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# **Potential Impact of Uncoordinated Domestic Plug-in Electric Vehicle Charging Demand on Power Distribution Networks**

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## **Abstract**

Electric vehicle (EV) user trials have been performed by a major UK electricity utility in cooperation with an automobile manufacture in order to determine the impact of domestic user charging on the regional power distribution system. Charging facilities are made available within the users' homes; delay timers are included and a dual electricity tariff is offered. User charging behaviour must be seen in the context of the wider household activity and has a significant influence on the EV charging demand. Unconstrained charging behaviours have been examined for two types of EV and two different associated charge rates. LV network models have been constructed in OpenDSS to assist in the determination of potential future impacts of EV charging demand. This paper presents the key finds of the LV network impact analysis, including peak power demand and voltage deviation.

*Keywords: BEV (battery electric vehicle), charging, demonstration, simulation, incentive*

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## **1 Introduction**

With recent developments in battery technology and economics, drivers are increasingly turning to electric vehicles (EVs) for their routine short-distance journeys. Since 2009 several electric vehicle user trials have been undertaken, in particular through collaborations between major UK electricity utilities and motor companies, [1, 2]. The purpose of these trials was to determine the extent of future impact of EV charging demand on the power distribution network. Domestic EV use patterns will of course have significant influence on the shape of the charging demand. An important outcome from these trials is an improved understanding of the expected loads and their timing, and also importantly the

uncertainties associated with domestic vehicle use.

Previous studies have analysed the potential impact of electric vehicle charging demand on the power system; but often these have ignored the nature of household activities [3, 4]. This paper presents the outcome of a thorough analysis of EV charging demand based on an on-going trial supported by the UK's Technology Strategy Board (TSB) and involving the Ford Motor Company, Scottish and Southern Energy (SSE) and the University of Strathclyde. This trial has assessed the impact of EV's on the distribution system when uncoordinated and unconstrained charging is allowed. The resulting load flow calculations indicate that, without any constraints on charging, significant increases to the existing peak loads on the distribution system will occur.

## 2 Uncontrolled Vehicle Charging

For uncontrolled EV battery charging, profiles have been generated under the assumption that when an EV returns home, it would immediately be put on charge and remain plugged in until charging was complete. This approach was followed in the simulations undertaken by Huang and Infield at the University of Strathclyde and described in [5]. The EV penetration was varied in 10% increments from 0% to 100%. Two types of plug-in electric vehicle, manufactured by two different automobile companies, have been modelled for the most recent network impact assessment. For the trials, households were fitted with one of two differently rated charging facilities as appropriate to the EV being used. The domestic houses using EV1 have a 13A rated charging facility, while the houses with EV2 have a 32A ‘fast’ charge facility. The time resolution for vehicle charging profiles have been converted from 10 minutes to 30 minutes basis. Both sets of domestic houses also have reduced evening tariffs for their electricity supply. The characteristics of the EVs and charging facilities are summarised in Table 1.

Table 1: Electric vehicle characteristics

	Electric Vehicle 1 (EV1)	Electric Vehicle 2 (EV2)
Battery capacity	28kWh, with 80% usable allowance	35kWh, with 80% usable allowance
Domestic Charging Facility	Single phase: 240V, 12A	Single phase: 240V, 31A Slow rate: 240V, 12A
Charging Period	7.49 hours	4.0 hours 9.4 hours with slow rate

For network modelling purposes, the EVs were distributed randomly amongst the houses connected to the network, thus only the distribution of the EVs on the network, and not the profiles themselves, needed to be generated anew for each run of the simulation. The chargers were assumed to operate at a constant power of 2.88kW or 7.44kW depending on the rating of the charger (13A or 32A), with the final

‘ramp down’ of the charger power at high SOC (as implemented in commercial EV chargers) ignored in these simulations for simplicity.

### 2.1 Monte Carlo Simulation Results

Multiple sets of charging profiles were available for each EV penetration on a given network, which provides the required statistical uncertainty. In the unconstrained and uncontrolled charging scenario where vehicles are charged immediately on return home, vehicle charge periods are less likely to overlap because an earlier arriving car is likely to have finished its charge by the time the next car arrives home, compared to the case of a timed charging approach in which all vehicle charging would start for example at the beginning of the low electricity tariff period.

