WESTERN POWER DISTRIBUTION
INNOVATION

NEXT GENERATION NETWORKS

LV CONNECT AND MANAGE

CLOSEDOWN REPORT

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Prepared by:	Samuel Jupe	18.06.2019
Reviewed by:	S Pinkerton-Clark	11.10.2019
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Contents

Executive Summary ... **5**
1 Project Background ... **6**
2 Scope and Objectives ... **6**
3 Success Criteria ... **7**
4 Details of Work Carried Out ... **7**
  4.1 The Solution Architecture ... 7
  4.2 Domestic Load Controller (DLC) Box Design ... 10
  4.3 Hereford Depot Equipment Trials ... 11
  4.4 Site Selection and Customer Engagement ... 16
  4.5 Equipment Installations ... 18
5 Performance Compared to Original Aims, Objectives and Success Criteria ... **19**
  5.1 Performance Compared to Aims and Objectives ... 19
  5.2 Performance Compared to Success Criteria ... 21
6 Required Modifications to the Planned Approach during the Course of the Project ... **22**
  6.1 Limiting the Deployment of BPL Infrastructure ... 22
  6.2 Pairing DLC boxes and LCTs in the Factory ... 22
  6.3 Adapting to Changes in the LCT Device Supply Chain ... 22
7 Project Costs ... **24**
8 Lessons Learnt for Future Projects ... **25**
  8.1 The Effectiveness of the Demonstrations Undertaken ... 25
  8.2 Significant Problems Discovered with the Trialled Methods ... 28
  8.3 Recommendations on How the Learning from the Project can be Exploited Further ... 28
  8.4 The Likelihood the Method will be Deployed on a Wider Scale in Future ... 28
  8.5 Knowledge Dissemination Events and Activities ... 29
9 The Outcomes of the Project ... **31**
  9.1 Live Trials: EV Charge Management (Import Limitation) ... 31
  9.2 Live Trials: PV/Battery Charge Management (Export Limitation) ... 33
  9.3 Setpoint Response Times (over mobile networks) ... 36
  9.4 Policies, Processes and Emerging Standards ... 37
  9.5 Technology Readiness Level Evaluation ... 37
10 Data Access Details ... **38**
11 Foreground IPR ... **38**
12 Planned Implementation ... **39**
13 Other Comments ... **40**
14 Contact ... **40**
Glossary ... **41**
Appendix A: The LV Connect and Manage FMEA ... **43**
Appendix B: Customer Engagement Plan ... **43**
Appendix C: Data Protection Strategy ... **43**
Appendix D: LCNI 2017 Dissemination Presentation ... **43**
Appendix E: CIRED 2018 Workshop Paper ... **43**
Appendix F: Balancing Act 2018 ... **43**
Appendix G: CIRED 2019 Conference Paper ... **43**
Appendix H: MPs Visiting Furzton ... **43**
Appendix I: Industry-wide Dissemination at the IET 2019 ... **43**
Appendix J: WPD’s EV Strategy ... **43**

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Executive Summary

Prior to LV Connect and Manage, technology for LV active network management (ANM), which extends communications and controls to customers' homes and is able to deal with bi-directional power flows, was still unproven and needed to be trialled by WPD in a low-risk way, to assess whether or not this option was a viable alternative to network reinforcement (for mitigating the rapid clustering effects of low carbon technologies).

The aims and objectives of the project were as follows: (i) Develop the LV Connect and Manage solution architecture; (ii) Monitor LCTs and compare aggregated power flows with operational limits; (iii) Design, build and operate an active management system for LV LCTs; (iv) Demonstrate the effectiveness of broadband-over-powerline for the bi-directional power flow control of LCTs; (v) Demonstrate the optimisation of real-time import and export patterns; (vi) Demonstrate how the solution can be used as a short-term or long-term intervention to avoid/defer network reinforcement; (vii) Develop new business processes for the deployment of DLC boxes into customers' homes.

The success criteria, by which the project was measured, were defined as follows: (i) Demonstration of the active management of low carbon technologies (energy storage and electric vehicles) by controlling load profiles and alleviating electricity network constraints; (ii) Development of a replicable architecture for the LV ANM solution, which can be utilised by WPD in their other Licence Areas and by other DNOs, more generally; and (iii) Development of novel business processes for deploying ANM technologies into LV networks. (This will include the specification and development of an installation guide for the LV ANM technologies).

We met all of the projects objectives and delivered the success criteria on time and 4% under budget.

LV Connect and Manage resulted in the following policies and emerging standards:

1. A policy for the retrofit of Connect and Manage substation monitoring equipment;
2. A process for standardising the installation of Connect and Manage equipment (DLC boxes) within customers' homes; and
3. A Technical Specification for Managed EV Charging Systems.

Whilst the technology has been proven, there are still some issues to be addressed before the LV Connect and Manage intervention can be implemented as part of WPD's Business-as-Usual activities:

1. Government policy and legislation needs to be in place to empower DNOs to intervene, giving them the option to deploy a DLC box-type solution within customers' homes if level of (uncontrolled) LCT uptake on a particular distribution substation puts every customer on that substation at risk of power cuts;
2. Manufacturers need to standardise the control interfaces of LCTs to guarantee interoperability;
3. Alternative communications and control paths to LCTs, alongside mobile communications, need to be developed to provide dual redundancy.

1 Project Background

Network reinforcement can be too expensive and too time-bound to respond to low carbon technology (LCT) connections on the low voltage (LV) network, particularly if rapid clustering occurs, such as with electric vehicles (EVs) and photovoltaic (PV) installations. Due to uncertainties in volume, location and type of LV connections, it is not possible or efficient for Western Power Distribution (WPD) to plan network reinforcement ahead of need. However, when the need does arise, network reinforcement (traditional base-case solution) can be too expensive and can take too long to deploy, delaying customers' connections to the network.

A comparison of PV installations registered for the feed-in tariff (FiT) and with WPD's data shows only ~60% match in notified LV connections. Despite forecasting, there is still a lot of uncertainty as connections might not materialise or might materialise in more abundance than expected. Rapid clustering of EVs can lead to overloads in the distribution network particularly if the electricity demand coincides with daily peak loading on the network. Similarly, rapid clustering of PV systems can lead to overloads but in the reverse power flow direction. Both situations put WPD's customers (both LCT customers and non-LCT customers) at risk of outages.

Technology for LV active network management (ANM), which extends communications and controls beyond customers' meters and is able to deal with bi-directional power flows, is still unproven and needed to be trialled by WPD in a low-risk way, to assess whether or not this option is a viable alternative to network reinforcement.

2 Scope and Objectives

Objective	Status
Develop the LV Connect and Manage solution architecture	✓
Monitor LCTs and compare aggregated power flows with operational limits	✓
Design, build and operate an active management system for LV LCTs	✓
Demonstrate the effectiveness of broadband-over-powerline for the bi-directional power flow control of LCTs	✓*
Demonstrate the optimisation of real-time import and export patterns	✓
Demonstrate how the solution can be used as a short-term or long-term intervention to avoid/defer network reinforcement	✓
Develop new business processes for the deployment of DLC boxes into customers' homes	✓**

* LV Connect and Manage concluded that broadband-over-powerline was not fit-for-purpose for providing the communications channel from substations into customers' homes.

** Whilst new business processes were developed as part of LV Connect and Manage, barriers to deployment still exist, related to customer acceptance of an LV Connect and Manage-type intervention in their homes and the right that UK DNOs have to enforce the intervention if network assets are at risk of overload.

3 Success Criteria

Success Criteria	Status
1. Demonstration of the active management of low carbon technologies (energy storage and electric vehicles) by controlling load profiles and alleviating electricity network constraints.	✓
2. Development of a replicable architecture for the LV ANM solution, which can be utilised by WPD in their other Licence Areas and by other DNOs, more generally.	✓
3. Development of novel business processes for deploying ANM technologies into LV networks. (This will include the specification and development of an installation guide for the LV ANM technologies).	✓

4 Details of Work Carried Out

The work carried out in this project is detailed in the following sections:

1. The solution architecture;
2. The domestic load controller (DLC) box design;
3. The Hereford depot equipment trials;
4. The site selection and customer engagement activities;
5. The equipment installations;

The EV (import limitation) trials and results, the PV/battery (export limitation) trials and results and the evaluation results of the set point response times for the import and export limitation trials are given in Section 9.

4.1 The Solution Architecture

The LV Connect and Manage solution architecture is given in Figure 4.1. This was partly informed by our own documents, outlining the proposed project scope, and partly informed by previous similar projects undertaken by Nortech.

4.1.1 Solution Architecture Components

iHost: iHost is a software platform, developed and supplied by Nortech Management Limited, which hosts the LV Connect and Manage central control algorithms and monitors downstream components (such as the LV substation equipment and the DLC equipment). In the context of LV Connect and Manage, iHost runs on a virtual server with hardware located in a secure data centre (hosted by Nortech). iHost, via a VPN link, provides graphical user interface (GUI) and reporting features for WPD and other system users to monitor and evaluate the system performance.

