DIRECT CONTROL OF EV CHARGING ON FEEDERS WITH EV CLUSTERS

Ellin SAUNDERS
EA Technology – UK
ellin.saunders@eatechnology.com

Tim BUTLER
EA Technology – UK
timothy.butler@eatechnology.com

Jairo QUIROS-TORTOS
University of Manchester – UK
jairo.quirostortos@manchester.ac.uk

Luis F. OCHOA
University of Manchester – UK
luis.ochoa@manchester.ac.uk

Richard HARTSHORN
Scottish and Southern Energy Power Distribution – UK
richard.hartshorn@sse.com

ABSTRACT

The My Electric Avenue project has established ten clusters of electric vehicle (EV) users on real UK feeders, and is currently running trials that explore EV user behaviours and the impact of charging vehicles on local networks. As part of the trials, the technology Esprit has been deployed to curtail EV charging during high feeder loads using Power Line Carrier (PLC) communication, to assess its capability to delay or prevent the need for network reinforcements whilst accommodating the needs and perceptions of EV users. With over 200 EVs in the field, this paper provides an overview of the trials and the technical and social data collected. Initial findings are presented on a case study basis relating to patterns of feeder currents and EV charging, coincidence of EV load, Esprit function in practice, and the reliability of PLC.

INTRODUCTION

Uptake of EVs is forecast to increase significantly [1] and remains a key area for governments to reduce carbon emissions, alongside the decarbonisation of the electricity sector. The effects of the uptake of EVs and other Low Carbon Technologies (LCTs) is an area of concern for distribution network operators, and demand side response is a key area of interest to mitigate impacts on the electricity grid. EVs are now becoming more commonplace [2] and following the roll-out patterns of other LCTs, namely solar photovoltaics, has shown that ownership can be clustered [3]. This can concentrate charging demand to a small area served by a common Low Voltage (LV) network. As has been previously reported by smart grid projects such as the Customer-Led Network Revolution (CLNR) [4], EV charging demand is coincident with domestic household demand, leading to increased peaks. Network operators therefore need a cost effective, easy to implement intervention that delays network reinforcement while supporting growth of EVs.

MY ELECTRIC AVENUE

My Electric Avenue (MEA) [5], conceived and awarded under the name Innovation Squared: Electric Vehicles (I^2EV), is a project funded by Ofgem's Low Carbon Networks (LCN) Fund, and was devised to investigate the effects of clustered EVs on single LV feeders. The project has established ten such clusters across Great Britain with 7-13 EVs, by recruiting groups of neighbours each leasing a Nissan LEAF all-electric vehicle. The trials offer a unique opportunity to monitor and control levels of EV penetration similar to that forecast to be connected to local networks in the future.

A key part of the My Electric Avenue project is to trial Esprit [6], a technology that can manage the EV component of electricity demand at a local level. Esprit is a control system designed by EA Technology and directly manages the EV charging points on a feeder by disconnecting them when phase currents exceed a threshold [7]. This effectively delays charging until capacity becomes available. A similar although separately developed control algorithm is also demonstrated in [8]. At present the Esprit control system uses Power Line Carrier (PLC) communication, which gives network operators full control over the communication signals and is license free. A subsidiary goal of the project is to investigate the effectiveness of PLC as a communication medium for a distributed control system.

As the field trials involve EV users from the general public, data is also being collected on charging and driving behaviour via both technical monitoring and social research. Such information will help to explore the effect, if any, of Esprit on the experience of using and charging EVs.

Esprit should ultimately act to prevent distribution network capacity from becoming a barrier to the uptake of EVs. A crucial aim is to control EV charging points in a consumer sympathetic way – social acceptability is therefore of as much interest as technical feasibility. To this end, the project is also monitoring the usage of vehicles where there is no management of charging, providing a control group to explore differences in perception. Combined with extrapolation of findings through simulation, the project will deliver important learning on the additional EVs that feeders can accommodate using a system to control EV load within the bounds of consumer acceptability.

My Electric Avenue has installed the Esprit technology at the cluster sites and deployed over 200 EVs. This paper presents an overview of the data that is being collected as part of the project, and illustrates initial case studies of behaviours within that data that will be the subject of further analysis as the project progresses.

