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OPENLV

OPENING UP THE SMART GRID

SDRC-3

Learning from Deployment of the Overall OpenLV Solution and Standard Guidelines for Application Development

ea technology

RIIO NIC NETWORK INNOVATION COMPETITION

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Contents

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Glossary

Term	Definition
ACRE	Action for Communities in Rural England
API	Application Programming Interface
APN	Access Point Name
BaU	Business as Usual
CI	Customer Interruption
CML	Customer Minutes Lost
CSE	Centre for Sustainable Energy
DNO	Distribution Network Operator
DTR	Dynamic Thermal Rating
FATs	Factory Acceptance Tests
GMT	Ground Mount Transformer
HV	High Voltage
ISD	Intelligent Substation Device *The enclosure installed as part of the OpenLV Project containing the LV-CAP™ enabled PC, the router, Digital I/O system, connections for Alvin Reclose™ units and system power supply.*
kVA	Kilovolt-ampere
LV	Low Voltage
LV-CAP™	Low Voltage Common Application Platform
LVNT	Low Voltage Network Templates
MSCW	The term MoSCoW itself is an acronym derived from the first letter of each of four prioritization categories (Must have, Should have, Could have, and Won't have)
MQTT	Message Queuing Telemetry Transport
NDA	Non-Disclosure Agreement
NIC	Network Innovation Competition

NOP	Normally Open Point
OHL	Over Head Lines
PMT	Pole Mount Transformer
PV	Photovoltaics
RTTR	Real Time Thermal Rating
SATs	Site Acceptance Tests
SDRC	Successful Delivery Reward Criterion
WPD	Western Power Distribution

Executive Summary

The OpenLV Project "the Project" is funded through Ofgem's Network Innovation Competition (NIC) funding mechanism. The Project commenced in December 2016 and is scheduled to complete in April 2020. The Project Partners are as follows: 1) Western Power Distribution (WPD): The Lead/Funding DNO (licensee); and 2) EA Technology: The 3rd Party Lead Supplier who is responsible for the overall delivery of the Project.

The Project has three phases: 1) Mobilise & Procure, 2) Design & Build and 3) Trial, Consolidate & Share. This Successful Delivery Reward Criterion (SDRC) report focuses on disseminating the learning gained from developing the OpenLV solution and standard guidelines for application development during the phases 1 and 2 of the project. This Enabling Works phase included the specification, procurement, installation and training for the OpenLV solution, together with application development guidelines for third parties developing applications for the LV-CAP™ platform.

Whilst learning points are detailed in the main body of the report, much of the learning is embodied in the appended documents (Appendix 1 through to 23) and reference is made to these documents where appropriate.

This document begins by providing an overview of the OpenLV project, its aims and objectives. It then considers specific aspects of the Enabling Works phase, detailing the solution that was realised and drawing out the key learning. Relevant project documentation that was produced during this phase and can be considered useful from a learning perspective is included as appendices to aid both the dissemination process and readability of the report. Key learning is summarised below and focuses on the specific aspects of the project, such as the work to deploy the LV-CAP hardware and then extends to the main work streams.

Enabling Works

Adopting a professional approach to installing equipment is essential, regardless of this being a temporary trial. Neatness is important as the substation setting is a working environment and any non-standard items need to be positioned so as not to cause any disruption. There are a range of substation topologies, physical layouts and construction making the rollout a complex operation requiring detailed planning. Initial selection considered a large number of sites, with surveys undertaken at several hundred to then arrive at the target eighty substations. This structured approach worked well and allowed equipment to be tested prior to deployment and pre-packaged to make on site work more straightforward. Specific testing regimes were developed to support workflows and included a range of formal, traceable test documentation.

Method 1 – Capacity Uplift

The two main types of installation were the Phase 1 virtual pairs and Phase 2 controlling pairs. Installation of virtual pairs necessitated selecting different network types to ensure a representative sample of each was achieved. Again, a structured approach proved invaluable and allowed sufficient pairs to be identified, albeit more widely geographically dispersed that originally anticipated. Constraints, such as excluding pole mounted transformer substations introduced further challenges in the selection process, but eighty sites were still readily secured. Selection of the controlling pairs required more detailed network analysis, as automated low voltage reconfiguration would be attempted when the equipment was fully commissioned. Ensuring the appropriate fault level was maintained was an important factor and have access to the right analysis tools and proficient staff was of great benefit. Operational safety continues to be paramount, so establishing the correct working methods was essential. Once the equipment is deployed on the network then its presence could impact normal operational activities; hence ensuring WPD staff had sufficient knowledge when encountering an unfamiliar configuration was recognised and addressed. Training materials and on-site signage were developed and used to deliver comprehensive training to staff in the relevant areas.