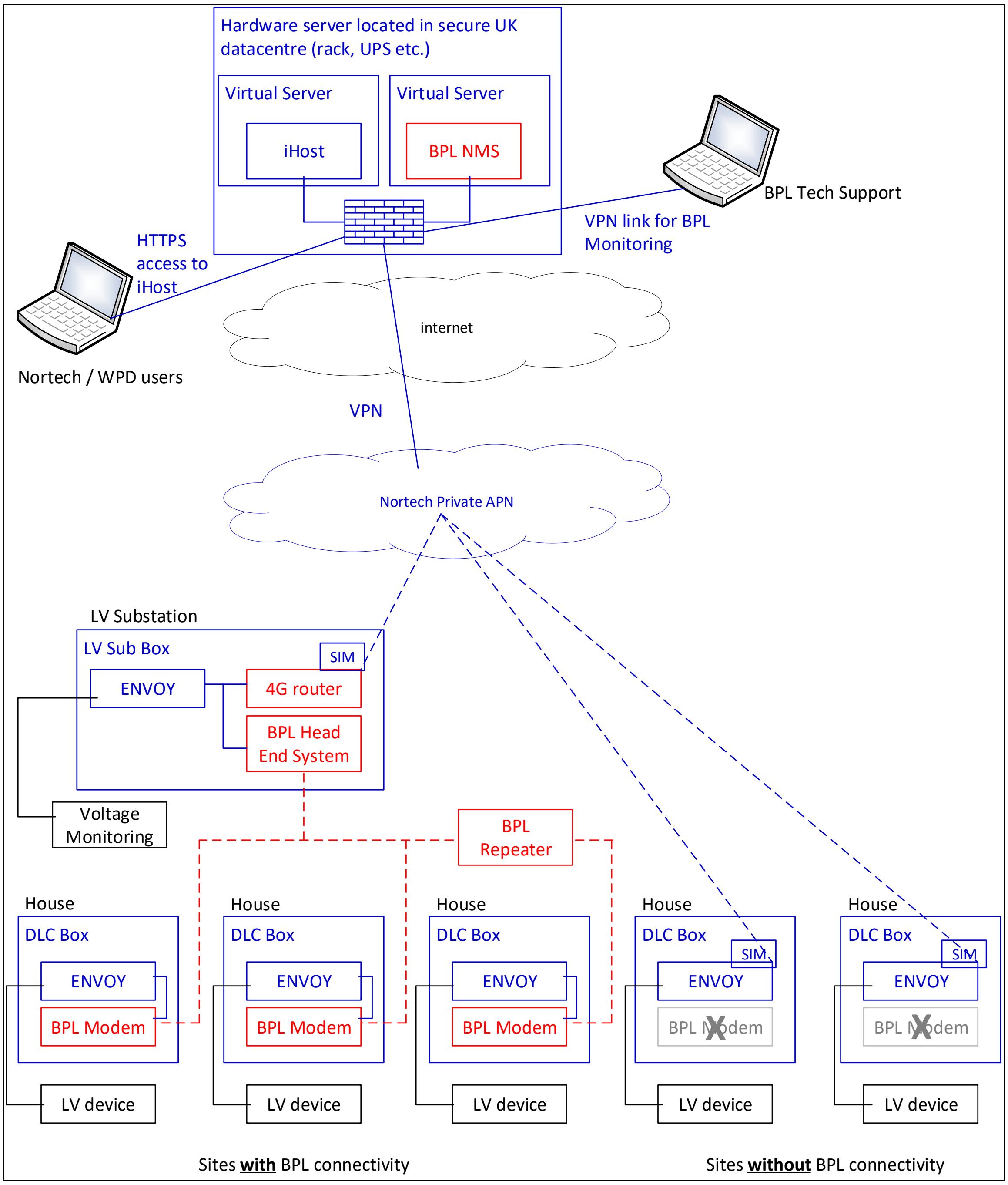

Figure 4.1 – The LV Connect and Manage solution architecture

Broadband-over-Powerline NMS: The Broadband-over-Powerline (BPL) Network Management System (NMS) is co-located with iHost in the secure data centre. The NMS is accessed remotely, via a virtual private network (VPN) link, and is used for monitoring and maintaining the BPL communications system. The BPL communications system comprises up to six ruggedized head-end modems (located in secondary distribution substations), up to 100 compact modems (located in DLC customers' properties) and ruggedized modems (used as signal repeaters between the distribution substation and customers' properties). The number of repeater units was to be determined as part of the BPL system implementation.

Secondary Distribution Substation Monitoring: The architecture of the secondary distribution substation monitoring system is shown in Figure 4.2. The components within the architecture are installed on the LV-side of the substation and include:

1. A device for power flow and voltage monitoring (as this is the expected constraint point within the power system);
2. An Envoy unit (monitoring the power flows and voltages, providing data aggregation functions and future-proofing the architecture for a distributed hierarchy of controls). This is particularly important if, for example, the communications link to iHost is lost;
3. A 3G/4G router (providing communications from the substation to iHost via the secure VPN tunnel); and
4. The BPL headend modem (providing communications over the LV network to customers' homes).

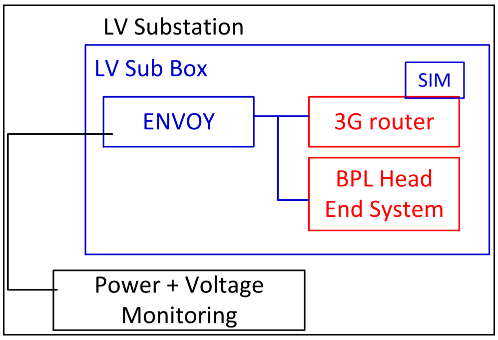

Figure 4.2 – The LV substation monitoring system

Domestic Load Control (DLC) for EV and PV customers: The architecture of the DLC box for EV and PV customers is shown in Figure 4.3. The components within this architecture include:

1. An Envoy (connected to the EV charge point/PV inverter system for set point controls and the BPL system for communications); and
2. A BPL compact modem (for communications back to the local substation).

The Envoy/BPL components are powered from the 230V AC supply within customers' homes and the Envoys have provision for mobile communications (via SIM cards) as a back-up communications path from the customers' homes to iHost or a primary communications path where the reach of the BPL system is limited.

Other system components: Other system components included the BPL repeaters (which were required, depending on the reach of the BPL signal from the secondary distribution substation to customers' homes and vice versa) and the VPN tunnel from site to the data centre (which was delivered using a 3G/4G router in the LV substation box connected to the Nortech firewall via an APN and VPN tunnel to provide a secure data pipe).

A comprehensive failure modes and effects analysis (FMEA) was conducted to evaluate the solution architecture and identify mitigations for the failure of critical hardware, software and communications components to feed into the component designs. The FMEA report is given in Appendix A.

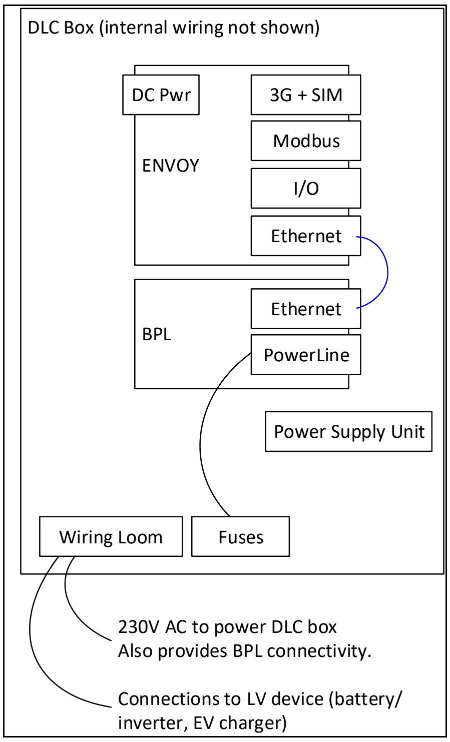

Figure 4.3 - The architecture of the DLC box

4.2 Domestic Load Controller (DLC) Box Design

The design of the domestic load controller (DLC) box is given in Figure 4.4.

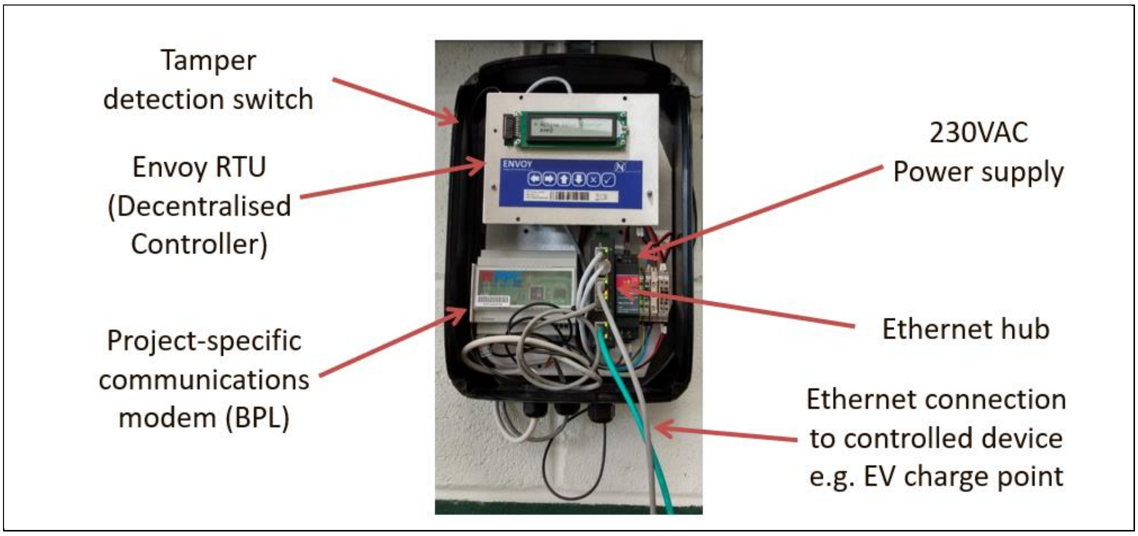

Figure 4.4 – The design of the domestic load controller (DLC) box

The DLC box contains the following components:

1. A tamper switch for intrusion detection, using a microswitch wired into the Envoy (a micro-RTU). The tamper switch is activated if the lid of the DLC box is removed and a remote notification (via email or text message) is sent to the system operator;
2. The Envoy micro-RTU, acting as the communications hub, protocol converter and a decentralised monitoring and control platform for the connected components (sending monitored data to iHost via DNP3 over BPL/GSM and controls to the LCTs via Modbus or Open Charge Point Protocol over Ethernet);

3. A project-specific modem to allow communications to the local substation via broadband-over-powerline;
4. A 230VAC supply, allowing the DLC box to be readily fitted in to customers' homes and powered from their standard mains supply (on a separate feed than the LCT under control);
5. An Ethernet communications switch, facilitating internal connectivity within the DLC box and external connectivity to one or more LCTs in the customers' homes. N.B. For security reasons, the Ethernet cabling is terminated inside the connected devices at both ends (i.e. within the DLC box, protected by tamper switch notifications, and the LCT, protected by specialist screws and electric shock intrusion warnings);
6. Ethernet connections to the LCTs, allowing for interoperability across a wide range of EV charge points, battery inverter, PV inverter and heat pump control systems via a standard interface.

The DLC boxes were designed with portable functionality, allowing them to be easily wired into customers' homes via a standard 230VAC supply and connected to the controllable LCTs via Ethernet or hardwired signals, such as RS485 or 4 – 20mA.

4.3 Hereford Depot Equipment Trials

The architecture described in Section 4.1, encompassing all components, was deployed in the first phase of the project within WPD's Hereford Depot to trial solution in a real-life environment. This de-risked the installation of equipment within customers' homes (minimising the likelihood of return visits to resolve integration issues). It also allowed WPD to develop the business process for equipment installations within the trial site substations and evaluate the performance of the system (including communications reliability and witness testing of the solution for controlling LCTs). The Hereford Depot equipment trials are described in the following sections:

1. The testbed architecture;
2. The substation installations (representing the DNO-side of the installations);
3. The LCT installations (representing the customer-side of the installations); and
4. The technical tests (conducted to prove end-to-end operation of the system).

4.3.1 Testbed Architecture

The testbed architecture is given in Figure 4.5 and comprised the following: (i) a decentralised ANM system within the LV substation (monitoring local voltages and power flows and allowing control signals to be generated based on local constraints); (ii) a 7kWh battery/inverter system interfacing with the on-site 50kW PV array and a DLC box configured with export limiting functionality; and (iii) a 7.4kW (32A) single-phase EV charge point interfacing with a DLC box configured for import limiting.

