WESTERN POWER DISTRIBUTION

INNOVATION

NEXT GENERATION NETWORKS

Algorithm Development and Testing

Electric Nation

LCN Fund
Low Carbon Networks

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Contents

Glossary

Abbreviation	Term
BaU	Business as Usual
DMS	Demand Management Service
EV	Electric Vehicle
ISP	Internet Service Provider
NIA	Network Innovation Allowance
OLEV	Office for Low Emission Vehicles
PIV	Plug-In Vehicle (different types of electric vehicles, including pure battery, plug-in hybrids and range extenders)
WPD	Western Power Distribution

1 Introduction

This report summarises the testing of demand management algorithms which has taken place using the EV test rig at EA Technology's office as part of the Electric Nation project. The testing has occurred over the period from late autumn 2016 to spring 2017. It also describes the design of the Electric Nation trial, and the way in which demand management will be implemented in the trial in its first year.

1.1 The Electric Nation Project

Electric Nation is the customer-facing brand of CarConnect, a Western Power Distribution (WPD) and Network Innovation Allowance (NIA) funded project. WPD's collaboration partners in the project are EA Technology (the authors of this report), DriveElectric, Lucy Electric GridKey and TRL.

Electric Nation, the world's largest electric vehicle (EV) trial, is revolutionising domestic plug-in vehicle charging. By engaging 500-700 plug-in vehicle drivers in trials, the project is answering the challenge that when local electricity networks have 40% - 70% of households with electric vehicles, at least 32% of these networks across Britain will require intervention.

The project is developing and delivering a number of smart charge solutions to support plug-in vehicle uptake on local electricity networks. A key outcome will be a tool that analyses plug-in vehicle related stress issues on networks and identifies the best economic solution. This 'sliding scale' of interventions will range from doing nothing to smart demand control, from taking energy from vehicles and putting it back into the grid, to traditional reinforcement of the local electricity network where there is no viable smart solution.

The development of the project deliverables is being informed by a large-scale trial involving plug-in vehicle drivers that will:

- Expand current understanding of the demand impact of charging at home on electricity distribution networks of a diverse range of plug-in electric vehicles - with charge rates of up to 7kW+, and a range of battery sizes from 20kWh to 80kWh+.
- Build a better understanding of how vehicle usage affects charging behaviour.
- Evaluate the reliability and acceptability to EV owners of smart charging systems and the influence these have on charging behaviour. This will help to answer such questions as:
  - Would charging restrictions be acceptable to customers?
  - Can customer preference be incorporated into the system?
  - Is some form of incentive required?
  - Is such a system 'fair'?
  - Can such a system work?

The results of this project will be of interest and will be communicated to the GB energy/utility community, UK government, the automotive and plug-in vehicle infrastructure industry and the general public.

This report focuses on the third of the trial aims shown above – i.e. the use of smart charging systems, how these influence charging behaviours and to what extent they can mitigate the impact of PIV charging on electricity networks.

1.2 Demand Management and Electric Nation

The operation of demand management as part of the Electric Nation project can be illustrated by the figure below.

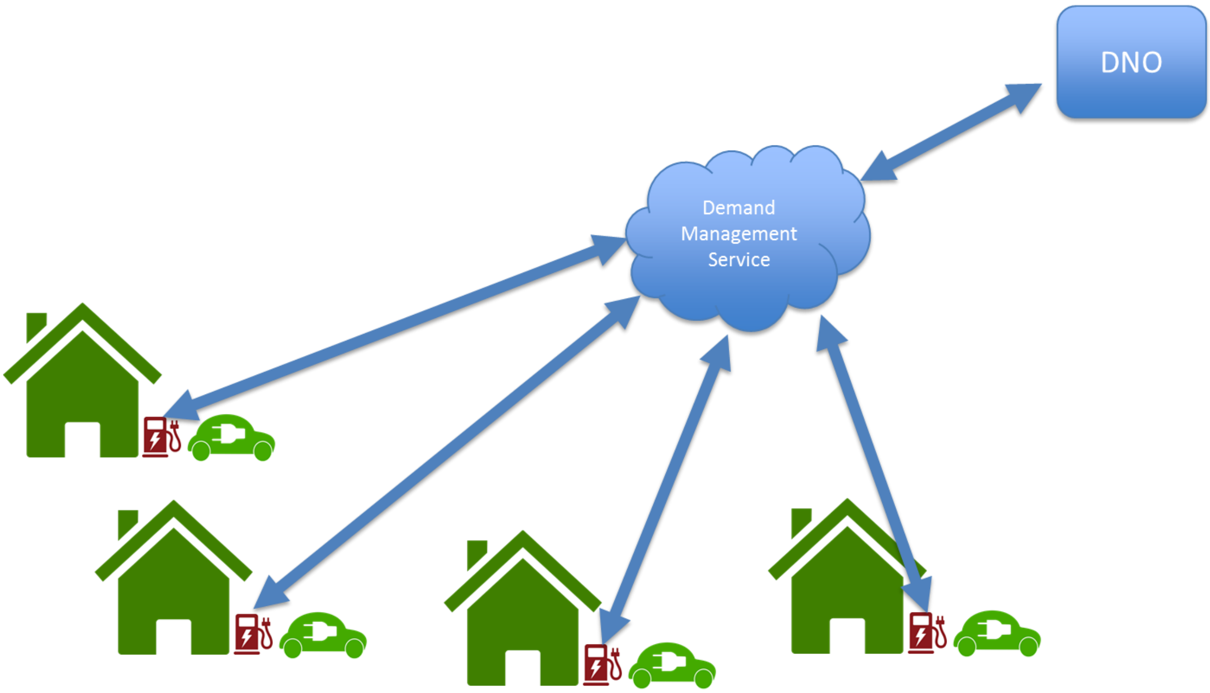


Figure 1: Illustration of Demand Management Service Operation

Information flows in both directions between multiple smart chargers and the demand management service (DMS) provider:

- Smart Charger to Demand Management Service: plug in status (is a car connected), current being drawn (when a car is present)
- Demand Management Service to Smart Charger: current available for charging

The DMS then uses this information to ensure that the total demand of groups of chargers (e.g. those connected to a particular substation) is within the limit which has been set by the Distribution Network Operator (DNO).

Two separate DMS providers are taking part in Electric Nation, GreenFlux[1] and CrowdCharge[2]. Each company uses different algorithms to allocate current to individual chargers. The amount of data they have available (e.g. car state of charge) and the way the customer interacts with their system will also differ between the two providers in later

[1] https://www.greenflux.nl/en/ Accessed April 2017
[2] http://crowd-charge.com/ Accessed April 2017

stages of the trial. The equipment installed in participant's homes varies slightly between the two providers:

- CrowdCharge: APT/eVolt[3] charger, plus separate controller box connected to customer's router, either directly or via a Wi-Fi bridge. Communications is over home broadband only.
- GreenFlux: ICU[4] charger connected to the customer's router either directly or via a Wi-Fi bridge. A GSM SIM card is also installed inside the charger, providing a back-up form of communications.

EA Technology are working with both CrowdCharge and GreenFlux to optimise the configuration of the algorithms used, and testing these configurations on the Electric Nation rig.

1.3 The Electric Nation Test Rig

A test rig has been designed, built and commissioned at EA Technology's offices in Capenhurst during Q1 and Q2 of the project. This consists of twelve chargers (six APT, six ICU) with additional monitoring equipment. The rig has two main purposes:

1. Testing the response of individual cars to changes in the current available (as the chargers are managed) and potentially pauses in charging. This is to confirm that all the vehicles which may take part in a smart charging event will follow the current made available by the charger, and return to full rate charging when the constraint is removed.
2. Confirming the behaviour of re-configured algorithms over multiple cycles to show that current is allocated fairly between chargers (no individual customer is penalised more in a demand management event than others) and that the DNO limit is not breached.

The behaviour of the chargers installed at the test system is monitored by CrowdCharge and GreenFlux and each company has provided a separate web portal through which EA Technology can also view this behaviour and in CrowdCharge's case, set up tests.

The test rig includes additional independent monitoring which can show the three key variables for management of charging:

1. The plug-in status of the charger - no car connected, car connected but not charging and car connected & car charging.
2. The current made available from the charger
3. The current drawn by the car.

[3] https://www.swarco.com/apt/Products-Services/eMobility Accessed April 2017
[4] http://www.icu-charging-stations.com/en/home/ Accessed April 2017

This is achieved via an interpretation of the pilot signal from the charger[5] and a current transformer installed around the live feed to the car.

A labelled photograph of one of the six 'panels' which make up the test system is shown below. Each charger within the test system is connected to both the power supply and an Ethernet cable. These Ethernet cables are fed back to a control room where they are linked to a controller (for CrowdCharge) or directly to a router (for GreenFlux). This mimics the way that communications are connected in trial participants' homes.

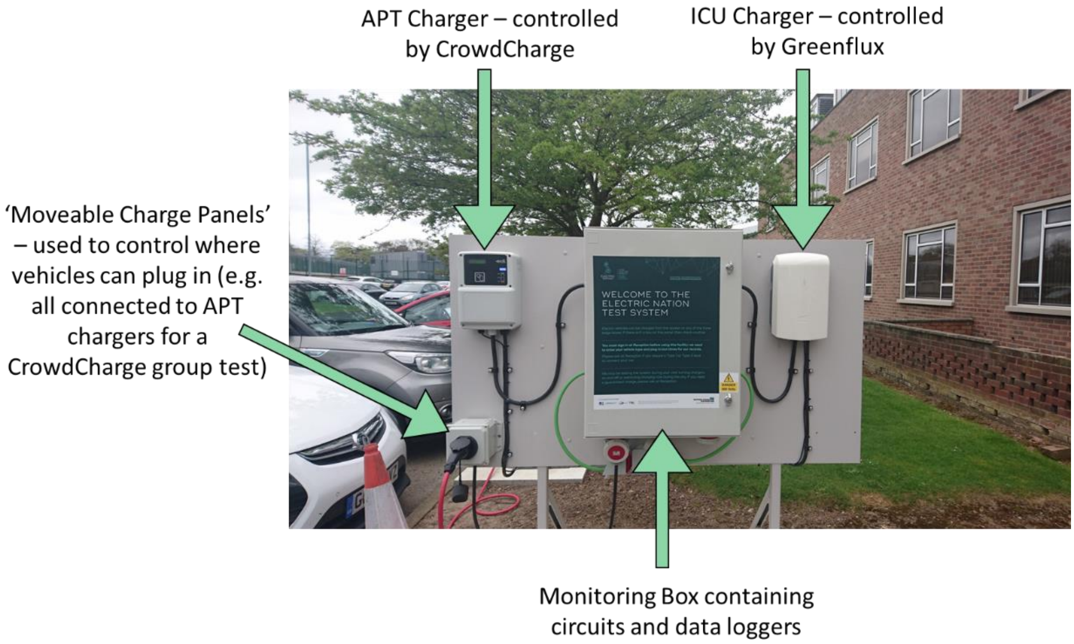


Figure 2: Labelled Diagram of Test System

1.4 Report Structure

This report provides a summary of the testing which has been carried out at Capenhurst and the algorithm configuration developments made by each DMS provider. It is structured as follows:

- Section 2: shows the results of testing individual cars – these tests address the 1st purpose of the system given in Section 1.3 above.
- Section 3: summarises algorithm re-configuration work and the tests which have been completed on the CrowdCharge and GreenFlux systems, including confirming the behaviour of chargers if communications are lost during a demand management event.
- Section 4: provides an overview of the next steps in algorithm development and testing, and how this links into the overall trial design.

