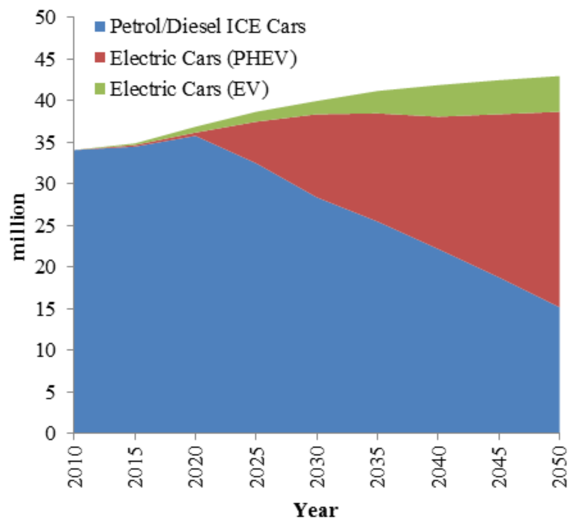


Figure 1. The prediction number of electric vehicles including plug-in hybrid and full electric from 2010 to 2050.

Within the energy sector, the UK Government has made its commitment to increase the amount of renewable generation capacity. This suggests that to ensure 15% of energy demand met from renewable sources by 2020, massive amount of wind generation need to be installed across the country. At the end December 2010 there were more than 4 GW of installed capacity of on-shore wind generation in the UK [6]. Modern wind turbine size has steadily increased over the years and the average new turbine is around 2.5MW. The UK has the richest offshore wind resource in the world. Offshore wind generation is expected to make the most significant contribution towards the Government's target of 15 per cent of energy from renewable sources by 2020. As recorded by the Department of Energy & Climate Change, wind generation has the largest installed proportion of the renewable sources with approximately 56 per cent as shown in Figure 2.

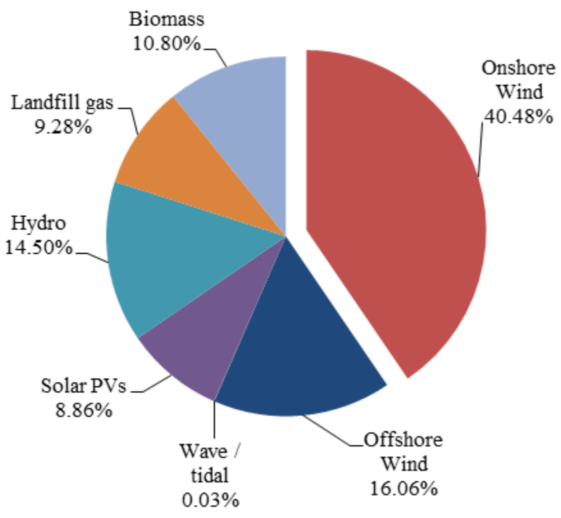


Figure 2. Installed on-shore and off-shore wind generation counts approx. 56.54 per cent among other renewable generations in the UK as recorded in 2011.

By 2020, the power distribution system in the UK will be more “intelligent” with roll-out of smart meters and demand side management available to assist DNOs manage the increasing demand from EVs and from new loads like heat pumps in domestic households. There are opportunities to use these domestic owned EVs as responsive load in order to reduce the risk of overloading the system; however, a potentially more important role is to support a high penetration of wind generation in the power system. Several studies have explored these. Bashash and his colleges developed a real-time controller for electric vehicle charging in order to improve the utilisation of wind generation [7]. Their controller tracks the wind power generation and shifts the electric vehicle charging to accommodate the wind availability. In [8], an electrolyser is used in a hydrogen filling station, where surplus wind energy would be used for producing hydrogen fuel for fuel cell electric vehicles. The concept of a fuel cell electric vehicle has not yet been accepted by the major automobile companies; however, the proposed solution needs to be assessed for the best overall system integration on the basis of cost-efficient, feasibility, and most important, efficiency. In contrast, instead of treating EV charging as additional load on the system, several studies have suggested the great opportunities of utilising the fleet of electric vehicle batteries as distributed power generation [9]. This issue is beyond the scope of the research presented here. In this paper, three aspects of the whole system modelling are explained in detail, including electric vehicle modelling, domestic demand modelling, and wind power generation. Different levels of electric vehicle penetration have been assumed in order to determine the potential amount of electric vehicle charging could be shifted to support regional wind farm operation.