Method 2 – Community Engagement

These sites were selected based on the requirements of the seven community groups participating in this project. Electricity network domain knowledge possessed by WPD and project staff was much greater than that of community groups. Therefore, the terminology used, and ways chosen to explore and explain how the network operates were adapted to be more suitable for a general audience. Even so, it became apparent that people unfamiliar with the design and operation of the public electricity network often make assumptions about what can be easily achieved. For example, network topology may not reflect the local geography in terms of streets being fed from a particular substation. Some community group initiatives are targeted at relatively small areas but monitoring the associated low voltage network requires equipment to be installed at multiple substations. This proved to be the case for the Marshfield Energy Group and Bath & West Community Energy, where additional substation needed to be monitored. This linked to our efforts to build and maintain the confidence of community groups, as this was key to sustaining their commitment to the project. Providing consistent and reliable data is essential. Poor or incomplete data, when transformed into visual representations for dissemination by groups to their community, can undermine the messages and make it harder for community group leaders to engage with the communities they represent.

Volunteer-led organisations do not normally possess either the time or requisite technical skills to develop Applications. Rather than this being an insurmountable barrier, innovative solutions can be found, such as using 3rd parties to develop “configurable” Apps, allowing a level of customisation to fit particular circumstances. The OpenLV project exploited this route, allowing CSE to develop a configurable App for use by the community groups that will be widely available at the end of the trial.

Method 3 – Wider Industry

Again, the site selection for Method 3 sites was driven by the requirements of the participants, who were a mix of commercial and academic organisations. A flexible approach to site identification, working closely with WPD to explore possible candidate sites worked well and allowed participants to have access to the particular network characteristics they requested. Accurate network configuration information and loading were valued, as they will allow LCT's to be positioned and operated during subsequent trial phase of the project. Application development was a major feature of Method 3, with a number of participants undertaking this task. The application development guidelines, development environment and toolkit provided by the project was aimed at assisting the whole process. By not only providing guidance documentation but also tangible support and a user-friendly development environment a number of applications have been realised and tested with relative ease, showing the value of this approach.

Key learning from specifying the solution, installing, testing and commissioning are all detailed in the relevant sections of the report, as well as those relating to application development guidelines and development kit learning. Some learning points are quite specific and detailed, such as the advantages of particular software configurations over others. Others are broad in nature, such as considering the competencies and skills of application developers, particularly those from community groups.

1. Introduction

1.1 Document Purpose

In this report we present the suite of documentation created as part of the OpenLV Project's 'Enabling Works', covering:

- System specifications;
- Site identification details;
- Installation documentation;
- Training information;
- Pre- and post-installation testing;
- Guidance for third parties developing applications for the LV-CAP™ platform;
- Learning points identified during the Enabling Works phase.

1.2 Background

Great Britain has about 1,000,000 Low Voltage (LV) feeders; these have largely been designed and operated on a fit-and-forget basis for the last 100 years, but things are set to change. LV networks are expected to see radical change as we, customers, alter our behaviour and requirements, stemming from the vehicles we drive, to the generation and storage devices we put onto and into our homes.

The technology to be trialled as part of the OpenLV Project provides a new, open and flexible solution that will not only provide the DNO, community groups and the wider industry with data from the LV network, but will also enable these groups to develop and deploy apps within LV substations. The OpenLV Project is seeking to prove the technology and assess how the provision of LV network data and the ability to develop and deploy apps can provide benefits to the DNO, community groups and the wider industry. These Methods are outlined in the below sub-sections.

