WESTERN POWER DISTRIBUTION

INNOVATION

NEXT GENERATION NETWORKS

ELECTRIC NATION (CAR CONNECT)

WPD_NIA_013

CLOSEDOWN REPORT

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Contents

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Executive Summary

When launched, Electric Nation was the world's largest home smart charging trial with nearly 700 Electric Vehicle (EV) owners taking part in the project. Between them, our participants provided data for more than 2 million hours of car charging data. Importantly they also gave us first hand feedback on what it is like living with an EV in the real world and how they found the smart charging experience.

The results from Electric Nation have global significance and allow electricity distribution network planners to replace high level axioms with statistically robust facts. The lessons from this project will greatly assist local electricity networks in accommodating home EV charging whilst ensuring that drivers always have the ability to charge when they need to.

The project kicked off in 2016 and ran for 3 years with a budget of 5.9 million pounds, concluding in October 2019. The project aimed to provide a well encompassed view of how EV's will affect the electricity distribution network, both at a local level and regionally across our four licence areas, allowing us to plan our network in preparation for the predicted 3 million EV's in our territory by 2023 and beyond.

The project can be split into three sections, Monitoring, Mitigation and Modelling. This report will be split into these three sections throughout, as each of the sections cover a different area of EV impact, but have dependencies on each other for overall deliverables.

The project started with monitoring Low Voltage (LV) networks and developing algorithms to detect EV charging on individual feeders, in partnership with Lucy Gridkey. The project used some of the observed charging signals from the previous EV Emissions project, as well as adding to the library by testing some newer EV's, and then training a model to detect these signals on a loaded LV feeder.

Electric Nation is probably best known for its large scale smart charging trial which tested a range of mitigation solutions on 673 real world drivers. This trial has provided us with facts about how EV drivers charge their vehicles at home, and how accepting they are to managed charging. We also carried out a small scale Vehicle to Grid (V2G) trial in the Mitigation phase, testing three Nichicon units to see if remote management was technically feasible and the effect that V2G would have on a variety of real world networks.

The final exercise from the project was to develop a Network Assessment Tool (NAT) to assess the impact on the network in the future. Together with profiles which were developed from the trial and prediction forecasts, the tool can accurately predict future pinch points on the network and then simulate solutions such as smart charging and Time of Use (ToU) tariffs. The NAT is currently being rolled out across WPD IT systems so our planning and design staff can use moving forward.

1 Project Background

As groups of neighbours acquire Plug-in Vehicles (PIVs), localised clustering of demand is likely to cause problems for electricity networks, as proven through the My Electric Avenue (MEA) project. MEA showed that approximately 30% of GB low voltage networks will need reinforcement by 2050, if adoption of electrification of transport is widespread (i.e. meeting DECC's High EV Market Growth Forecast). This represents a present day cost of £2.2bn to UK customers – Transform Model® analysis, based on UK Government forecasts of nearly 40 million PIVs on UK roads by that time. The UK Government is committed to the electrification of transport – as illustrated by its recent investment into ultra-low carbon vehicles such as its extension of grants for PIV chargers, PIV car subsidies and the Go Ultra Low Cities Scheme.

When Electric Nation was conceived, it was not understood which parts of distribution networks would be affected by PIV market growth, and there was no tool available for assessing real LV networks to identify those at risk from PIV penetration and to identify the technical efficacy and economic viability of smart solutions (PIV demand control and V2G) against traditional network reinforcement.

The MEA project demonstrated that a simple form of PIV demand control on single LV feeders is a potentially viable option for managing peak PIV induced loads. The technology used in MEA (EA Technologies Patented Esprit) is not currently technically or economically viable and would be limited to single LV feeder demand control using a relatively unsophisticated on-off control method.

Since MEA, "smart" chargers which are controllable for access and billing purposes have been developed for the public charging arena. Alongside these smart chargers, control services have been developed and deployed to carry out the access control and billing services. These smart chargers also give the option to modulate the power taken by PIVs, giving a more refined set of demand control options than trialled in MEA. It is thought that these technologies could be adapted for domestic charger control to provide demand control services to Distribution Network Operators (DNO) across LV areas (rather than just single feeders). However, it is not known whether the application of these technologies to customers charging PIVs at home is technically viable and acceptable to customers. The technical challenges include: ensuring secure and reliable communications between the charger and control services; providing customers with information about the charging of their PIV; allowing the customer to state preference as to when they are charged (ensuring the control is as "fair" as possible to all); and investigating what, if any, compensation or incentives customers require to participate in PIV demand control. The PIV market has and will continue to diversify with a range of battery sizes fitted to PIVs and nominal charge rates growing (from 3kW to 7kW+), making possible peak loads higher and adding complexity to the challenge of PIV demand control.

In addition, V2G services and associated technologies are being developed in the UK and abroad. The impact of mass V2G services on LV networks needs to be understood, especially as some V2G services (such as transmission frequency services) may adversely affect distribution network operations, in a similar way to solar PV generation. V2G could be a solution as much as a problem for LV network congestion, in that export mode could be used to address peak PIV demands - but as V2G has not been developed sufficiently at this time this is a poorly understood option. Furthermore, adapting the PIV demand control services to utilise V2G export mode to address PIV induced peak loads has not been proven, this tool and the conflict between PIV demand control to meet DNO Demand Side Response (DSR) needs and other services V2G can provide has not been investigated.

2 Scope and Objectives

Objective	Status
Assessing (non-meshed) LV networks to predict which parts of our LV network will be susceptible to PIV penetration	✓
Determining whether PIV/V2G demand control services can be used to avoid or defer reinforcement.	✓
Give GB Distribution operators the tools and solutions monitor LV networks to detect PIV charger installation growth.	✓
Give GB Distribution operators the tools and solutions to by procure and deploy PIV/V2G demand control solutions as soon PIV induced LV network stresses arise.	✓

3 Success Criteria

Success Criteria	Status
An LV Network Assessment Tool for DNOs (an add-on to the widely used WinDEBUT LV design tool) that analyses and quantifies PIV related stress issues on LV networks (to LV area scale), including: i. Heuristics enabling rapid assessment of PIVs on LV networks through "topological" modelling of LV networks ii. Ability to include known PIV charger installations iii. Ability to forecast future PIV charger installations based on PIV market growth and forecasts iv. Flexibility allowing for future charger rating and PIV battery size developments b. Identifies best economic PIV solution: Demand Control/V2G/Reinforcement.	✓
A functional specification for a technique to monitor and understand the effects of electric vehicle charging on LV networks across different levels of penetration.	✓
Adoption of project findings into WPD's EV Strategy and EV Charge Management Hierarchy – report on consultation with EV charging stakeholders.	✓

4 Details of Work Carried Out

For this section, I have split it into three main sections following the timeline and breakdown of the project; monitoring, mitigation and modelling.

4.1 Monitoring

Working with Lucy Gridkey, we aimed to utilise their monitoring technology to train an algorithm to detect PIV's charging on a low voltage network feeder.

A decision was required at the start to determine whether the processing of the data would be done locally at the substation or at the head end (i.e. the Data Centre). Due to the level of processing expected to be required to carry out this analytics and that there was no need for that real time information to be available at the substation the decision was made to target the algorithms at the Data Centre.

Based on this, the top level method planned was:-
1. Collect sample signatures from as wide a variety of vehicles (pure EV and hybrids) as possible and starting and finishing in different states of vehicle charge
2. Once collected these signatures could be analysed to look for similarities/differences and also for any common characteristics particularly at switch on and completion of charging and then the development of an algorithm to look for these characteristics
3. Synthetically combine these sample signatures with a range of different profiles from LV monitoring
4. Test the algorithm on these combined load profiles to determine its effectiveness

The initial step was to study and understand the charging profile of a variety of vehicle types.

This work was done in parallel with the WPD EV Emissions Testing study in which the Power Quality signature (specifically the harmonic content) of a variety of vehicle types were measured and analysed. This project was run at the Millbrook Proving Ground where a selection of EVs were charged using a dedicated charging point – this consisted of 4 single phase chargers on a separate three phase supply. A GridKey LV monitoring system was installed alongside the Power Quality meters at Millbrook and set to record the voltages and current on each of the chargers.

The measurements were set to a one minute reporting period and parameters captured included mean, min and max currents and voltages, real and reactive powers and Total Harmonic Distortion (THD). These parameters were reported back to and stored on the GridKey Data Centre via a secure GPRS link and a weekly CSV file produced and emailed to TTP.

Millbrook then provided a weekly log which identified type, date, time, start charge condition, end charge condition for all vehicles which had been charged in the previous week. This was then compared to the CSV such that a library of charge profiles has been generated. This has extended the work done on My Electric Avenue to create a library for different vehicle types that can be used for other projects in the future.

Inspection of the raw charging profiles from the different vehicles showed that from one charge to another of the same vehicle type resulted in a repeatable profile however from one vehicle type to another there were differences – some were current limited and some were power limited (so when looking at a trace of power against time the power limited ones had a flat "charging period" whereas the current limiting types had variations due to voltage changes). Also the vehicles had a range of battery cell balancing – these varied depending on the state of the battery. In summary there were a lot of variations. In Figure 1 below are 4 types of charging profile that were recorded.

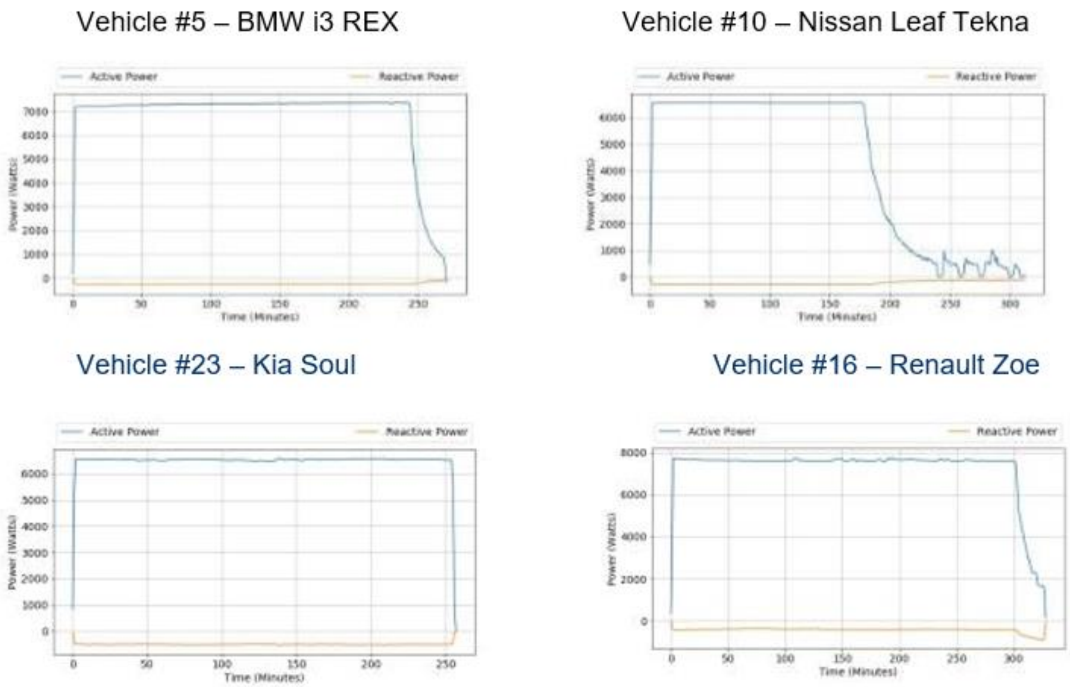

Figure 1. Showing four of the charging profiles observed

We also looked at power, current and THD in these raw data traces - particularly at the start of the charging cycle – there was a very small reactive power component and this was fairly constant throughout the charging cycle; with no noticeable change in THD – certainly not something that could be detected when there were other electrical background loads/noise. We also repeated this looking at the 1-second data which is available from the GridKey unit and this did not show any specific features in the profiles.