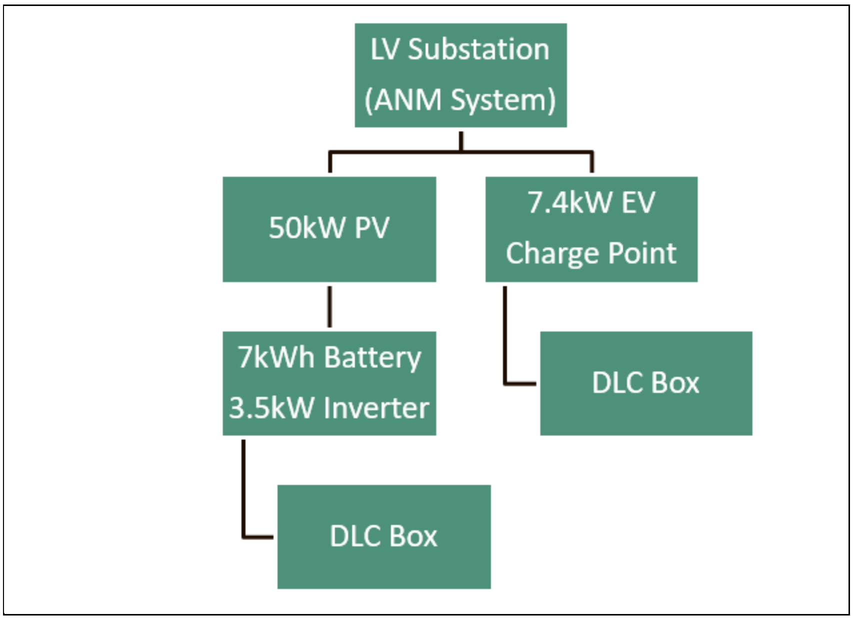

Figure 4.5 - The Hereford Depot testbed architecture

4.3.2 Substation Installations (DNO-Side)

Figures 4.6 and 4.7 illustrate the equipment installed within the secondary distribution substation feeding the Hereford Depot. Figure 4.6 shows the WPD fitter with the decentralised ANM controller prior to fitting onto the outside of the LV fuse cabinet. The decentralised ANM controller was designed with magnetic mounting feet to allow it to be installed on the side of metallic infrastructure within the substation, allowing it to be readily ported to other substations (when the future need arises) and mitigating the requirement for drilling holes through the fabric of the LV cabinet (which is prohibited within WPD's policies as it affects the integrity of the LV cabinet and could lead to the risk of moisture ingress).

Figure 4.6 – The decentralised ANM controller

From left-to-right in Figure 4.7, the following equipment can be seen: (i) a Gridkey MCU with Ethernet adapter for high-resolution (10-second) monitoring of voltages, currents and (bi-directional) power flows within the distribution substation; (ii) the decentralised ANM platform for controlling the LCTs and communicating the Gridkey data to iHost via mobile communications; (iii) the LV fuse board with modified fuse handles allowing the Gridkey voltages to be monitored via

4mm banana-plug socket connectors; and (iv) solid and flexible split-core Rogowski coils allowing the electrical currents to be monitored.

As part of the retrofit of the monitoring equipment into the LV substation at the Hereford Depot, it was observed that an outage was required in order to swap out the existing fuse handles for the modified fuse handles (with the 4mm connectors). In this case, the Hereford Depot was powered by an on-site generator and arrangements were made to back-feed the trial sites so that no customers experienced interruptions to their supply.

Figure 4.7 – Secondary substation equipment

4.3.3 LCT Installations (Customer-Side)

Equipment representing the customer-side of solution architecture was deployed via a battery energy storage system with a DLC interfacing with the battery inverter (as seen in Figure 4.8) and a controllable EV charge point interfacing directly with the DLC (as seen in Figure 4.9).

Figure 4.8 – Installation of battery, inverter and DLC representing customer-side equipment

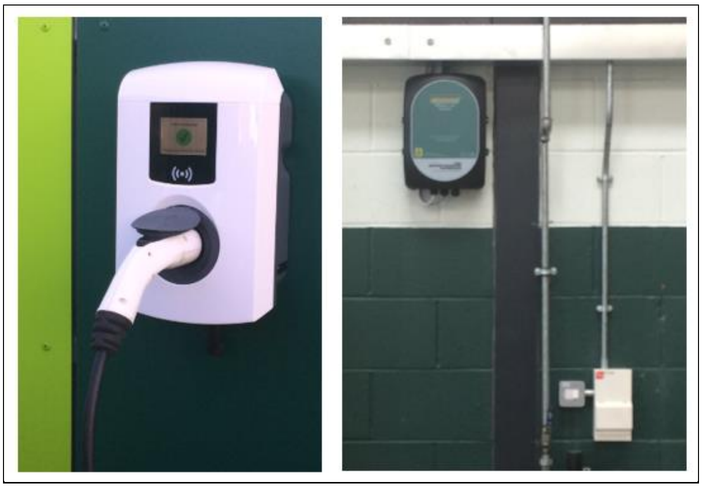

Figure 4.9 – Installation of controllable EV charge point and DLC representing customer-side equipment

4.3.4 Technical Tests

The solution architecture and equipment installations described above allowed the following technical tests to be carried out:

1. Proving the feasibility of managing the EV charging rate in the range 0 – 32A via BPL and GSM;
2. Proving the feasibility of managing the PV/battery energy storage discharge rate via BPL and GSM;
3. Demonstrating the auto-failover of communications from BPL to GSM and vice-versa; and
4. Demonstrating the principles of operation of the import and export limitation systems to protect the integrity of the distribution transformer and cable assets.

Figure 4.10 shows a Nortech engineer configuring the DLC box for communications with the battery inverter system in preparation for the export limitation technical tests.

Figure 4.10 – Nortech engineer configuring the DLC box for export limitation tests

In order to represent the complete end-to-end system a Nissan Leaf EV was connected to the controllable charge point. The results of the import limitation and export limitation tests are given in Figures 4.11 and 4.12 respectively.

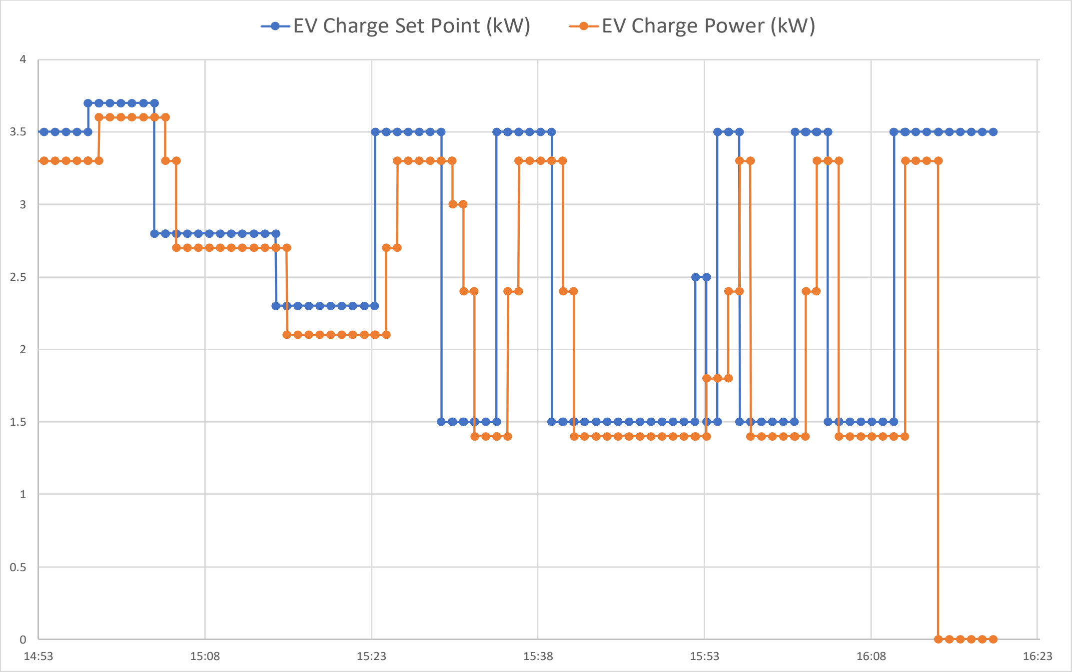

Figure 4.11 – Results of the import limitation technical tests

Considering Figure 4.11, in the time period 14:53 to 15:38, manual set points were sent to the EV charge point to control the rate of charge (blue trace) and the response of the EV to charge reduction and increase signals was observed (orange trace). From 15:53 onwards, the set points were generated automatically by linking the allowable capacity for EV charging to the real-time electrical demand at the depot and artificially lowering the upstream substation thermal limit to trigger a constraint. This test proved the end-to-end system functionality for import limitation of the EV charge point.

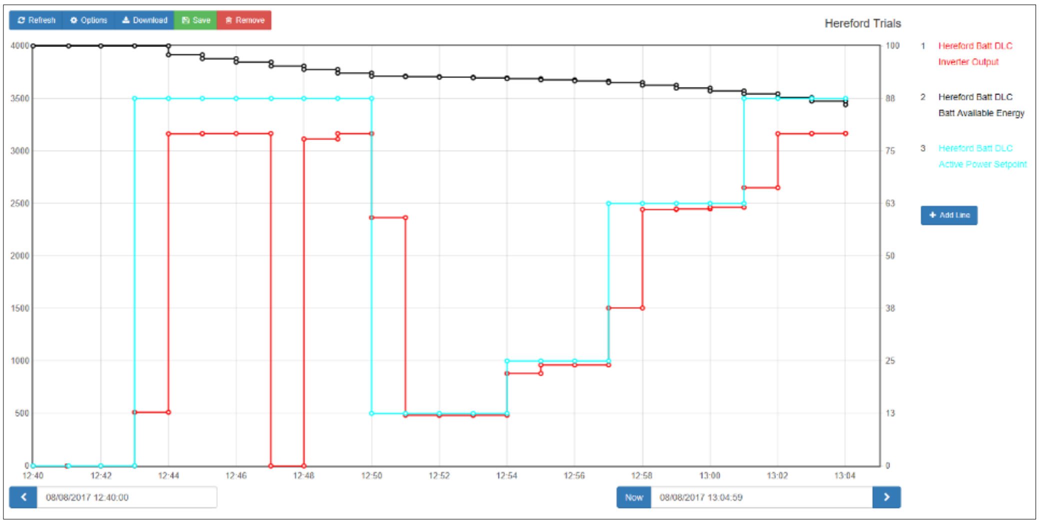

Figure 4.12 – Results of the export limitation technical tests

Considering Figure 4.12, the response of the battery/inverter system (red trace) to export limitation signals (blue trace) was tested and the capacity of the battery was monitored (black trace). This test proved the end-to-end system functionality for export limitation of the battery energy storage system.

4.4 Site Selection and Customer Engagement

4.4.1 Site Selection

Six sites were selected for project trials, three in the West Bridgford area of Nottingham and three in the Furzton area of Milton Keynes. The West Bridgford sites were selected based on WPD's records of existing EV charge points connected within the area. In addition, Nottingham was of named one of the first Go-Ultra Low cities by the Office for Low Emission Vehicles (OLEV). The Furzton sites were selected based on WPD's records of high PV penetrations in the area.