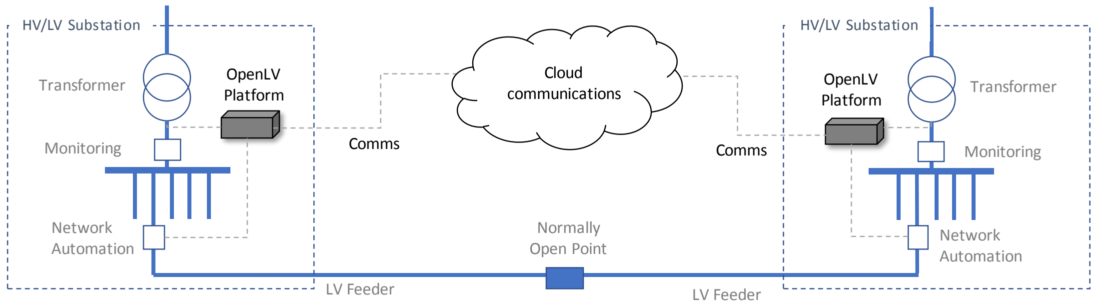
1.2.1 Method 1: Network Capacity Uplift

Figure 1 provides an overview of the systems architecture that will be deployed to complete Project trials for Method 1 – Network Capacity Uplift.

As part of the Project trials for Method 1 apps will be used to increase the capacity of existing LV assets through the application and implementation of Dynamic Thermal Rating of the LV Transformer and through meshing LV Feeder(s) on the LV network.

Dynamic Thermal Rating is a method whereby the rating of an asset (e.g. cable or transformer) can be temporarily increased due to previous favourable conditions (e.g. colder weather or the asset is currently cool due to light loading).

Meshing (connecting LV network areas together) can share spare capacity between two networks to prevent cable or transformer overloads.



What

- Check network capacity against thermal rating of transformer; when breached, close two radial circuits to mesh the LV network
- Deploy two proven techniques
  - ‘Dynamic Thermal Ratings App’ and
  - ‘Network Meshing App’.
- Together with a ‘Network Control App’ to operate/configure the network

How

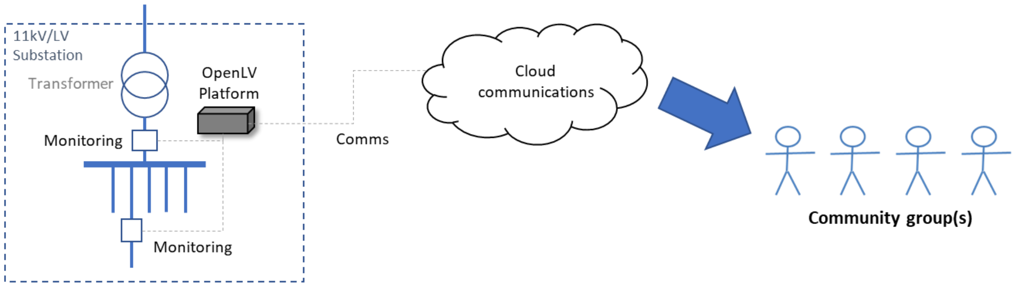
- Assess WPD’s network to identify candidate circuits
- Deploy LV-CAP™ to 60 substations
- Monitor how the solution would operate over several months
- Install actuators on 5 circuits (2 ends each) to prove end-to-end control
- Assess and report on performance

Figure 1: Method 1 – Network Capacity Uplift

1.2.2 Method 2: Community Engagement

Figure 2 provides an overview of the systems architecture that will be deployed to complete Project trials for Method 2 – Community Engagement.

As part of the Project trials for Method 2, Community Groups will either, make use of the LV network data provided by the OpenLV Platform, and/or develop and deploy apps to provide benefits to individual Communities.



What

- To work with key community groups to understand whether Apps can be developed and installed on the platform
- Identify funding sources that customers / communities can use to develop specific Apps

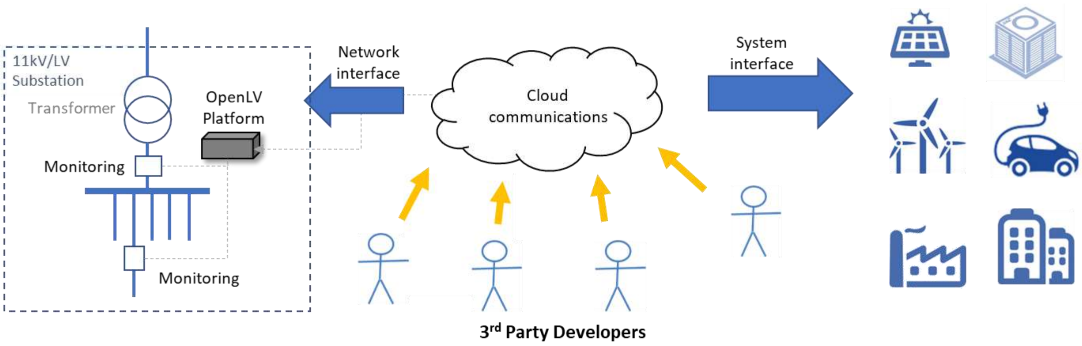
How

- Community engagement to promote availability of platform / LV network data
- Make available 10 LV-CAP™ units for deployment
- Provide communities access to relevant data
- Funding to develop specific Apps to be raised outside of the project budget, e.g. public funding / private sector