A previous project, known as Project Galaxy, also looked at load profiling for certain types of load. On a one minute basis this measured a series of electrical parameters which were then compared to a standard profile. This was created by isolating the load from any background noise and then measuring the same parameters. In that case there were repeatable features, particularly in the switch on profile, which could be detected and then combined with other parameters to create an algorithm that reliably identified the specific type of load.

Initially for the Electric Nation project we tried to use the same analytic techniques as used on Galaxy – traditional pattern correlation, probabilistic analysis etc. However, as the only real trigger was a 7kW load, this increased the probability of false alarms to an unacceptable level. There were other similar sized loads of that type, for example electric showers which would trigger the analytics.

A completely new and alternative approach was therefore adopted using a neural network "self-learning" approach; this is shown in Figure 2 below:

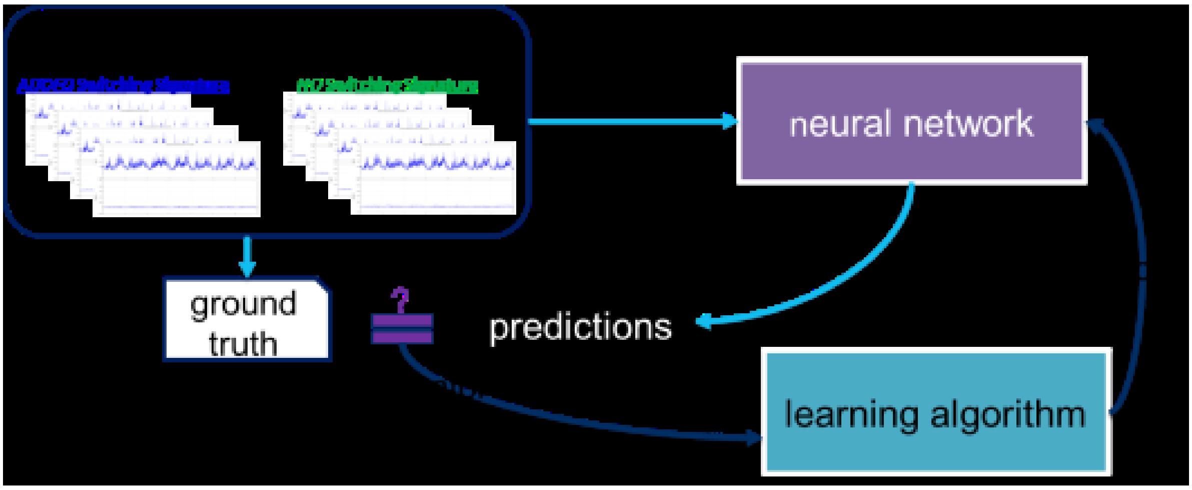

Figure 2. The neural network approach

In order to further simplify the problem we limited the algorithm to try and detect a maximum of one PIV charge switch on and one switch off event per hour and that both of these would be circa 7kW. This allowed the development of a multi-layered convolutional neural network algorithm which is a standard technique used for this type of analytics.

Combining with "Standard" load profiles
Obtaining suitable load profiles which did not have PIV charging in them already was difficult. It was not known if there were any vehicle charging points on the particular feeders of the sample data or more particularly whether these charge points were being used. If there was an unknown charge event already happening this would skew the results. We were also limited to combine the EV sample data with data with the same reporting period (i.e. 1 minute).

To minimise the risk, we used some of the oldest (2013-2014) 1 minute data we had collected from other projects on the principle that there were few charging points/PIVs in 2013. We also chose data from geographic areas which had low penetration of PIVs to further reduce the risk. This resulted in a relatively small sub-set of suitable data however we were able to have a range of feeder loading levels which were all from residential areas. We also expanded this data set by artificially modifying the data to increase and decrease the background loads.

Algorithm Testing
The algorithm was allowed to "learn" using the background data and then testing was carried out to both look for:

- **positive detections** (i.e. when there was a vehicle present)
- **false-positives** (i.e. when there was not a vehicle present but there was other electrical background noise which the algorithm mistook for a vehicle charging).
- **false negatives** (i.e. when a vehicle was present but the algorithm mistook it for background noise)

4.2 Mitigation

To get a rigorous set of trial results, 500–700 participants would be recruited. With PIVs accounting for just 1.5% of vehicles in 2017, and the trial being restricted to the Western Power Distribution region, a strong promotion, recruitment and retention operation would be required. The trial employed two companies for this: EA Technology and DriveElectric.

The publicity push was a great success, and the team met its recruitment goals. The campaign included the following activities:

- Project leaflets distributed in car showrooms
- Targeted posting on PIV-focused websites and forums
- Test drives arranged
- Connections made in WPD-covered cities with Go Ultra Low schemes to attend events and publicise the project
- DriveElectric's own leasing customers targeted
- Project launched at LCV2016, the UK's premiere low carbon vehicle event
- Robert Llewellyn interviewed Electric Nation team members and put the interviews on the Fully Charged Show YouTube channel, with 100,000 highly relevant subscribers and many more viewers
- Press releases were fed to media outlets detailing milestones and raising awareness among PIV owners and buyers
- The website was regularly updated with news items for maximum search engine visibility

The trial successfully recruited 700 drivers with 673 being taken through to the live trials. All vehicles were owned or leased by the participants or their employers, the trial did not supply vehicles. Forty-five different PIVs were used, from 18 manufacturers. The most common brands were BMW, Tesla, Nissan, VW, Mitsubishi and Mercedes-Benz. Vehicles fell into three categories:

- **Battery electric vehicles (BEV)** – a purely electric vehicle that is powered by a battery and an electric motor, with no internal combustion engine.

- **Plug-in hybrid (PHEV)** – a combustion-engine vehicle with a battery-powered electric motor, each of which can power the wheels independently or together. The battery can be charged by plugging in, and the vehicle itself can charge the battery when in use. (PHEVs are distinct from “self-charging hybrids”, which are entirely powered by petrol, and therefore have no place in this trial.)
- **Range extended (REX)** – a plug-in electric motor powers the wheels, but there is also a small combustion engine that acts solely as a generator to charge the battery if required.

Once the participants had been recruited, they were given a free smart charger which was installed into their home by project installation teams. At this point communications were established and the chargers were brought online.

The smart chargers for the trial were supplied by Alfen and eVolt, two of the biggest names in smart charging technology, with GreenFlux and CrowdCharge supplying the back-office systems that controlled power delivery and took instructions from drivers. The trial participants were distributed roughly half and half between the two back-office suppliers.

The chargers fed information back to the trial administrators, such as whether they were plugged in and, if so, whether they were charging. Over the course of the trial, two million hours’ worth of charging activity data were captured.

GreenFlux and CrowdCharge could also send instructions to the chargers, telling individual chargers to switch off or reduce the charge, as would be the case in a genuine smart charging network. This was key to the trial, as it would simulate expected demand management. Thorough testing of the algorithms was carried out before the systems were delivered to participants.

The trial was split into three sub-trials to mimic different potential future scenarios.

Trial 1: Blind

To simulate a future where greater demands are put on power substations by PIV charging, the trial organisers would limit charging to the various vehicles when demand was high. For that reason, participants who habitually charged up outside of the peak hours rarely, if ever, had their charging limited. Similarly, owners of 3.6 kW vehicles would have been limited less often than those with 7 kW vehicles. As the trial was blind, users were unaware if their charge was being managed or not, this was an advantage as it prevented users from changing their behaviours to work around the managed charging. Figure 3 below shows the overall capacity allowed to a group of chargers based on seasonal base demand.

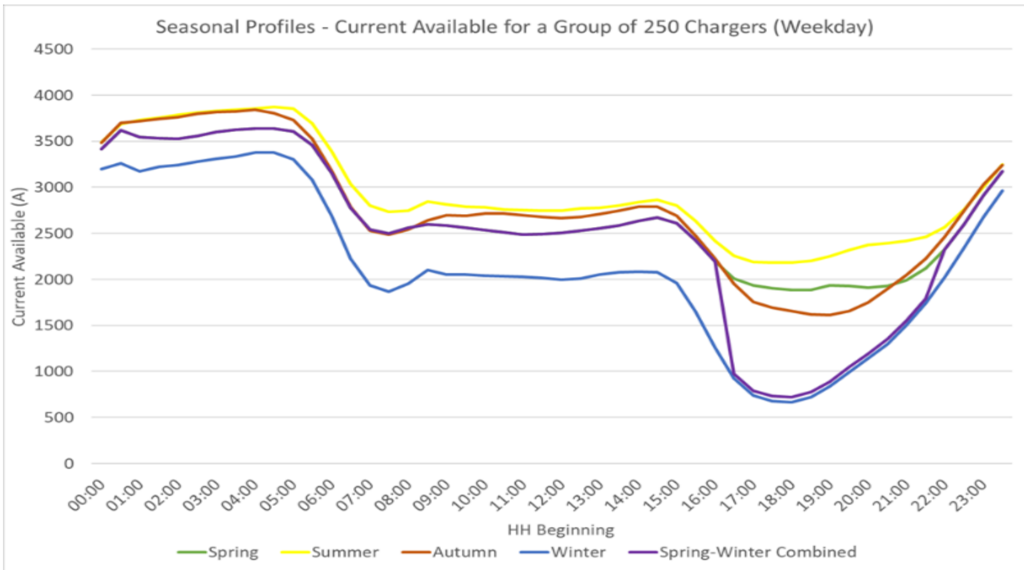

Figure 3. Seasonal capacity profiles

Figure 4 below shows how much power was delivered to the chargers on average per day. The system was reactive to plug in and plug out events, and would therefore constantly adjust the limitations.

Figure 4. Current allocated to chargers in demand management

Trial 2: Interactive

Trial 2 introduced interaction and customer demand into the equation, as participants were given phone apps that would allow them to have some control over their charging. The systems used differed slightly between charger suppliers.

- CrowdCharge users told the app how much charge their vehicle currently had, and how much they needed the next day. The system would then ensure that sufficient power was delivered to top up the battery to meet users' needs.
- Those using GreenFlux had the option to override the system and opt-out of smart charging, by pressing the high priority button, they would instantly get a full rate charge and they would then avoid any limitations during that session.

Those who did not request prioritisation would have their power managed normally.

For both groups, a limited charge was available to share between participants, although the total power available was slightly more generous than in Trial 1.

Trial 3: Incentivised

In Trial 3, the options available in Trial 2 were modified to include a "Time of Use Tariff" (ToU) so users could earn shopping vouchers if they opted to charge outside of peak hours, reflecting the fact that energy is cheaper off-peak. Figure 5 shows when the high and low tariff periods are.

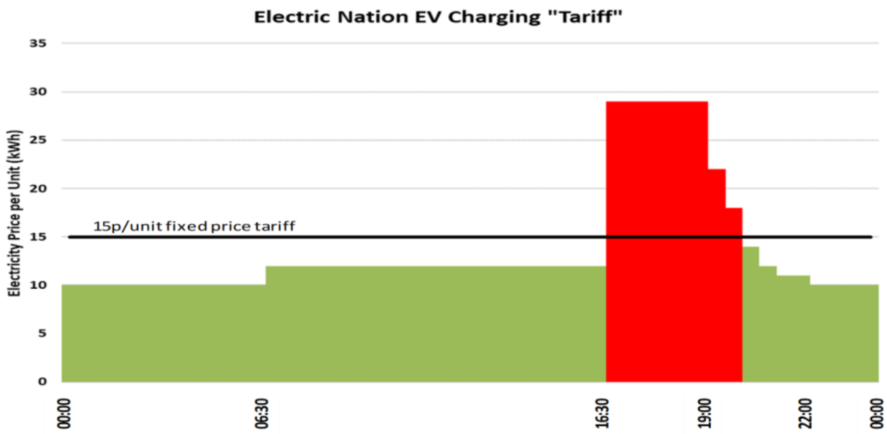

Figure 5. The simulated ToU tariff

Again, the systems differed slightly between the two Smart Charging providers.