Control and monitoring equipment was installed in the following 6 distribution substations:

Substation No.	Substation Name
942197	GRASSCROFT BLETCHLEY (FURZTON)
942196	PARKSIDE FURZTON
942183	PERRACOMBE FURZTON
881417	WEST BRIDGFORD RUGBY ROAD
881418	WEST BRIDGFORD COMPTON ACRES
881089	WEST BRIDGFORD HAWTHORNE PARK

4.4.2 Customer Engagement Activities

Two Customer Engagement Contractors were appointed by competitive tender to market the project to WPD's customers in the selected trial locations and recruit customers to participate in trials. Based on WPD's learning from previous projects, companies local to the trial locations were selected and effectively recruited customers to participate in trials using the following mechanisms:

1. Customer engagement meetings;
2. Door-to-door marketing and leafletting campaigns;
3. Publicity on social networks; and
4. Development of a project-specific website: www.wpdconnectandmanage.co.uk

In addition, a customer engagement video was produced to introduce the project, explain its aims and objectives, and outline the benefits for participation.

The Customer Engagement Plan and Data Protection Strategy documents for the project are given in Appendices B and C respectively. In order to simulate interest in the project, trial participants were given the option to keep the LCT equipment at the end of the trial or to have it removed by WPD without charge. WPD also used the customer engagement campaign as a mechanism for raising awareness of the Priority Services Register (PSR). Aggregating data and anonymising customers were key features of the data protection strategy and worked effectively.

An example customer engagement meeting is given in Figure 4.13 for the Furzton trial participant recruitment.

Figure 4.13 – Customer engagement in Furzton for battery/energy storage participants

4.4.3 Customer Participation: Milton Keynes Clusters

Figure 4.14 shows the clusters of participants (marked as dots on the map) that were stimulated by the customer engagement activities in Furzton, Milton Keynes. The figure also shows examples of the battery energy storage and DLC equipment installations in customers' homes.

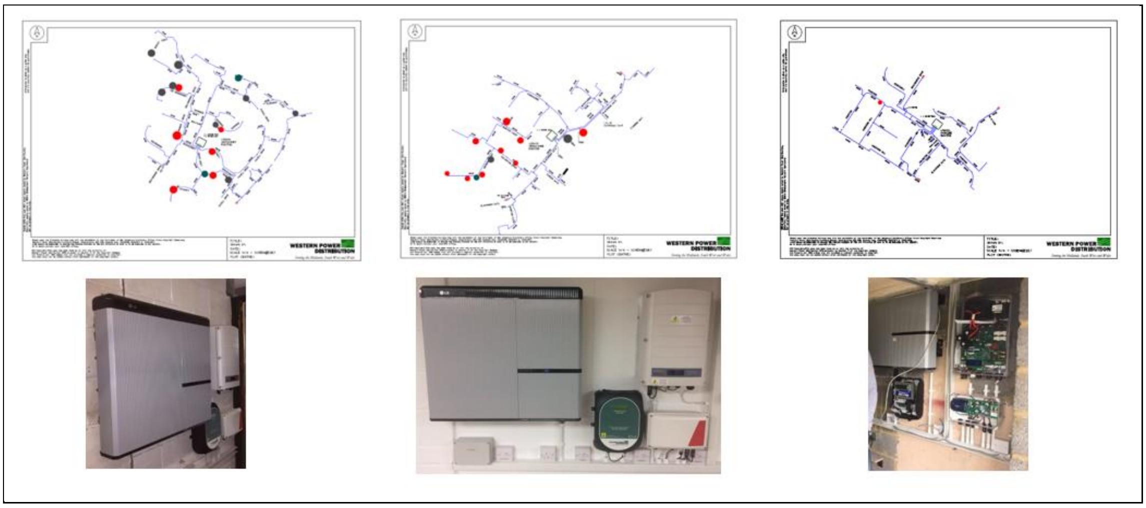

Figure 4.14 – Clusters of participants in Furzton with examples of battery, inverter and DLC installations

For this part of the trial, two of the three substations had sufficient uptake and clustering of customers to allow battery export limitation to be demonstrated, fulfilling this objective of the project.

4.4.4 Customer Participation: West Bridgford Clusters

Figure 4.15 shows the clusters of participants (marked as dots on the map) that were stimulated by the customer engagement activities in West Bridgford, Nottingham. The figure also shows examples of the EV charge point equipment and DLC installations in customers' homes.

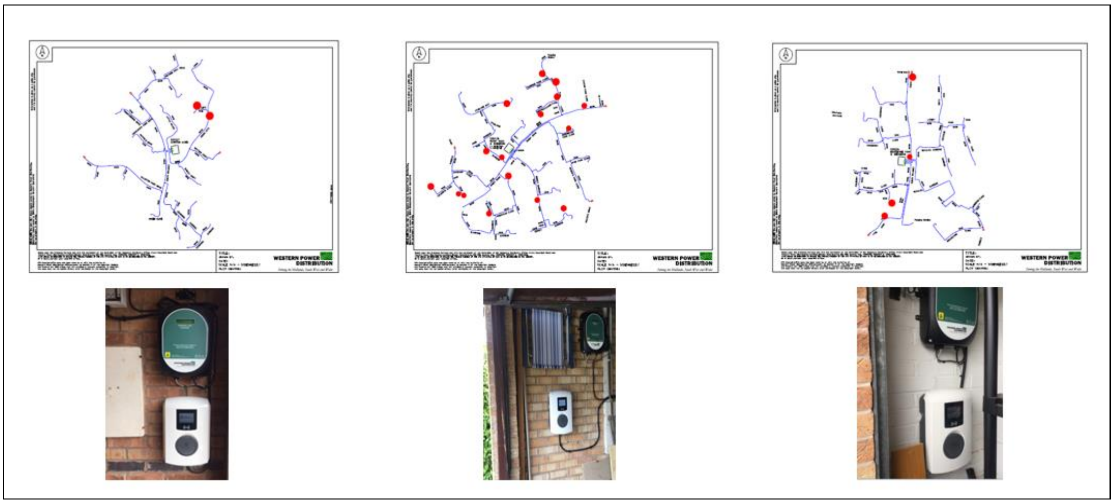

Figure 4.15 – Clusters of participants in West Bridgford with examples of EV charge point and DLC installations

For this part of the trial, one of the three substations, in particular, had sufficient uptake and clustering of customers to allow EV import limitation to be demonstrated, fulfilling this objective of the project.

4.5 Equipment Installations

A detailed example of a typical installation of the EV charge point and DLC equipment is given in Figure 4.16. The DLC box is co-located with the LCT to minimise long communications cable runs, which were deemed to be unacceptable from the customers' perspective. Each DLC box had a small external antenna to maximise signal strength for mobile communications. In each installation, the DLC box and LCT were fed from separate mini circuit breakers (MCBs) in the consumer unit and contactor switches were used to trip the LCT in the event of loss-of-power (and hence communications and controllability) to the DLC box.

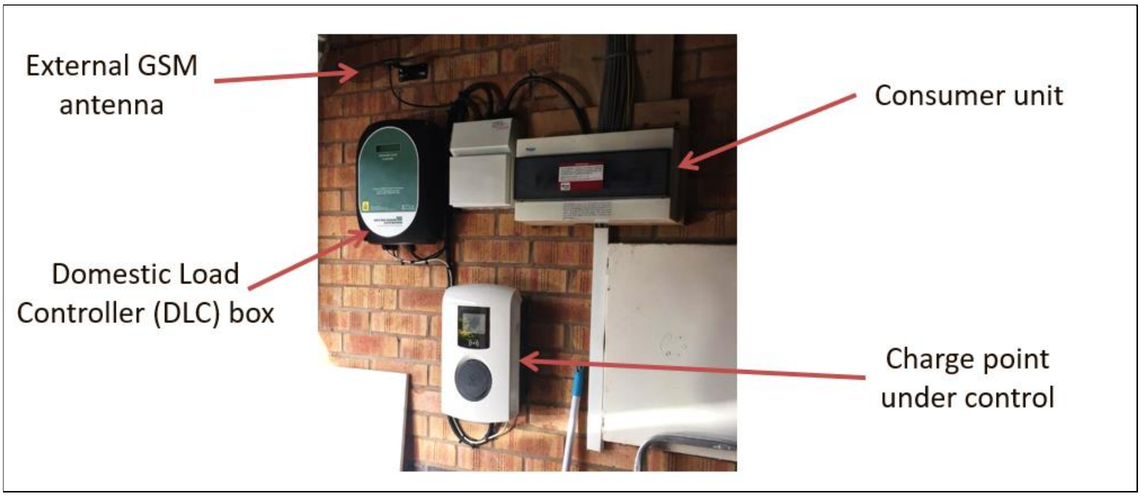

Figure 4.16 – Typical example of the EV charge point and DLC installation in customers' homes

5 Performance Compared to Original Aims, Objectives and Success Criteria

5.1 Performance Compared to Aims and Objectives

LV Connect and Manage had the following aims and objectives:

1. Develop the LV Connect and Manage solution architecture;
2. Monitor LCTs and compare aggregated power flows with operational limits;
3. Design, build and operate an active management system for LV LCTs;
4. Demonstrate the effectiveness of broadband-over-powerline for the bi-directional power flow control of LCTs;
5. Demonstrate the optimisation of real-time import and export patterns;
6. Demonstrate how the solution can be used as a short-term or long-term intervention to avoid/defer network reinforcement; and
7. Develop new business processes for the deployment of DLC boxes into customers' homes.

LV Connect and Manage met all of its original aims and objectives as summarised in Table 5.1 and the sections of the report referenced therein.

Table 5.1 – Summary of project performance against aims and objectives

Objective	Status	Comment
Develop the LV Connect and Manage solution architecture	✓	An architecture was developed for the LV Connect and Manage solution which specified the communications and control components needed to facilitate the control of LCT devices (for further details see Section 4.1)
Monitor LCTs and compare aggregated power flows with operational limits	✓	LCT power import and export was monitored, aggregated and continuously compared with operational limits for both EV and Battery Energy Storage Systems (for further details see Section 9)
Design, build and operate an active management system for LV LCTs	✓	An active network management system was designed, built and operated autonomously for the connection and management of LV LCTs (for further details see Sections 4 and 9)
Demonstrate the effectiveness of broadband-over-powerline for the bi-directional power flow control of LCTs	✓	The effectiveness of broadband-over-powerline was demonstrated for the bi-directional power flow control of LCTs and it was concluded that this communications medium was not fit-for-purpose for the LV Connect and Manage solution (for further details see Sections 4 and 8)

Objective	Status	Comment
Demonstrate the optimisation of real-time import and export patterns	✓	The optimisation of real-time import and export patterns was demonstrated by continuously matching the setpoints of the LCTs to the available capacity in the network (for details see Section 9)
Demonstrate how the solution can be used as a short-term or long-term intervention to avoid/defer network reinforcement	✓	By conducting live trials and proving that the LV Connect and Manage system was able to control LCTs according to network constraints and capacity available, it was demonstrated that this solution could be used as a short or long term intervention for the avoidance/deferral of network reinforcement (for further details see Section 9)
Develop new business processes for the deployment of DLC boxes into customers’ homes	✓	New business processes were developed for the deployment of DLC boxes into customers’ homes, including a policy for the retrofitting of LV Connect and Manage equipment into secondary distribution substations and an installation guide for electrical contractors fitting the DLC boxes into customers’ homes (for further details see Sections 4, 8 and 9)

5.2 Performance Compared to Success Criteria

As part of the LV Connect and Manage project registration, WPD specified the following Success Criteria:

1. Demonstration of the active management of low carbon technologies (energy storage and electric vehicles) by controlling load profiles and alleviating electricity network constraints;
2. Development of a replicable architecture for the LV ANM solution, which can be utilised by WPD in their other Licence Areas and by other DNOs, more generally; and
3. Development of novel business processes for deploying ANM technologies into LV networks. (This will include the specification and development of an installation guide for the LV ANM technologies).