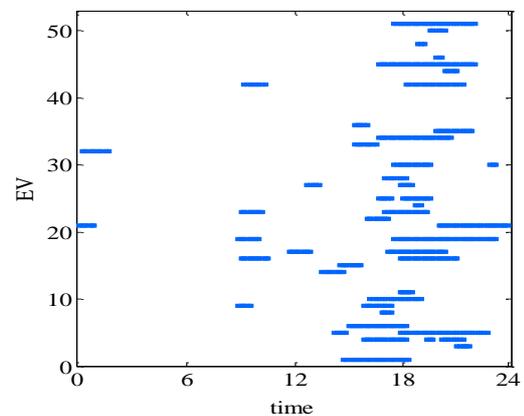


Figure 2. Individual EV charging demand within 24hours for one selected feeder.

As illustrated in Figure 1, the realisations of uncontrolled vehicle charging profiles with 100% EV penetration varies within each set of Monte Carlo simulation results. The uncertainty of vehicle charging reflects the nature of human domestic activities. However, as expected, the charging peak occurs around evening time as the majority of EVs return home at this time of day. This is illustrated in Figure 2, which shows the number of cars charging throughout a typical day – the 13A and 32A charging profiles were generated from the same arrival times and energy requirements, however fewer 32A vehicles are charging at any given time.

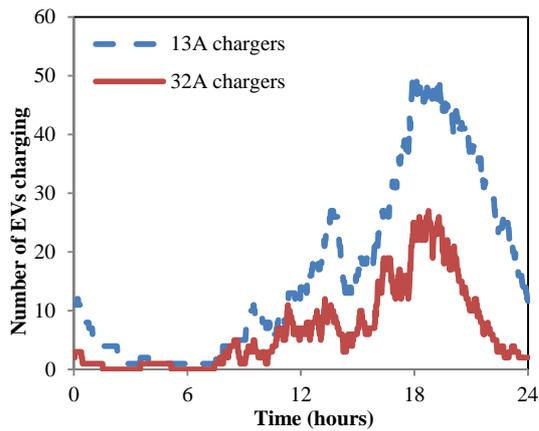


Figure 2. Simulated number of EVs charging throughout a typical day in the unconstrained scenario for the network, with 100% EV penetration.

### 3 Low Voltage Network Modelling

The impact of EVs on the low voltage network have been analysed using the OpenDSS modelling software to undertake the power flow calculations. The network is based on data for low voltage feeders in the southeast of England obtained from SSE. Phase information was not available, and the phases were assigned to each house assuming a relatively balanced network alternating between each phase. For two of the networks, a single feeder was modelled, while the third network included details from each of the 5 feeders connected to the substation. Domestic household load profiles were created using the simulation tools developed by Richardson et al and described in [6]; this is referred to as the CREST profile in this paper. The time resolution of the CREST profiles has been converted to half hour basis.

Table 2: Characteristics of modelled networks

	Network 1	Network 2	Network 3
No. Feeders	5	1	1
No. Houses	226	49	62
Transformer Rating	750kVA	500kVA	500kVA

## 4 Impact Analysis

Peak power, line current and voltage deviation are the key parameters to be investigated using the LV network power flow calculations. The following sections discuss the potential impacts and opportunities arising from uncoordinated electric vehicle charging.

### 4.1 Peak Power

The substation transformer was taken to be rated at 750kVA. A selection of simulated peak power values for each time step in the day is shown in Figure 3 for the substation transformer, during the month of September. The peak power recorded at the substation is increased in all simulations as calculated for the CREST profiles. However, unlike the predictions, no instances were observed in which the substation or feeder power limits were exceeded. This is surprising as one would expect uncontrolled charging to be more likely to exceed the substation power limits.

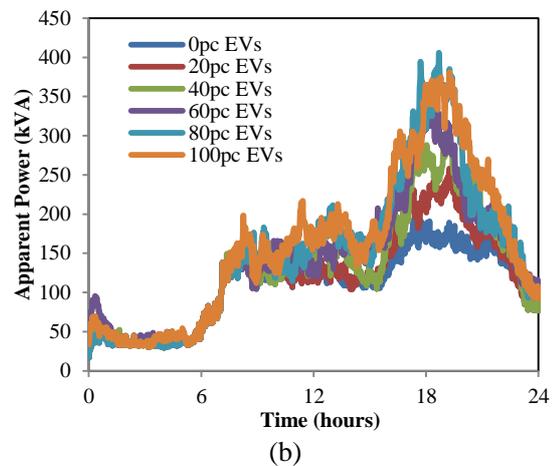
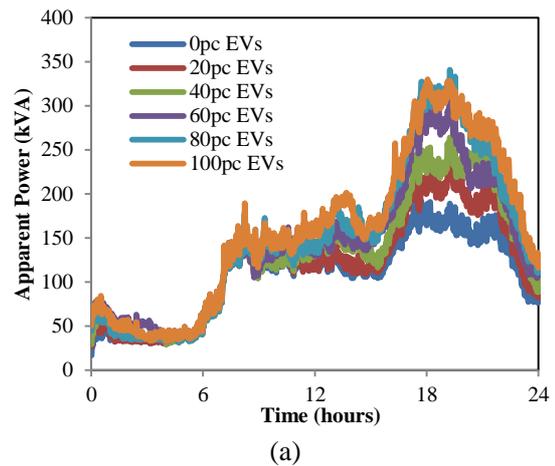


Figure 3: Simulated substation peak power at each time step in the day in September, for a) 13A EV chargers, CREST profile, b) 32A EV chargers, CREST profile.