- CrowdCharge used the same journey plan as in Trial 2, but the system would try to use the cheapest tariff given the plan unless instructed otherwise. So:
  - If a user got home from work and told the app that they needed to drive 50 miles later that evening, the cheaper tariff would be ignored and charging would be prioritised over cost.
  - If they didn't need the car until the following morning, the charger would wait until the cheaper tariff kicked in.
  - If no instructions were given, the vehicle would charge up regardless of tariff.
- Under GreenFlux, drivers used the app to decide if they wanted to prioritise time or cost, and the charger would charge straight away or only charge when off-peak, respectively. A user's preference would remain the same every day unless changed. However, as in Trial 2, users could opt to be prioritised, so the car would charge regardless of tariff. The app also gave users information on charges and the impact their choices had had on their rewards.

V2G Mini Trial

In the V2G mini trial we wanted to test the technology to establish if it could be controlled remotely and the feasibility for using as flexibility in the future, as well as assessing the impact on the local distribution network.

The project originally intended to install 5 V2G units, however, as the technology is relatively new, there was limited suppliers to choose from, of which some had several months lead time.

The project decided to go for the Nichicon charger, of which three units could be delivered by January 2019. These units were installed, and three test Nissan Leafs were provided by Drive Electric so to mitigate any issues that may arise around battery degradation or damage to customer's vehicles.

Once the installations were complete, a set of profiles (Figure 6) were developed to cycle the cars on. These profiles were designed around both supporting the network around baseline load peaks, and testing the capability of the vehicles and charger/control equipment. These profiles were cycled on a monthly basis between users to ensure that each user experienced each of the different profiles.

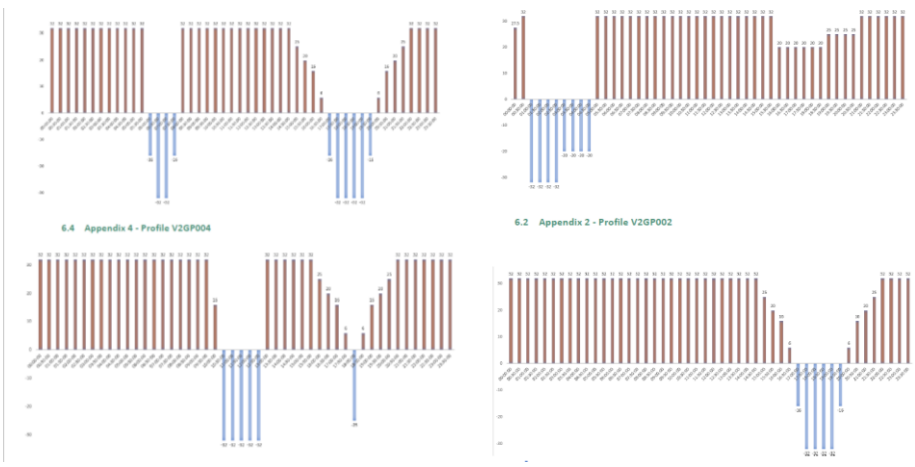

Figure 6. Four V2G profiles that were applied

The local network was then monitored with a variety of sensors including a Lucy Gridkey unit in the substation, and PM1000 and PM7000 recorders at adjacent properties on the same phase. Data was collected either via automatic notification for units connected over GSM, or by a weekly technician visit to manually download data.

This Data was then analysed together with the V2G charger data to look for patterns or 'spikes' in voltage or harmonics as the unit changed between charge and discharge.

4.3 Modelling

This section of the report summarises the complete development of the Network Assessment Tool (NAT) which began in Q4 2016. A key output of the NAT is to allow us via a software tool, to understand the likely impact of PIVs on our low voltage networks using network data that is derived from core business systems, without excessive post-processing. LV network planners will be provided with this new platform to view and assess LV networks under future Electric Vehicle market scenarios and assess the potential benefit of using alternative smarter methods to delay or avoid the need to reinforce networks overloaded by EV charging loads.

The challenges that exist with all DNO data systems is recognised, so methods have been developed within this project to deal with data inaccuracies and incompleteness; these are likely to be applicable to all GB DNOs.

Three distinct development phases were split up as per the following;

- A data transformation tier, combines and translates internal and external data sources to describe each LV asset, LV customer, forecast data and geographical context. Raw data imports are stored in an initial database which have been mirrored into a staging database. The initial import database stores all original data to allow for validation activities and improve the overall data integrity. The final output from this tier is a mass validated structured relational dataset containing complete LV network connectivity across various asset bases with spatial locations.
- A business logic tier, here bespoke bulk import routines and heuristic spatial algorithms work together to create the required relationships access each asset base to derive actual connected networks. Where data quality is exceptionally low a network estimation routine is executed to assimilate an assumed network. High level EV forecasts are assigned down to a customer level using bespoke methods and subsequently each LV network is passed over to the DEBUT2.0 engine for constraint assessments to be completed. The output from this tier is a mass set of network performance results by each constraint type; thermal substation, thermal cable and voltage drop. These results are also rolled up and aggregated to Energy Supply Areas (ESAs) to allow for wider interpretation.
- A presentation tier, a Postgres database has been used which is well suited to web-mapping services. This interrogated via Geoserver which is used to share the spatial database data to the bespoke web application which then provides the front-end data interactions to be performed. Two primary use cases have been catered for in the design of the user interface; a strategic view which present aggregated results for wide-area assessments to be carried out, and, a tactical view which LV planners can interrogate the performance of particular networks and assess specific local areas.

Overview of the System Components

Finalised Multi-tier Architecture

To manage developments, the software architecture is partitioned into three distinct elements which make up the multi-tier architecture. That is, the data transformation tier, the business logic tier and the presentation tier. Figure 7 below illustrates the completed data flow through the software architecture and the sub-elements which support each tier.

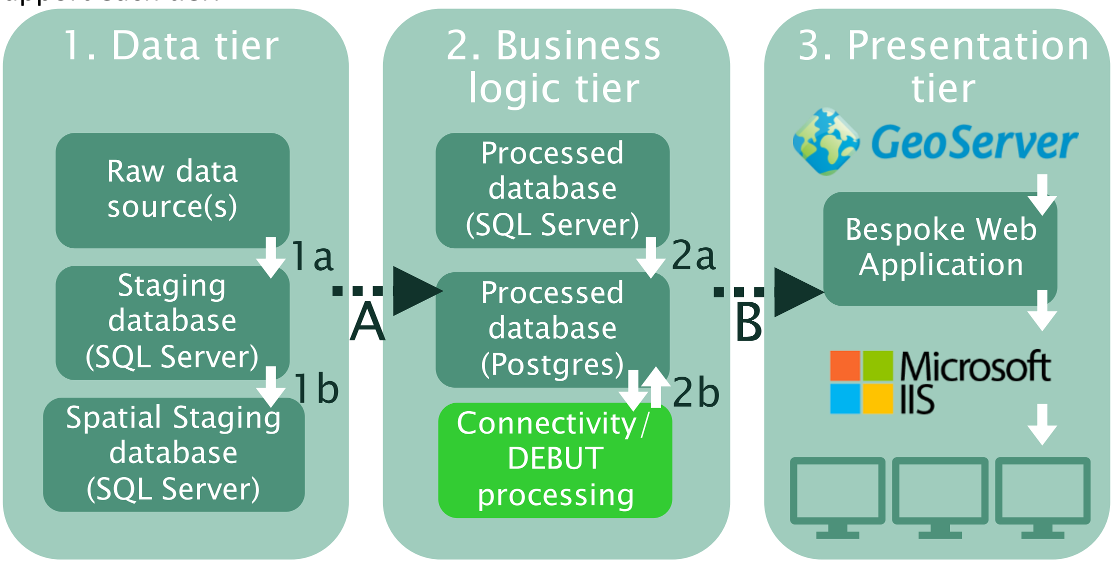

Figure 7. three distinct elements of software architecture

To explain the above stages:

- 1a (Data tier): Raw data imports are stored in an initial database which are mirrored into a staging database. The initial import database stores all original data to allow for validation activities and thus improve data integrity overall.
- 1b (Data tier): Pre-process migrated raw-data, to validate and update missing data, where possible. For example, location data is checked and where possible a spatial location is created off the best available data which could be easting and northings, grid references or even postcodes.
- A (Data tier -> Business Logic): The spatially pre-processed and validated data is passed over to the business logic tier, where it will be re-associated and processed to identify and define each network.
- 2a (Business Logic tier): Consolidate and restructure data into the defined schema upon which the algorithms and spatial re-associations are based. This database is then mirrored to an object-relational database management system, which enables simpler front-end integration.
- 2b (Business Logic tier): Custom routines to carry out the algorithmic processes which spatially re-associate the datasets and define the available networks for DEBUT2.0 processing. DEBUT2.0 outputs on the anticipated worse case voltage drop and cable/substation utilisations before and after any future (e.g. PIV) loads are added as dictated by the forecasts.

- B (Presentation tier): A database format suited to the web-mapping services (Postgres) database has been used. This interrogated via Geoserver which is used to share the spatial database data to the bespoke web application which then provides the front-end data interactions to be performed.

In section 9.3 (Modelling Outcomes) each tier of the tool will be covered in detail to describe the operation and functionalities available within the NAT tool.

5 Performance Compared to Original Aims, Objectives and Success Criteria

Success Criteria	Outcome
An LV Network Assessment Tool for DNOs (an add-on to the widely used WinDEBUT LV design tool) that analyses and quantifies PIV related stress issues on LV networks (to LV area scale), including: i. Heuristics enabling rapid assessment of PIVs on LV networks through "topological" modelling of LV networks ii. Ability to include known PIV charger installations iii. Ability to forecast future PIV charger installations based on PIV market growth and forecasts iv. Flexibility allowing for future charger rating and PIV battery size developments b. Identifies best economic PIV solution: Demand Control/V2G/Reinforcement.	The project successfully delivered the Network Assessment Tool to include the criteria specification. The tool is able to assess the LV network with current PIV demand, and forecasted uptake up to 2030. The tool will also except manual input for PIV numbers, and can deploy solutions such as smart charging or ToU tariffs to re-analyse the network and give the user an option to defer re-enforcement.
A functional specification for a technique to monitor and understand the effects of electric vehicle charging on LV networks across different levels of penetration.	Through working with Lucy Gridkey, we now understand the effects of EV charging on the low voltage network, and what charging traces look like through monitoring. We have also developed an algorithm to detect PIVs charging which has a reasonably high probability of detection (>95%) for 7kW chargers.
Adoption of project findings into WPD's EV Strategy and EV Charge Management Hierarchy – report on consultation with EV charging stakeholders.	The project hosted a stakeholder workshop which saw a wide range of various industry stakeholders give feedback on the findings and help shape our forward approach. The findings from this workshop and the project have informed our decisions within our EV strategy and charging hierarchy.

6 Required Modifications to the Planned Approach during the Course of the Project

The project set the target to recruit 700 drivers, at the time when the project was conceived this was deemed to be a reasonable sample size and achievable given the low numbers of PIV's available at the time. The trial successfully recruited 700 PIV drivers, of which 673 went through to installation and live trials. We decided not to proceed with 27 of the installations due to;

-Customers internal wiring not suitable for car charger.
-High cost network upgrades needed.

It was also decided that to re-open the recruitment to recruit and additional 27 drivers would be disproportionately expensive for little extra value as 673 would give us an ample data set.