Figure 2: Method 2 – Community Engagement

1.2.3 Method 3: OpenLV Extensibility

Figure 3 provides an overview of the systems architecture that will be deployed to complete Project trials for Method 3 – OpenLV Extensibility. As part of the Project trials for Method 3, the Wider Industry will either, make use of the LV network data provided by the OpenLV Platform, and/or develop and deploy 'apps' to provide benefits to: DSOs, Platform Providers, 3rd Party Developers and Customers.



What

- To enable companies to develop innovative algorithms and applications for either the DNO, or it's customers

How

- Publicise the opportunity to 3rd parties
- Make available standard App 'container' for third parties to use for their development
- Make available 10 LV-CAP™ devices for substation deployment
- Funding to develop specific Apps to be raised outside of the project budget, e.g. private sector

Figure 3: Method 3 – OpenLV Extensibility

1.3 Report Structure

The structure of this report is as follows:

- **Section 2: Overview of the OpenLV Solution –** Provides an overview of the OpenLV solution explaining how it works with reference to technical specifications;
- **Section 3: Installation Documentation –** Provides an overview of installation documentation for the intelligent substation devices;
- **Section 4: Installation and Configuration Confirmation –** Provides evidence that the third-party system has been installed and configured to support widescale deployment;
- **Section 5: Training Overview –** Provides an overview of the training provided to project staff involved with installations of the OpenLV solution and WPD staff who may have contact with it during operational activities;
- **Section 6: Acceptance Testing –** Provides an overview of the acceptance tests undertaken for the OpenLV trial equipment;
- **Section 7 – Standard App Development Guidelines –** Outlines the guidelines that were provided to third-party organisations to enable them to develop apps as part of the project;
- **Section 8 – App Development Kit –** Outlines the tools that were made available to third parties to develop applications;
- **Section 9 – Learning Points -** Summarises the learning from the previous sections of the report;

2. Overview of the OpenLV Solution

The trial system being deployed in the OpenLV Project consists of a combination of hardware and software. The purpose of the project is to demonstrate the capability of a software platform (LV-CAP™), to provide distributed intelligence capability to the LV network and make useful data available to third-party companies, Universities and community groups.

LV-CAP™ is a hardware agnostic software platform, designed as a framework on which third-party applications can be run. The framework provides a number of core services for third-party application developers to utilise, including access to data gathered by the platform, communications functionality and data storage.

The LV-CAP™ software platform will be installed on an embedded PC. Communications will be provided via an ethernet connected modem. LV network data will be provided by a connected Lucy Electric GridKey MCU520 platform. Thermal monitoring of the local transformer and ambient temperature will be undertaken using thermal probes.

2.1 Enclosure - External

The overall solution is to be deployed within a suitable, non-conducting enclosure, capable of being mounted via multiple methods, including direct wall mounting or magnetic mounting on a transformer.

Figure 4 shows an example of the enclosure mounted on a transformer, demonstrating the magnetic bracket and mounting capability. Key features of the enclosure are highlighted in the picture.

