IMPACT OF ELECTRIC VEHICLE CHARGING ON RESIDENTIAL DISTRIBUTION NETWORKS: AN IRISH DEMONSTRATION INITIATIVE

Peter RICHARDSON
University College Dublin
Ireland
peter.richardson@ucd.ie

Michael MORAN
ESB Networks
Ireland
michael.moran2@esb.ie

Jason TAYLOR
EPRI
USA
jtaylor@epri.com

Arindam MAITRA
EPRI
USA
amaitra@epri.com

Andrew KEANE
University College Dublin
Ireland
andrew.keane@ucd.ie

ABSTRACT

This paper presents details of an electric vehicle impact assessment trial currently being undertaken in Dublin, Ireland. The trial involves three stages, each of which are described in this paper. The first stage investigated the potential impact from electric vehicle charging on the operating conditions of existing residential network. During the trial, electric vehicles were driven and charged by typical residential electricity customers. The data recorded during the trial details the charging patterns of the vehicles and the associated effects on the network. Stages 2 and 3 of the trial, which are currently ongoing, will involve examining basic control charging techniques and the effects of network reconfiguration respectively.

INTRODUCTION

The development of electric vehicle (EV) technology is seen in many countries as an important component in reducing harmful greenhouse gas emissions in the transport sector. Policy incentives together with advancements in the development of EV technology will see an increase in the uptake of this technology in future years. However, the majority of electricity distribution systems across the world were not designed to be able to accommodate high penetrations of EVs. For example, some EVs will charge at a rate of 3.3-6.6 kW and for as long as 6-8 hours for a full charge. This type of load is considerably different to traditional loads that could be expected to be found in residential networks. As a result, the introduction of a substantial number of EVs in residential networks could significantly alter typical demand patterns and lead to adverse effects, such as excessive voltage drop and overloading of network components [1]-[5].

Understanding how domestic EV usage is likely to affect distribution system operation will be crucial to maintaining a reliable network in the future. As such, the distribution system operator (DSO) for the Republic of Ireland established an EV field trial demonstration project which commenced at the beginning of 2011 as part of a wider Smart Grid Demonstration Programme [6]. The EV field trial project is part of a collaborative effort to evaluate potential issues at the distribution system level from initial low penetration levels of EV loads, and to gain insight into the potential impact from higher penetration levels that are possible in the future. Future stages of the trial, which are described later in the paper, will investigate basic controlled charging techniques as well as using network reconfiguration as a means of reducing the impact of widespread EV charging on residential networks.

OUTLINE OF FIELD TRIAL - STAGE 1

The objective of Stage 1 of the field trial was to gain an understanding of the technical effects that may result from EV usage. In particular, the focus of the trial was on assessing the impacts from EV charging on residential network operating conditions. By allowing existing electricity customers to use and charge EVs as they required, it was possible to record how the additional load affected network parameters such as customer voltage levels and component loading.

Initially, a residential low voltage (LV) network was selected as the trial network for the deployment of the EVs. Two Mitsubishi iMiEVs [7] have been made available for the field trial through the DSO. Stage 1 of the field trial took place over a twelve month period, with the cars rotated to customers located at positions of interest on the same feeder, as determined by simulation of the feeder. Each selected customer was provided with the car for three months. The vehicles were deployed as a pair, i.e. the two vehicles were allocated to two customers for three months at a time. This allowed eight customer points of connection to be assessed over the one year period. For the final part of the impact assessment stage, seven vehicles were made available and given to customers, which facilitated analysis of a 10% penetration of vehicles on the network.

At each selected customer point of connection a smart meter was installed to track the overall demand of the customer's residence. This meter recorded average, maximum and minimum voltage, current and power factor measurements every 10 minutes. Another meter was installed at the EV charger of the participant's household to record the EV charge demand. A power quality meter was also installed at the 10/0.4 kV transformer which recorded 30-second resolution data of the overall loading on the feeder.

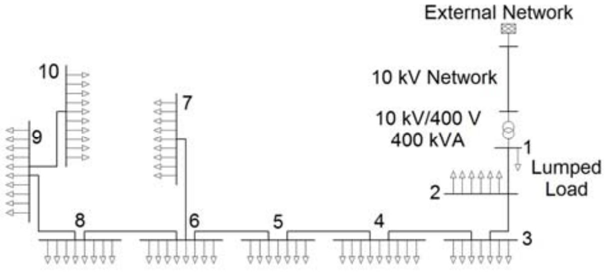

Fig. 1 Schematic diagram of residential distribution network for EV field trial.