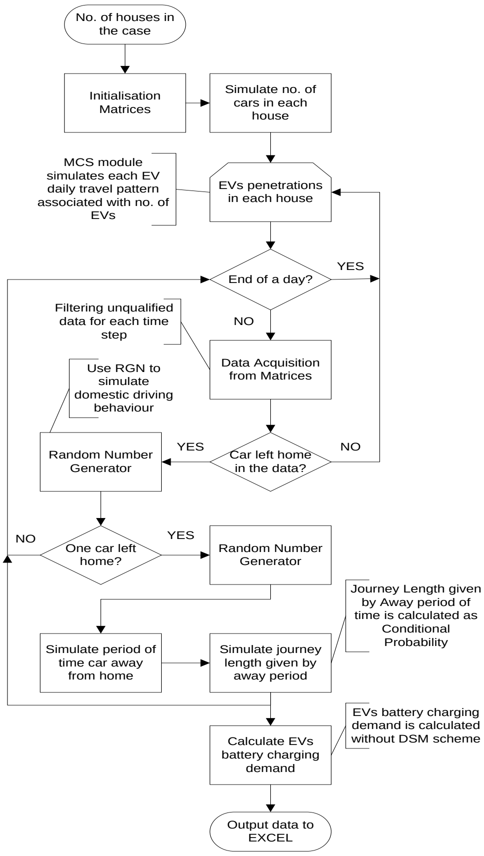


Figure 4. Advanced model of Monte Carlo simulation structure for calculating individual electric vehicle on-board battery charging demand.

2 Whole System Modelling

2.1 Electric Vehicle Modelling

For electric vehicle battery charging, profiles have been generated under the assumption that when a EV returned home, it would immediately be put on charge and remain plugged in until charging was complete. For simplicity, a constant charging rate is used. In this study, home is the only place for EV users to charge up, although working places and public parking lot could be considered in the future research.

Monte Carlo Simulation (MCS) has been used to identify the typical weekday driving pattern for given EV penetrations and battery’s State of Charge (SOC) on return home. SOC determines the requirement for recharging. This approach was followed in the simulations undertaken by Huang and Infield as described in [10]. Figure 4 illustrates the structure of Monte Carlo simulation (MCS) modelling for calculating individual electric vehicle battery charging demand.

The EV penetration as a proportion of all domestic vehicles was varied in 10% increments from 0% to 100%; with the number of EVs on the network at any time dependent of course on the assumed penetration. Two types of electric vehicle, manufactured by two different automobile companies, have been modelled for the network impact assessment. As assumed in the scenarios, households were fitted with two differently rated charging facilities. Domestic houses using EV1 have a 13A rated charging facility, while the houses with EV2 have a 32A 'fast' charge facility. The characteristics of the EVs and charging facilities are summarized in Table I.

Table 1: Characteristics of the EV used in the model.

Vehicle A	
Battery	35kWh, 400V DC
Domestic Charger Rating	Single phase, 230V 50 Hz, 32A Also has 13A capability
Vehicle B	
Battery	28kWh, 380V DC
Domestic Charger Rating	Single phase, 230V 50 Hz, 13A

2.2 Domestic Demand Model

Generic domestic power profiles were generated using an open source domestic power profile generator created at the University of Loughborough, [11]. This model uses house occupancy to generate a profile of times during the day when different numbers of occupants are active (e.g. at home and awake) in ten minute periods throughout the day. An example is shown in Figure 5.

The occupancy profile is then combined with UK appliance ownership rates, daily activity data and average daylight hours for a given month to generate a single domestic power profile. Profiles can be generated for weekdays or for weekends: an example weekday power profile, based on the occupancy profile and irradiance data shown in Figure 5, is shown in Figure 6. The predominant interest of the research at this stage is on weekday use and commuting to work behaviour in particular.