The active management of low carbon technologies (energy storage and electric vehicles) was demonstrated by controlling load profiles and alleviating electricity network constraints. This was achieved by artificially lowering the thermal limit of secondary distribution transformers in order to create an artificial constraint, which then triggered a control response in the LV ANM system.

A replicable architecture for the LV ANM solution was developed, based on off-the-shelf communications and control technologies, which can be utilised by WPD in their other Licence Areas and by other DNOs, more generally.

Novel business processes were developed for deploying ANM technologies into LV networks. This included the development of a policy for the retrofitting of LV Connect and Manage into secondary distribution substations and an installation guide for electrical contractors fitting the DLC box into customers' homes. Both of these processes were used to install the equipment for the LV Connect and Manage live trials, resulting in tried-and-tested procedures.

In summary, the project met all of its success criteria as described above, with further evidence detailed in Sections 4 and 9.

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

Three modifications to the planned approach occurred during the project:

1. Limiting the deployment of BPL infrastructure and procuring additional SIM cards (as a result of BPL limitations);
2. Pairing DLC boxes and LCTs in the factory, and testing communications and controls prior to installation in customers' homes; and
3. Adapting to changes in the LCT device supply chain.

6.1 Limiting the Deployment of BPL Infrastructure

The original ambition of the project was to trial the effectiveness of BPL at the six substation sites as given in Section 4.4.1. However, early results from the Hereford Depot BPL installation and the first project site showed that BPL was not fit-for-purpose for the LV Connect and Manage application. This was because the system was found to be sensitive to electrical noise and attenuation in the LV network and difficulties were encountered with signal propagation into customers' homes through the consumer unit. As a result, it was not possible to determine the number of repeaters that would be needed to provide complete BPL coverage to the LCTs clusters on a particular substation and there was not sufficient confidence that control signals could be transmitted over BPL during the peak times of electrical network loading (i.e. when it was most critical, anticipating that EV charging could coincide with the daily teatime peak).

Alternative options were considered for BPL deployment within this project (such as installing a repeater unit in each customers' metering box alongside running Ethernet cable from the BPL repeater to the DLC box). However, these options were discounted because it would have involved recruiting additional customers (with no stakeholder interest) to participate in trials and there was no guarantee the metering box in customers' homes was located near the DLC and LCT (so Ethernet cable runs would have been required to deliver the end-to-end communications and controls). In both cases, WPD deemed that this would cause unnecessary disruption to its customers. To limit cost overruns for this particular aspect of the project, further deployment of BPL infrastructure was halted, and additional SIM cards were procured to extend communications and controls to the entire fleet of DLC boxes.

6.2 Pairing DLC boxes and LCTs in the Factory

The LCTs (EV charge points and battery inverters) required software configuration in order to allow the ANM system to communicate with them and control them. The skillset required to program the communications settings into the LCT devices is not readily available amongst electrical contractors (i.e. it takes them out of their comfort zone). To address this, the LCTs and DLC boxes were paired in the factory, and communications and controls were tested prior to installation of the equipment in customers' homes. This approach also reduced the likelihood of return visits to customers' homes to resolve interoperability issues.

6.3 Adapting to Changes in the LCT Device Supply Chain

The pace-of-change of LCT devices (such as EV charge points, batteries and inverters) is fast moving as the various technologies mature. This meant that the LCT devices originally intended for procurement were superseded by newer variants by the time customers were recruited to participate in the trials. Moreover, some of the technologies selected for installation into customers' homes were discontinued by the manufacturers during the project lifecycle. This mean that alternative technologies needed to be identified, procured and tested.

Whilst increasing equipment delivery and installation lead times slightly (by a few weeks), this did not affect the overall project delivery programme and helped to demonstrate that the DLC box was interoperable with LCTs from a variety of different manufacturers.

7 Project Costs

Activity	Budget (£)	Actual (£)	Variance (%)
Project Delivery	200,000	199,688	- 0.2
Communications equipment	120,000	119,771	- 0.2
Monitoring	40,000	37,805	- 5.5
Control	400,000	399,556	- 0.1
Batteries and inverters	250,000	244,557	- 2.2
EV charge points	25,000	26,075	+ 4.3
Customer engagement and dissemination	200,000	197,463	- 1.3
Equipment installation	100,000	99,777	- 0.2
WPD PM + Installation	100,000	99,849	- 0.2
Dissemination Modelling	20,000	19,350	- 3.3
Total (Exc. Contingency)	**1,455,000**	**1,443,891**	**-0.8**

All project aspects were delivered within 10% tolerance of the original budget and the overall project met all its objectives on time.

A £220,000 contingency budget was incorporated in the original project budget and NIA Project Registration and PEA Document. A total of £52,725 of the contingency budget was used. This was due to variations in exchange rates (procuring equipment from overseas suppliers) and the additional requirement (a software modification to the monitoring equipment) to provide increased granularity of substation power flows and voltages for optimised LCT controls.

8 Lessons Learnt for Future Projects

Throughout the project lifecycle, a series of lessons learnt were recorded. This section discusses the learning in detail and demonstrates the valuable learning that has been gained from this project. The lessons learnt have been categorised in the following ways:

1. The effectiveness of the demonstrations undertaken;
2. Significant problems discovered with the trialled methods;
3. Recommendations on how the learning from the project can be exploited further; and
4. The likelihood the method will be deployed on a wider scale in future.

In addition, the knowledge dissemination events and activities have been summarised in Section 8.5.

8.1 The Effectiveness of the Demonstrations Undertaken

8.1.1 Hereford Depot Installation

The Hereford Depot trial facilitated system integration and allowed the end-to-end system to be tested and refined in a low-risk and easily accessible environment. This significantly de-risked the installation of equipment within customers' homes and minimised the risk of needing return visits.

The recommendation for future projects is that a testbed environment is included as part of the project design to facilitate the integration and testing of technologies in a low-risk way.

8.1.2 Customer Engagement

The customer engagement activities were effective in recruiting the required number of participants within the project trial areas to demonstrate the active management of LCT clusters. The success of the engagement activities was attributed to the use of specialist marketing companies, local to the areas in which WPD was looking to recruit participants. In addition, the variety of engagement methods (leafletting, social media and the customer engagement video) engaged a wide variety of participants.

The project has raised awareness amongst WPD's customers of the valuable role it plays in society. All customers retained their LCTs at project close down.

The recommendation for future projects is that similar recruitment methods are utilised and, in particular, marketing and recruitment firms local to the target customer base are employed.

8.1.3 Data Protection

As well as standard data protection practices, customers' data was protected in two key ways, which were designed into the project delivery processes: (i) Assigning a unique ID to each customer (which anonymised the customer and meant project-specific power systems data could then be used by project partners without the need for the transfer of personal data); and (ii) Aggregating customer load profile data (so that the data of individual customers was protected).

The recommendation for future projects is that the anonymising and, where appropriate, the aggregation of data should be designed into the data protection processes.

8.1.4 Remote Commissioning

The deployment of DLC boxes with mobile communications facilitated commissioning remotely and this resulted in a number of benefits: (i) The cost of commissioning was reduced as specialist staff involved in the commissioning process did not have to travel to customer sites; (ii) Customer identities and personal data were protected as the only organisations that interacted with them directly were the Customer Engagement Contractors and the Electrical Contractors; and (iii) dependence on the BPL system deployment was removed.

The recommendation for future projects is that low-cost, proven communications technologies (such as mobile communications) are designed into the solution architecture particularly when a new communications system is being trialled or an existing communications system is being used but in a new application.

8.1.5 Quantification of LCT Control Response Times

LV Connect and Manage has delivered a comprehensive quantification of LCT control response times over mobile networks, as given in Section 9.3.

The round-trip times for communications show that, with suitable design mitigations for communication interruptions, the mobile network is fit-for-purpose for controlling LV LCTs, particularly when aggregated across a population of controllable devices.

The recommendation for future projects is that the roundtrip time of communications and control systems is quantified to allow the performance of the system to be evaluated effectively.

8.1.6 Solution Portability

As part of the customers trials, the ease and portability of DLC box solution was demonstrated by deliberate swap-outs of the DLC boxes. The time taken to swap over the DLC box was quantified as less than 10 minutes with the overall time for porting the solution heavily dominated by customer availability and time taken to travel to site.

For any DNOs looking to adopt a DLC-type intervention, the requirement for portability should be included within the solution design requirements.

8.1.7 Dual-Tariff Customers

Learning emerged from the customer engagement activities that showed that customers without PV were interested and able to participate in trials. This was because they had a dual-tariff arrangement with their electricity supplier and were able to charge the battery at night (on the lower-cost tariff) and discharge the stored energy into the home (and power network) during the daytime. This led to an additional business case for LV Connect and Manage that was not identified at project conception.

The recommendation for future projects is that the business case for the project is periodically re-evaluated and refined as the project delivery progresses.

8.1.8 Battery Operating Modes

A key learning point for DNOs as they transition to DSOs is that the battery energy storage systems can be configured (by the end user) to operate in different modes. This means that the battery could be installed by the customer with the intention of self-consuming the energy behind the meter but, if regulations change, there could be an incentive for the customer to reconfigure their battery system to export power onto the electricity network. If this happens with a cluster of customers on the same substation, the electricity infrastructure assets could be at risk of damage. At present, DNOs / DSOs have no visibility of the configuration change and no control over the battery system if the customer choses to reconfigure it from self-consumption to network export mode.

The recommendation for future projects is that careful consideration is made of the functionality of LCTs and, in particular, how their functionality can be reconfigured by the end user (or a third party such as an aggregator) which could lead to inadvertent impacts on other systems such as the electricity distribution network.