FIELD TRIAL NETWORK

The test network chosen for the EV field trial was located in a suburb of Dublin, Ireland. The feeder represents a modern underground LV network. The households connected to the feeder are typical 3/4 bedroom, semi-detached residential buildings each of which has a driveway to allow off-street parking. A schematic diagram of the network is shown in Fig. 1. The original network configuration of this feeder served 54 households. For the purpose of the field trial, the network was reconfigured to increase the network impedance and the number of customers served by the feeder to a total of 78. This was achieved by closing a normally open point between node 8 and node 9 and relocating it to include nodes 9 and 10. The feeder is fed via a radial 3-phase cable to mini-pillar junction boxes (i.e. the feeder nodes) which feed individual houses via single-phase service cables. The nominal voltage for LV networks in Ireland is 230/400 V with a range tolerance of ±10%. The 400 V feeder is stepped down from the 10 kV system via a 10/0.4 kV transformer which also supplies 3 other feeders, represented by the lumped load at node 1 in Fig. 1. The transformer is not equipped with tap changing capability. The sending voltage for the network is set upstream at the 38/10 kV transformer which does have tap changing capability.

RESULTS AND DISCUSSION

Prior to Stage 1 of the trial, a series of power flow simulations were performed on a model of the test network in order to determine suitable locations for the EVs. From this analysis, EVs were allocated to households where charging was most likely to have the greatest effect on network operating conditions. Throughout the trial, data was gathered by the various metering devices which provided information relating to the charging behaviour of the EV users and also the operating parameters of the network.

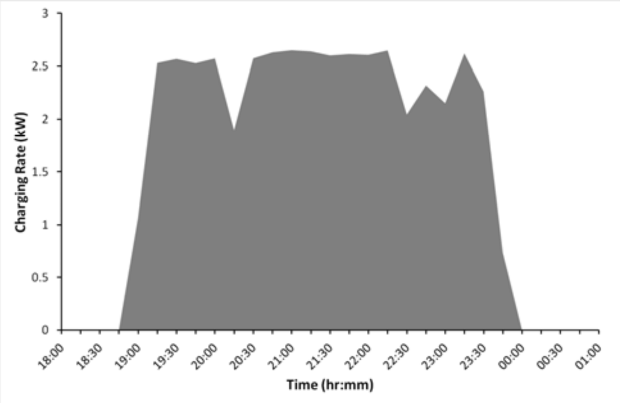

Fig. 2 Sample charge profile of an EV used in the field trial.

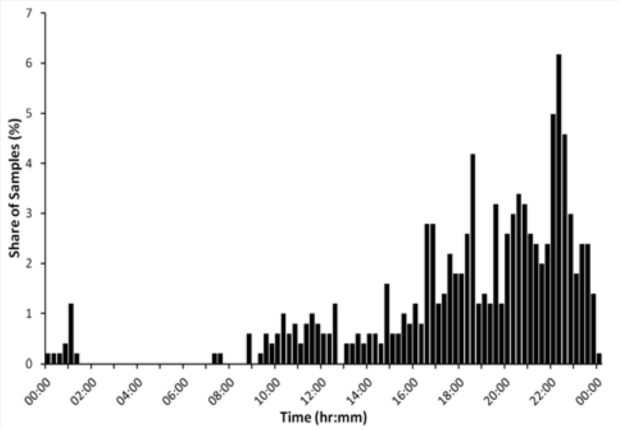

Fig. 3 Probability distribution function of EV connection times recorded during the field trials.

Electric Vehicle Charging Characteristics

Each EV charging point had a meter installed which recorded the active power demand of the EV during charging periods. A sample charge profile for a vehicle is shown in Fig. 2. The charging rate of ~2.7 kW is similar to the daily peak demand of many of the households in the trial network. From all of the meter readings taken over the 12 month period, it was possible to determine distribution functions of likely EV charging characteristics such as connection times for charging and the daily energy demand.

Connection Times

The distribution of recorded connection times for EV charging during the field trials is given in Fig. 3. It is evident that the majority of EV charging connections occurs after 4 pm each day with the highest probabilities of connection occurring at approximately 6.30 pm and again at 10.30 pm. This would suggest that there are some EV owners who connect for charging upon arrival home from the workplace (assuming typical business hours). The second peak indicates that a significant number of connections occur just before night time suggesting that some owners postpone charging until after the last trip of the day.