[5] For details of the pilot pin signal and its use, please see Annex A of BS EN 61851-1:2011. Electric Vehicle Conductive Charging System.

2 Testing Response of Individual Vehicles

2.1 Introduction

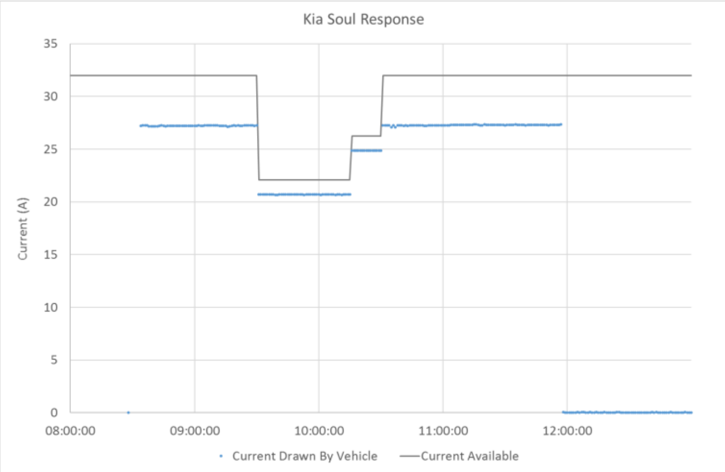
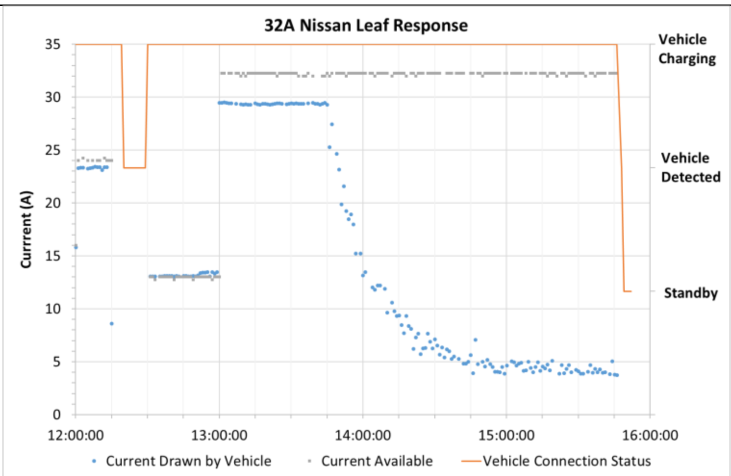
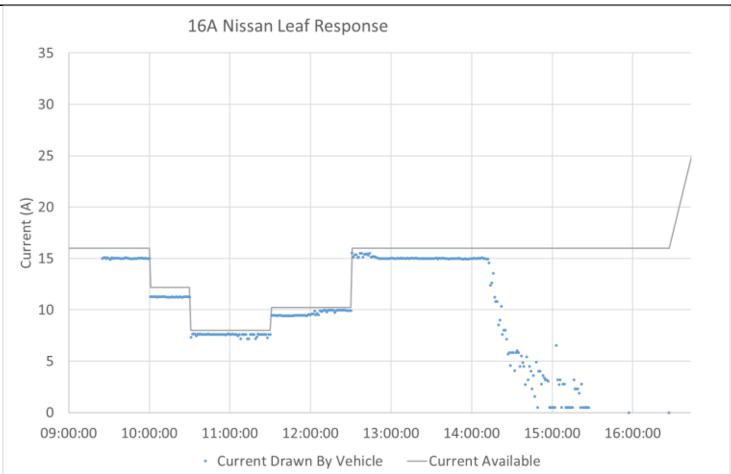
Participants in the Electric Nation trial can drive any PIV, so long as they are eligible for an Office for Low Emission Vehicles (OLEV) Homecharge grant. It is therefore important that both DMS providers are confident that these vehicles will respond as expected – i.e. that they follow the current made available by the charger and then return to normal, unrestricted charging. One of the purposes of the test system is therefore to test the response of individual vehicles to changes in current available, and pauses in charging.

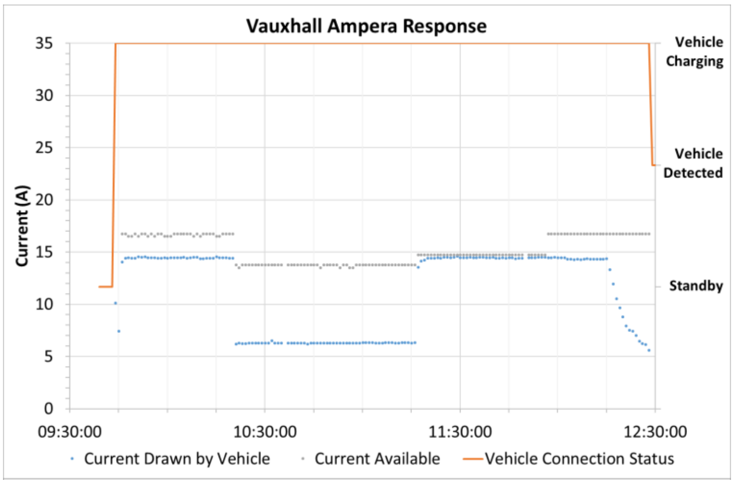
2.2 Testing Completed

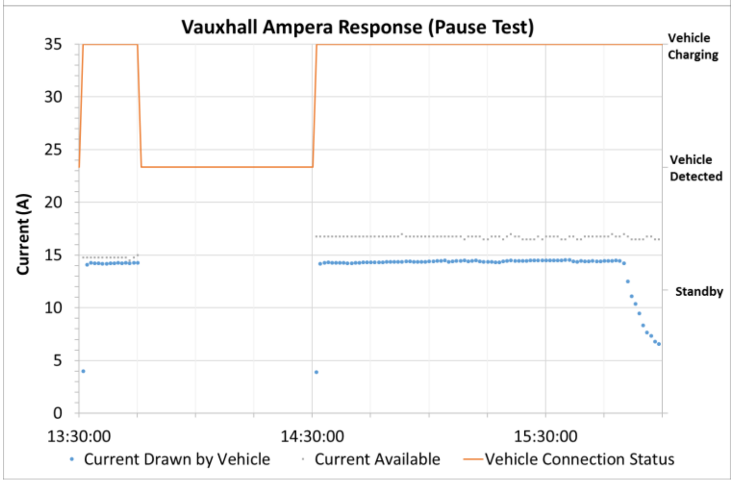
During the first year of the project the following vehicles have been tested to varying extents:

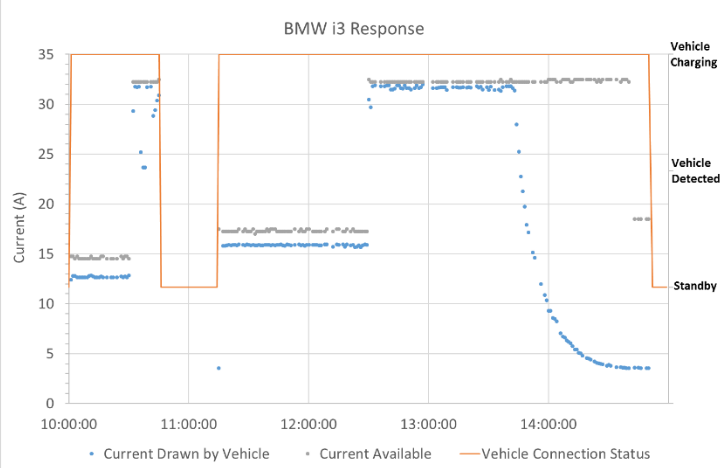
- Kia Soul (2016 model, 66 plate)
- 32A Nissan Leaf (2015 model, 65 plate)
- 16A Nissan Leaf (2014 model, 14 plate)
- Vauxhall Ampera (2012 model, 62 plate)
- BMW i3 (pure battery version) (2016 model, 16 plate)
- 40kWh Renault Zöe (2017 model)
- Tesla Model S (85kWh battery capacity)
- Hyundai IONIQ (pure battery version)

A variety of test cycles have been used to test each vehicle. Ideally each car would be tested on a separate schedule containing an increase and decrease in current available and a pause in charging. Where this has not taken place as part of a standalone (single vehicle) test then each of these scenarios will be covered by using the car as part of a group test. The results of this testing, and key points to note, are given in the table below.

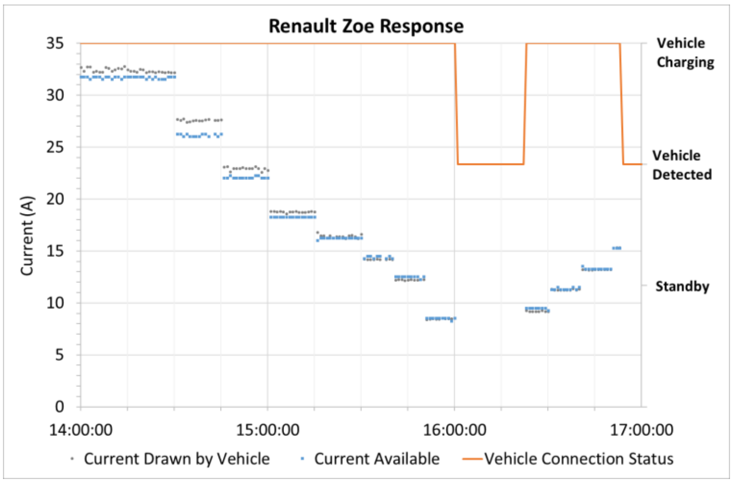
Car	Test Result	Points to Note
Kia Soul		Car draws slightly less than current allowed but responds to increases and decreases in current available. Although a pause was not tested on the day shown, this has been included within group tests – demonstrating that the car stops and restarts charging as expected (e.g. see Figure 7 in Section 3.2.2).
32A Nissan Leaf		The car draws slightly less than the nominal 32A during unconstrained charging (13:00 onwards). Following a pause (12:15 – 12:30) the vehicle begins charging again.
16A Nissan Leaf		Car closely follows current made available. Although a pause was not tested on the day shown, this has been included within group tests – demonstrating that the car stops and restarts charging as expected.

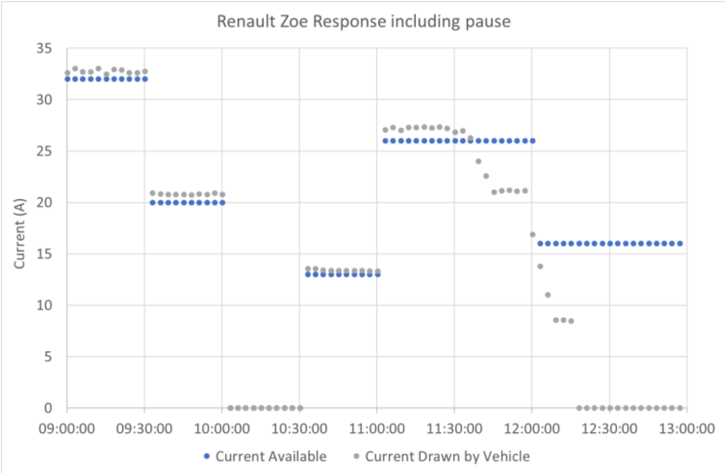
<table>
<tr><th>Car</th><th>Test Result</th><th>Points to Note</th></tr>
<tr><td>Vauxhall Ampera</td><td>


</td><td>The Vauxhall Ampera is a plug-in hybrid with a nominal rating of 16A. It accurately follows a current limit of between 14 and 16A. However, when 13A or less is available the current drawn is either 6A or 10A, depending on a setting within the vehicle. This can be observed in the period between 10:30 and 11:15 on the 1st graph.