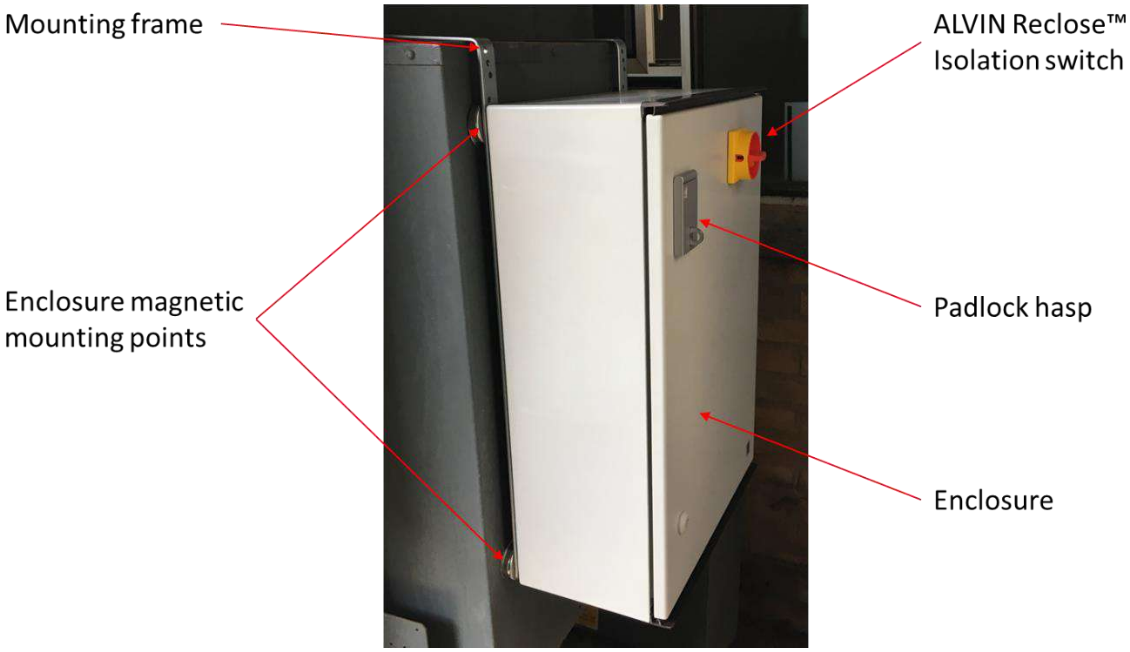


Figure 4: OpenLV Solution - Enclosure

The enclosure is a plastic based enclosure with an IP66 rating and is capable of being mounted via multiple methods. Figure 4 demonstrates the enclosure magnetically mounted on the side of an item of switch-gear with a mounting frame supporting some of the weight. If the enclosure is to be wall-mounted, the mounting frame can be removed, and the same **mounting points** utilised for bolting wall brackets to the enclosure, see Figure 5.

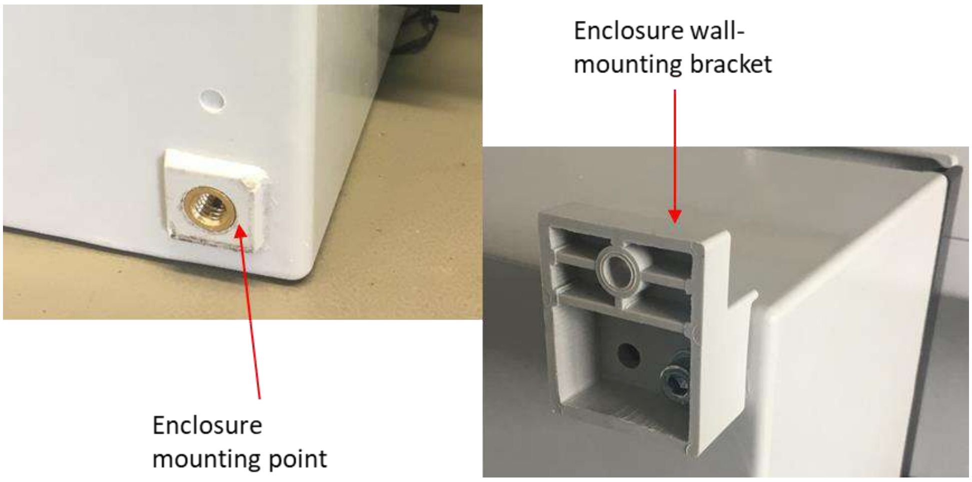


Figure 5: OpenLV Solution – Enclosure mounting points

In the event the unit is to be mounted on top of the LV fuse board enclosure, the magnets will still be utilised to prevent accidental dislodging of the enclosure.

The outside of the enclosure includes an **isolation switch** to be utilised if necessary for disconnecting the Alvin Reclose™ devices from the LV-CAP™ platform control system. This switch can be locked 'off' to prevent inadvertent or unauthorised reactivation of the system whilst workers are present on-site.

As such, the front mounted isolation switch must be easily accessible in substations where Alvin Reclose™ units are also installed for the implementation of automated network meshing.

A **padlock hasp** is included to prevent unauthorised access to the LV-CAP™ platform; only the OpenLV Project team will have the ability to unlock the enclosure, once access to the substation has been provided or authorised by WPD.