8.1.9 Customer Benefits

LV Connect and Manage has resulted in the following benefits for WPD’s customers:

1. Development and demonstration of an intelligent interface to accelerate connection of LCTs (storage, EVs, heat pumps);
2. Avoidance and/or deferral of network reinforcement;
3. A reduced amount of street works (as network reinforcement can be timed to coincide with other street works whilst the DLC intervention is in place);
4. Provision of greater flexibility to allow customers to export more power during non – peak hours or/and use stored energy in a ‘self-consumption’ mode; and
5. Facilitating the consume energy by customers in more sustainable, environmentally friendly way, reducing CO_2 emissions as LCT uptake increases.

In addition, through the various customer engagement activities, WPD was able to increase awareness of the Priority Services Register: https://www.westernpower.co.uk/customers-and-community/priority-services/priority-services-register

The recommendation is that any DNO project involving residential customers should encompass, within its scope, activities to raise awareness of the Priority Services Register.

8.2 Significant Problems Discovered with the Trialled Methods

8.2.1 Broadband-over-Powerline

In order to overcome attenuation in the LV network, the deployment of BPL infrastructure needs to be sufficiently dense. This is appropriate for metering-type applications where there is a requirement to monitor data at every household, the BPL repeater can be co-located with the meter (on the DNO-side of the consumer unit) and the dispatch of communications can be timed to coincide with the BPL up-time.

The original ambition of the project was to trial the effectiveness of BPL at the six substation sites as given in Section 4.4.1. However, early results from the Hereford Depot BPL installation and the first project site showed that BPL was not fit-for-purpose for the LV Connect and Manage application. This was because the system was found to be sensitive to electrical noise and attenuation in the LV network and difficulties were encountered with signal propagation into customers' homes through the consumer unit. As a result, it was not possible to determine the number of repeaters that would be needed to provide complete BPL coverage to the LCTs clusters on a particular substation. In addition, there was not sufficient confidence that control signals could be transmitted over BPL during the peak times of electrical network loading (i.e. when it was most critical, anticipating that EV charging could coincide with the daily teatime peak).

Alternative options were considered for BPL deployment within this project (such as installing a repeater unit in each customers' metering box alongside running Ethernet cable from the BPL repeater to the DLC box). However, these options were discounted because it would have involved recruiting additional customers (with no stakeholder interest) to participate in trials and there was no guarantee the metering box in customers' homes would be located near the DLC and LCT (so Ethernet cable runs would have been required to deliver the end-to-end communications and controls). In both cases, WPD deemed that this would cause unnecessary disruption to its customers. To limit cost overruns for this particular aspect of the project, further deployment of BPL infrastructure was halted.

8.3 Recommendations on How the Learning from the Project can be Exploited Further

Three key areas have been identified, in which the learning from the project can be exploited further:

1. The development of LCT profiles;
2. The assessment of load duration curves and validation of network asset ratings in light of modified load duration curves;
3. Re-visiting the design principles of LV networks to account for the erosion of load diversity if LCTs continue to connect in an unmanaged and uncoordinated way; and
4. The standardisation of a Technical Specification for Smart EV chargers.

8.4 The Likelihood the Method will be Deployed on a Wider Scale in Future

If the following key areas are addressed, it is highly likely that the LV Connect and Manage solution will be deployed on a wider scale in future:

1. Standardisation of communications and control interfaces to LCTs. At present a wide variety of protocols and interfaces to LCTs exist, some of which are bespoke to the LCT manufacturer. Whilst the DLC box supports a wide variety of interfaces and protocols, there

are still device-specific developments needed for control of some LCT clusters. In addition, the recommended best practice is to regression test LCT control interfaces every time a software update is made;

2. Deploying low-cost LV substation monitoring equipment to give DNOs greater and more granular visibility of electrical substation and feeder loading profiles. Based on this, an accurate assessment of the timing and need for network reinforcement can be evaluated and the Connect and Manage intervention can be deployed in the meantime; and
3. Clarifying the powers and legal recourse that WPD has to enforce a Connect-and-Manage solution if network assets are at risk of overload. The current process is for customers to connect-and-notify the DNO of an LCT connection within their homes. This relies on electrical contractors completing and submitting the necessary paperwork on behalf of the customer, which does not happen in every case. Therefore, government policies (similar to the Automated and Electric Vehicles Act 2018) are needed to empower DNOs to intervene to prevent overloads.

At present, LCT uptake has been slower than anticipated at the original conception of the project and so the need case for the LV Connect and Manage intervention is growing but yet not widespread.

8.5 Knowledge Dissemination Events and Activities

LV Connect and Manage disseminated knowledge via the following events and activities:

1. The LCNI conferences, including a presentation at the 2017 LCNI conference (see Appendix D);
2. A paper publication and presentation at the International Workshop on Electricity Distribution (CIRED) in June 2018 (see Appendix E);
3. A presentation at WPD’s Balancing Act Conference in November 2018 (See Appendix F);
4. A paper publication and presentation at the International Conference on Electricity Distribution (CIRED) in June 2019 (see Appendix G);
5. Various customer engagement and dissemination events throughout the course of the project;
6. Hosting a visit to Furzton by the MPs for Milton Keynes and Milton Keynes South (See Appendix H);
7. A project-specific industry-wide dissemination event at the IET in May 2019 (See Figure 8.1 and Appendix I); and
8. A brochure publication on the project and its key learning outcomes.

Figure 8.1 – Industry-wide dissemination of LV Connect and Manage at the IET, Birmingham, May 2019

In addition, LV Connect and Manage forms an integral part of WPD's EV Network Strategy (See Appendix J) and WPD has actively fed its learning into other DNO projects such as the work by SSEN on standardising managed EV charging.

9 The Outcomes of the Project

This section provides comprehensive details of the outcomes of LV Connect and Manage and covers the following aspects:

1. The results from live trials of EV charge management (import limitation);
2. The results from live trials of battery dischargement management (export limitation);
3. Set point response times over mobile communications networks;
4. Policies and emerging standards resulting from this work; and
5. The TRL development of the LV Connect and Manage intervention.

9.1 Live Trials: EV Charge Management (Import Limitation)

This section demonstrates the design, build and operation of an ANM system for LV LCTs, focusing on the import limitation of power to EV charge points. For each of the monitored charge points, the power was aggregated within iHost and compared to set point limits. The charge points were controllable in the range of 16A to 32A and controlled with varying degrees of set point granularity (from 4A steps to 0.5A steps) to demonstrate the optimisation of real-time import patterns.

The cluster of 16 EV participants was configured into the LV ANM system as seen in Figure 9.1. Each customer participant was allocated a unique identification to keep their identity anonymous and protect their individual consumption data. Moreover, individual demand profiles were not needed or recorded as this project focused on the aggregated effects of LCT clusters on distribution transformer power flows.

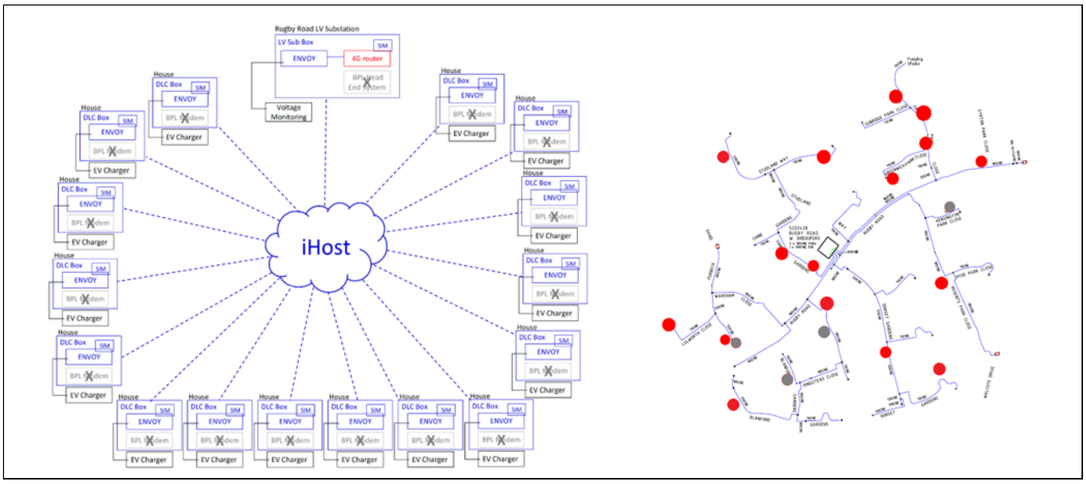

Figure 9.1 – Clustering of LCTs for the EV import limitation live trials

Example results from the live trials of the EV import limitation are illustrated in Figure 9.2 (for a week of continuous operation) and Figure 9.3 (for a day of operation).

The ANM system operates in the following way (using the example of a power flow constraint on the distribution transformer, which was artificially lowered for the purposes of the trial):

1. Real-time power flow (aggregated from the individual feeders of the distribution substation) is monitored and communicated to iHost (as shown by the red traces);
2. iHost continuously compares the power flow with the operational limits of the distribution transformer (as shown by the green trace in each graph);

3. If the monitored power flow breaches the operational limit of the substation (as can be seen during the ‘teatime’ peak loading each day), a signal is sent to all the controllable EV charge points to throttle back their charge by an equal amount;
4. The charge point limitation signal is continuously adjusted to maximise the allowable charge whilst keeping the network within its operational limits (as shown by the blue and amber traces on each graph);
5. If an individual EV charge point becomes uncontrollable (for example, due to a communications outage) this is automatically removed from the ANM system (until communications restoration) and the other charge points are throttled back further.

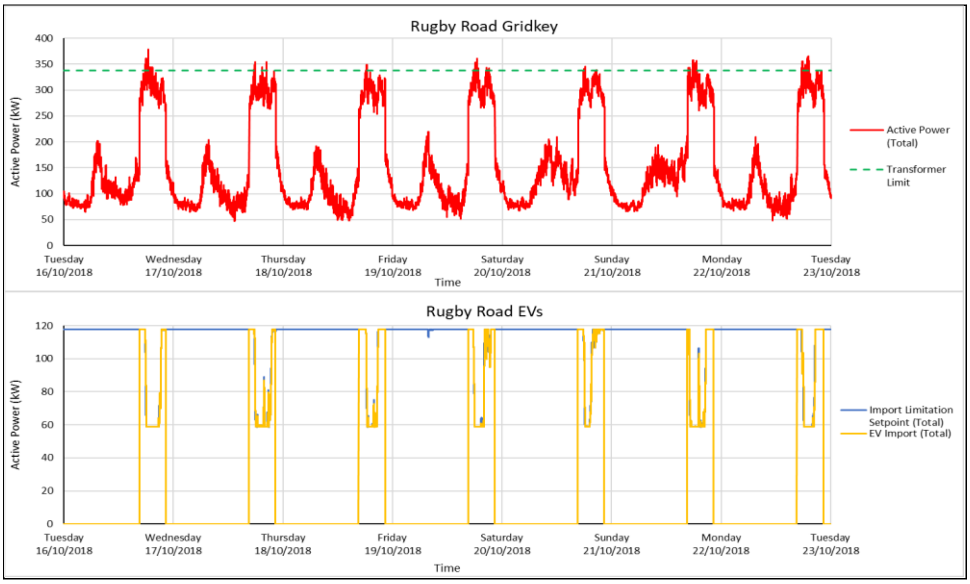

Figure 9.2 – Operation of the ANM system for limiting the import of EVs (one-week view)

Considering Figure 9.3 it can be seen that the import limitation signal is dispatched to the EV charge points between 18:30 and 21:00 in the evening. This coincides with participants returning home from work and plugging in their EV to charge. Between 19:00 and 20:00 the limitation signal is temporarily relaxed. This is because there was capacity in the electricity network to allow increased EV charging during this period. Outside of the hours of 18:30 to 21:00, customers were able to charge their vehicle without constraint.