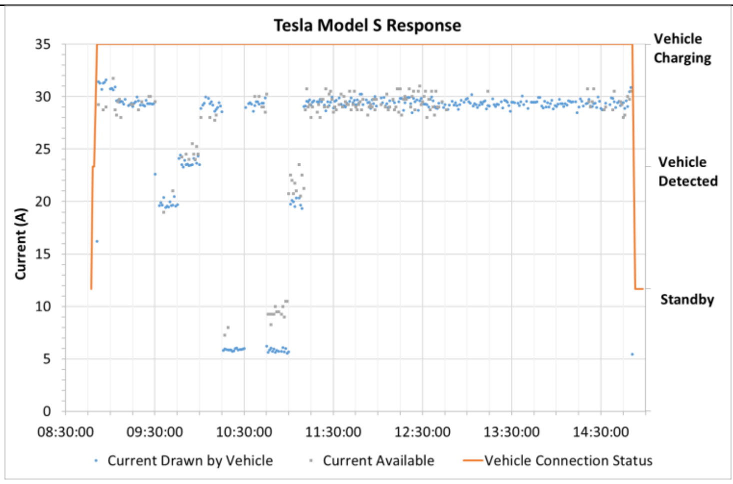
The second graph shows the vehicle responding correctly to paused charging between 13:45 and 14:30. After the pause the vehicle continues to charge until it reached a high state of charge just after 15:45.</td></tr>
<tr><td>BMW i3</td><td>
</td><td>Car closely follows current made available and the pause in charging.

The irregular current drawn from 10:30 is due to cell equalisation and is not related to smart charging.</td></tr>
</table>

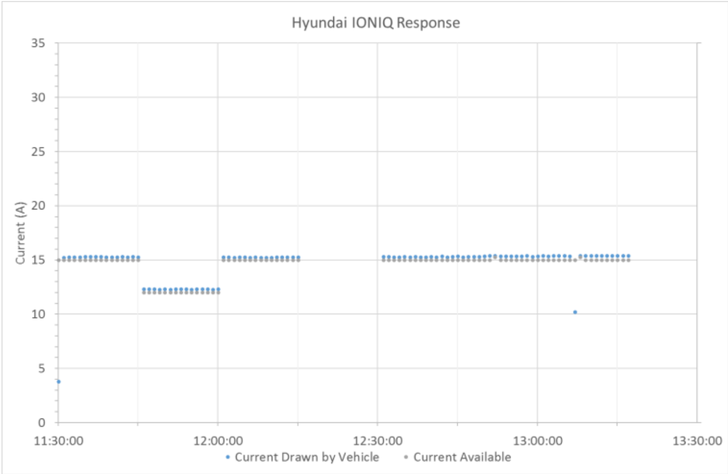
<table>
<tr><th>Car</th><th>Test Result</th><th>Points to Note</th></tr>
<tr><td>40kWh Renault Zöe</td><td>


</td><td>Current drawn is generally equal to, or just higher than the current allocated.

When the Zoe was offered 6A (16:00) it stopped charging and the charge event needed to be re-started to begin charging again (i.e. car unplugged). A response <u>by the car,</u> lead to the 'plug-in status' (orange line on 1st diagram) changing from vehicle charging to plugged in, but not charging.

However, charging can be paused and re-started <u>by the charger</u> – as shown in the 2nd graph where a pause occurred between 10:00 and 10:30.</td></tr>
<tr><td>Tesla Model S</td><td>
</td><td>Car closely follows the current made available from the charger.

It was not possible to test the response of the vehicle to a pause in charging. This will be carried out when it is next possible to charge a Tesla Model S on the rig.</td></tr>
</table>

<table>
<tr><th>Car</th><th>Test Result</th><th>Points to Note</th></tr>
<tr><td>Hyundai IONIQ</td><td>
</td><td>Car draws all current made available. Although the cycle shown from this test allowed a maximum of 16A the Hyundai IONIQ charges at 32A when unrestricted.

The vehicle charging was successfully paused and restarted between 12:15 and 12:30.</td></tr>
</table>

Table 1: Results of Testing of Individual Car's Response to Demand Management

2.3 Conclusions

The majority of the tests completed to date have been completed successfully with the car responding correctly all commands. The exceptions to this are:

- The Vauxhall Ampera charges at either 6 or 10A when 13A or less is made available from the chargepoint. The cars on-board computer allows the driver to set the current to be drawn from the home charger unit when plugged into a standard domestic socket – this value can either be 6 or 10A. It is believed that if the charger allocates 13A or less then the on-board computer detects that the vehicle is plugged into a domestic socket and therefore charges at the 6 or 10A setting. However, the Vauxhall Ampera has not been available as a new car in the UK since 2015 and it is therefore unlikely that Electric Nation participants will join the trial with this vehicle.
- The 2017 40kWh Renault Zöe stops charging when offered 6A or less from the charger. If this occurs, then the only way to begin charging again is to restart the transaction. This is not practical and could prevent a car charging once a constraint was removed. Both DMS providers must therefore ensure that their systems will not allocated less than 7A to any chargers. If it was necessary for a charger to be allocated less than 7A then this could be achieved by pausing the charging (enacted by the charger), which has been successfully demonstrated for all cars tested to date.

The project team will continue to pursue opportunities to test other makes/models in the coming months.

3 Testing of Demand Management Service Providers and Algorithm Development

The same incremental testing process has been used for both DMS providers, stepping through tests of increasing complexity, as follows:

1. Single car, constant demand limit
2. Single car, varying demand limit (no pause and with pause)
3. Group of chargers, constant demand limit
4. Group of chargers, varying demand limit, all vehicles plugged in throughout the test
5. Group of chargers, varying demand limit, car unplugged during the test to confirm capacity is released to other vehicles.
6. Behaviour during loss of communications.

Results from Steps 1 and 2 are shown in Section 2 above, where the test results come from both GreenFlux and CrowdCharge. This section focuses on the results of testing Steps 3 – 6 with both DMS providers.

The tests in Steps 3 – 5 are equivalent to the DNO providing the DMS provider with the available network capacity (kW) for PIV charging, and requiring them to allocate this power amongst active chargers within a group (e.g. those fed from a particular substation). It should be noted that the profiles used within this testing are not necessarily representative of available DNO capacity. They have been designed to test the capability of the DMS providers' systems – i.e. using a minimum amount of available capacity and changing more quickly than may be necessary for DNO purposes.

3.1 Testing of CrowdCharge System

3.1.1 Testing of Group Demand Management

Group of Chargers – Constant Demand Limit

This is the simplest form of group demand management, whereby a fixed amount of capacity is available throughout the test and the total current from all active chargers must be managed within this limit.

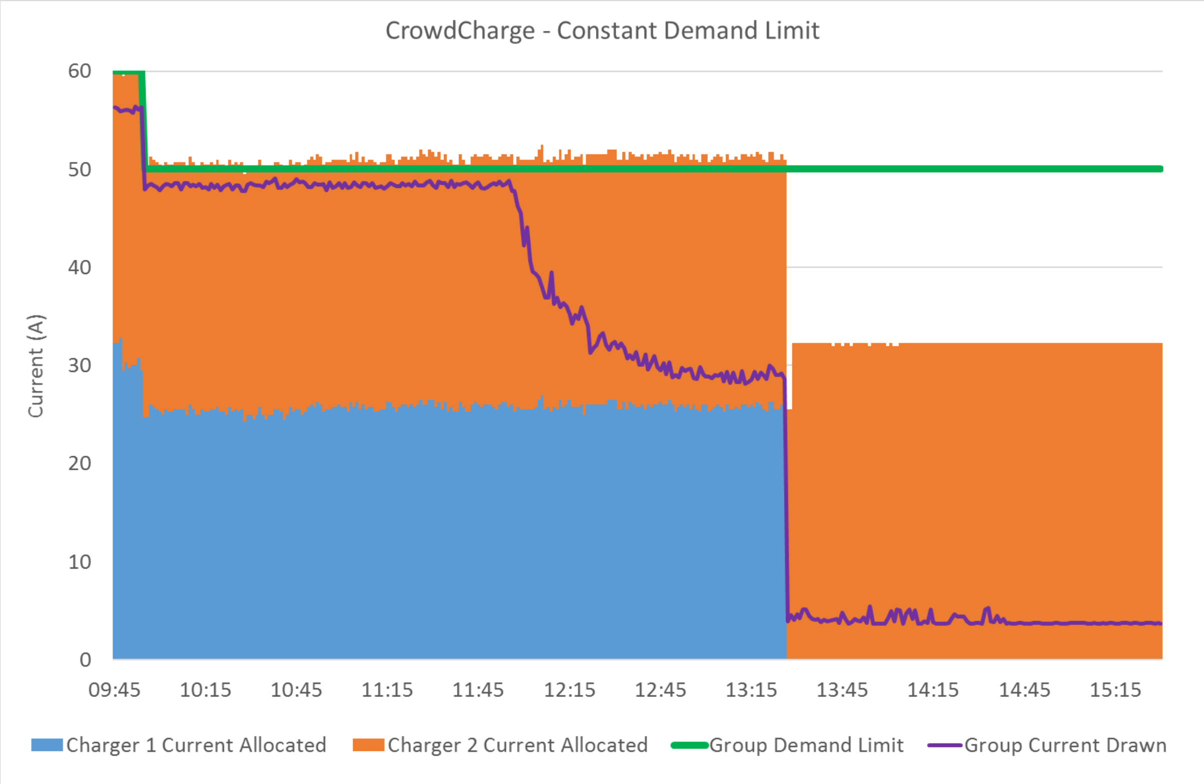


Figure 3: CrowdCharge Constant Demand Limit Test Results

The current allocated to each of the active chargers is shown by the blue and orange areas (essentially stacked columns showing the current allocated to each charger for each minute). The slight minute-to-minute variations which are visible are due to slight variations (noise) in the monitoring circuit signal. This shows that each charger was treated equally when the demand limit was reduced to 50A at around 10:00. The current drawn by the group stayed constant until approximately 12:00, when the current drawn by one car began to decay as it reached a high state of charge. At approximately 13:20 one vehicle (connected to Charger 1) finished its charge cycle, so the charger was no longer active and this current was released to the remaining active station. Demand management was successful as the current drawn was always less than the limit, and both stations were treated equally.

Group of Chargers – Varying Demand Limit, all vehicles plugged in throughout the test

In this test the demand limit (equivalent to the available capacity for PIV charging) changes during the plug-in event.

The graph below shows the behaviour of a group of chargers, where chargers 1 -3 are connected to a 32A (7kW) PIV, and charger 4 to a 16A (3.5kW) PIV.