During the project change request CRF001 was raised to change the project deliverable "A functional specification and commercial framework for future procurement and deployment of PIV/V2G demand/Export control services by DNOs to delay or avoid network reinforcement in cases where PIV installation numbers create network stress".

It was decided that the current deliverable no longer aligned with current industry thinking which had developed rapidly since the project conception in 2015. It was also clear that OFGEM had no appetite for DNO's to directly smart charge its customers. Thus the deliverable was changed to "Adoption of project findings into WPD's EV strategy and EV charge Management Hierarchy – report on consultation with EV charging stakeholders. This ensured that learning from the project was directly transferred into business as usual, and informed WPD's approach to future network issues due to PIV loading.

7 Project Costs

Activity	Budget	Actual	Comments
EA Technology Ltd, Trial & Analysis	£3,094,360	£3,104,853	Additional £10,493 approved as a part of CRF1 for production of trial report.
TRL, Project Management	£226,807	£226,807	
Lucy Gridkey, Monitoring phase	£255,480	£255,482	Additional £2 spent for equipment variations.
Fleetdrive, Recruitment and installations	£2,129,376	£2,175,615	Additional £46,240 approved as a part of CRF to cover additional installation costs.
WPD Project Management	£96,000	£107,005	Project management weighed heavily during mobilisation.
Total	£5,802,023	£5,869,762	1.2% Overspend

8 Lessons Learnt for Future Projects

The table below details the key learning that has been generated in the different areas of the project.

Topic/Area	Learning Generated
Internet of Things	The challenge for the project is that charger manufacturers are limiting their thinking to development of in-house condition monitoring and customer services (e.g. remote switching and energy monitoring), a very few are thinking about additional services like demand control for the utilities. The charger community is very young and co-operation, standardisation, collaboration is not really in their mind-set. Nor, it appears, is the cost of mobile phone comms, the cost advantage of broadband internet comms and cyber security (at least, outside of their own systems). As the project aimed to utilise customer's home broadband internet connections for charger comms it became apparent that systems integration expertise would be required to assist in ensuring secure and reliable internet communications to/from chargers to overcome the lack of understanding of the issues in the charger manufacturing community. The Learning: Specifically for IoT type devices for the home/industry/commerce that are connected through the internet 1. If time/budget allows select experts to support similar projects involving IoT type devices before a project is started 2. Build a list of suitably qualified and experienced practitioners for future projects involving IoT type devices
Pilot Installations	The project concentrated on testing and proving what were rightly viewed as "critical" equipment - the chargers and communications equipment. Ancillary equipment such as power switches and USB power supplies were viewed as "low risk" items as they are in market items and used commonly with very low failure rates. Testing of ancillary equipment before pilot installation may have identified RCD issues we are currently having. Installer training post pilots was very useful in terms of ensuring installers understand procedures and processes, clarifying procedures and processes based on installer feedback and

	reinforcing practical aspects of communications commissioning and troubleshooting
Customer Behaviour	Customers switch off chargers for variety of reasons including (i) Waiting for vehicle delivery (ii) When away, (iii) Because they don't like the light on charger possibly attracting people on street to enter their property This leads to false "loss of communication" alerts that waste project staff time chasing down the customer only to find charger has been switched off. This also leads to problems with communications system not coming back on line if not switched on correctly. 20% of trial participants have not participated in the customer surveys - there is no penalty for customers not doing this (NB Impact Utilities say that 80% returns is actually very good for this type of project). At the outset of the project it was assumed that receiving their "free" smart charger would be reward enough to gain customer participation at this stage. (NB completion of further trial surveys are rewarded by issuing shopping vouchers for completed surveys). While the project has a £150 clawback from customers who do not participate in the trial or withdraw during the trial, this has not been used to date and is perceived by the project team as a drastic measure and could possibly damage the project's and WPD's reputation if used. A platform/system should be set up in order for peer to peer feedback/collaboration on the project (e.g. Facebook group/Social media outlet). This would allow common communication between interested participants which could be monitored/queries answered. Analysis could also take place to identify unforeseen behaviours/attitudes which in turn could be fed into a knowledge base to increase understanding and learning for all (switching off chargers picked up early). Participants have asked if a group exists to communicate to other participants.
Charger Suppliers	ICU, manufacturer of one of the charger models being supplied to the customer trial, had an internal communications problem - Sales neglected to pass on correct firmware configuration to manufacturing department. Consequence was that over 100 units were despatched and installed in customer homes with the wrong configuration. This was only noticed when plans were

	being drawn up for implementing demand management on a small number of customers who had entered the trial first. The error would have prevented demand management being implemented. The learning: (i) Ensure suppliers have adequate QA systems in place to ensure this type of mistake does not happen and (ii) Implement systems to check configurations of similar devices are correct as soon as they installed in customer premises.
Knowledge Base	An online, user friendly knowledge base should be established at the start of any project. This should be accessible by all parties involved to increase learning and efficiency (customers, installer, customer engagement team, market research team, technical team etc). Customer feedback can be feed into this as the project develops in order to enhance overall customer experience and collaboration between parties. This can then be offered to customers on initial contact from project team. This would allow a simple way for all involved to develop learning as the project advances.
Installers	During the early stage of the project regular meetings/training days should take place in order to renew process, raise issues, review installation procedures with the aim to share learning from all involved and increase knowledge. This would save time and resources later in the project e.g fixing comms later instead of establishing quick fixes on installation.
Customer Engagement	In spite of thorough internal review of the customer research questionnaires, it has been found that some trial participants are misinterpreting one theme of the customer survey questions, related to their "satisfaction with their current charging arrangements" and tend to go off on a rant about the lack of wider charging infrastructure. This is not a critical issue and can be resolved by looking at customer responses elsewhere in the questionnaire. The learning is that future questionnaires should be tested on people who are not involved directly in delivery of the project before being used on trial participants.
Industry Standards	Should not assume that the established legislation and codes of practice can cope with new technology. E.g Max demand calculation, ENA form, IET specifications, and OLEV guidelines. Implementation and interpretation of OCPP differs across the charger manufacturing community.

	Learning: just because a protocol exists doesn't mean it's implemented as a standard by those who promote compliance
Customer Recruitment	Several areas of learning have been recorded in this area: -Ensuring the correct, high detailed questions are asked within the qualification process, in particular around electrical supply and installation will help to manage the customers' expectations as the recruitment phase continues to installation. -At the start of the recruitment process, DriveElectrric asked prospective participants to pay a £150 upon signing up to the project with the participant agreement to cover the admin costs in case they then decide to leave. Also the idea was for this to act as a deterrent from leaving the project early. This process was utilised for approx. 4 weeks during the autumn of 2016. The vast majority of prospective participants argued that this did then not make the project 'free to join' and subsequently would not progress any further through the qualification process. This caused the qualification of customer to be a struggle. DriveElectric then decided to reverse the process fee and inform customer that if they decided to remove themselves from the project before the closer date of 31/12/18 they would then be required to pay the £150 then. -During the qualification call with participants Electric Nation asked if they would be willing to provide telematics data once they have their unit installed. Out of all approved surveys, 71% of these participants initially agreed to providing telematics data in principle however only 8% of these have given permission to collect data to date or signed to agree to it. Therefore the learning is all participants should agree and sign to provide vehicle telematics as a project requirement before the charger has been installed. This could contribute to an increased number of telematics participants on the project however it is important to note recruitment may not have been as successful if this was a project requirement. POSITIVE - A part of the successful recruitment can be attribute to the participant receiving a free charger and installation worth between £1000-£1500 with only 1 real project requirement in that they must return 2 baseline market research surveys. Learnt that 1) participants are keen to join if they receive a free piece of advanced technology and have to do little in return and 2)

	leading on from this that perhaps the project could of request more from the participant in return from the free charger and installation. POSITIVE - 'Friends Recommendation' to the project was the fourth highest lead source behind search engine 'Google' in first, and EN website and social media second and third respectively. Out of the total approved surveys, 10% were from recommendations to the project which is a large conversion rate. At the start of the recruitment phase it may have been overlooked of the benefit of asking participants to recommend friends and family to the project. Providing incentives for recommendations could be utilised on future WPD project to increase the conversion rates further. DE was responsible for recruiting 700 participants in line with the project milestones and processing 3000 enquires to the project. Automation of the qualification and order process could speed up the process to reach the milestones even earlier then DE completed them while also increasing customer's recruitment and charger order experience. Recommendations: 1) Automating the survey process via an app/web form to complete the survey which is then return and instantly imported into a system which pre-cals a pass, fail or in need of work status; inform customer of project requirements and FAQs on a video; automate process of EOI survey send out and participant agreement; create account for application process that customer can log into to receive status of order/updates/issues.
Marketing & PR	Just because you find a project brand/name is free to use, don't assume someone else isn't also looking to use same name - coincidences do happen. By coincidence this project was seeking to use "Electric Nation" as a customer facing brand for the project at the same time Nissan were developing a pan-European social media campaign about use of electric vehicles. We might have avoided any conflict between the project and Nissan by applying for a TradeMark at the point we decided to use the name.
Project Planning and dissemination	Earlier engagement with Government departments and agencies and perhaps other DNOs that are key stakeholders in a project should be engaged at the outset of a project (if not before). This is particularly the case where the innovation project's scope encompasses issues that;

	(i) May have an impact on wider society, (ii) Consumer markets (e.g. the uptake of PIVs in this case), (iii) Government policy, legislation, etc. Engagement with these stakeholders could help form the project and tasks/activities to attempt to address their concerns/issues/questions (where possible/practical) and would avoid potential overlap and duplication of activity.
App Development	The process for gaining Apple Apps approval takes far longer than it does for Android Apps. The development and testing of the GreenFlux App has utilised the Android format. Once the App functionality was settled the development of an Apple App was relatively simple, but the process of gaining Apple approval was very time consuming. Updates to an app (e.g. wording changes) require the verification process to be passed again. Limiting updates and allowing additional time within the project timeline can address this issue. This should be factored in to future projects where mobile phone Apps are to be used.
NAT Development	The quality of network asset data varies considerably across WPD's four license areas, therefore the outcome of NAT data processing and network assessment success varies with the quality of input data. Project Assumption:" WPD have sufficient network data to populate the network assessment tool" - Learning: WPD's LV substation data is good enough for NAT requirements; Cable/OHL data varies from adequate to poor, depending on age of data, leading to NAT feeder translation performance issues, customer (MPAN) data appears good though this is difficult to test (especially domestic/commercial customer type) and number of missing data points cannot be tested other than identifying substations and feeders with no customers.
Telematics	When qualifying customers, the project only asked if the participant would be willing to provide telematics data once their charger was installed. As a result the telematics recruitment has suffered with less than 30 vehicles agreeing to supply telematics data on state of charge. Learning: In real terms participants are reluctant to provide

	telematics data once they have received their free charger already. On future projects, providing telematics data needs to be a project requirement. By having the participant sign they agree to provide telematics data to have the free smart charger installed, this could increase the uptake of telematics data on the project. However this could hinder the success of the recruitment so it must be thought of carefully before committing to telematics as a project requirement.
V2G Installations	In the mini-V2G trial, one of the chargers (V2G0011) lost comms to the Crowd Charge platform thus resulting in the specified charging testing profiles not being implemented. This downtime in comms was not noticed automatically by the Crowd Charge system; a manual check of the charger picked up that the comms/charger had faulted. Therefore, for future WPD projects it would be sensible to have an automatic notification system for participant/operational team to increase the uptime of connectivity and subsequently controllability for the DNO. The Crowd Charge comms module that is required to control the bidirectional charger connects to the participant's internet via WIFI (and/or GSM sim, if required). On installation, 2 of the sites suffered issues with WIFI connectivity only days after installation; this could be because the installer was able to connect over WIFI because the garage door was open however, once the install was complete and door closed, this loses connection due to the new direct route the WIFI signal tries to takes through the most direct route. Therefore it is suggest that during qualification process, a method is introduced for participants to test WiFi signal at the chargers location to interpret if the connection is strong enough for WIFI connectivity alone, or if SIM connection should be included.