2.2 Enclosure - Internal

The enclosure contains most of the key components of the OpenLV solution, specifically the industrial PC (Advantech UNO-2484G), the modem and digital I/O terminal providing connections to the thermocouples and Alvin Reclose™ devices.

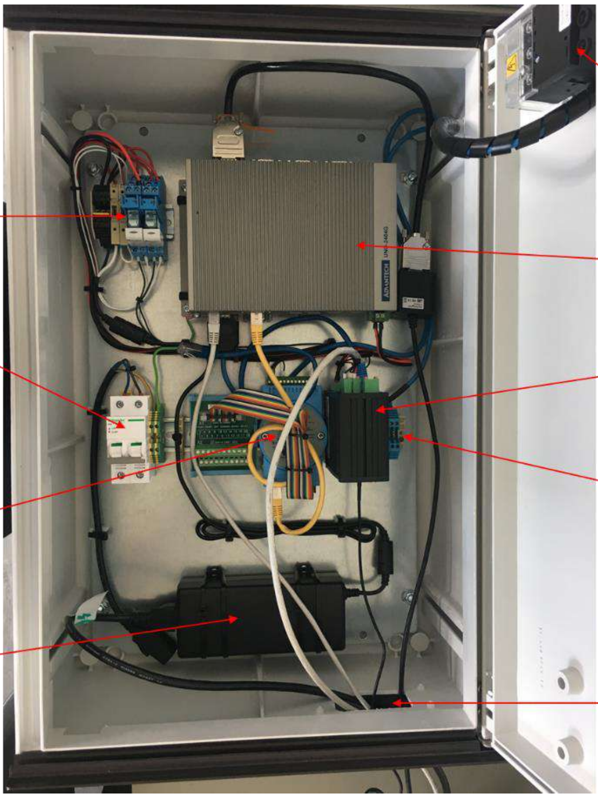


Figure 6: OpenLV Solution – Enclosure Internals[1]

Connections to and from the enclosure pass through the cube glands at the bottom of the enclosure and will be routed as appropriate on a site-by-site basis.

The **Advantech UNO-2484G** industrial PC is the primary component in the trial hardware, running the LV-CAP™ software platform and all the applications developed for the trials. The unit is a relatively high specification for the trials, as at the time of equipment ordering capacity was included to allow for:

1. Sufficient data capacity (hard drive – HDD) for the storing of all data to be gathered, and generated by the platform, for the full duration of equipment installation.
2. A sufficiently powerful Central Processing Unit (CPU) to provide adequate processing capability to 'run' all software containers known at the project outset, and have spare capacity for a 'worst case' scenario of all additional containers for Method 2 and 3 participants.

[1] The enclosure shown in Figure 6 has a temporary power cable for direct connection to the power supply. When installed on-site, the incoming power feed will be routed through the isolation switch on the left, allowing the power to be disabled for all system components within the enclosure.

3. Sufficient random-access memory (RAM) to meet the same requirements as for the CPU.
4. Multiple network and serial ports to allow versatility of connections for Method 2 and 3 applications, after all Method 1 requirements were met.

The **Router / modem** provides the PC a link to the APN (Private Network) separating all OpenLV assets from the wider internet. Through this link, the LV-CAP™ platform can communicate with the Command & Control iHost server, deliver data to the 3rd party data server hosted by Lucy Electric, or accept remote connections from authorised individuals within the project.

The **Digital I/O** unit is utilised to connect temperature sensors, (external, internal and transformer oil pocket), allowing direct monitoring of the temperatures. It can also be used to provide additional connectivity to third-party hardware if required, with a corresponding software application.

The **power supply** is rated for all equipment within the enclosure and the output is routed through the **isolation switch** enabling electrical isolation of the interior of the enclosure.

The **power terminals** distribute power to the separate components and can be controlled by the router to allow remote resets of the router and PC in the event either experience problems.

2.3 Ancillary equipment

2.3.1 Alvin Reclose™ devices

Alvin Reclose™ devices will only be installed in 10 substations (five pairs) within the project trial.

These devices will be connected to the LV-CAP™ platform when installed allowing the system to control operation of the circuit breaker within each device.

For the avoidance of doubt, the autonomous protection functionality within the devices will continue to operate as normal and cannot be overridden by the LV-CAP™ platform.

Figure 7: OpenLV Solution – Alvin Reclose™ devices

A deployment of Alvin Reclose™ units, using typical 'off-the-shelf' variants, will automatically attempt to reclose the circuit breaker after opening in the event of a fault. This functionality has been disabled, at the request of WPD, for the units being installed as part of the OpenLV project.