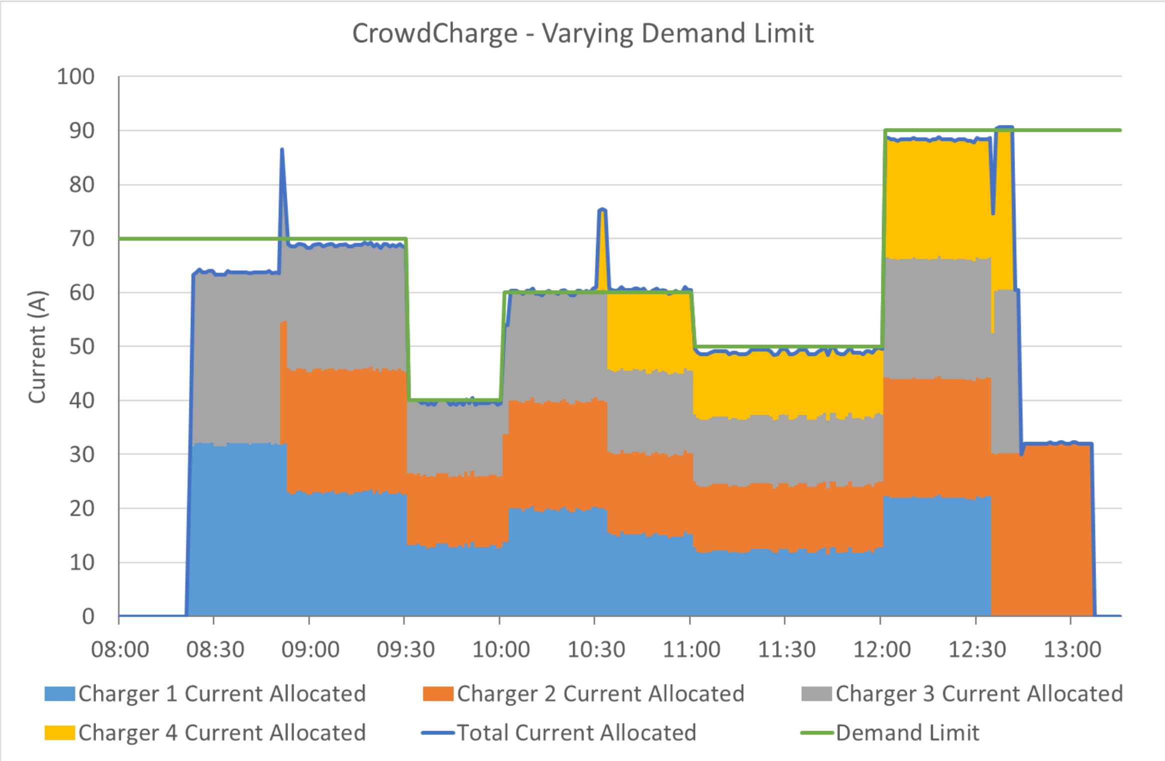


Figure 4: CrowdCharge - Varying Demand Limit Test Results

The current allocated to each individual charger varied throughout the test as follows:

- 8:00 – 9:30: a demand limit of 70A was applied to the group. Once the third PIV is connected at around 8:45 (start of the orange block) the current allocated to all three chargers reduces, as the unconstrained demand of three chargers (3 x 32A = 96A) would have exceeded the limit of 70A.
- 9:30 – 10:00: the charging rate of all three chargers is reduced in accordance with the reduced demand limit.
- 10:00 – 11:00: at 10:00 the charging rate increases due to the increase in demand limit. At 10:30 a fourth PIV (16A nominal rating) was connected (yellow area), causing a reduction in the current limit for the first three.
- 11:00 – 12:00: all vehicles are allocated a reduced charging rate as the group demand limit is reduced.
- 12:00 – 13:15: The charging rates of all four PIVs increased due to a higher demand limit. As vehicles reached the end of the charge cycle this released capacity for the remaining active chargers – e.g. at around 12:35 when Charger 1 was no longer active.

Overall this test produced the expected results, based on the current allocation algorithm configuration used by CrowdCharge at this stage of development. The graph above appears to indicate very short excursions from the demand limit (e.g. at around 8:45). These occur when an additional PIV is connected due to a slight delay as the DMS provider's system registers that another charger is active, and reduces the current available to all chargers in the group. The length of the excursion is short but if the current values are sampled during the excursion then it is shown until a new sample is taken (one minute later). Short duration excursions are unlikely to have an implication for the network operator for thermal issues.

This test also illustrates one potential future area of algorithm configuration development. In the example above, all chargers are allocated current equally, regardless of the car being charged, and this could lead to more current being allocated to a single charger than the car will use. Consider a 50A limit applied to two active chargers connected to one 16A and one 32A PIV. If the limit is split equally then each PIV has 25A available, so the 16A PIV is 'unconstrained' and the 32A PIV charges at 25A. However, if account was taken of the nominal rating of the vehicles then it would be possible for both vehicles to charge at their nominal rate without exceeding the demand limit. A future iteration of the algorithm configuration could determine the charging rate of the vehicle which is connected and use this to alter the amount allocated, potentially freeing up capacity for other vehicles.

Group of Chargers – Varying Demand Limit, vehicle unplugged during test

In this test a vehicle is unplugged partway through a demand management event. The purpose of this is to confirm that this releases capacity to other PIVs. The vehicle is then plugged back in, and should begin charging again, with the other vehicles allocated less current as the group limit is shared between a larger number of charge points. This is likely to be representative of real demand management events within the trial, as cars within the group will begin and end charging events at different times.

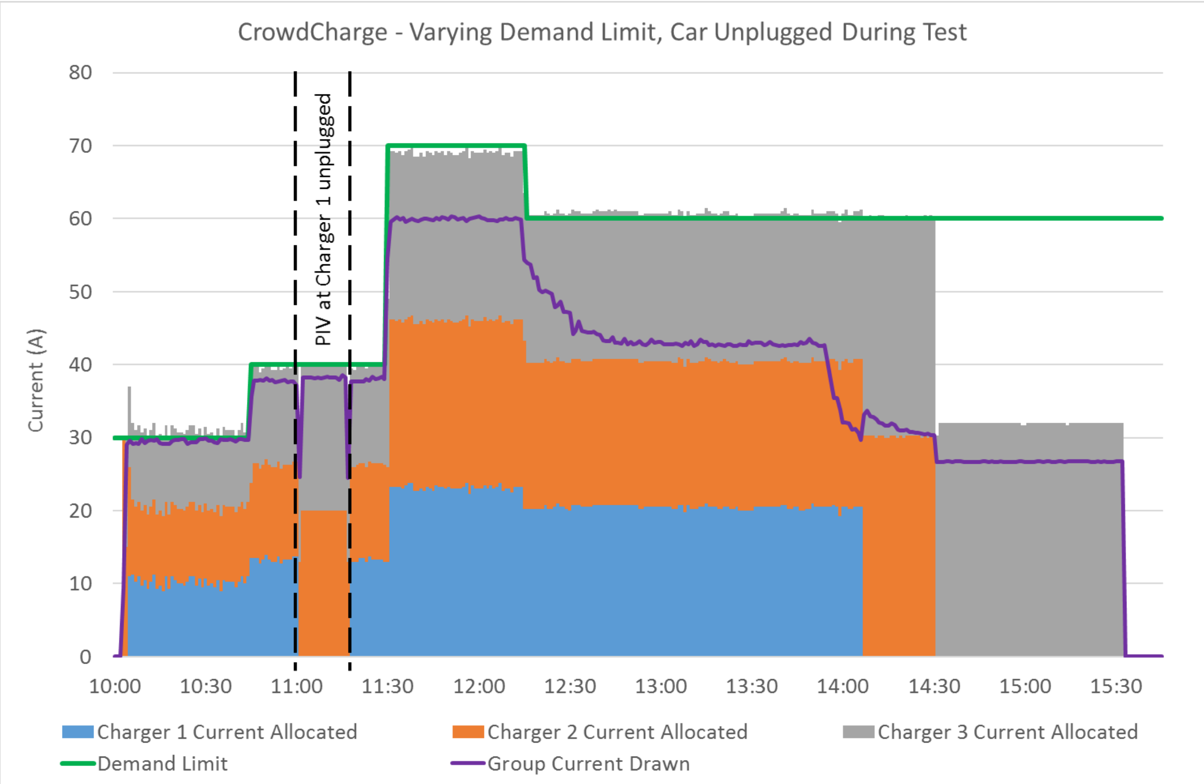


Figure 5: CrowdCharge - Varying Demand Limit with PIV Unplugged Test Results

The results show the correct behaviour. The demand limit increased at 10:45, and the current allocated to all three chargers increased. When the PIV at Charger 1 was unplugged (11:00) the current allocated to the remaining two charge stations increased. The PIV at

Charger 1 was reconnected at 11:15 and the current allocated to Charger 2 and 3 decreased again.

The behaviour throughout the rest of the test was also as expected. From 12:15 the PIV at Charger 1 was reaching a high state of charge so the current drawn by the group decays. It finished charging at around 14:00, releasing capacity to Chargers 2 and 3. The end of the charge cycle for the PIV at Charger 1 provides another opportunity where the current being drawn could be used to refine the allocation algorithm – e.g. by allocating less current to Charger 1 and making this available for the other two charge stations.

3.1.2 Testing behaviour during a loss of communications

One potential scenario within the trial is that communications between the DMS provider and an individual smart charger could be lost during a demand management event – for example if the trial participant switches off their router, or there is an issue with their phoneline or Internet Service Provider (ISP). It is therefore important to understand what impact this would have on smart charging for two reasons:

- If a lack of communications could result in 'unconstrained' charging then this has the potential to exceed the demand limit set by the DNO.
- If the charging rate is constrained due to a lack of communications then the impact on the customer from managed charging would be higher (e.g. their car charges more slowly and so does not reach the desired state of charge/available range in time for their next journey). In terms of the overall Electric Nation trial then this higher customer impact could lead to dissatisfaction which would be reported within the customer research. However, this dissatisfaction would be due to a communications issue and not the overall acceptability of the smart charging concept.

The resilience of the communications solutions used (Ethernet only or Ethernet with SIM back-up) is being monitored as part of the Electric Nation project and will be shared in later project reports.

Two scenarios have been tested using the CrowdCharge system:

- Test 1: A short loss of communications that occurs on a single charger during the demand management event. Communications are restored before the charge event finishes.
- Test 2: A longer loss of communications. In this test communications were lost, then sometime later the charge event was finished (i.e. vehicle was unplugged). A new charge event started before communications restored.

These tests were completed at the same time, using different chargers within the same group. The resulting behaviour is shown below.