9 The Outcomes of the Project

9.1 Monitoring outcomes

The aim of being able to detect PIV's charging on individual feeders turned out to be more complex than expected – other than a typical "top hat" shape there was little that (electrically) determined it to be a PIV rather than some other load.

There is an alternative of seeing the 7kW rising ramp and then trying to eliminate other things it could be however this only works if you know all the other things it could be so this is not really a practical solution.

Although we were able to get a reasonably high probability of detection (>95% for individual hourly samples), this was partially as a result of limiting the problem (so only looking for circa 7kW vehicles and also only looking for one switch on event per hour) and partly by optimising the algorithm for accurate positives (at the expense of a higher (~75%) negatives accuracy). In other words, the algorithm seldom reported a car charging when one was not there but more often missed a car that was in fact charging.

The decision to carry out the calculations at the Data Centre end rather than locally at the monitor was absolutely correct for this project – there was a lot of processing and more particularly storage required for the neural network and the GridKey MCU520 has only very limited processing capability. The downside of this decision is that the current algorithms are restricted to operating on data at 1 minute intervals. In the context of identifying EV charging this is far from ideal since the chargers typically change state over a much shorter time period so a lot of potentially useful information is lost. Moving to more rapid time reporting, 1 second data or even data at 5Hz, is expected to offer a lot of scope for improvement. The concern however is the cost of backhauling this much greater volume of data.

Since the start of the project, GridKey has introduced a newer MCU – known as the MCU318. Although it still only has limited processing capability in order to minimise the price of the unit, it does contain a Cortex M4 which is considerably more powerful than the PIC processor in the MCU520 and does have spare processing capacity and some available memory.

The MCU318 is sampling the current and voltage sensor data at 6.4kHz and is calculating parameters at 5Hz. The system is already carrying out waveform captures for use both on distance to fault analytics and also for future PQ software upgrades.

So a potential solution could be to carry out some of the processing locally on this new generation of GridKey devices. This will require some innovation in numerical computing as well as algorithm development because of the very limited processing and memory resources on those cost focussed units but we think there is good scope for performance improvements using this approach.

Overall the project has demonstrated that detecting EV charging profiles is difficult but possible however it requires better than 1 minute data resolution to be successful.

9.2 Mitigation outcomes

Our trial observed how users charged their PIVs and created a transaction record each time a vehicle was plugged in. Each transaction record had three pieces of data:

- What time the vehicle was plugged in
- What time it was unplugged
- How much energy was transferred to the EV

It is worth noting that the plug-in time is not necessarily the time charging started. If a driver set the timer in their car to take advantage of an off-peak rate in their energy tariff, but plugged in during peak price hours, charging would not start immediately.

A total of 98,656 weekday and 35,541 weekend charging events were recorded, and these are shown in Figure 8 below. As expected, the distribution is flatter at weekends, mirroring waking hours rather than commuting times. Around 28% of all weekday plug-in events occurred between 17:00 and 18:59. When measuring participants' habitual charging times, the results from Trial 3 (incentivised) are not taken into account, as they are influenced by the trial, and not people's usual routines. Trials 1 and 2, however, did not attempt to influence drivers, so the figures represent normal use.

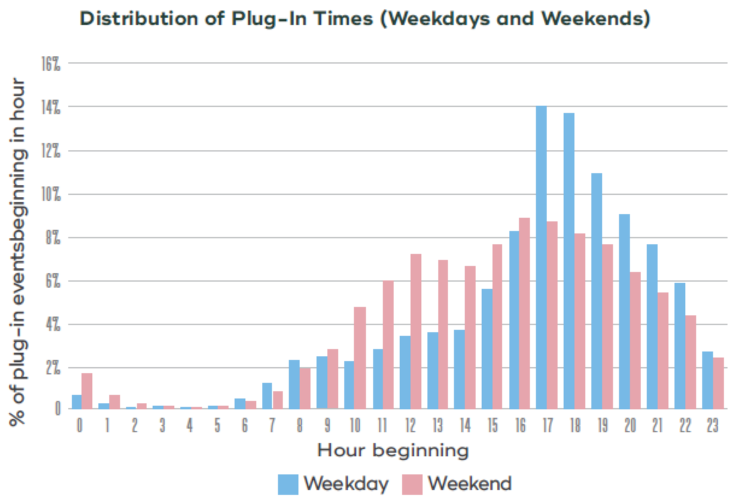

Figure 8. Distribution of plug in times

While the time the car was plugged in was detected in each transaction, this does not necessarily coincide with the time the charger was delivering power. PIV owners can set a timer on their vehicles, so charging might start later. This would usually be done to take advantage of cheaper night-time electricity, and is more convenient than staying up until midnight to plug in.

Figure 9 below compares the difference between weekday plug-in times and when charging began. It shows that while around 14% of users plug in around 17:00 to 18:00, only around 11% of charging events start in this hour. There is a noticeable jump in vehicles being charged in the midnight hour, despite less than 1% of plug-in events taking place then. This can only be accounted for by the use of timers.

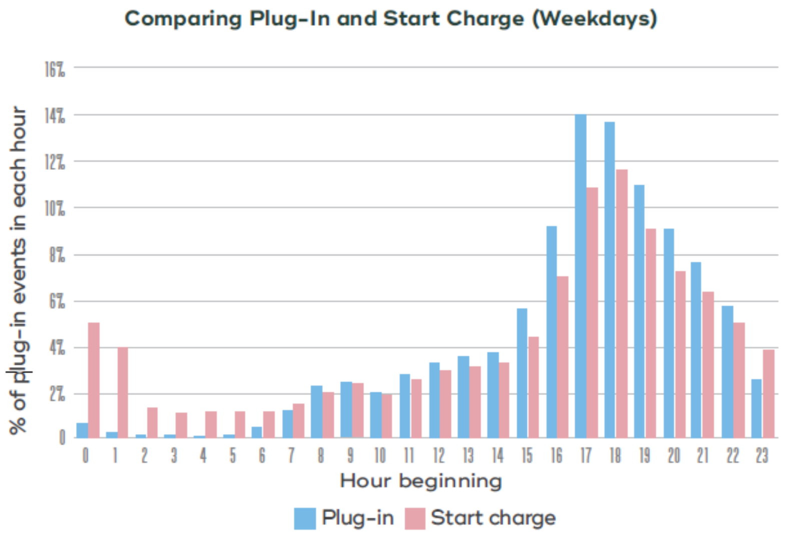

Figure 9. Plug in times vs charge start times

It is worth noting that most electricity customers do not have a separate night-time tariff, so there is no incentive for them to wait until after midnight to charge. Also, some drivers have no choice when it comes to charging times – drivers' needs do not always follow the 9 to 5 pattern. The trial found that when people plugged in during the day, they tended not to use a timer, as there would be no financial benefit; also, if the vehicle was required later that same day, delayed charging was not an option. Timer use picks up for those who plug in between late afternoon and early morning, as those people are more likely not to need their vehicles until the next day. Timers are used in 20% of charging events in the week, and 17% of events at weekend.

The majority of owners of PIVs usually do not charge their vehicles at home every day. So knowing how often they do charge is a critical factor in calculating demand and the need to manage and incentivise consumption over the 24-hour period. Factors that influence how often drivers charge at home include:

- Average daily mileage
- Battery size
- Whether the driver also charges elsewhere

The trial discovered that the average number of charges was between three and four a week. Only 14% of users charged their vehicles at least once a day, and 72% of those were PHEV drivers. Figure 10 shows how this breaks down over type of PIV and battery capacity.

Charging Frequency for Different Vehicle Types

Category		Median Charging Frequency (Charge Sessions per Day)
All Participants		0.52
PEV Type	PHEV	0.76
	REX	0.45
	BEV	0.39
Battery Capacity	Less than 10kWh	0.73
	10 to 25kWh	0.63
	25 ro 35kWh	0.39
	35kWh +	0.31

Figure 10. Charging frequency of different battery capacities

Plug-in hybrids were charged more often than range-extended vehicles, with battery-only vehicles needing recharging the least often. If all users charged up every day, it would put a very different complexion on the figures from the previous section because capacity would be reached more often.

The amount of energy that has to be delivered to vehicles is just as important as the time of day when vehicles charge from a power capacity point of view. Electric Nation gathered a good deal of data on energy use, including linking this with information on battery sizes, time of year and a range of other factors.

Along with the weight and performance characteristics of the vehicle, the battery capacity is a key determinant of range, and also influences the frequency of charging and how much energy is delivered each charge. For the purposes of the trial, we divided batteries into four size groups:

- Less than 10kWh
- 10–25kWh
- 25–35kWh
- More than 35kWh

When charging up the largest batteries (+35kWh), they tended to start at between 50% and 84% charged. For the smallest batteries (less than 10kWh), they tended to start between 17% and 48% charged. The two middle groups showed similar behaviour to each other, starting between 30% and 70%. These measurements tally with what would be expected. The smaller the battery, the lower the vehicle range, and so the more likely it is that it is fully discharged when at the start of each charging event.

At present, the small numbers of PIVs on Britain's roads means there is never a need to manage demand. The trial's aim was to reach findings assuming demand was scaled up so that PIV take-up was much more widespread, as per medium-term predictions. The area of most concern regarding demand overload is not necessarily power generation to supply PIVs; it is the capacity of substations serving localities. Electric Nation simulated this part of the power infrastructure by dividing the chargers into groups and managing supply when those group members collectively reached the group's demand thresholds.

This happened when the demand for groups of chargers would have been greater than the available network capacity.

CrowdCharge and GreenFlux
In Trial 1 (blind), CrowdCharge and GreenFlux used slightly differing systems. CrowdCharge started managing when it was no longer possible to allocate 7kW to all the chargers that were plugged in and demanding energy.

As GreenFlux knew which vehicles were 3.6kW and which were 7kW, it only started managing when those specific power demands could not be met. If some 3.6kW vehicles were charging this meant that a larger number of chargers could be active before management was needed. A series of capacity profiles were implemented to account for seasonal changes and the number of vehicles in the group.

Winter demand and management
In Figure 11 below, the left graph shows 24-hour weekday demand during the winter (5 January to 11 March) for chargers managed by CrowdCharge, while the right graph shows the same period for chargers managed by GreenFlux. For reasons described earlier, winter is the season of maximum energy demand for EVs, so the daily peaks in winter are the most significant to measure from a capacity and management point of view.

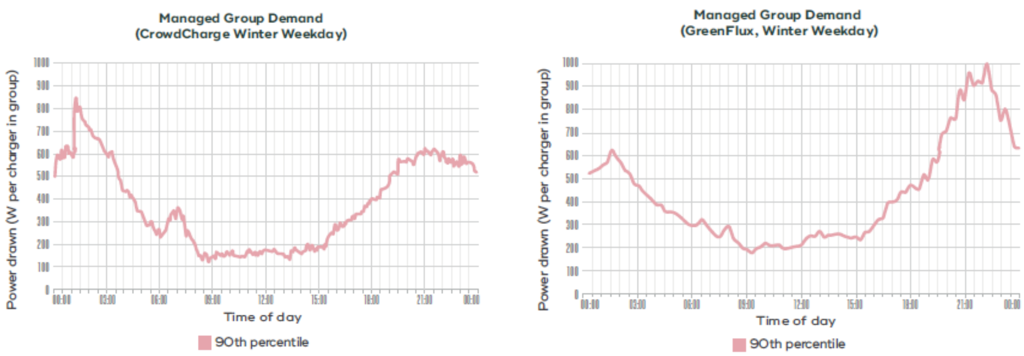

Figure 11. CrowdCharge and Greenflux group demand

The amount of demand for electricity to charge PIVs during the evening peak led to demand management becoming active:

- In the CrowdCharge group, 8% of Trial 1 charging events were subject to demand management, with 75% of participants experiencing management at some point. Those with vehicles rated at 16A (3.6kW) were less likely to be managed than the 32A (7kW) vehicle drivers, as the current allocated by CrowdCharge rarely fell below 16A.
- In the GreenFlux group, 17% of Trial 1 charging events were subject to demand management, with 81% of participants experiencing management at some point.