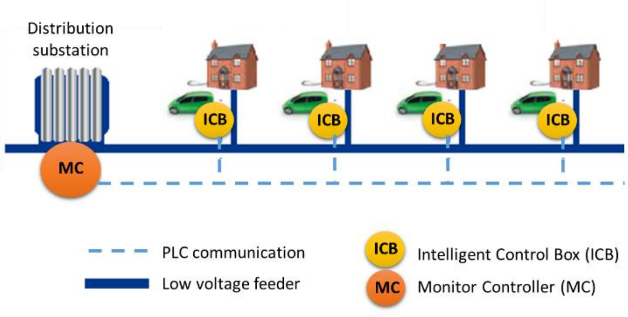

Fig. 1. Network schematic of Esprit technology, using Power Line Carrier (PLC) communication

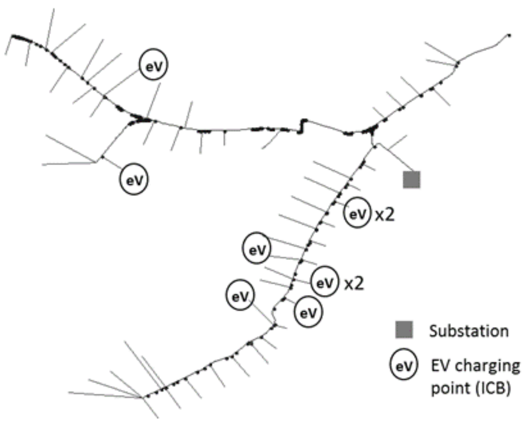

Fig. 2. Feeder serving the ML cluster, with trial EVs and charging points at seven properties. Two properties have two EVs each.

Table 1. Residential clusters in the MEA technical trials

Cluster ID	*Households on feeder*	*Trial EVs*	*'EV penetration level': Trial EVs as % of households*
CC	149	8	5%
CRG	122	10	8%
WC	72	10	14%
GC	57	9	15%
ML	57	9	16%
JD	62	10	16%
SS	54	11	20%
SS2	61	12	20%
BL	22	7	32%

ESPRIT TRIALS

The Esprit technology has two parts: a Monitor Controller (MC) at the substation and an Intelligent Control Box (ICB) connected to each of the EV users' charging points (Fig. 1). The MC monitors the feeder current on each phase and, in the event of an overload being detected, it sends control signals via PLC to ICBs on that phase to curtail charging, disabling those charging points. During times when the network can accommodate some but not all of the EVs, an embedded control algorithm has been designed to cycle the charging points to spread the available capacity between EV users.

To trial and gauge the consumer acceptability of Esprit, My Electric Avenue is designed around sets of technical and social field trials of EV users. **Technical trials** consist of local clusters of EV users, whose homes or premises are supplied by the same LV distribution feeder. Fig. 2 illustrates one of these feeders. Esprit is in the process of being trialled at ten such locations within the licence areas of Scottish and Southern Energy Power Distribution and Northern Powergrid, involving a total of 99 EVs. Nine of the feeders are residential, and one serves commercial premises. Table 1 characterises the residential MEA clusters. Penetration of trial EVs on the LV network as a proportion of properties ranges from 5-32%. All cluster networks have been assessed as having the capacity to accommodate the additional EV load without the Esprit system, noting the trial nature of the project. Esprit's threshold level (the phase current level that will trigger curtailment) is set artificially low during the field tests, in order to frequently trigger the control mechanism.

Social trials consist of EV users geographically dispersed across Great Britain, and currently comprise 121 vehicles. As their charging points are not controlled by Esprit, they form a base case of un-curtailed EV users whose behaviours and attitudes can be compared to participants who are being curtailed.

From these field trials two broad types of information are being collected. Firstly, **technical data** (further described below) is collected to create realistic profiles of key parameters such as feeder currents and voltages, EV charging times and their aggregate load on the network. Data will also provide characteristics of delayed charging and EV user behaviour under curtailment, reduction in headroom achieved by the Esprit logic for different settings, and the ability of PLC communication to achieve reliable direct control of loads. In addition to offering valuable insights for network operators and further research, such data is used within the project to verify network models. These in turn enable simulations of EV usage, the impact of Esprit control on a wider set of feeders, and modelling of different EV penetration levels. Secondly, **social data** is collected through questionnaires and interviews with participants, and will be used as a basis for social research to assess consumer acceptability of Esprit. This paper focuses on technical data.