The increase in peak power per house caused by the introduction of EVs confirms that the 32A chargers have only a slightly larger impact on peak power than do the 13A chargers for this scenario. Using Excel to calculate a linear relationship between the peak power increase per house and EV penetration, forced through the origin since if there are no EVs there can't be an increase in peak power, gives the following results:

- 13A CREST profiles:  $7.6 \pm 0.2W$  per house, per %EV penetration.
- 32A CREST profiles:  $11.6 \pm 0.4W$  per house, per %EV penetration.

In other words, for the 13A chargers the CREST profile predicts that on a network with 200 houses, and a 10% penetration of EVs, the overall peak power would increase, on average, by  $7.6 * 200 * 10 = 15200W$  or 15.2kW. The 13A CREST profile results show lower peak power increment than the 32A results, which are little more divergent. It is believed that the CREST profiles create a realistic prediction of the impact of EVs on substation peak power for the uncontrolled charging scenario, as shown in Figure 4.

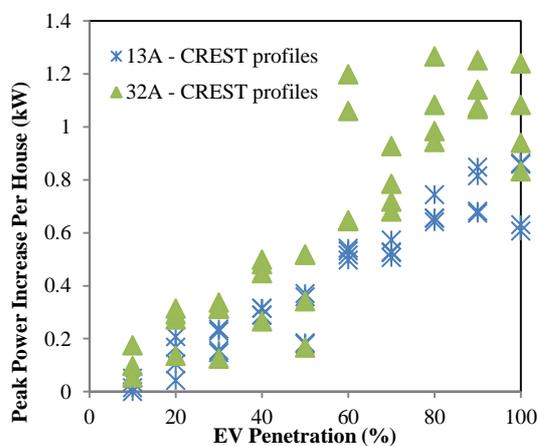


Figure 4. Increase in peak power per house for different penetration levels of EVs.

From Figure 4 it seems that the 13A chargers have a comparable impact on peak power as the 32A chargers, over most EV penetration levels in the uncontrolled case, until ~70% penetration. This surprising result is likely due to the fact that a higher power charge means a faster charge and in the uncontrolled scenario vehicle charges are much less likely to overlap because an earlier

arriving car is likely to have finished its charge by the time the next car arrives home.

## 4.2 Line Current Limits

Peak line currents were analysed based on the number of houses per phase for one selected feeder. The results are shown in Figure. 5.

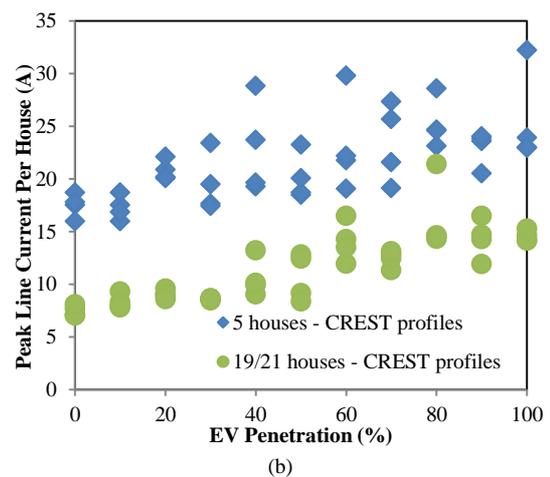
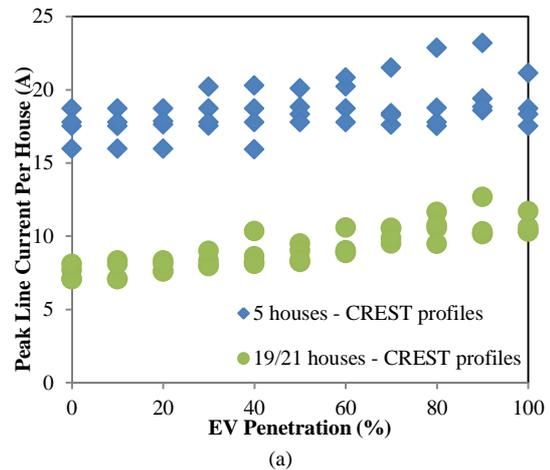


Figure 5. Peak line currents per house for different penetrations of EVs, given: a) 13A chargers, b) 32A chargers.