For CrowdCharge, weekday management happened every weekday during winter, but only during the evening peak (specifically 16:23–22:25). Within that time range, it was rare that management was triggered after 21:30. At the weekend, any management occurred between 16:00 and 20:59, and was always less restrictive than typical weekday management. However, during some weekends there was no need for management at all.

With GreenFlux, winter management happened on 40% of weekdays, always between 17:00 and 21:15, and 30% of weekend days, always between 16:30 and 19:00.

One of the aims of Electric Nation was to discover the effect different energy tariffs would have on drivers' charging habits, particularly when this was supported by smart charging. This was chiefly to minimise stress on substations during the peak hours shortly after the evening rush hour, particularly in winter.

One result of cost optimising was that there was a sudden surge in demand at 22:00 as can be seen in Figure 12. Virtually all of the participants who had delayed charging until after peak tariff switched on at the same time. Indeed, the surge was much more sudden than a normal end-of-rush-hour demand rise, which happen over several hours as drivers gradually arrive home. Furthermore, the surge maxed out higher than at any point during the previous trials.

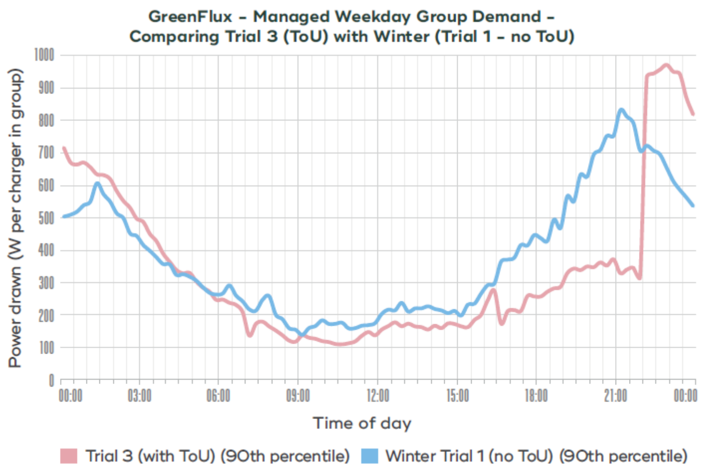

Figure 2. Impact of ToU tariff

The 22:00 surge did not reach the overall limits for a substation, as the usual evening peak was over, with people winding down for the night. Because only vehicle chargers were being monitored for the trial, this spike is from vehicle charging only, not overall electricity consumption.

Sudden step changes like the one shown at 22:00 can *potentially* cause issues for the electricity system. This is a useful observation rather than a problem, however. There are technical solutions such as randomising switch-on times which could be deployed to make any rise in demand less sudden. It does illustrate how smart charging is a crucial element in any tariff-based system, as without smart charging this management would not be possible.

During weekends, the same simulated tariffs applied, and the phenomenon continued to occur at 22:00. As the night progressed, demand settled into a pattern similar to that seen in the non-tariff winter trials. The total amount of energy delivered on weekend days was less than during the working week, although demand for charging was generally slightly higher during the day. Both findings follow expectations, as commuters are at home and can charge at any time during the day. Sunday's demand was higher than Saturday's, but lower than a typical weekday's.

Drivers in Trial 3 were incentivised to change their charging behaviour with a 'reward value' system. All participants began the trial with a reward value of £10. Each unit of electricity their charger used during the peak period would decrease their reward balance by 13p. Each unit their charger used overnight would increase the balance by 5p. At the end of the trial participants received a shopping voucher equal to their reward value. On average, participants received £21 from the nine-week trial. The largest reward was £80.

The incentive, combined with smart charging and the app, had a significant impact on drivers' behaviour. The app certainly helped the switch by making it a simple choice between high and low cost (here simulated by the vouchers). Before tariffs were introduced in Trial 3, there wasn't the option to choose a lower cost, unless participants were already on a time of use tariff (such as Economy 7). It is therefore reasonable to assume that the majority of PEV drivers do respond to such incentives. They had two other options – to ignore the incentive altogether or prioritise time – but actively accepted it. Remember also that some of the high-tariff chargers might not have had a choice as they might have needed their vehicles during the night.

9.3 Modelling Outcomes

The NAT displays information at multiple levels and has been intuitively designed so that any user that is familiar with general mapping tools will be able to pick this up with little to no prior training. When the tool is loaded, the first zoom level presented provides illustrative boundaries for each of our four Licence Areas as in Figure 13.

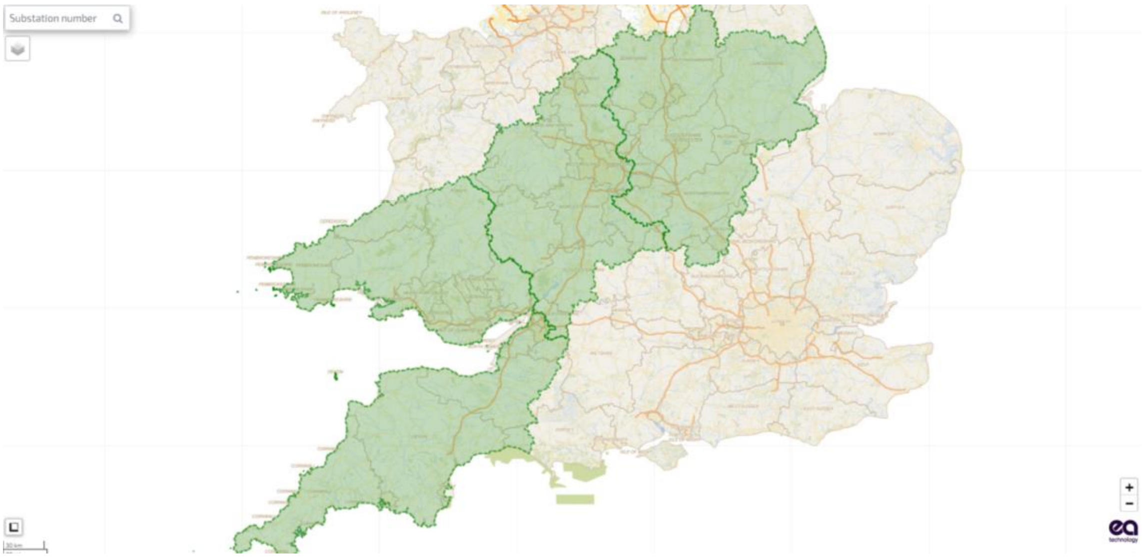

Figure 13. Levels of the NAT – License Areas

Upon zooming in further, the boundaries will be updated to present the next level of detail, this is the 'strategic view' which is based at the Energy Supply Area (ESA) level. ESAs are defined as geographic areas served by the same upstream network infrastructure to a Bulk Supply Point or Primary Substation. These ESA boundaries were developed through GIS analysis by Regen. The EV constraint analysis results have been aggregated up to each ESA and can be found by selecting an ESA boundary which will open a new sidebar which can be seen in Figure 14.

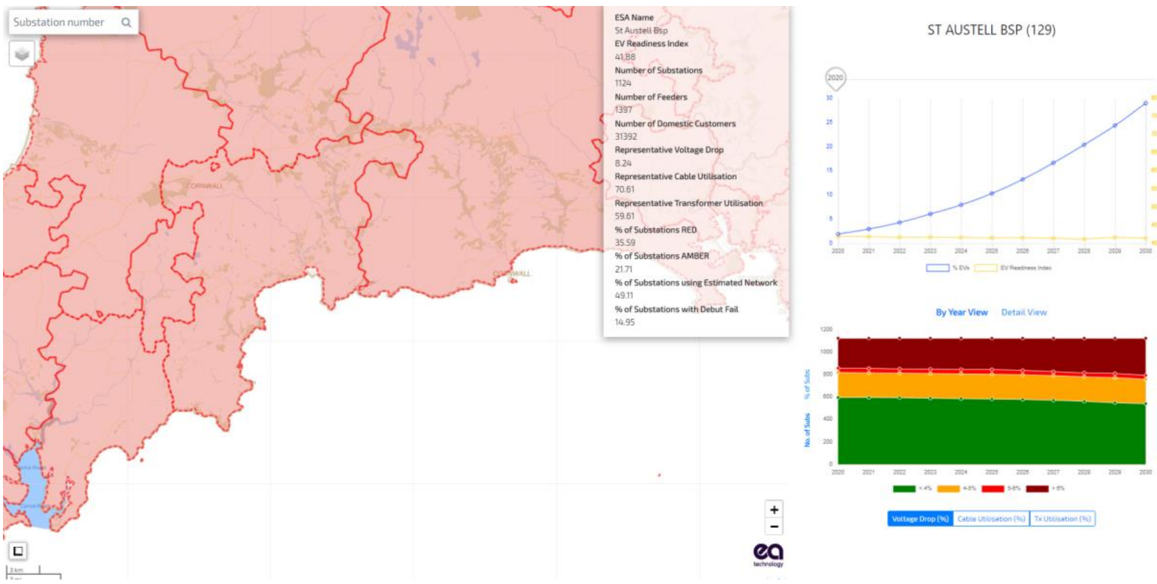

Figure 14. Levels of the NAT – EAS sidebar

Zooming in further will then provide the third and most detail level is the 'tactical view', based at the local level where locations of distribution substations, actual LV networks and LV customers can be viewed at detail alongside the network constraints results.

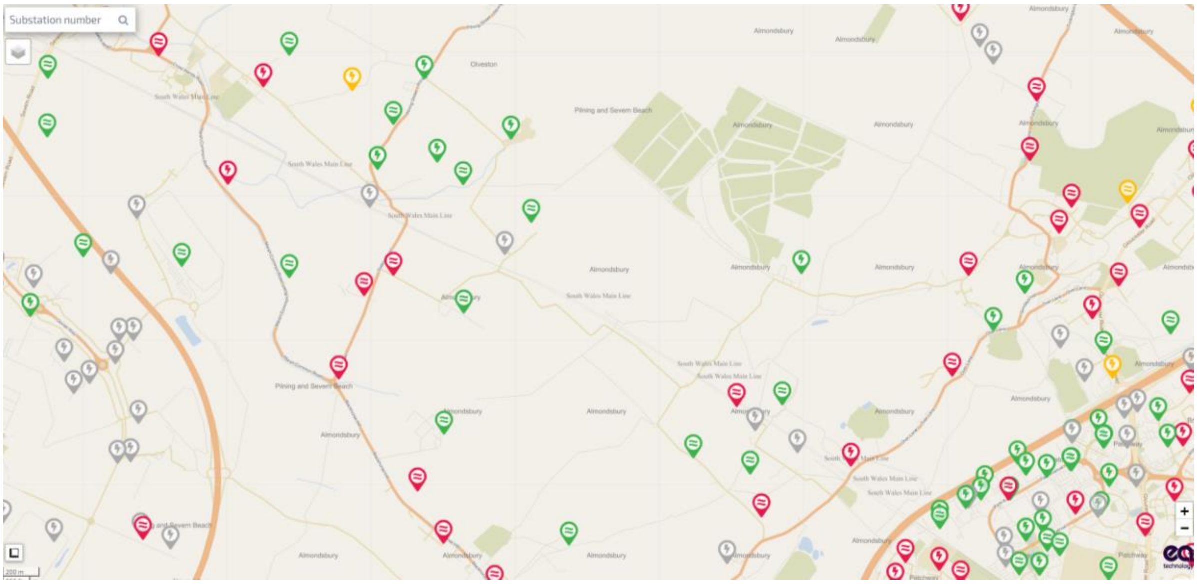

Figure 15. Tactical view – Distribution substations

When a distribution transformer is selected, the network and customers served will be displayed. A sidebar and popup will also come into view, giving the resulting outputs from the PIV constraint analysis along with further details and specifications for the chosen network.