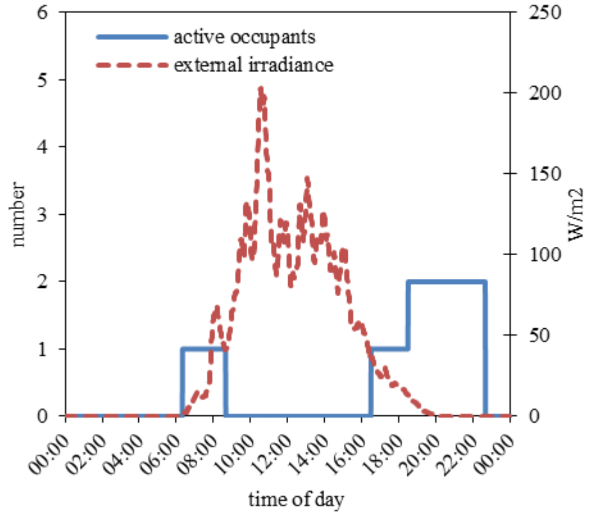


Figure 5. Sample active occupancy profile from the CREST model for a household with 2 occupants. The average external irradiance for a day in January is also shown.

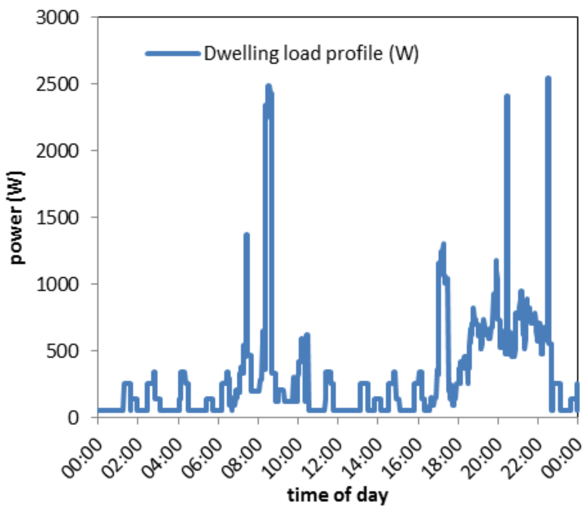


Figure 6. Sample of single house power profile simulated using the Loughborough University (CREST) model.

2.3 Wind Farm Monitoring Data

The wind farm data used within this paper is from an operational Scottish Power owned wind farm. The data was made available through the PROSEN project, a multi institution consortium undertaken in 2006. The wind farm consists of 26 600kW Bonus stall regulated turbines producing a total capacity of approximately 15MW [12].

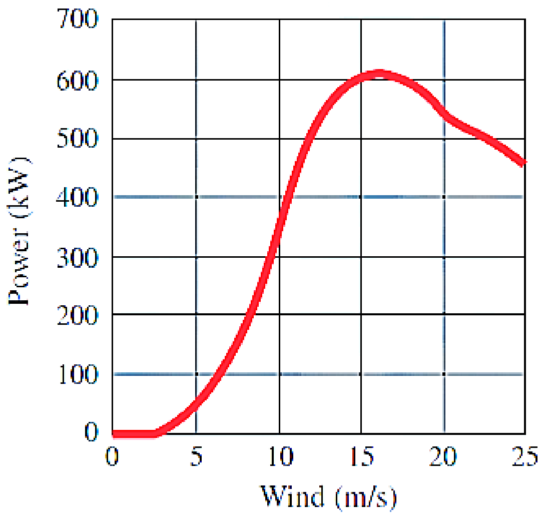


Figure 7. The power curve of the Bonus 600kW stall regulated turbine.

The data is extracted from the wind farm SCADA (Supervisory Control and Data Acquisition) systems which produce a variety of parameters at 10 minute averaged intervals. The parameters used within this paper are the active power and the anemometer measured wind speeds for each turbine. SCADA systems are typically centralised data management systems which monitor and control entire wind farm sites acquiring data from the real-time monitoring units (RTUs) installed at each turbine across the entire wind farm [13].