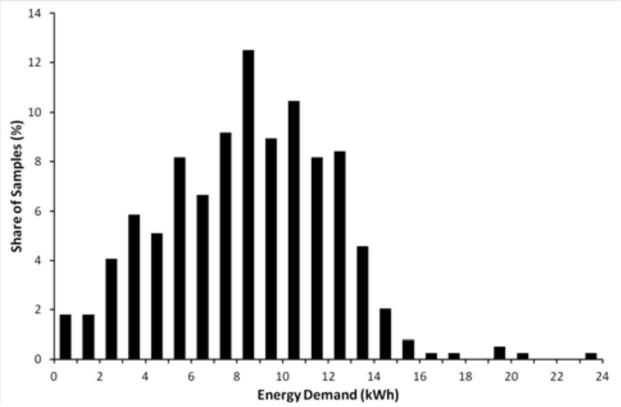

Fig. 4 Probability distribution function for the daily EV energy requirement.

Energy Requirement

The distribution function of the daily energy requirements of the EVs recorded during the field trials is shown in Fig. 4. Each EV had a battery capacity of 20 kWh. However, it is evident that there are some cases when the total daily energy requirement exceeded the rated battery capacity. This indicates that there were a number of occurrences when an individual EV was connected for charging at least twice within one 24-hour period. The most common daily EV energy requirement was between 8 kWh and 9 kWh, approximately half of the rated battery capacity of the EVs. Energy requirements close to 0 kWh or 20 kWh (i.e. rated capacity) are less frequent, possibly indicating that EV owners were reluctant to allow their EV battery to approach full depletion and/or felt it was not necessary to charge if the state of charge is above approximately 75%.

Network Impact

Fig. 5 shows the average and minimum voltage values recorded over a 24-hour period for a household located towards the end of the feeder. It is evident from the graph that even though the average value recorded may be comfortably within the limits, there may be short term occurrences where the values are recorded outside acceptable limits, as defined in [8]. This is demonstrated in Fig. 5 where the minimum 10-minute voltage value recorded at approximately 7 pm was 0.89 pu (204.7 V).

LV network demand profiles do not have the benefit of aggregation that analysis of higher voltage networks benefit from. The use of a high power device for short time periods will not always be completely captured within an average value ten minute window. This may pose unforeseen issues in networks with a large penetration of EVs due to the increase in a household's base demand caused by EV charging. Therefore, due consideration for the maximum and minimum 10-minute values should also be given when analysing such LV network data.

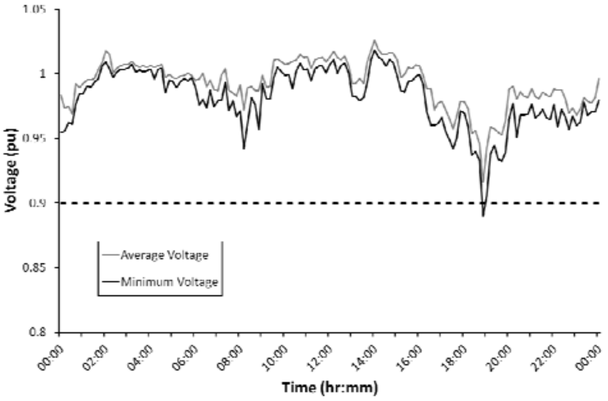

Fig. 5 Voltage and current profiles for a household showing an example of the minimum voltage falling below the lower permitted limit of 0.9 pu.

FURTHER WORK

One of the main issues facing the DSO in relation to the charging of electric vehicles is the voltage drop on the feeder due to the increased demand from the EVs. Thermal ratings of cables and transformer ratings for this network are not significant factors as the capacity is seen to be sufficient to accommodate high percentages of EV charging. It is clear however that the hosting capacity of the LV network must be increased to mitigate the voltage concerns, particularly towards the end of the feeder. Two options that are due to be trialled are Smart Charging and Paralleling of the LV network.

Stage 2 - Smart Charging of Electric Vehicles

In order to conduct this part of the trial, which is taking place from December 2012 to February 2013, seven vehicles again are currently deployed on the field trial network, with the phase allocation as follows: 4 EVs on S phase, 2 on R phase and 1 on T phase, all EVs are also placed toward the end of the feeder.

The peak demand for the network is between 6.30 pm and 8.30 pm and this demand is compounded by high levels of coincident charging on the network at the same time (Fig. 3) resulting in voltage dips as seen in Fig. 5. Smart Charging will serve to eliminate this peak by shifting the time that the particular EV will be charging. The software platform that is controlling the charging regime is a ‘self learning’ platform that will take into account the daily usage needs of the driver and ensure there is enough charge plus a contingency for the next time the EV is used. The driver is also able to interact with a tablet type device to input anything that may be above the charge level that is predicted by the software.

This particular stage is being broken into two parts. The first part is concerned with each EV location operating independently while the second part of the trial involves a central controller that can take into account the charging regimes necessary at each dwelling.