Figure 9.3 – Operation of the ANM system for limiting the import of EVs (one-day view)

9.2 Live Trials: PV/Battery Charge Management (Export Limitation)

This section demonstrates the design, build and operation of an ANM system for LV LCTs, focusing on the export limitation of power from battery energy storage systems.
For each of the monitored battery systems, the power was aggregated within iHost and compared to set point limits. The battery inverters were controllable in the range of 0A to 16A and able to receive a continuous scale of electrical currents to demonstrate the optimisation of real-time export patterns.

The cluster of 12 battery energy storage participants was configured into the LV ANM system as seen in Figure 9.4. As with the import limitation trial, each customer participant was allocated a unique identification to keep their identity anonymous and protect their individual consumption data. Moreover, individual export profiles were not needed or recorded as this project focused on the aggregated effects of LCT clusters on distribution transformer reverse power flows.

For the purpose of the trial, the batteries were reconfigured from ‘self-consumption’ mode (limiting the discharge of the battery to match the demand within the household) to grid-tied export mode (discharging the battery to the level requested by the ANM system). This is equivalent functionality to vehicle-to-grid (V2G).

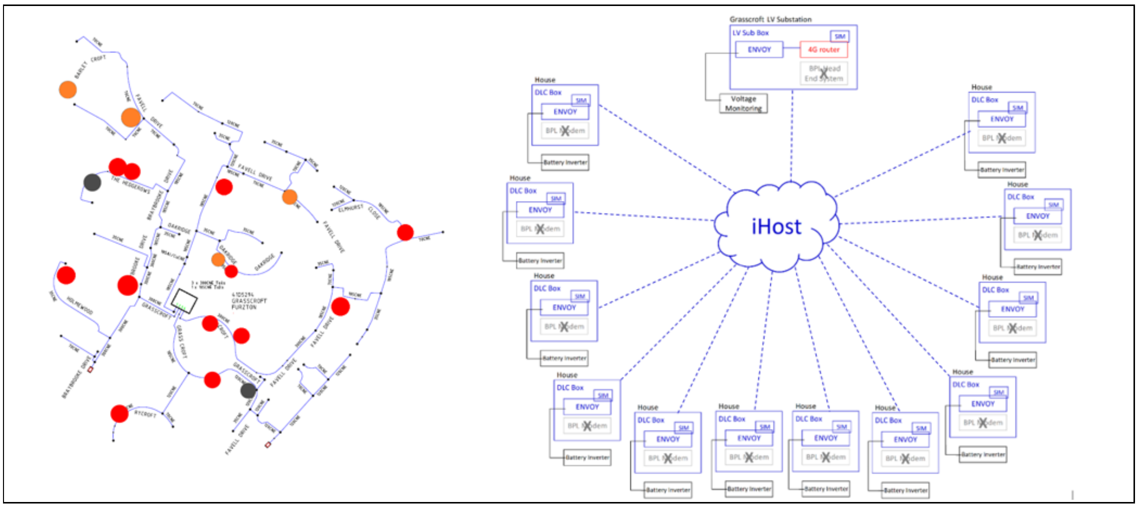

Figure 9.4 – Clustering of LCTs for the battery export limitation live trials

Example results from the live trials of the battery export limitation are illustrated in Figure 9.5 (for spring-time operation), Figure 9.6 (for summer-time operation) and 9.7 (for a more granular view the export limitation operation).

The system operates in reverse with respect to the import limitation functionality. When a reverse limit on the distribution transformer is breached the export of the batteries is limited and the power flow through the distribution transformer (in the forward direction) is increased. Since the penetration of PV systems and battery systems was not sufficient to cause reverse power flow through the distribution transformer, the reverse power flow limit was artificially applied in the forward direction.

When the transformer power flow is below the export limit, battery export is limited (to increase the power supplied by the distribution substation). When the transformer power flow is above the export limit, battery export is increased (to reduce the power supplied by the distribution substation).
In the future, this mode of operation could be used to increase distribution network efficiency and reduce losses by utilising local generation and storage systems to supply electricity locally within the LV network.

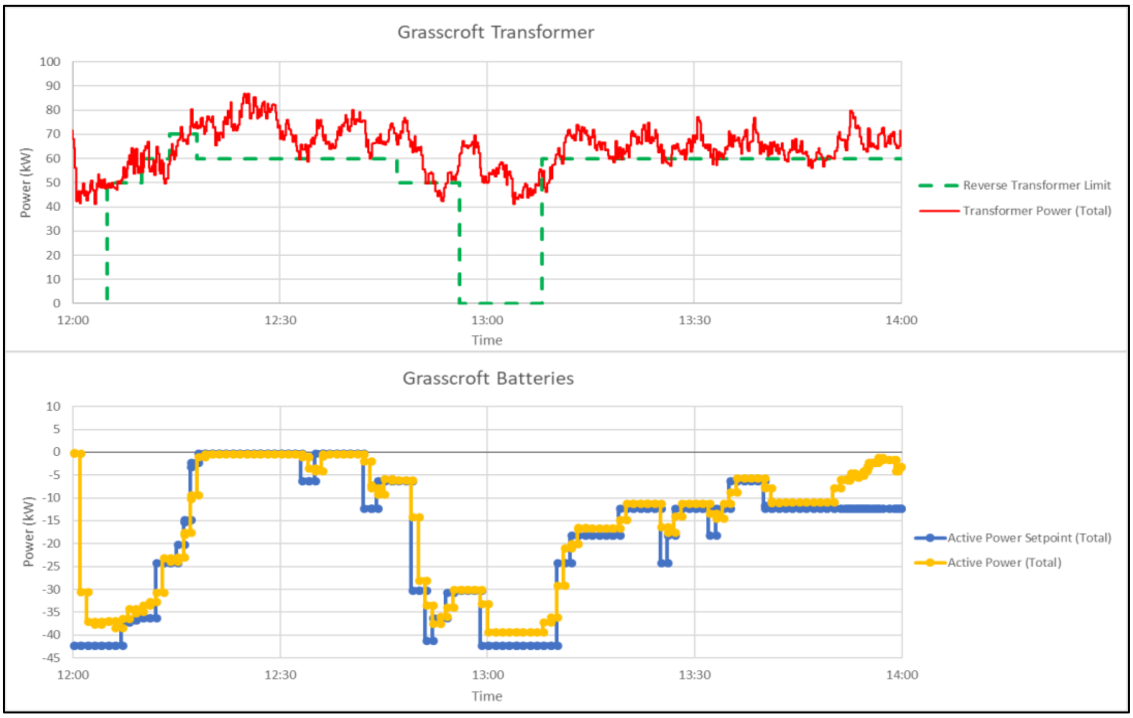

Figure 9.5 – Operation of the ANM system for limiting the export of batteries (spring-time example)

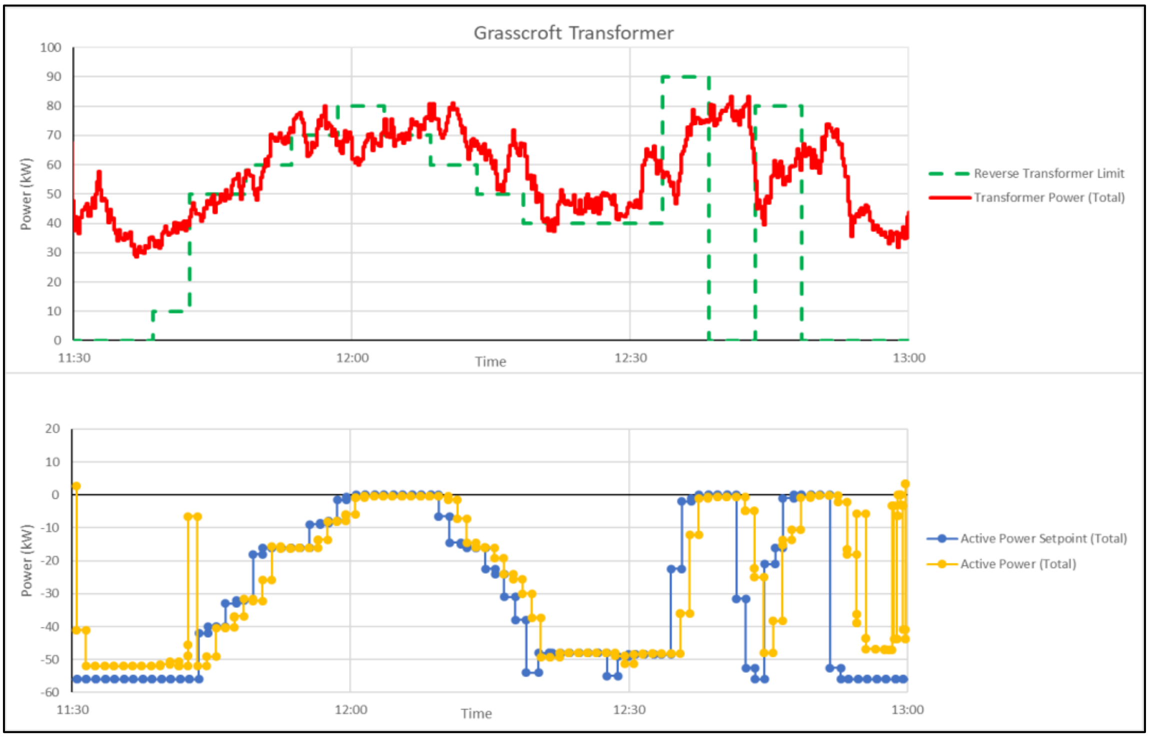

Figure 9.6 – Operation of the ANM system for limiting the export of batteries (summer-time example)