This recorded data is then compiled, formatted and transferred via the site network infrastructure to the HMI (human machine interface) where this compiled information is presented to the operating personnel in graphic form. The HMI link to the RTUs provides the capability for trending, diagnostic data and management information such as scheduled maintenance procedures etc. to be presented and managed in a clear and concise manner. As the volumes of data generated from each turbine quickly accumulate, it is necessary that the data is averaged over the 10 minute intervals and this is common for the majority of SCADA systems. This however does represent a loss in accuracy for detailed diagnostic processing; however for the purpose of this paper this data resolution is sufficient to match both the EV model and the CREST domestic electricity load synthesis model.

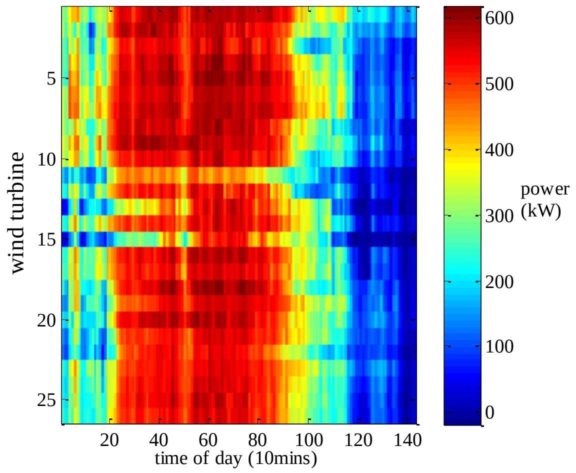
3 EV charging as responsive demand supporting wind farm operation

The charging of the domestic electric vehicles could overload existing distribution network transformers unless an appropriate control strategy is applied. However, the advantage is that these electric vehicles can be used as responsive demand supporting the integration of wind farm output in the power system network. It is interesting to explore the potential problems of electric vehicle charging in the absence of any coordinated control scheme. In this analysis, as already mentioned, it is assumed that charging starts whenever an EV arrives home since this is the most likely and secures approach from the car users' perspective; this is the so called dumb charging. It is also likely to be the worst case from a distribution system point of view. The distribution network parameters used are taken from the study conducted in [14]. For this case study, the total number of households supported by the primary distribution transformer is 1,262. The MCS model calculates the number of cars owned among these households, in this case 1,753. The penetration levels of electric vehicle are assumed at 10%, 50% and 100%. Table I lists the parameters used in the case study. The domestic demand profile over 24 hours is simulated at both the primary and secondary transformers using the by Loughborough (CREST) model. The total energy consumed by domestic users as simulated as supplied by the primary transformer is 17.56 MWh over the 24 hours.

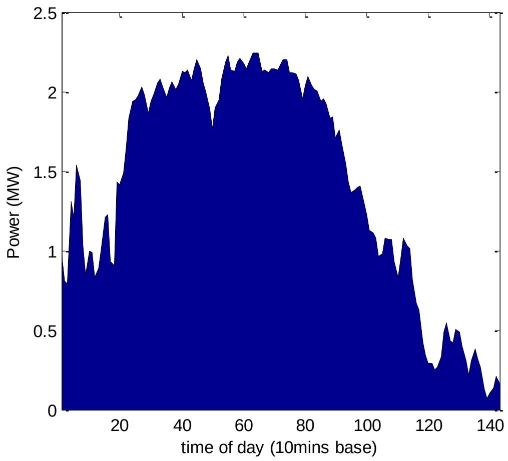
Table I. Case study parameters used in the simulation.

	Primary transformer	Secondary transformer
Households	1,262	214
Vehicles	1,753	292
Electric vehicle (100%)	1,753	292
Electric vehicle (50%)	867	146
Electric vehicle (10%)	175	29
Wind penetration	15%	

One of the most challenging aspects of the integration of wind generation in a power distribution system is to accurately forecast the power output of the wind farm. Due to the intermittency of the wind power, it is necessary plan carefully to fully take the advantage of wind farm power output to meet local demand including that from the domestic sector. From the SCADA data sample, it is clear that the wind turbines generate at rated power (600kW) from 3am to 3pm for the day in question as shown in Figure 9. The amount of wind energy generated by the wind turbines within 24 hours is 226.16 MWh. Base on the wind generation penetration level of 15%, the amount of energy transmitted to support domestic loads is 33.92 MWh.