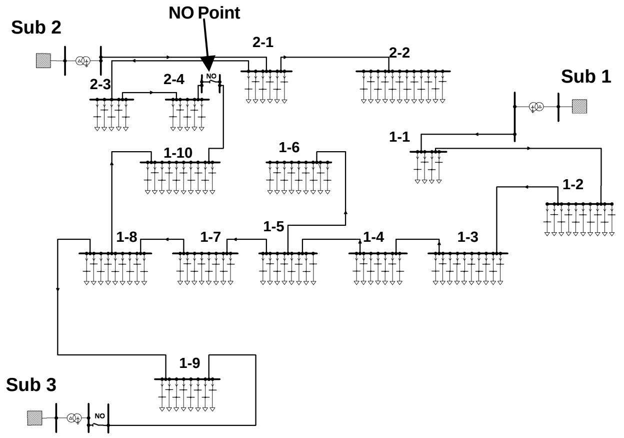

Fig. 6 Detailing the three MV-LV Sub Stations feeding into the trial area (Note: trial area is fed from Sub 1)

Stage 3 - Paralleling of LV Network

Stage 3 of the EV field trial is due to take place from November 2013 to February 2014. As the network under investigation is of an urban nature there are possibilities when it comes to back feeding from a different transformer via a normally open point.

For this stage of the trial it is proposed to install a device at the normally open point between the trial feeder and a neighbouring feeder. This will allow reinforcement at the points of the feeder worst affected by the introduction of EVs by paralleling or meshing the two transformers via the LV network thereby increasing the capacity of the network.

For this aspect of the trial the paralleling device will be placed at the normally open point between nodes 2-4 and 1-10 as detailed in Fig. 6 above. It is worth noting that in order for a device like this to operate effectively it must be placed at a normally open point which has quite different demand curves on either side. If demand curves are similar and there is a power draw through the device then it would suggest the wrong placement of the normally open device. Robust controls and network protection will also need to be put in place in the case of paralleling network as there are significant risks associated with operating an LV network in this configuration i.e. circulating currents, thermal ratings of cables surpassed and the possibility of back feeding onto a high impedance fault. Each of these aspects will be assessed in the presence of EV charging on the network during this stage of trial.

CONCLUSION

The first stage of the EV field trial has produced a number of interesting results from the point of view of the DSO. Measurements from the trial provide high quality data at points on the network that generally have little or no data recording capability. They also provide information on the EV usage behaviour, which will be valuable for predicting when charging is likely to occur and predicting what the resulting impact on the network will be. The developing picture this data forms will be an important element in understanding the potential impact that EVs and residential energy resources may have in the future.

Stages 2 and 3 of the trial will also provide valuable information in this regard. Understanding how controlling EV charging, in order to avoid creating additional load during peak demand hours, could affect owners will be crucial if large EV penetrations are to be realised. Examining the effects of network reconfiguration in the LV distribution system will also provide useful information in terms of maintaining sufficient power quality in the presence of EV charging.

ACKNOWLEDGEMENTS

The authors would like to thank Dr Damian Flynn of University College Dublin for his input to the project.

REFERENCES

[1] R. A. Verzijlbergh, M.O.W. Grond, Z. Lukszo, J.G. Slootweg, and M.D. Ilic, 2012, "Network impacts and cost savings of controlled EV charging," *IEEE Transactions on Smart Grid*, vol. 3, no. 3, pp. 1203-1212.

[2] J. Taylor, A. Maitra, M. Alexander, D. Brooks, and M. Duvall, 2009, "Evaluation of the impact of plug-in electric vehicle loading on distribution system operations", *Proceedings IEEE Power and Energy Society General Meeting*, Calgary, AB, Canada.

[3] P. Richardson, D. Flynn, and A. Keane, 2010, "Impact assessment of varying penetrations of electric vehicles on low voltage distribution systems", *Proceedings IEEE Power and Energy Society General Meeting,* Minneapolis, MN, USA.

[4] L. Dow, M. Marshall, L. Xu, J. Romero Aguero, and H.L. Willis, 2010, "A novel approach for evaluating the impact of electric vehicles on the power distribution system," *Proceedings IEEE Power and Energy Society General Meeting*, Minneapolis, MN, USA.

[5] J.R. Pillai and B. Bak-Jensen, 2010, "Impacts of electric vehicle loads on power distribution systems," *Proceedings IEEE Vehicle Power and Propulsion Conference (VPPC).* Lille, France.

[6] A. Walsh and T. Fallon, 2011, "ESB networks Smart Grid demonstration pilot," *Proceedings IEEE Power and Energy Society General Meeting*, Detroit, MI, USA.

[7] Mitsubishi iMiEV, Mitsubishi Motors Corporation. URL: http://www.mitsubishi-motors.com/special/ev/

[8] EN50160, Voltage characteristics of electricity supplied by public electricity networks, 2010.