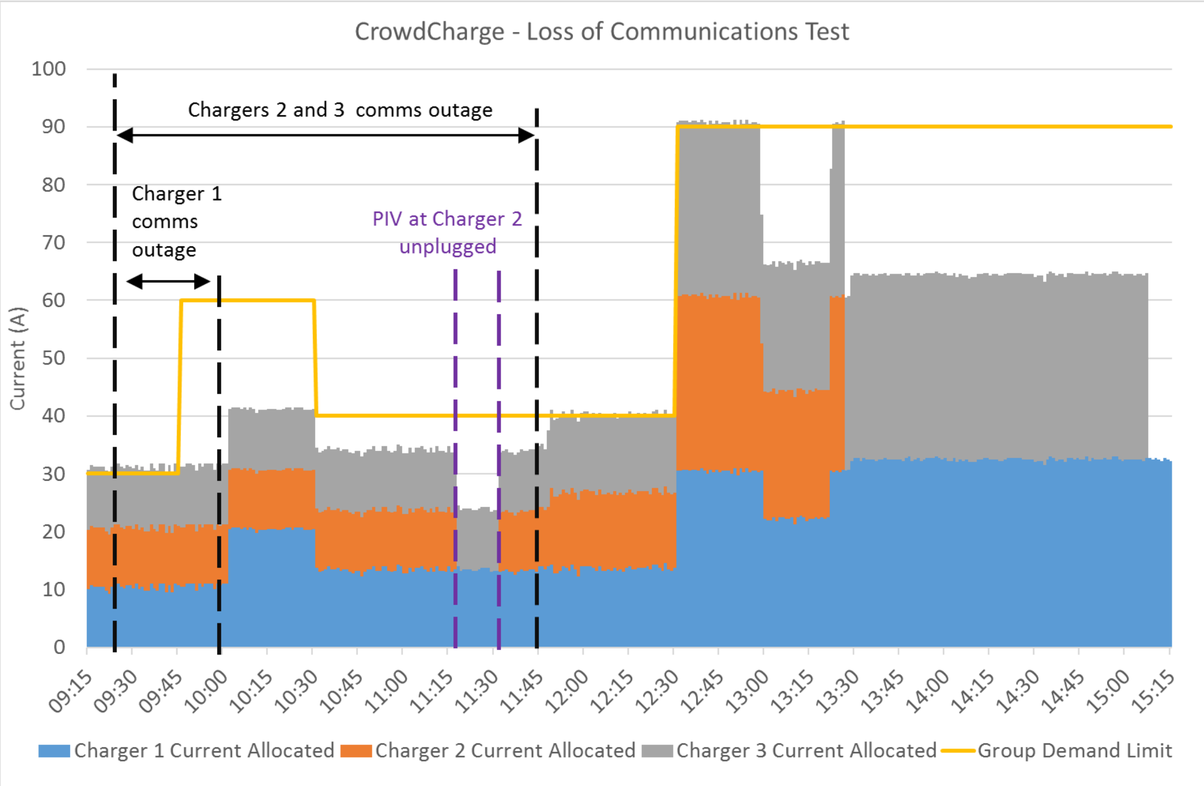


Figure 6: CrowdCharge - Loss of Communications Test Results

The results can be summarised via by following the sequence of events shown on the graph:

- 9:15 – three PIVs connected with a group current limit of 30A, each charging at 10A.
- 9:20 – the communications connections from all three charge points were removed.
- 9:45 – despite a scheduled increase in the demand limit from 30A to 60A, none of the chargepoints were allocated additional current, as without communications they are “unaware” of the additional current available.
- 10:00 – communications were re-connected to Charger 1. There was a slight delay whilst they re-established, but shortly afterwards the current allocated to Charger 1 increased to 20A, in accordance with the higher demand limit. Chargers 2 and 3 continued to be allocated 10A as communications to these charge points was still disabled.
- 11:15 – the PIV connected to Charger 2 was disconnected. However, as there was no communications from this charger the DMS providers back office was unaware that the charger was no longer active, so no additional current was allocated to the remaining two charge points.
- 11:30 – the PIV at Charger 2 was reconnected and continued to charge at 10A, as this was the last received instruction before comms were disabled.
- 11:45 – communications were re-connected to Chargers 2 and 3 and they then charged at an increased rate due to the increase in the group demand limit from 30A (when comms were removed at 9:20) to 40A.

The activities completed for Chargers 1 and 3 correspond to Test 1 as described above – i.e. a loss of communications within a charge cycle. The activities completed for Charger 2 correspond to Test 2, where a loss of communications persists through multiple charge sessions. In this case the charger stores the last received current allocation and continues to charge at this rate for multiple sessions until communications are restored.

This test was completed successfully, as the expected behaviour occurred in each test case.

3.2 Testing of GreenFlux System and Algorithm Configuration Development

3.2.1 Algorithm Configuration Development

An extended period of testing has taken place using the GreenFlux system. During this period an initial development to the smart charging algorithm was made whereby the 'unconstrained' charge rate of the vehicle is detected, and this is then used to allocate current throughout the charge event. The results shown below relate to this updated algorithm configuration, as this is the version which will be deployed into the Electric Nation trial as the 1st algorithm configuration iteration (see Section 4 below).

3.2.2 Testing of Group Demand Management

Group of Chargers – Constant Demand Limit

In this test a 61A limit was applied to three chargers throughout the whole day. Three 32A (7kW) PIVs were connected, in varying states of charge. The resulting behaviour is shown below.

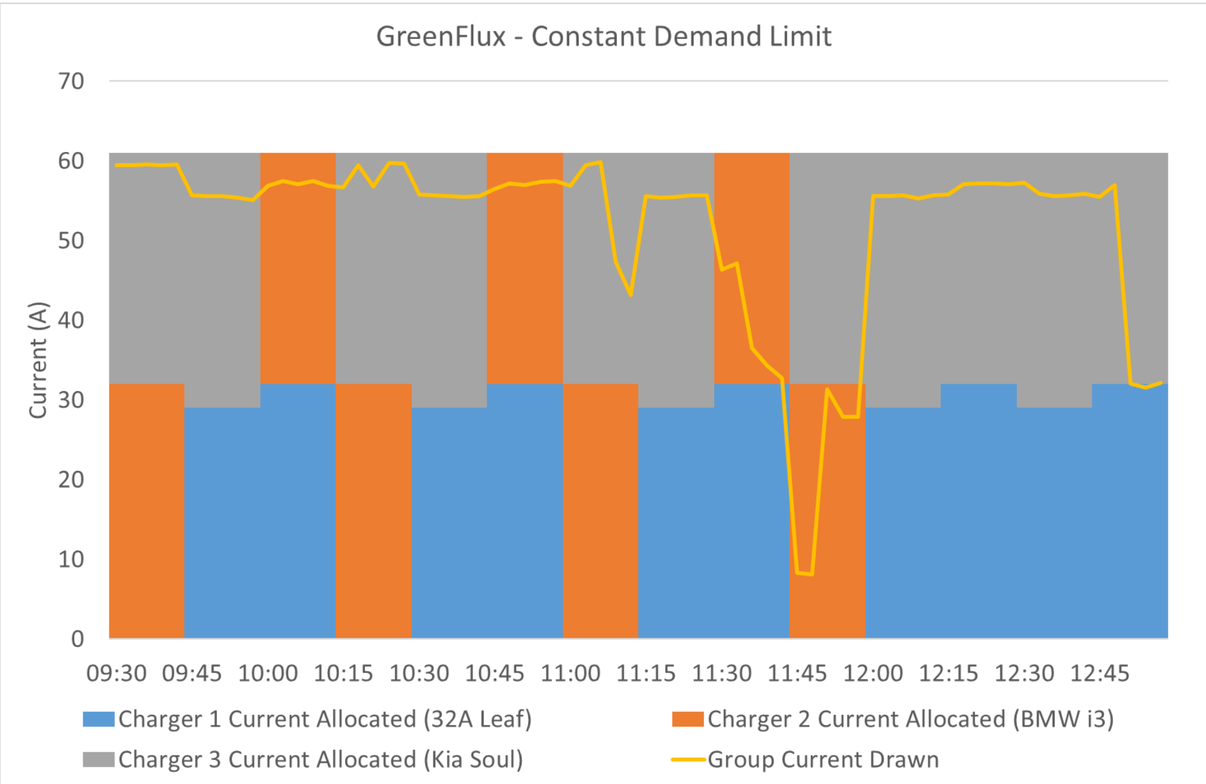


Figure 7: GreenFlux - Constant Demand Limit Test Results

The behaviour shown above can be summarised as follows:

- 9:30 – 11:00: There are slight variations in the total current drawn by the group. Although all three cars involved in this test have a nominal rating of 32A, they draw slightly different amounts of current when unrestricted (28, 32 and 27A respectively). Therefore, the variation in total current drawn observed in this period is due to the effect of changing current allocation to individual chargers, and the current drawn by each car.
- 11:00 – 12:00: during this period the BMW i3 was nearly fully charged, and the therefore the current it drew steadily decreased, leading to a reduction in the group current drawn.
- 12:00 onwards: The BMW i3 had completed its charge cycle and was therefore not allocated current. From this point onwards the remaining two cars charged more quickly until both were full.

This test was completed successfully as the total current drawn was always less than the group limit of 61A. All three cars were treated equally.

Group of Chargers – Varying Demand Limit, all vehicles plugged in throughout the test

Two examples of testing using a varying demand limit are shown within this section. The first involved three cars (all nominally 7kW, a Kia Soul, Nissan Leaf and Renault Zöe).

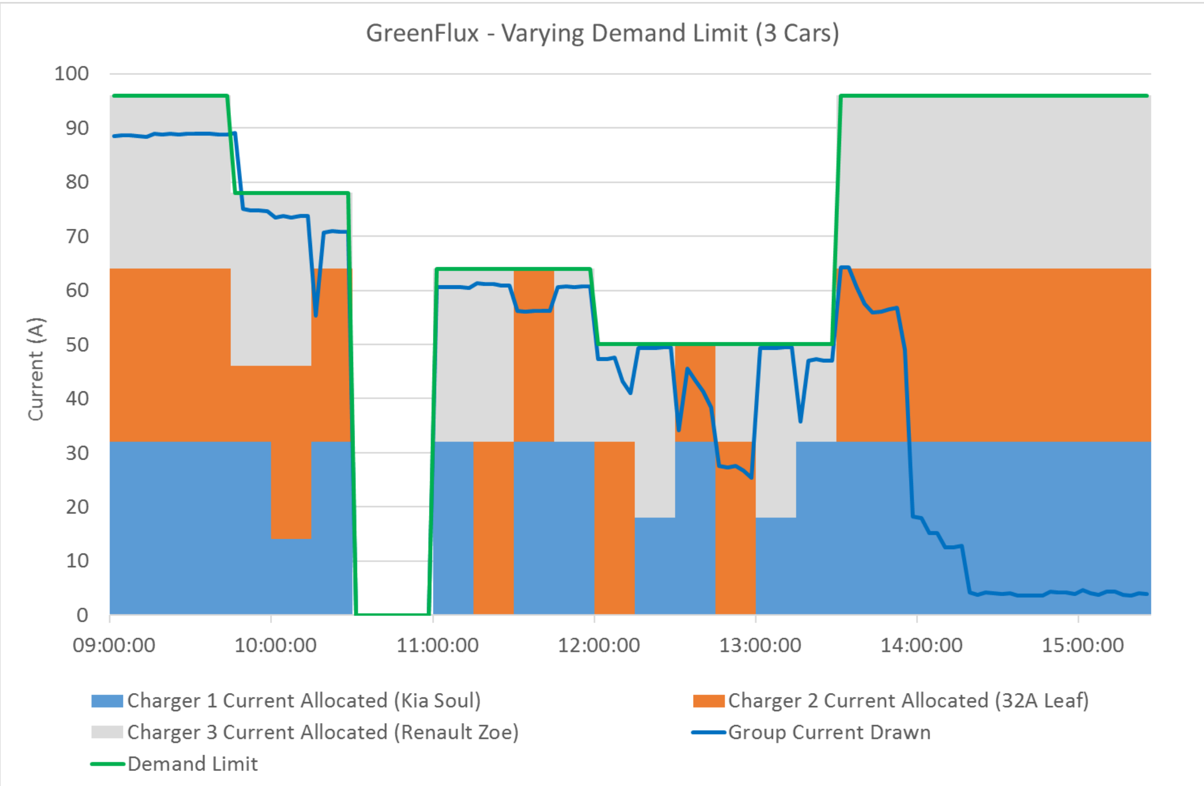


Figure 8: GreenFlux - Varying Demand Limit Test Results (3 Cars)

This example demonstrates successful demand management, using a varying demand limit. The total current drawn by the group is always less than the limit which was applied. Chargers were treated equally until 13:00. After this it may appear that Charger 2 (orange area) was 'unfairly' allocated no current for a 30 minute period – however, this is correct behaviour, as the car had reached a high state of charge, and the current it was drawing therefore declined. This example also demonstrates the ability to pause and re-start the charging of the 2017 model year Renault Zöe, as between 10:30 and 11:00 no current was available. The vehicle continued to charge from 11:00 onwards.