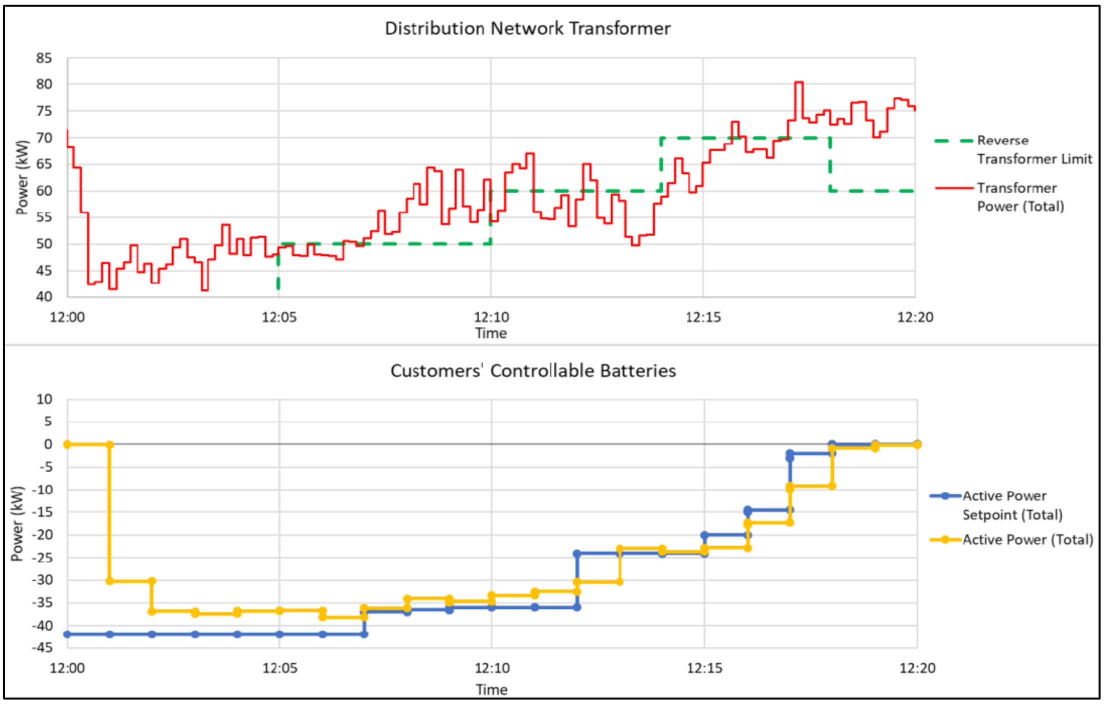

Figure 9.7 – Operation of the ANM system for limiting the export of batteries (more granular example)

9.3 Setpoint Response Times (over mobile networks)

This section quantifies the performance of setpoint controls delivered to the LCTs over mobile network communications within the ANM system. 3G roaming SIM cards were used within the trial as this delivered speed (reduced communication network latency) and increased resilience (as the SIM cards would automatically switch onto a different network provider in the event of a primary mobile network outage). In the sections that follow, the round-trip communication times (from control trigger to readback of setpoint change) were recorded for the battery/inverter system trials and the EV charge point trials.

9.3.1 Battery/Inverter Systems

The times taken for the readback confirmation of setpoint changes for the battery/inverter systems are given in Table 9.1. 288 setpoint controls were triggered during the response time quantification trial. Of these, 276 controls (95.8%) were confirmed within 1 minute and all controls were confirmed within 4 minutes.

Table 9.1 – Readback times for battery/inverter controls

Time for readback confirmation of setpoint	Number of setpoint controls	Percentage out of 288 controls
Less than 1 minute	276	95.8 %
1 - 2 minutes	8	2.8 %
2 - 3 minutes	3	1.0 %
3 - 4 minutes	1	0.3 %

9.3.2 EV Charge Points

The times taken for the readback confirmation of setpoint changes for the EV charge point systems are given in Table 9.2. 7573 setpoint controls were triggered during the response time quantification trial. Of these, 7493 controls (98.9%) were confirmed within 5 seconds and all controls were confirmed within 10 seconds or following retries.

Table 9.2 – Readback times for EV charge point controls

Time for readback confirmation of setpoint	Number of setpoint controls	Percentage out of 7573 controls
Less than 1 second	891	11.77%
1-2 seconds	4126	54.48%
2-3 seconds	1156	15.26%
3-4 seconds	1151	15.20%
4-5 seconds	169	2.23%
Longer 5 seconds	80	1.06%

9.4 Policies, Processes and Emerging Standards

LV Connect and Manage resulted in the following policies and emerging standards:

1. A policy for the retrofit of Connect and Manage substation monitoring equipment (see Appendix K);
2. A process for standardising the installation of Connect and Manage equipment (DLC boxes) within customers' homes (see Appendix L); and
3. A Technical Specification for Managed EV Charging Systems (see Appendix M).
4. WPD Policies and Standard Techniques for the implementation of this solution have been developed and are available upon request.

9.5 Technology Readiness Level Evaluation

The Technology Readiness Level at the start of the project was 5 (technology validation in a relevant environment). The Technology Readiness Level at project completion was 9 (actual system 'flight proven' through successful operations). To date, two additional WPD projects have made use of the DLC box component of LV Connect and Manage: I&C Storage and Smart Energy Isles. Further details of these projects can be found on our Innovation website: *https://www.westernpower.co.uk/innovation*

10 Data Access Details

As part of the project close-down, aggregated LCT profiles will be published on WPD's project data page:

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

In addition, WPD has built an offline instance of the ANM solution with a database of monitoring and controls for future reference.

11 Foreground IPR

The foreground IPR generated by LV Connect and Manage is summarised in Table 11.1 together with the ownership.

Table 11.1 Foreground IPR, Ownership and Access

IPR	Ownership	Access Location
Business Case metrics for Connect and Manage	WPD	Project Registration Document (Smarter Networks Portal)
Project Data	WPD	WPD's Project Data Page (see Section 10)
The Connect and Manage solution architecture	WPD / Nortech	This report (see Section 4.1)
Project Dissemination Papers and Presentations	WPD / Nortech	This report (see Appendices D-I)
Policy for the Retrofit of Connect and Manage Equipment in LV Substations	WPD	This policy is available upon request
Process for Standardising the Installation of DLC Equipment in Customers' Homes	WPD / Nortech	This policy is available upon request
Technical Specification for Managed EV Charging	WPD / Nortech	This policy is available upon request

12 Planned Implementation

The business case for LV Connect and Manage was re-visited at the end of the project and two primary streams of benefits were identified:

1. The value to customers of having their LCT connection onto the network expedited by a connect-and-manage mechanism. Whilst it is intangible to quantify the value of the customer experience and satisfaction if the electricity network is not being a barrier to the installation of their LCTs, the cost of inconvenience can be quantified. For example, if an EV customer has a dual-tariff but, due to network restrictions, for the first six months of ownership can only charge their car at work (peak tariff and administration) and not at home (off-peak), this could cost the customer an additional £300 in electricity bills (based on a 50-mile daily commute). A connect-and-manage intervention that costs less than £300 would, in this case, potentially be attractive to the customer.
2. The benefit to WPD (and other UK DNOs) of mitigating the risk of power outages when clusters of LCTs reach such a level that assets are overloaded and electrical faults occur. In this case, there is an established mechanism for monetising the cost of customer interruptions (CIs) and customer minutes lost (CLMs), and the cost (financial and carbon) of alternative mitigations such as deploying emergency diesel generators whilst the network faults is repaired.

As part of the project close down activities, the Innovation Team has disseminated the outcomes of LV Connect and Manage to key stakeholders across its business and work is currently underway to specify how WPD will make use of the DLC box and the triggers that will result in deployment of the Connect and Manage intervention.

In addition, WPD commissioned a piece of market research to assess customers' perceptions of managed charging / discharging and, in particular, their willingness to accept short-term managed control for expedited LCT connections and to mitigate the risk of street-wide power outages (due to overloads from the clustering effect of LCTs). This work concluded that, with the reasons articulated in an accessible way to WPD's customers, up to 7 in every 10 existing EV owners would be willing to accept the retrofit of a DLC box within their homes (and without a further incentive needed) to mitigate the risk of a street-wide power outage (which would result in them not being able to charge their car at all). It is anticipated that the acceptance of a DLC-type intervention by new LCT customers could be even higher particularly if managed charging is mandated for all new connections.

Whilst the technology has been proven, there are still some issues to be addressed before the LV Connect and Manage intervention can be implemented as part of WPD's Business-as-Usual activities:

1. Government policy and legislation needs to be in place empower DNOs to intervene, giving them the option to deploy a DLC box-type solution within customers' homes if network assets are at risk of overload and the level of LCT uptake on a particular distribution substation puts every customer on that substation at risk of power cuts;
2. Standardisation of control interfaces and performance of LCTs by manufacturers to guarantee interoperability of LCTs; and
3. The development of alternative communications and control paths to LCTs, alongside mobile communications, to provide dual redundancy (for example, via the auxiliary load switch of smart metering infrastructure).

13 Other Comments

WPD would like to express its thanks to the various parties that contributed to this project's success:

- The residents of West Bridgford participating in the EV trials;
- The residents of Furzton participating in the battery/energy storage trials;
- Nortech Management Limited;
- The Dairy;
- The Big Wheel;
- Stratford Energy Solutions; and
- EV Charging Solutions.

14 Contact

Further details on replicating the project are available from the following point of contact:

Future Networks Team
Western Power Distribution,
Pegasus Business Park, Herald Way,
Castle Donington, Derbyshire
DE74 2TU
Email: wpdinnovation@westernpower.co.uk

Glossary

Abbreviation	Term
AC	Alternating Current
ANM	Active Network Management
APN	Access Point Name
BPL	Broadband-over-Powerline
CIRED	International Conference on Electricity Distribution
DLC	Domestic Load Controller
DNO	Distribution Network Operator
DSO	Distribution System Operator
DNP3	Distributed Network Protocol 3.0
EV	Electric Vehicle
FiT	Feed-in Tariff
FMEA	Failure Modes and Effects Analysis
GSM	Global System for Mobile Communications
GUI	Graphical User Interface
HTTPS	Hypertext Transfer Protocol Secure
IET	The Institution of Engineering and Technology
I/O	Input / Output
LCNI	Low Carbon Networks and Innovation
LCT	Low Carbon Technology
LV	Low Voltage
MCB	Mini Circuit Breaker
MP	Member of Parliament
NIA	Network Innovation Allowance
NMS	Network Management System
OCPP	Open Charge Point Protocol
PSR	Priority Services Register
PV	Photovoltaic
RTU	Remote Terminal Unit
SSEN	Scottish and Southern Electricity Networks

Abbreviation	Term
TRL	Technology Readiness Level
UK	United Kingdom
UPS	Uninterruptible Power Supply
VPN	Virtual Private Network
V2G	Vehicle to Grid
WPD	Western Power Distribution
3G	Third Generation (Mobile Network)
4G	Fourth Generation (Mobile Network)

Appendix A: The LV Connect and Manage FMEA

Appendix B: Customer Engagement Plan

Appendix C: Data Protection Strategy

Appendix D: LCNI 2017 Dissemination Presentation

Appendix E: CIRED 2018 Workshop Paper

Appendix F: Balancing Act 2018

Appendix G: CIRED 2019 Conference Paper

Appendix H: MPs Visiting Furzton

Appendix I: Industry-wide Dissemination at the IET 2019

Appendix J: WPD's EV Strategy