Technical data

Two separate systems deliver the monitoring of the project's technical data. Network monitoring and Esprit control data is obtained from the MCs and ICBs installed within the technical clusters. ICBs transmit their readings via PLC to the MC installed in the substation. The MC is connected to a SCADA RTU (Remote Terminal Unit), which in turn transmits data to a cloud server. The data set includes data up to every 10min of:

- Feeder current at substation, per phase (A)
- EV current at charging point (A)
- Voltage at charging point (V)
- Esprit curtailment status of charging point (binary)

Additionally, EV charge and journey data from the Nissan LEAFs is provided via Nissan's CARWINGS telematics system, and include vehicles from both the technical and social trials. This data set includes:

- Start and end time of charge events
- Battery charge level at start and end of charge events
- Start and end time of journeys
- Distance and energy consumption of journeys

Nearly 40,000 charge events and over 150,000 journeys have been recorded thus far as part of the technical and social trials.

INITIAL FINDINGS

With the technical and social trials currently in progress, the following section presents samples of technical data collected from residential clusters to date. Whilst the project is in the early phase of data analysis, and will deliver thorough findings at a later stage, this data provides a preliminary characterisation of different aspects of the trials, and highlights issues that are of relevance to direct control of EV loads on real feeders using Esprit.

Feeder and EV loads

Fig. 3 shows average daily 3-phase feeder currents at a subset of the MEA clusters during November 2014. Clearly resembling a familiar residential daily load curve, this pattern confirms the presence of 'valleys' into which the load of EVs that are connected during peak hours could conceivably be shifted. As trial EVs were in use, the currents include charging vehicles. However at the penetration level of the MEA clusters EVs have been shown to make a relatively minor contribution to the average load during the day, as further described below, and Fig. 3 therefore provides a relatively good indication of the shape of base household load in the clusters in the autumn/winter period. Differences in feeder current magnitude reflect the varying demographics and number of premises on the feeders.

A key issue for network operators is whether EV charging coincides with peak loading on the network, potentially giving rise to the need to curtail that additional load. Charge data from the CARWINGS dataset during November 2014, when EV charging was not curtailed by Esprit, is characterised by the distribution of charging times shown in Fig. 4. With a shape that shows similarities with residential base demand, this period of the trial indicates that a significant proportion of the charging events within the project have occurred during the evening when residential demand is at its highest, whereas fewer cars have been charging in the early morning hours when household demand is at its lowest. In terms of EV charging behaviours alone, therefore, this data confirms the technical potential to shift EV load from peaks into the early morning valleys if required, using a technology such as Esprit.

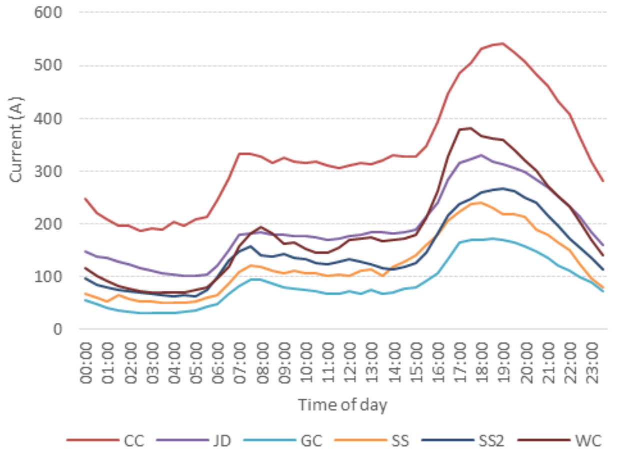

Fig. 3. Average daily 3-phase feeder current in clusters (November 2014)

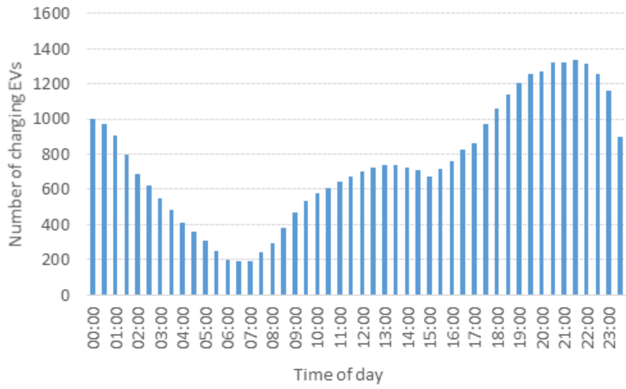

Fig. 4. Number of EVs charging at different times of the day during November 2014, across technical and social trials.