For the 13A chargers on 5 house lines, the peak line currents using the CREST profiles are more stable for different numbers of EVs than the 19/21 houses lines. The CREST profiles also predict higher peak line currents when there are few EVs on the network, and for some cases, they predict lower peak line currents even when there are more EVs (this is shown in more detail in Figure 5). The 19/21 house lines consistently show a slightly higher predicted peak line current using the 32A chargers than the 13A chargers case. This is probably because the larger number of houses

means that it is unlikely that most of them will have a high current draw at the same time, so the higher average power of the CREST profiles becomes more significant.

### 4.3 Voltage Deviation

The voltages at selected houses, found at the ends of long lines, were monitored for both Network 1 and Network 3. The lowest voltages of those monitored were found at the end of the two single phase lines, and the minimum voltages for these lines from the various monthly simulations are shown in Figure 6. For the 13A chargers, the CREST profile simulations did not predict any voltage drops below the UK limit of 216.2V, assuming a nominal substation voltage of 250V line-neutral. The 32A chargers were predicted to create occasional voltage dips below nominal from 60% EV penetration onwards using the CREST profiles.

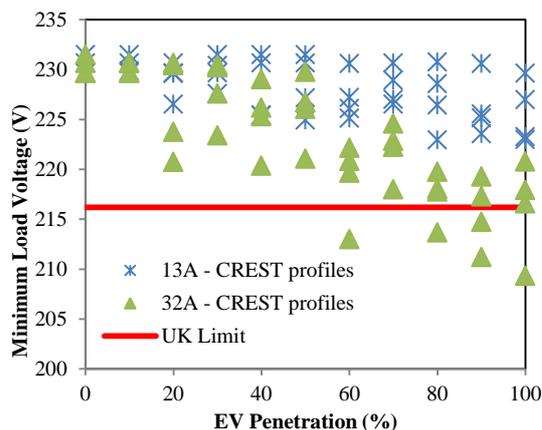


Figure 6. Minimum voltages from selected loads during the monthly simulations.

## 5 Conclusions

This paper has illustrated the key findings of the impact of the unconstrained and uncontrolled vehicle charging on the realistic low voltage network. Three key parameters, peak power, line current and voltage deviation, have been investigated. Although low penetrations of EVs are not likely to cause any problems to the distribution network, these potential problems can be deferred or prevented entirely using controlled charging strategy assuming that the vehicle charging current remains low (13A was modelled here, however 16A may also be acceptable) and provided that there are no competing overnight loads such as storage heaters on the network. If the vehicles have 32A

chargers, the preliminary results of the uncontrolled charging simulations indicate that they are less likely to increase peak substation power, increase peak line currents, and increase voltage deviations. In this preliminary analysis the voltage deviations were a more significant problem for this scenario than excessive line currents.

The next step of the research will focus on the demand management of vehicle charging by controlling or shifting the vehicle charging depends on the network load as well as including the situation of flexible electricity price.

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## References

- [1] NISSAN UK, "Nissan Leaf Joins UK Electric Vehicle Trial", available online: <http://afnoble.nissan.co.uk>. Accessed on 14th May 2012.
- [2] Arup, "UK's largest electric vehicle trial – first findings", available online: <http://www.arup.com/>. Accessed on 15 June 2010.
- [3] J. Taylor, A. Maitra, M. Alexander, D. Brooks, and M. Duvall, "Evaluations of Plug-in Electric Vehicle Distribution System Impacts," in the Proceedings of IEEE Power and Energy Society General Meeting Minneapolis, USA, 2010, pp. 1-6
- [4] K. Clement-Nyns, E. Haesen, and J. Driesen, "The Impact of Charging Plug-In Hybrid Electric Vehicles on a Residential Distribution Grid," IEEE Transactions on Power Systems, vol. 25, pp. 371-380, February 2010.
- [5] S. Huang and D. Infield, "The Impact of Domestic Plug-in Hybrid Electric Vehicles on Power Distribution System Loads," in the Proceedings of the 2010 International Conference on Power System Technology (POWERCON), Hangzhou, China, 2010, pp. 1-7.
- [6] I. Richardson, M. Thomson, D. Infield, and C. Clifford, "Domestic electricity use: A high-resolution energy demand model," Energy and Buildings, vol. 42, pp. 1878-1887, 2010.

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