The test rig at Capenhurst includes six chargers for each DMS provider, therefore the largest test possible involves six cars. This was completed using the GreenFlux system during March 2017, with a varying demand limit. The results of this test are shown below.

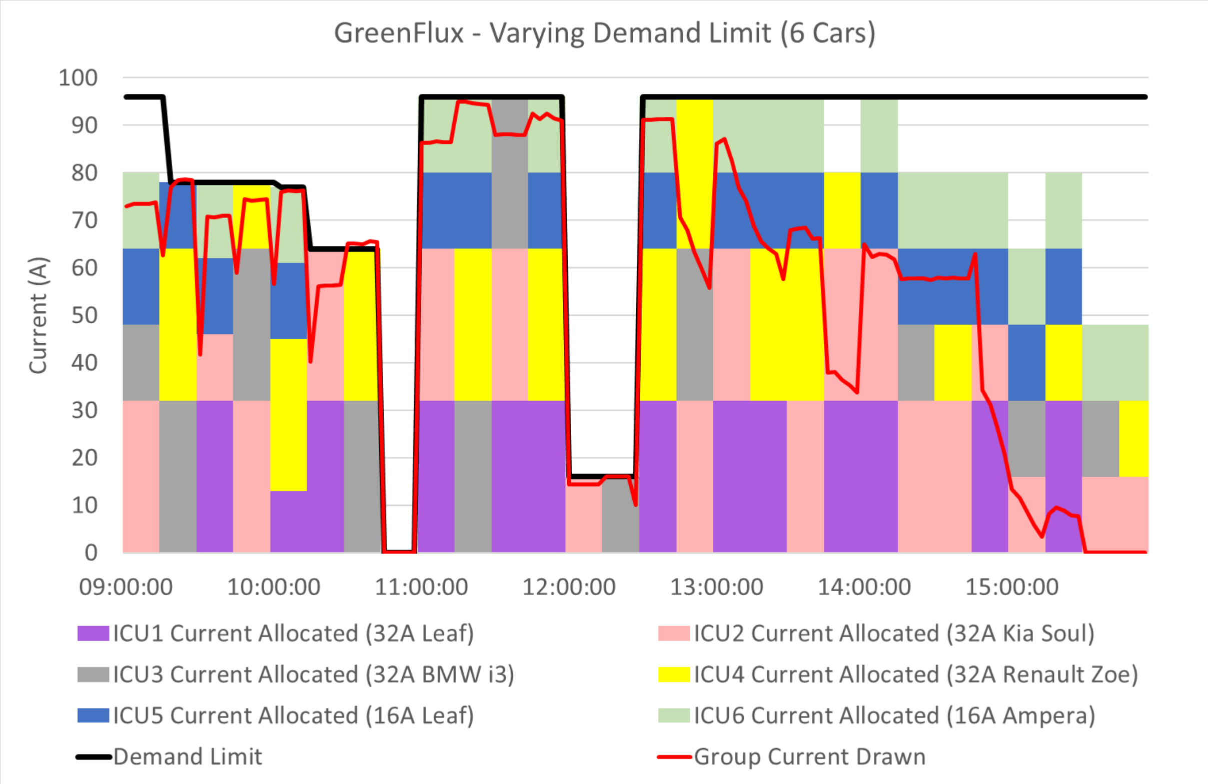


Figure 9: GreenFlux - Varying Demand Limit Test Results (6 Cars)

This test was also successful – the key points to note are:

- The current drawn by the group was always lower than the specified demand limit. The slight variations in current drawn during the morning period (e.g. comparing the quarter hour blocks between 9:15 and 10:15) were due to the differing current drawn by nominally 32A cars. From around 12:30 onwards the current drawn by the group decays as each vehicle battery reaches a high state of charge in turn.
- Charging was successfully paused and restarted between 10:45 and 11:00.
- Chargers which were connected to 16A vehicles (ICU 5 and 6) were allocated a maximum of 16A throughout.

Group of Chargers – Varying Demand Limit, vehicle unplugged during test

During demand management events within both the trial, and also any potential Business as Usual (BaU) roll-out of managed charging, it is likely that vehicles would both start and finish charging during constrained periods. It is therefore important to demonstrate that the smart charging algorithms respond correctly to these events: by lowering the current available to all vehicles in response to additional PIVs arriving, and releasing capacity to the remaining cars when a PIV is disconnected.

This test was therefore designed to demonstrate this behaviour occurring. Three cars were used during the test (two nominal 7kW, one nominal 3.5kW). The resulting behaviour is shown below.

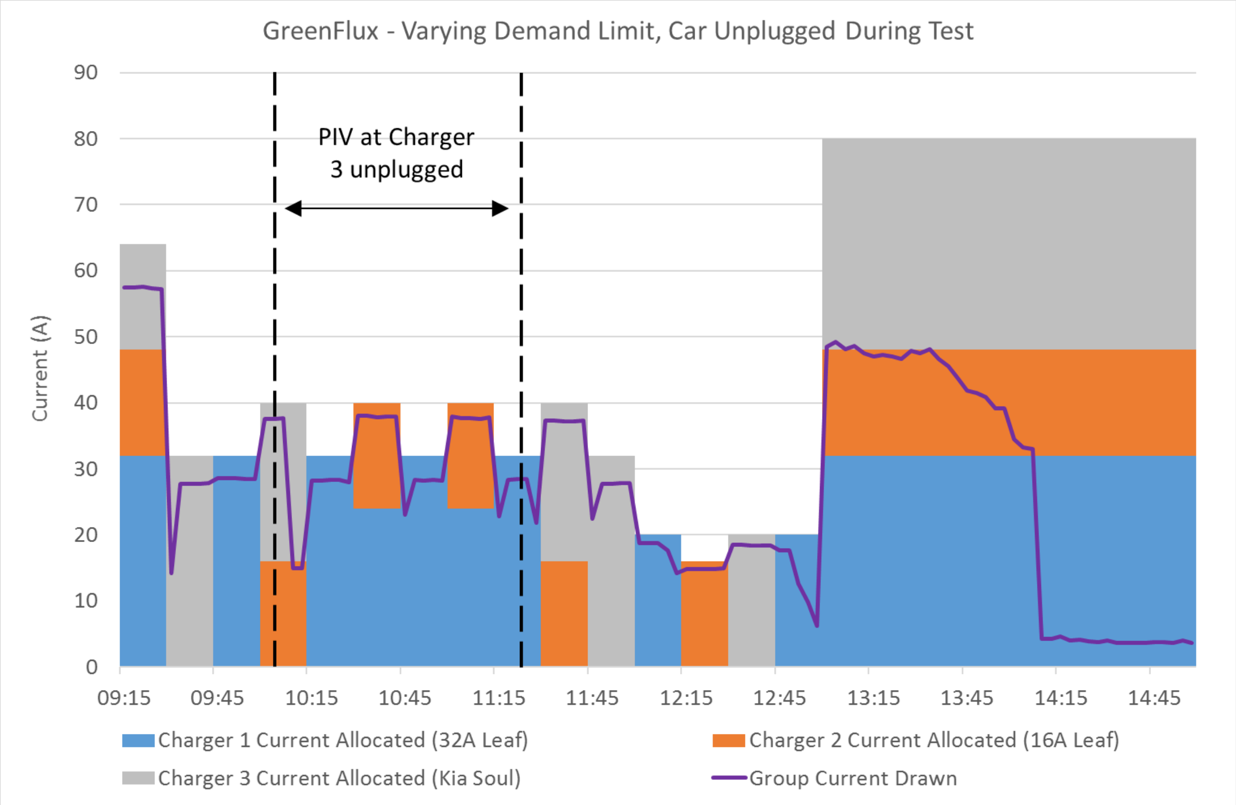


Figure 10: GreenFlux - Varying Demand Limit, Car Unplugged During Test Results

The key points to note from this test are:

- When a charger is connected to a nominally 3.5kW (16A) car (Charger 2 in this example, orange area) it is only ever allocated a maximum of 16A. This is due to the algorithm configuration development completed by GreenFlux during the first year of the project.
- Shortly after the car at Charger 3 was disconnected (around 10:05) it was no longer allocated any current, allowing Chargers 1 and 2 to share the available current.
- After it was reconnected (around 11:20) it began to be allocated current again.

These results therefore demonstrate the current allocation algorithm performing correctly as cars are connected and disconnected during a demand management event.

3.2.3 Testing behaviour during a loss of communications

The behaviour of an individual smart charger during a loss of communications under the GreenFlux system depends on the length of the interruption. The charging profile is sent to each charger in advance (based on the limit and group demand at the time), such that the charger effectively has its instructions for a short period. If the interruption in communications is short (less than the length of stored instructions) then the stored profile is used. However, an interruption for a longer period will result in chargers reverting to a 'safe' value until new instructions are received. In the absence of a safe value it would be possible that all chargers would operate at their maximum rating (32A) regardless of the available network capacity. This safe value is therefore effectively a compromise between allowing the customer to continue charging in the event of a loss of comms, whilst also limiting the potential impact on the network.

Two tests involving a loss of communications were completed, to confirm behaviour for 'short' and 'long' interruptions.

Behaviour During a Short Loss of Communications

In this test communications were removed from two chargers during a demand management event. The length of the interruption was designed such that the chargers should 'ride through' the interruption using a stored profile, including a change in demand limit. The resulting behaviour is shown below.

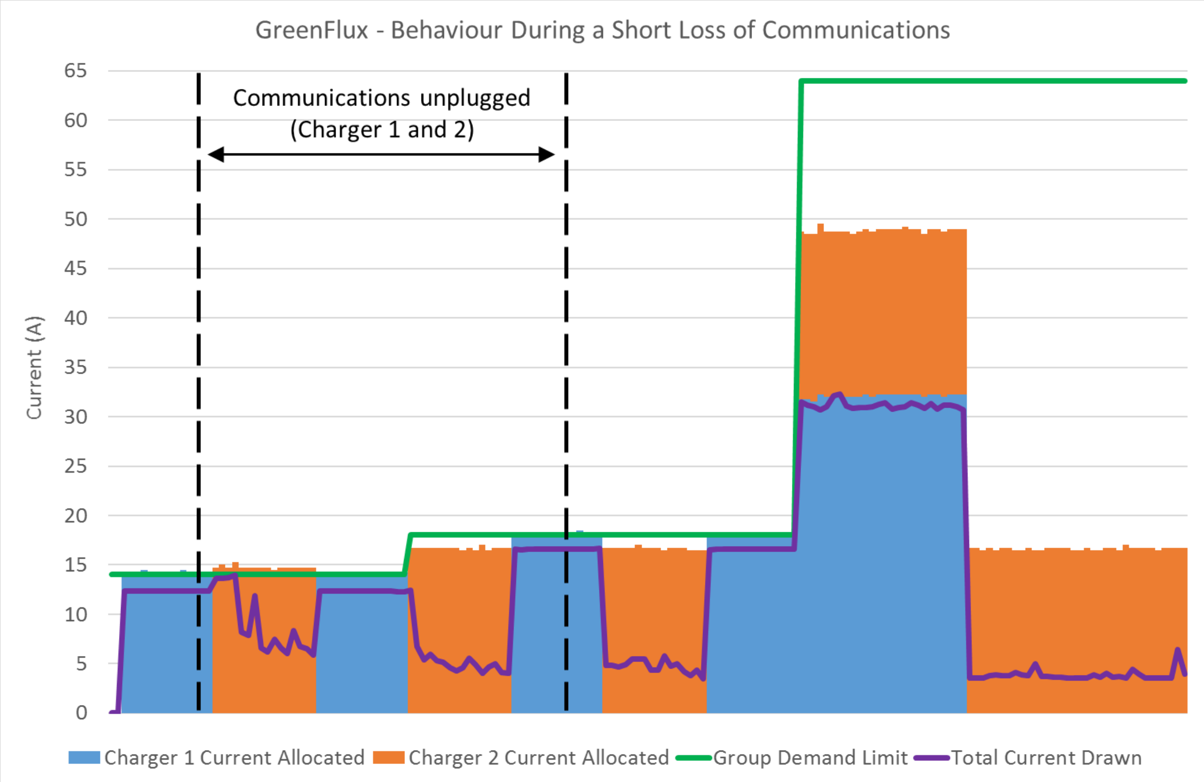


Figure 11: GreenFlux - Short Loss of Communications Test Results

This test was completed successfully. The chargers continue to operate according to the profile throughout the interruption. This included a slight increase in the current allocated to each charger around halfway through the interruption, when the group limit was increased from 14 to 18A.