Figure 16. Tactical View – LV Networks

The components within each level will be described in the following sections.

Strategic View – ESA Results Summaries

This is a view of the aggregated effects of PIVs across an ESA. This view is obtainable by either zooming down one level from the initial licence area presentation, or by zooming out from the substation-level view of the map, and then selecting an ESA of choice.

The intended use of a view at this level is twofold. The first use, illustrated by the graphs which display automatically, is a way of illustrating the loadings and capacity system-wide (ESA-wide in this case), and how this change as more EVs are added. If a user is more interested in digging into the detail, there is an additional graph which allows the user to identify vulnerable networks within the ESA and therefore target their investment analysis.

ESA Analysis Sidebar – EV uptake and EV Readiness Index graph

The first graph displayed on the sidebar will show the expected percentage uptake of EVs with time, aggregated from all the constituent substations. There is also an additional metric which has been created for this aggregation stage; the EV Readiness Index (EVRI). On an additional y-axis, the EVRI will be plotted, so the relationship between the two quantities is easily visible. Underneath the graph, the percentage forecast for the selected year will be displayed. This is illustrated in Figure 17.

Above this graph is a slider which allows the user to select the year of interest. This differs slightly from the currently implemented NAT design, in which the year selector is a part of the EV uptake graph. This design was changed in order to make the User Interface (UI) cleaner, as there are more data series on the graph at this level. It is expected that this design change will be subsequently applied to the substation-level sidebar to maintain consistency.

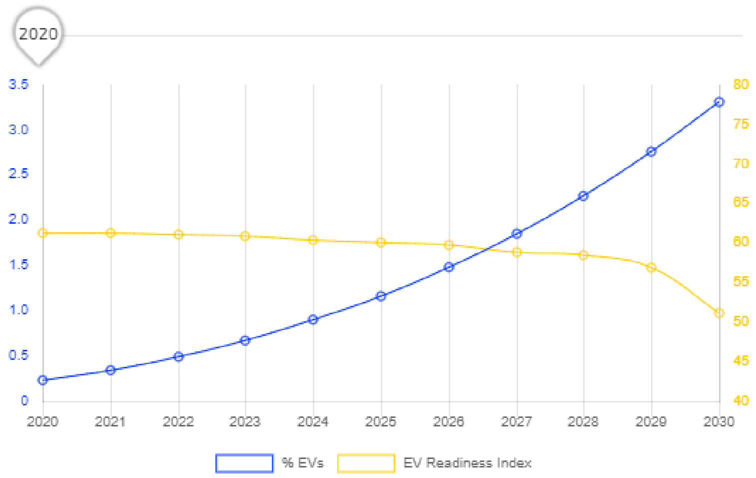

Figure 17. EV uptake graph and year slider

The EVRI is a number between 0 and 100% which indicates how well the overall network will cope with electric vehicles in a selected year. An EVRI of 100% corresponds to the entire ESA network being within the configured threshold of the constraints being measured (Thermal Transformer, Thermal Cable and Voltage). It is worth noting that most ESAs do not start with an EVRI of 100%, as there are many substations which are already over statutory limits for either voltage drop, cable utilisation, or transformer utilisation.

This metric was created for two main reasons. Firstly, because the RAG colour system, while useful against a specific constraint or at a substation level, it does not give much granularity at an ESA level. If there are e.g. five red ESAs, the EVRI metric enables the user to identify which one is worst. Secondly, the RAG analysis looks at the network at a substation level – it is based on the three failure metrics' maxima for the substation, regardless of how many of the substation's feeders are overloaded. A single overloaded feeder causes the entire substation to be labelled red. The EVRI takes the number of feeders into account as well, which better reflects the health of urban networks in particular.

To calculate the EVRI: EVRI = 100%*(1 - x_1 - x_2)

where x_1 is the maximum of:

(the fraction of all feeders which have volt drops of over 5%,
the fraction of all feeders which have cable utilisations of over 100%,
the fraction of all substations which have transformer utilisations of over 100%)

where x_2 is 0.5* the maximum of:

(the fraction of all feeders which have volt drops of between 4% and 5%,
the fraction of all feeders which have cable utilisations of between 90% and 100%,
the fraction of all substations which have transformer utilisations of between 90% and 100%)

ESA Analysis Sidebar – Breakdown graph

Underneath the EV uptake graph is a stacked area graph indicating the progressive change in the number of substations which fail by each of the three metrics. This is illustrated in Figure 18.

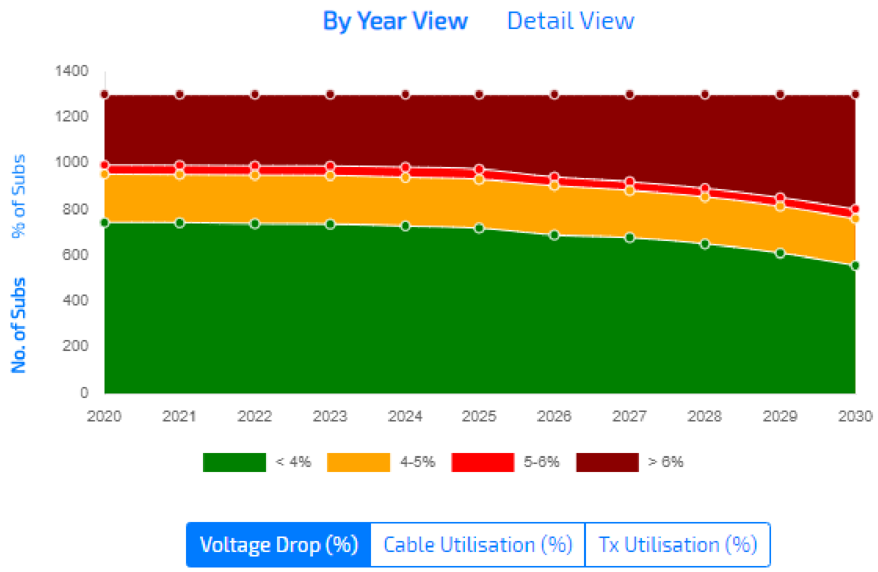

Figure 18. Results breakdown Graph

The user will select one of the three failure metrics – voltage drop, cable utilisation or transformer utilisation. The metrics are broken down into four categories; green, amber, red, and dark red, representing the network being fine, borderline under-limit, borderline over-limit, and highly over-limit respectively. The graph reflects how many substations are in each category and how this changes over time. This view allows the user to easily see what proportion of the network is in danger of breaching limits, and how this is likely to change as the number of PIVs increases.

The four categories on the graph are currently defined for voltage drop as: <4%, 4-5%, 5-6%, and >7%. The overload point is defined here as 5% as most of the networks do not include service cables, so a proportion of the statutory voltage drop limit is left for this. The corresponding groups for the two utilisation metrics are: <90%, 90-100%, 100-110%, and >110%.

ESA Analysis Sidebar – Detailed breakdown graphs

The stacked area graph can be swapped for a more detailed graph, shown in Figure 19, while keeping the view of the uptake graph and year slider above. This graph will display data only for the selected year via the year slider on the above PIV uptake graph.

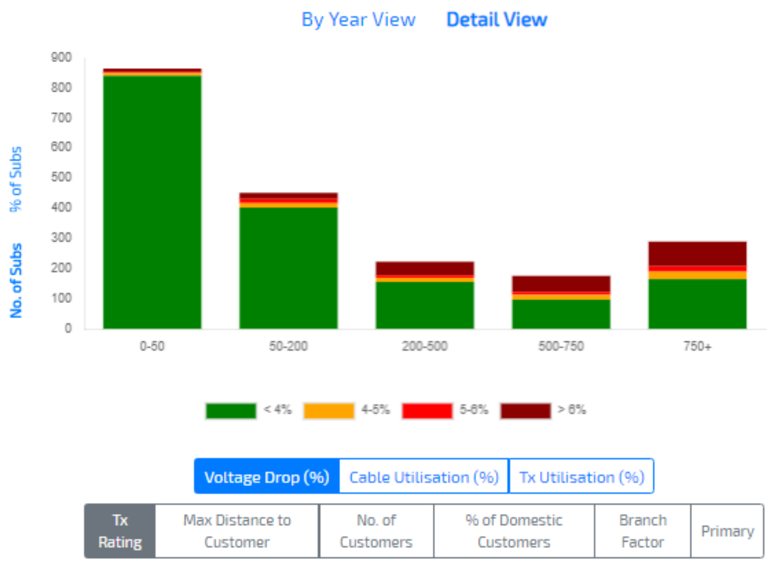

Figure 19. Detailed results breakdown graph

The detailed breakdown graph is a histogram in which the data is broken down by a substation-level characteristic. This allows the user to identify features of networks within the ESA which are vulnerable to the presence of PIVs. It also allows the user to perform more targeted analysis of the planned investment within an ESA.

As with the previous graph, the buttons above the bar graph allow the user to select which failure metric is to be studied (voltage drop, cable utilisation or transformer utilisation). The buttons below the graph select the units of the x-axis. There are six categories by which the data can be broken down:

- Transformer rating
- Maximum feeder length from the substation

- Number of customers per substation
- Percentage of a substation's customers which are domestic
- Branching factor (an artificial number indicative of how much the network is prone to branching, calculated per substation)
- Primary: some ESAs cover the scope of more than one primary substation – this allows it to be known if the problem is limited to the scope of one primary, or across all, in order to target investment

To calculate branching factor for a substation:

- For each feeder, count how many nodes have more than two cables (i.e. when one cable splits into more than one at a joint).
- If the node branches into two, count once. If the node branches into three, count twice, etc.
- Divide this total count by the number of feeders

ESA Analysis Sidebar – Ancillary popup

The collapsible popup is very similar in design to the version which appears at the substation level. This popup is designed to be an at-a-glance display of a few key attributes for the selected year and ESA. It will display a variety of static descriptors; such as:

- Number of constituent substations and feeders
- Number of domestic customers (those likely to gain EVs)
- Percentage of substations which use the estimated network, or fail calculation entirely (due to data quality issues in the base asset data)

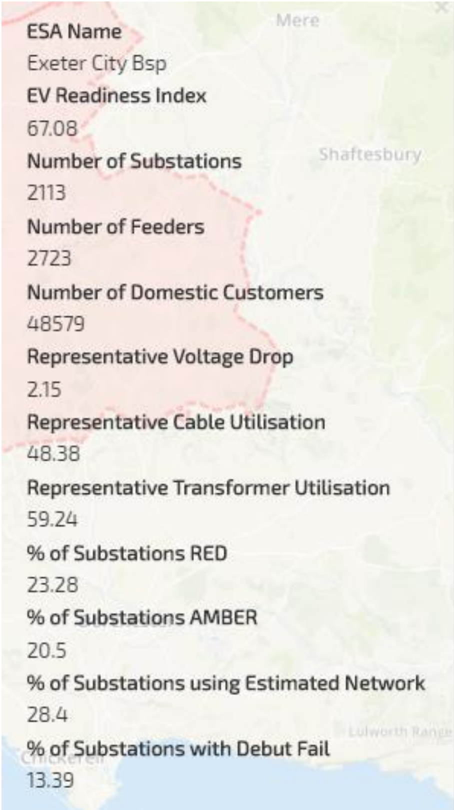

Figure 20. Ancillary Popup

Also displayed are a number of statistics for the ESA for the selected year, which will change value if the selected year is changed:

- EV Readiness Index
- Average maximum voltage drop, cable utilisation and transformer utilisation
- Percentage of constituent substations which are red, and amber

Tactical Analysis Mapping Elements

Within the main mapping window each element has been designed to be as intuitive as possible. These elements are mostly dynamic and selectable, each element and ancillary function is described in the below sections.