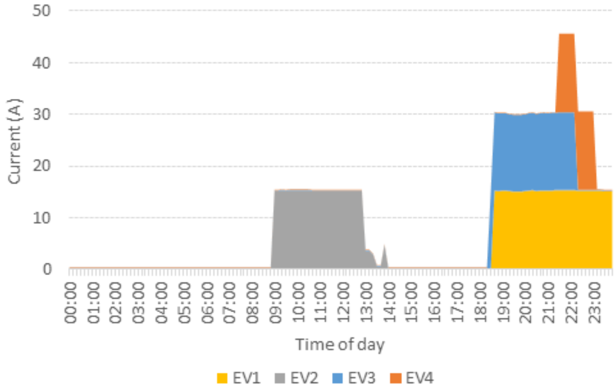

Fig. 5. Aggregated EV charging during individual day in the ML cluster

As Fig. 4 implies, monitored EV charges have shown higher than expected levels of diversity, but with the presence of a considerable evening peak. MEA technical clusters provide the opportunity to monitor the nature of coincident charging load in practice on real feeders, capturing what might occur when localised areas of EV penetration emerge. Of particular interest to system operators is the amount of diversity in EV charging demand. To date, a maximum of three EVs have been seen to charge simultaneously within any of the residential clusters of 7-12 cars. Fig. 5 shows an example of such an event on one particular day.

The project's findings will subsequently be used to inform the industry of appropriate design demands for EV charges, taking account of the levels of charging diversity expected. EVs present a large and continuous demand onto networks compared with most household appliances. This is illustrated by Fig. 6, which shows the feeder current and EV charge contribution for a single day in the ML cluster during Q3 2014 (July-September). Coincident charging of up to three EVs with 3.5kW rated charging increases the total feeder current by up to 45A, boosting the peak value seen on that feeder by 20% and raising the network load for a sustained period. This may be further exacerbated with 7kW charging enabled vehicles.

By contrast, Fig. 7 compares the average daily feeder current during Q3 with the average EV contribution, expressed as a percentage of the peak load. Viewed on this basis, charging EVs contribute at most 10% during peak loading. Whilst this helps to demonstrate the step change in network demand that can result from low to medium levels of EV penetration, it does not fully capture the impact during individual days such as Fig. 6. Data from the MEA trials and associated simulations will help to identify whether a curtailing technology such as Esprit is required only during a certain number of days of the year. If that is the case, low cost and ease of implementation would be particularly important features.

Demonstration of curtailment

Esprit has been rolled out across the technical clusters, to curtail EV charging when the feeder current exceeds the set threshold. Initial data demonstrates its functionality in practice; Fig. 8 shows the current on one phase in the CRG cluster ("Base load + EVs"). Just before 9pm the two simultaneously charging EVs bring the phase current above the threshold at 80A, whereupon Esprit interrupts the charging. Once the phase current reduces, the control algorithm in this instance allows the EVs to continue to charge 40min later and, as a consequence, the time when the phase current exceeds the threshold has been reduced.

The delay between the threshold breach and the curtailment of EV charging shown in Fig. 8 is in part due to the monitoring of ICBs (which can result in a temporal shift between collected EV current data and feeder current by up to 20min), and in part due to the frequency of the Esprit control algorithm. Experience gained during the project will allow settings to be optimised. For example, the Esprit threshold could be lowered to account for such delays, causing EV curtailment earlier.