Behaviour During a Long Loss of Communications

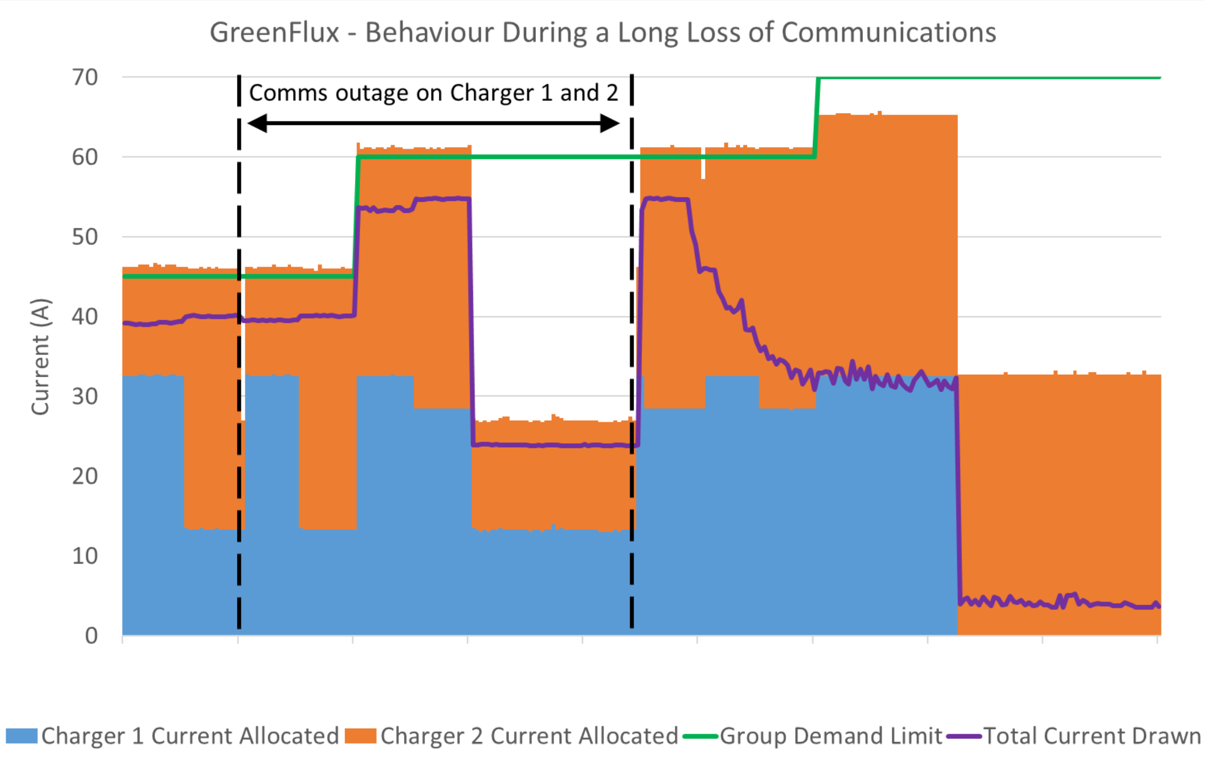


Figure 12: GreenFlux – Long Loss of Communications Test Results

This test was completed successfully, with the system behaviour occurring as expected by the DMS provider. The chargers continued to operate according to the pre-sent schedule for a period of time, including increasing the demand limit (roughly a third of the way through the interruption). After the defined period of time both chargers stepped down to the 'safe value', despite the higher current limit until comms were restored. Once communications had been restored the current allocated to both chargers increased in accordance with the demand limit.

In common with the other group tests shown above the current drawn by the group was always kept within the group limit, including during the loss of communications.

3.3 Conclusions and Next Steps

Both DMS providers have successfully passed the test programme stages set out at the start of this section. This provides sufficient confidence that the current versions of the algorithms are suitable for deployment in the Electric Nation trial.

There are opportunities to further develop the algorithm configurations which are used to share the available current between chargers within a group. These could include elements such as:

- Further use of measured current data from chargers to optimise the current allocated to each point (e.g. to capture vehicles at the end of their charge cycle).

- Ability to interact with customer preferences, either via a simple over-ride option during demand management events, or using more complex user preference data.
- Including state of charge information from vehicles to prioritise those vehicles in greatest ‘need’.

The DMS providers will continue to develop their algorithms during the lifetime of the project (see Section 4 below), and the test system will be used again to trial these developments prior to roll-out of new iterations to Electric Nation participants.

4 Trial Design and Next Steps

4.1 Introduction

The testing completed using the Electric Nation rig, summarised above, has shown that the 1st iterations of both DMS providers algorithm configurations are ready for deployment into the trial. Both providers have consistently demonstrated their algorithms ensure demand is less than a prescribed limit, and that customers are treated equally.

The next step is therefore to plan the introduction of demand management to participants' smart chargers, consistent with the project aims of evaluating the reliability and acceptability to EV owners of smart charging systems. There is a wide range of potential variables affecting the reliability and acceptability of demand management of PIV charging, such as:

- The charging behaviour of the PIV owners – this could be affected by driving pattern (e.g. miles per day), range of the PIV (size of battery) or other lifestyle factors that impact on the timing and frequency of charging (e.g. times when the vehicle is at home for charging).
- The network capacity available for charging – this will vary between different networks depending on the level of 'non-PIV' loading, and also by weekday/weekend, season, weather conditions, among other factors.
- The smart charging system used – how charging is managed and how customers can interact with this (e.g. their ability to override an event, how often they chose to override managed charging).
- Customer attitudes towards demand management – potentially linked to their charging behaviour, but also their previous experience of PIV charging (i.e. have they been able to charge without any demand management previously) and attitudes towards energy use.

Clearly, to study the impact of all these variables in turn, using statistically significant samples of customers, would necessitate a trial of much greater length than is available. It is therefore necessary to design a trial in which it is possible to first identify the key factors to be investigated (those which have the greatest impact), and then study these for a sufficient period of time. The reliability and acceptability of smart charging can then be evaluated using a mixture of quantitative data showing charging events (from the DMS providers) and more qualitative, attitudinal data based on customer surveys (collected by Impact Utilities).

This section summarises the trial design work completed to date and the planned use of smart-charging during Electric Nation.

4.2 Year 1 of the Trial

Installations of smart chargers (i.e. customers entering the trial) have been underway since January 2017, with 100 installations completed as of the end of April. The entry of customers will continue throughout 2017 as potential participants register their interest in the project, complete the eligibility/registration process and an installation is arranged.

One variable which may affect the customer acceptability of smart charging is whether customers have experience of unrestricted PIV charging before experiencing PIV demand management. This is one of the factors which Electric Nation will examine in the first year of the trial. To do this, it is necessary to have a "control" group of customers who have experienced unrestricted PIV charging ("Charge at will") before being subjected to PIV demand management. This control group will provide a baseline of data regarding charging behaviours and attitudes towards charging that can be used in two ways. Firstly, it can be compared with the groups charging behaviour and attitudes once managed charging begins. Secondly, the attitude of the "control" group can be compared with customers who enter the trial directly into PIV demand management (i.e. who have no experience of the "charge at will" regime).

From previous experience (My Electric Avenue[6]) and on the advice of the Customer Research experts employed by the project (Impact Utilities) a three month period of "charge at will" is deemed sufficient. This allows customers to become familiar with their PIV and form habitual charging behaviours (having overcome, for example, range anxiety issues with their new PIV). After the "charge at will" period demand management will be introduced. This will then require a minimum of a further three months to allow them to experience and adapt to PIV demand management (if they do at all). So, for the first customer entering the trial in January, they would be allowed to "charge at will" for three months and then be subjected to demand management for the remainder of the trial. The experience of the customer for the first year of the trial is shown in the timeline below.

	Month											
Customer	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	Charge at will			Managed charging								

Customers entering the trial in February would be treated similarly (numbers entering the trial used are for illustrative purposes only).

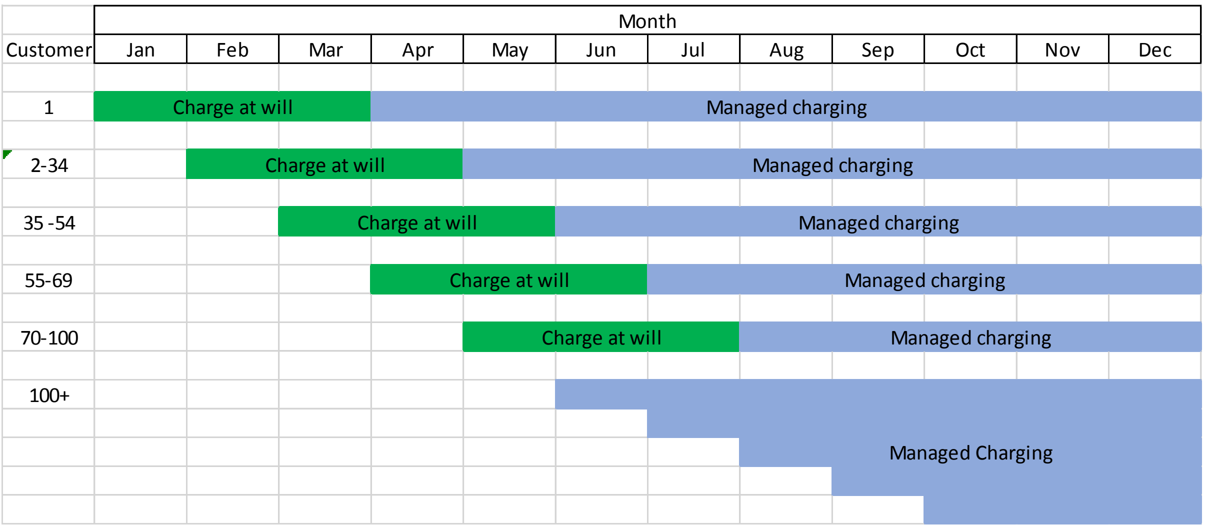
	Month											
Customer	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	Charge at will			Managed charging								
2-34		Charge at will			Managed charging							

The aim of including a 'charge at will' group is to understand the impact which drivers prior experience of PIV charging before the introduction of demand management has on the acceptability of smart charging. To draw firm conclusions from this (and any other trial within Electric Nation) the "charge at will" group must be statistically significant, requiring

[6] A three year Low Carbon Network Fund project delivered by EA Technology on behalf of Scottish and Southern Energy Networks. For further details see: http://myelectricavenue.info/ Accessed April 2017

around 100 participants. As installations are staggered, the build-up of the “charge at will” cohort will also be staggered over several months, as shown below.