Distribution Substations

In the above Figure 15 the display level whereby the distribution substations come into view can be seen. The icons for these are colour coded by the aggregated RAG score of the entire network performance.

Figure 21. Distribution Substation Icons

The icon variants are as follows;

- A green icon indicates all constraint levels are at a healthy level
- An amber icon highlights the network is nearing a constraint
- A red icon indicates that a constraint has been reached
- A grey icon is present where no network assessment has been completed due to lack of sufficient data
- A blue icon is displayed when the manual mode is entered and results are pending as a calculation is first to be performed

An additional variant of these icons whereby an approximation symbol is in presented in the middle of the icon as per Figure 22. The same colour status variants provided in the above apply. These indicate that an estimate network is being used as the raw data has not been translated correctly. This is covered in further detail in section 5.3.

Figure 22. Distribution substation icons with estimated networks

Customers

All customers fed from a selected distribution substation are displayed as a circular coloured icon. The colour of the icon is related to the colour of the related feeder which also relates to the results table in the sidebar.

A customer's attributes can be viewed by selecting the icon which will bring a new popup onto the display as illustrated in Figure 23 below.

MPAN
2200010972227
Substation Number
330106
Feeder Number
10
Meter Class
Domestic Unrestricted Customers
Meter Timeswitch Class
801
Measurement Class
A
DEBUT Consumer Type
ONE (3600, 0)
Energisation Status
E
Existing Electric Vehicle?
No
Estimated Location?
No
Phase
2
Distance from Substation (m)
146.87

Figure 23. Customer attributes popup

Cables/Conductors

All cables and conductors which make up a feeder are colour coded along with the customers being supplied from each feeder in the selected substation. Each cable segments attributes can be viewed by selecting the segment and a new popup will be displayed as illustrated in Figure 24 below.

Length
37
Type
CS 95
Source
LvRoute
Computed Substation Number
330106
Computed Feeder Number
10
ID
3026393
DEBUT Cable Type
CS 95
Rating (A)
259
Max Current (A)
10.6121
Max Utilisation (%)
4.1
Max Volt Drop (%)
0.45

Figure 24. Cables/conductors attributes popup

Electric Vehicle Indicator

Customers can have electric vehicle chargers associated, either as a starting position or an assumed uptake through the forecast being applied or with in the manual mode assessment. If the base data indicates an PIV is already present a red ring around the customer will be presented. Otherwise if the PIV position has been assumed in the other mechanisms a blue outer ring will be presented.

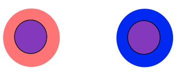

Figure25. EV placement indication

Network Results Popup

When a distribution substation is selected to view the network and its results, an additional popup is displayed alongside the main sidebar. This popup provides the key results and information about the substation and worst results of each constraint on all feeders supplied.

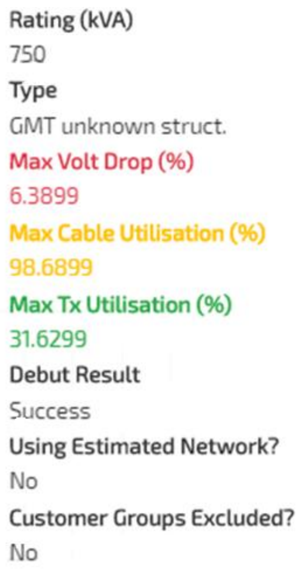

Figure 26. Network results popup

Tactical Analysis Sidebar

Upon either searching for or manually finding and selecting a distribution substation. A sidebar will be displayed onscreen to provide the detailed results for the chosen substation.

The substation's name and number are still presented at the top of the side bar. Below this, the PIV uptake graph associated with the year slider at the top. At the bottom, a colour coded comparative table of constraint results for all feeders fed from the selected substation. This table is split into the base year and the selected year on the slider above to allow a quick comparison of how the constraints change over time due to the PIV uptake.

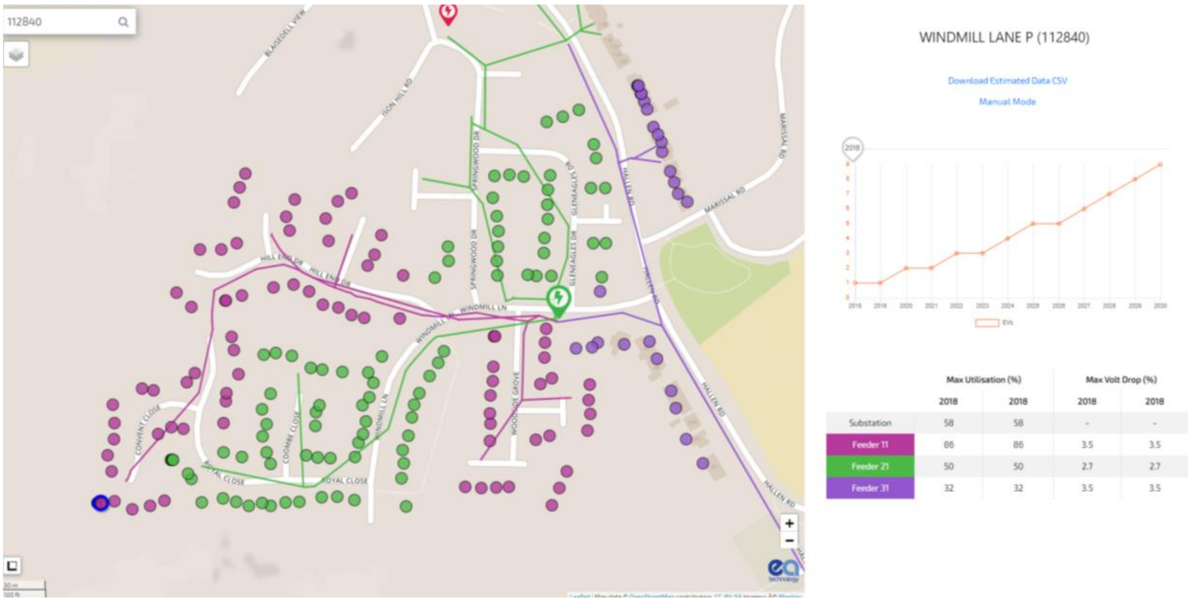

Figure 27. Sidebar interface

On the map, the outgoing feeders are colour coded which align with the key in the results table in the sidebar for quick identification of the correct results row.

Manual Mode

This allows the user to manipulate the PIV uptake penetration for an LV substation. Thus, for a given LV network, an LV designer will be able to test how many PIVs can be introduced before some form of intervention is required, beyond the initial scope of the derived forecast. Figure 19 shows the tool, which can be located using the 'Manual Mode' toggle located on the side bar.

Figure 28. Custom EV penetration tool

The designer operates the slider to choose a penetration percentage. This percentage figure represents the proportion of customers on the network that have a PIV. Therefore, 100% penetration means each consumer has been allocated a PIV. The maximum allowed penetration is 200% (two EVs per consumer). Alternatively, a specific number of EVs can be introduced to the network using the input box. The EV allocation to the substation is then distributed to customers using the Three-Bucket Method (described in the previous Quarterly Report). This ensures full alignment with the deployment locations of each EV across all EV assessment methods and through time. As the user manipulates the penetration levels, the map is continually updated with EV allocations.

Once the desired percentage penetration has been selected, the user clicks 'Calculate'. The DEBUT engine then runs a one-off network calculation 'on the fly' for that network set up and returns the results in a matter of seconds.

The results table is then updated. The below figures show examples for a network with a penetration of 10%, 50%, and 100% respectively.

Figure 29. 10% penetration

While the transformer is still operating within limits, Feeder 40 is now nearing a volt drop constraint as its approaching 5% on the main.

10 Data Access Details

Anonymised trial data is now available on the WPD data portal, linked below. The data includes data on plug-in values, charging values, charging restrictions and vehicle details according to Electric Nation user number.

The data is available on downloadable EXCEL spreadsheets and whilst every effort has been made to ensure the data is suitable and useable, we are not able to guarantee any results or respond to individual data inquiries.

www.westernpower.co.uk/Innovation/Contact-us-and-more/Project-Data.aspx)

11 Foreground IPR

IPR Generated	Owner
Nomenclature for "address" of network assets	WPD
Method to Audit provision of DNO PIVDCS by remote collection of current data from clamp/meter attached to input to PIV Charger	WPD EA Technology Ltd CrowdCharge
System Integration techniques, designs and learning	WPD CrowdCharge GreenFlux
Network Assessment Tool	WPD EA Technology Ltd
Materials to support DNO BaU integration, including Policies, procedures, training	WPD
Project Reports	WPD
Project Datasets	WPD
Specification of DNO "esprit" signals	WPD EA Technology Ltd CrowdCharge
PIV User behaviour reporting	WPD EA Technology Ltd CrowdCharge
PIVDCS performance analysis/reporting methodologies and graphical representations of these	WPD EA Technology Ltd
Smart Charger communications learning	WPD EA Technology Ltd

12 Planned Implementation

Electric Nation has provided a wealth of information and data, with a legacy that has already shaped the way that we will be building our network for the future to accommodate PIVs.

There are two main benefits to WPD that we will be carrying forward to Business as Usual (BaU) and company rollout, these are the adoption of findings into our EV strategy and rollout of the NAT.

12.1 Adoption of findings into WPD EV charging strategy

The findings from the project have already been adopted into WPD's EV Charging Strategy (Appendix B). The information from the trial has shown us that in fact the majority of PIV users are not likely to be plugging-in everyday and charging from empty, but more likely every 2-3 days and charging from half charge.

Off the back of these finding we have assessed our network and established that the vast majority of our ground mounted substations will be able to cope with one 35kWh charge (About 150 Miles range) for every customer connected every 5 days. Combining this with the learning from Electric Nation, our network will be able to cope with the imminent take up of PIVs.

Where constrains are seen on the network we will work with energy suppliers to procure smart charging services or encourage the take up of ToU tariffs to reduce peak PIV demand, which the project has proven to technically feasible and successful.

12.2 Rollout of the Network Assessment Tool

The Network Assessment Tool will be deployed onto WPD systems and a redacted version used as a public facing tool on our website. The aim of making it available to the public is to share the learnings from the project and to be transparent about capacity on the network, particularly with the expected increase of PIV charger applications.

We are now looking to expand upon the NAT in a phase two project to replace our current modelling software WinDEBUT, which will equip all of our network planners moving forward into a lower carbon future.

13 Contact

Further details on replicating the project can be made available from the following points of contact:

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Pegasus Business Park,
Herald Way,
Castle Donington,
Derbyshire
DE74 2TU
Email: wpdinnovation@westernpower.co.uk

Glossary

Abbreviation	Term
BEV	Battery Electric Vehicle
CSV	Comma Separated Values
DNO	Distribution Network Operator
DSR	Demand Side Response
ESA	Energy Supply Area
EV	Electric Vehicle
EVRI	Electric Vehicle Readiness Index
GPRS	General Packet Radio Service
LV	Low Voltage
MEA	My Electric Avenue
NAT	Network Assessment Tool
PHEV	Plug-in Hybrid Electric Vehicle
PIV	Plug In Vehicle
PV	Photo Voltaic
REX	Range Extended
SoC	State of Charge
THD	Total Harmonic Distortion
ToU	Time of Use
UI	User Interface
V2G	Vehicle to Grid

Appendix A

Customer Trial Report Produced by EA Technology can be downloaded here:
https://westernpower.co.uk/downloads/64378

Appendix B

WPD's EV Charging Strategy can be downloaded here:
https://www.westernpower.co.uk/downloads-view/29293