Whilst the project has demonstrated that it is technically feasible to curtail EV charging, this intervention increases

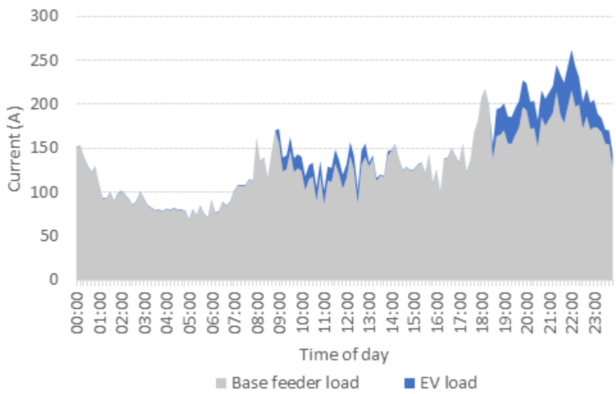

Fig. 6. EV contribution to feeder load during a day in ML cluster

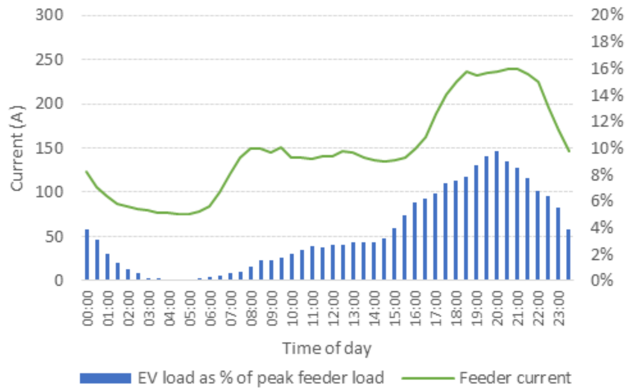

Fig. 7. Average half-hourly EV contribution to feeder load in ML cluster (Q3 2014, e.g. July-November)

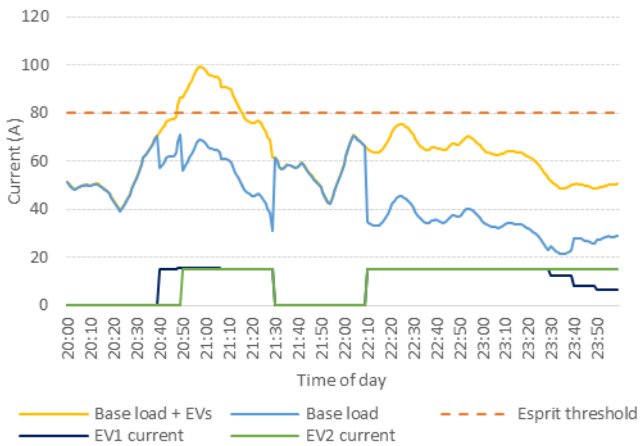

Fig. 8. Two charging EVs interrupted by Esprit in CRG cluster

the charge duration. Taking one example from the trials, Esprit disconnects a charging EV during the evening peak in the CRG cluster. In this instance the user wished to charge the vehicle from approximately a 40% battery level to a full charge. Uninterrupted this would have completed in 5h 7min, but it took 33% (1h 40min) longer as the charge was curtailed four times during a four hour window. Impacts of such delays on users is likely to depend on a number of factors, such as at how soon the user had intended to use the car after beginning the charge, the amount of energy in the battery at the start and end of the charge, and whether the car gradually received charge or was permanently interrupted for a sustained period. Data collected by the project provides the opportunity to quantify such factors as part of the technical trials. Social data will also contribute to the analysis, in particular whether curtailment affects attitudes towards EVs.

Power Line Carrier (PLC) communication

Esprit uses PLC and therefore the project has an opportunity to investigate the reliability of the PLC communication medium as an option for distributed monitoring and control applications, noting that only one manufacturer is being used. In this instance, Esprit's ability to curtail EV charging during times of high demand is clearly dependent on PLC communication reliability. Each ICB acts as a repeater for other ICBs connected to that phase and separate repeating devices can also be used to address weak signal strengths.