Once this cohort is fully populated, customers entering the trial will then be subjected to demand management from the day they enter the trial.



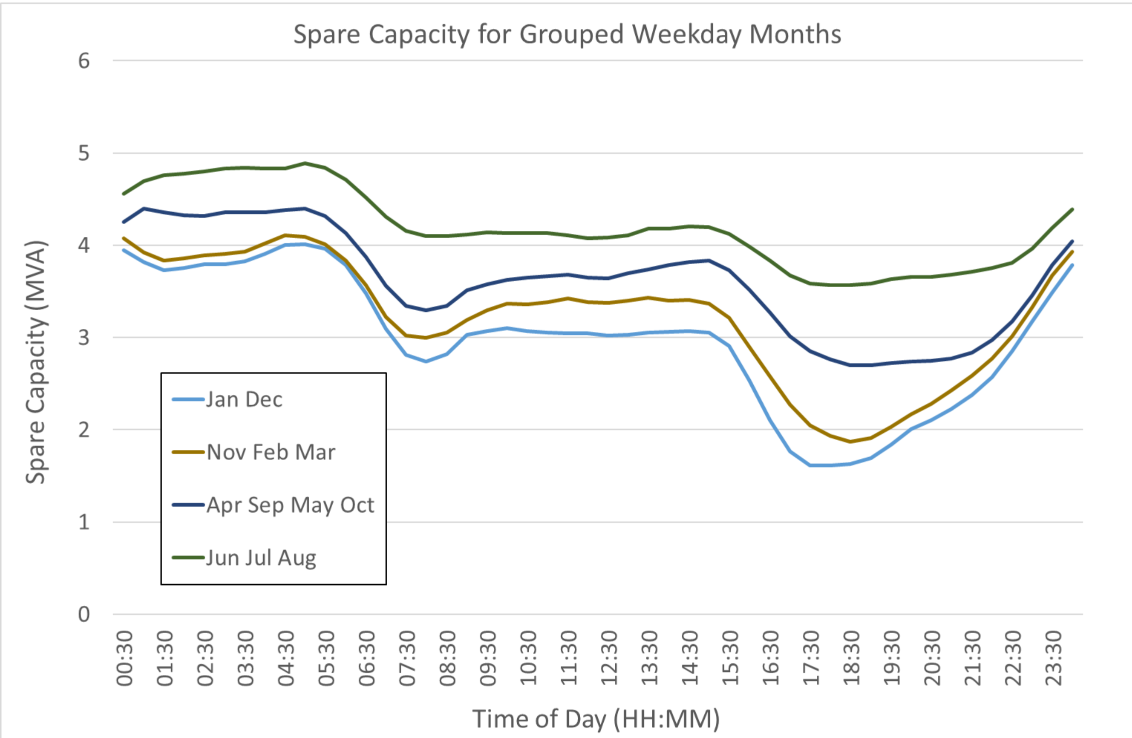
Using the recruitment projections in this example, and owing to the phased recruitment process the “charge at will” cohort programme will not be completed until the end of July. They will then require a three month period of PIV demand management in order to make a valid comparison of any changes to their charging behaviour or attitudes to charging, this phase of the trial would not finish until at least the end of October.

In addition, potential differences in the two demand management systems being used in the trial (GreenFlux and CrowdCharge) may be reflected in customer reactions to the systems through their charging behaviours and attitudes to charging. This means that the minimum 100 customers entering the trial under “charge at will” need to be replicated in each arm of the trial.

As discussed above, PIV demand management regimes will vary with each season, due to differences in the available capacity for charging, as “non-PIV” load is seasonal (higher loading in winter). These differences in “non-PIV” load also exist between different times of day and weekday vs. weekend, leading to differences in the demand management regime.

PIV related load is also likely to be slightly higher in winter, due to increased vehicle energy use. This increased energy usage is caused by factors such as the battery temperature and additional heating and lighting loads.

The example below, using data from a WPD HV feeder in the Nottingham area (Figure 13), shows that this feeder has four distinct "seasonal" demand profiles – reflected here as spare (or available) capacity for PIV demand (the difference between the available capacity and "non-PIV" load). By comparing the light blue and green lines, it can be seen that PIV demand management would have a much lighter impact on customers during the summer than in the depths of winter.



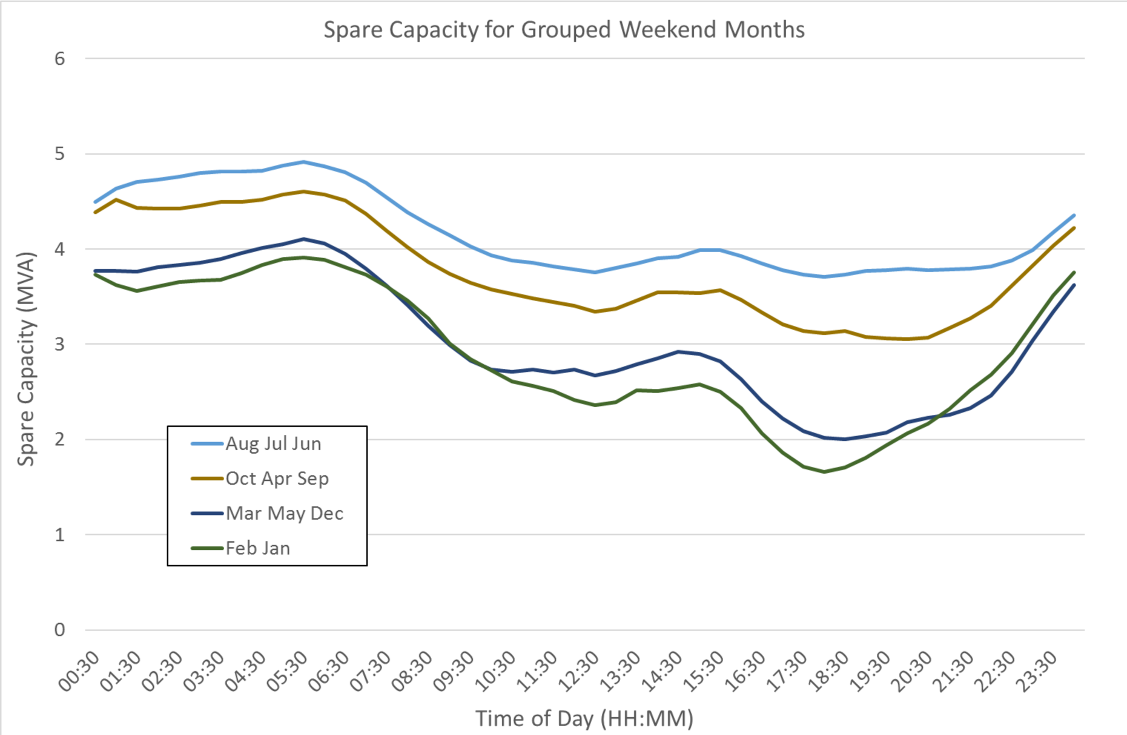


Figure 13: Examples of Available Network Capacity (Weekday and Weekend)

The PIV demand management regime (how much charging is affected by demand management) may influence customer acceptability of the system. For example, if demand management in summer is negligible then a customer who has only experienced "summer" demand management may have a very positive attitude towards smart charging. However, the same customer may have a different opinion under a "winter" regime when their charging is delayed for longer.

External factors also have the potential to influence the feedback from customers regarding smart charging. These relate to customers' overall attitudes to "life in general" (such as their state of health, daylight hours, the weather etc.) but could nonetheless be reflected in feedback regarding smart charging. These effects are also seasonal, generally being negative influencers in winter and at least neutral or positive in summer.

The aim of the trial is to accurately understand customer acceptability of smart charging as it would be deployed in a BaU scenario. One "real-life" scenario is clearly the level of demand management necessary during winter, alongside customers' attitudes/receptibility to smart charging over the same period.

Because of these seasonal factors, it has been agreed that the first phase of the project should be extended to the end of December to ensure that all project participants entering the trial in the first year should experience some variance in PIV demand management, including the winter period, as this is where PIV demand management will be at its most "harsh". Those entering the trial first will, of course, experience more variation than those that join later, but all customers will experience the autumn shoulder and winter periods. This will make the trial more "realistic" in terms of the amount of PIV demand management customers will be subjected to according to season.

To avoid the potential of confusing or unduly influencing customers in this first phase of the trial it has also been concluded that major changes to the PIV demand management systems should not be made during this first year. So, unless critical performance issues are identified (such as leaving customers without charge in the vehicles) any further PIV demand management configuration changes (such as control algorithm, additional functionality i.e. Vehicle telematics and mobile phone apps) will not be implemented until the second year of the trial. The potential for these critical performance issues has been reduced as far as possible via the testing completed using the Electric Nation rig, as described in Section 3.

4.3 Year 2 of the Trial

At the end of the first year of the project a full analysis of the trial data gathered to date will be undertaken. The aim of this is to analyse the factors affecting charging behaviour and any difference in attitudes towards smart charging between the "charge at will" and "straight into demand management" cohorts. This analysis will also aim to identify other factors influencing charging behaviour and attitudes, such as:

- Differences in the two PIV demand managements systems (CrowdCharge vs GreenFlux)
- Vehicle usage (driver type)
- Battery size
- Hybrid vs pure battery vs range extender battery

This analysis will be used to identify those factors which most strongly influence charging behaviour and attitudes towards PIV demand management and so those which should be studied in the second year of the trial. This information will be used to define the trial cohorts for the 2nd year of the trial.

4.4 Next Steps

The next steps in relation to the roll-out of demand management are as follows:

- Continued customer recruitment and installations (managed by Drive Electric) to fill the "charge at will" cohorts for both GreenFlux and CrowdCharge. These customers will experience a three month period of unrestricted charging.
- EA Technology to arrange the introduction of demand management to the "charge at will" cohort after the three month period has elapsed, and supply necessary profiles of available capacity (group demand limits) to GreenFlux and CrowdCharge. These limits will be scaled according to the number of participants so that a representative amount of demand management occurs. New limits will be supplied to the DMS providers as the number of customers in the managed charging group grows.
- Ensure that customers entering the trial once the "charge at will" cohort is full enter demand management immediately following installation of their smart charger.

- Collect and analyse data provided by the DMS providers and Impact Utilities in readiness to define the trial cohorts for the 2nd year of the trial. Data from smart chargers, and any feedback received by Drive Electric will also be closely monitored to ensure that any performance issues are identified and resolved in a timely manner.

Algorithm configuration development and testing will also continue during this period, as follows:

- Test the response of further makes and models of vehicles to confirm they are suitable for demand management.
- Work with both DMS providers (CrowdCharge and GreenFlux) to agree the 2nd iteration of their demand algorithm configuration to be deployed at the start of the 2nd year of the trial.
- Implement this 2nd algorithm configuration iteration on the Electric Nation rig and ensure this has passed all the necessary tests prior to its deployment in the trial in early 2018.