(a)



(b)

Figure 9. The wind farm monitoring data from 26 wind turbines within 24 hours in April. (a) 2-D view of the power output; (b) the aggregated wind power (15% penetration).

Figure 10 shows the electric vehicle charging demand profile simulated from the MCS model with 10%, 50% and 100% penetration levels. The amounts of energy required for charging these EVs are 1.26MWh, 6.27MWh and 12.56MWh for the three penetrations respectively. The amount of wind generation in the system is sufficient to charge these EVs; however, the time difference between the high wind power and electric vehicle charging peaks are the biggest challenges for distribution network operator as illustrated in Figure 11. Electric vehicle users can change their recharging behaviour. Demand side management is a most effective and robust way to manage EV charging demand. With the rapid development of smart grid, DNOs would be able to gathering information from smart meters installed in each house and monitor the load profile and send appropriate market or other signals to consumers (EV owners) to encourage them to modify their charging profiles.

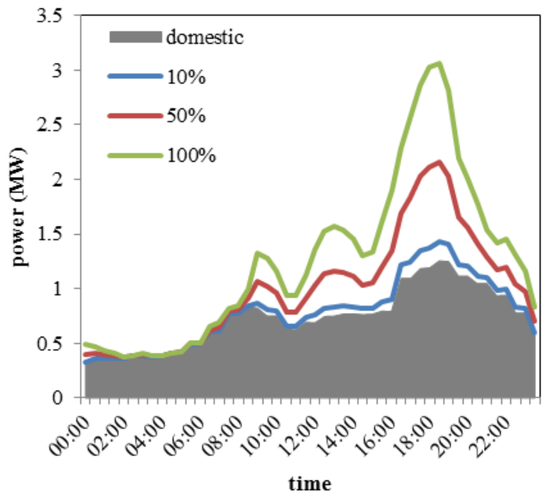


Figure 10. The aggregated electric vehicle charging load increases the existing domestic demand peaks.

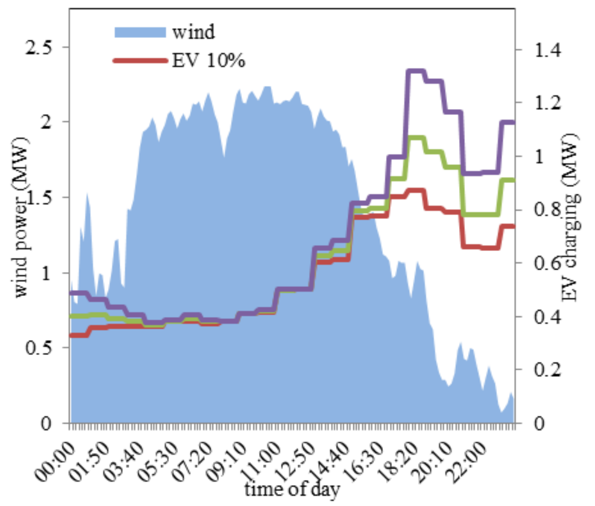


Figure 11. The electric vehicle charging profiles shows the time difference with wind power output.

4 Conclusion

The rapid development of electric vehicle market leads to increasing ownership and electricity demand in the domestic sector. However, benefit can be derived from these domestic owned electric vehicles, supporting regional distribution network operations, if they are utilised as responsive load. This paper has explored these opportunities and in particular the potential of EV charging load to absorb otherwise surplus energy from local wind farms in the context of high penetration of wind generation in the power system. Monte Carlo simulation has been used to generate electric vehicle charging profiles. Domestic load profiles have been created for the case study and wind farm monitoring data has been used to to provide an example of typical wind power temporal variation. The outcome of this case study suggests that the amount of wind energy generated from the wind farm is sufficient to charge high levels of electric vehicle penetration;

however, the significant time period between the peak in the EV charging load and the time of maximum wind power output could be minimised by applying an appropriate charging control strategy with smart grid in the future that responds to wind availability.

Acknowledgements

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