Reliability appears heavily dependent upon conductor length, as indicated in Fig. 9 where the probability of communication rapidly drops at 180m. Initial trial results have also demonstrated the ability of an MC to contact over 85% of a cluster's ICBs during the majority of the day (Fig. 10) on a simple feeder with few branches (Fig. 2). One ICB struggles to maintain contact, while another consistently sees a drop in reliability after 8pm which overlaps with part of the peak period when EVs are most likely to need to be curtailed. As expected, reliability is higher closer to the substation, but reasonable levels (>85%) have been achieved as far away as 250m. Overall patterns that are beginning to emerge suggest that reliability vs. distance depends on network topology as well as time of day. Poor reliability has also been experienced during daylight hours where a customer has a solar PV installation. The range of MEA technical clusters will generate additional data that will allow the project to explore PLC reliability further as the project progresses.

CONCLUSION

The My Electric Avenue trials are now underway. This paper has demonstrated ways in which the data generated by the project can be used to assess the impact of real EV clusters on feeders, and whether network reinforcement can be deferred by applying direct control via PLC to disconnect EVs in a reliable and socially acceptable manner.

ACKNOWLEDGEMENTS

The My Electric Avenue project is funded by the Ofgem Low Carbon Networks (LCN) Fund, via Scottish and Southern Energy Power Distribution. The authors would like to thank all project partners involved [5].

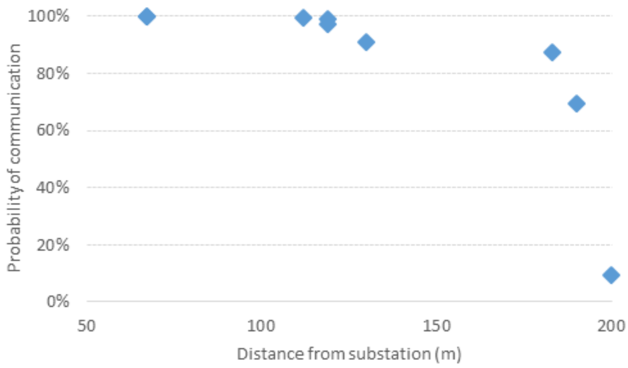

Fig. 9. Probability of communication with ICBs every 10min vs. distance from substation along the feeder (ML cluster, September 2014)

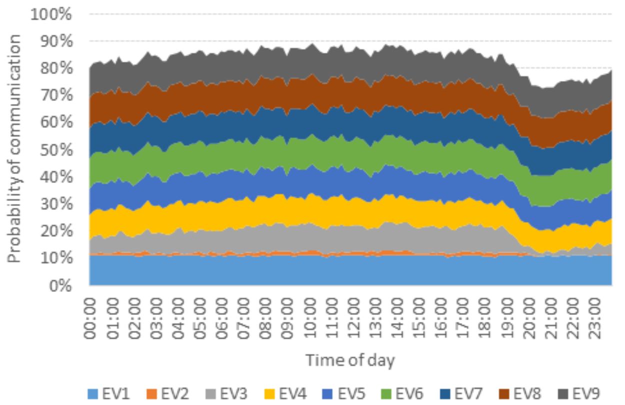

Fig. 10. Probability of communicating with all nine ICBs every 10min during the day (ML cluster, September 2014)

REFERENCES

[1] Department for Energy and Climate Change, 2011, "The Carbon Plan: Delivering our low carbon future"

[2] Office for Low Emission Vehicles (OLEV), "Number of newly registered ultra low emissions vehicles", September 2014: https://www.gov.uk/government/publications/number-of-newly-registered-ultra-low-emissions-vehicles

[3] Smart Grid Forum, 2012, "Assessing the Impact of Low Carbon Technologies on Great Britain's Power Distribution Networks", EA Technology

[4] Customer-Led Network Revolution. Available: http://www.networkrevolution.co.uk/

[5] My Electric Avenue. Available: http://myelectricavenue.info/

[6] J. Sinclair, EA Technology Ltd (2014), "Electric Power Demand Management", UK Patent GB 2494368 B

[7] M. Gillie; G. Nowell, 2013, "The Future for EVs: reducing network costs and disruption", Hybrid and Electric Vehicles Conference 2013, IET, 6-7 Nov. 2013

[8] K. Petrou; J. Quiros-Tortos; L. F. Ochoa, 2015, "Controlling Electric Vehicle Charging Points for Congestion Management of UK LV Networks", in IEEE PES ISGT, Washington, USA, 2015, pp. 1-5