The installed units will instead open the circuit breaker in the event of a fault and will require manual intervention by a WPD engineer to reenergise the circuit, in a similar manner to replacement of a fuse.

The units installed as part of the OpenLV Project have been clearly marked and labelled as being part of the trials, and as being unsuitable for general deployment, in order to prevent them inadvertently entering WPD's regular operation processes.

2.3.2 LV System monitoring – Lucy Electric GridKey MCU520

Monitoring of the LV network within the OpenLV Project is via a GridKey MCU520 platform that communicates with the LV-CAP™ hardware via an ethernet connector.

Depending on the substation arrangement, the MCU520 monitors either:

1. All feeders and summates the values to provide the total transformer load; or
2. The LV busbars and the single feeder (to be meshed).

The first option is always applied for Method 2 and 3 substations.

The MCU520 is designed to be installed via the use of magnetic mountings or direct wall-fixings. Each site inspected at the site-survey (phase 2) stage will identify the preferred installation arrangements.

Figure 8: OpenLV Solution – GridKey MCU520

2.3.3 Temperature monitoring

The dynamic rating application utilises calculated transformer and monitored ambient temperatures to model the available and predicted capacity of the transformer in question. The ambient temperature will be measured using a thermocouple temperature probe installed within a radiation shield (note that in the picture the probe is partially removed from the shield) to prevent or mitigate the effects of wind and direct sunlight on the thermocouple.

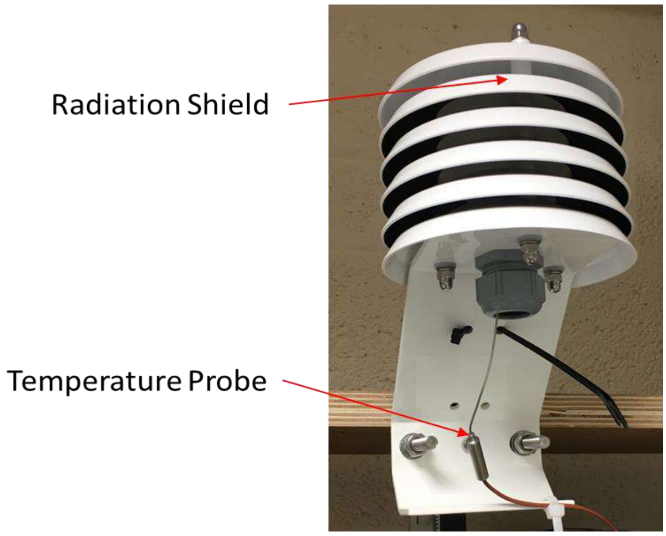


Figure 9: OpenLV Solution – Thermal probe & radiation shield

The internal temperature of the associated transformer will also be monitored (to allow comparison of the calculated and actual values), utilising a similar thermal probe, however a radiation shield is not required in this instance. Instead the transformer thermal pocket will be filled with oil with the probe inserted and secured to monitor the top-oil temperature.

Figure 10: Example of a transformer oil pocket and cap

Figure 11: Example transformer oil pocket and test cap, including thermal probe

2.4 Processes and Communication links

The complete test system implemented as part of the OpenLV Project is shown schematically below in Figure 12.

The LV-CAP™ platform utilises multiple communication links to receive data from voltage, load and temperature sensors in the substation before processing and storing the data, and then uploading the necessary elements to the respective servers (iHost Server and Data Server).

LV-CAP™ enabled platforms are designed to operate effectively with intermittent telecommunications, gathering and processing data as required regardless of the availability of a data connection. When a platform has a viable data connection, periodic checks of the Command & Control server are undertaken, downloading new software or configuration settings if required, whilst also uploading selected data files.

Similarly, data sets selected for upload to the Data Server, enabling Community Groups and 3rd Party Companies to access are also uploaded at this time.

It is possible to directly connect[2] to the individual LV-CAP™ platforms, both when on-site through physically connecting to the router in the enclosure, or remotely through the APN. This approach is not normally required as installation, removal and configuration of the platform software is managed through the iHost Command & Control Server, although the option is available, primarily for troubleshooting purposes.

[2] Details of the cyber-security in place preventing unauthorised access are not covered in this SDRC. A review of the system's cyber-security arrangements has been undertaken with both the report and response being published later in the project.

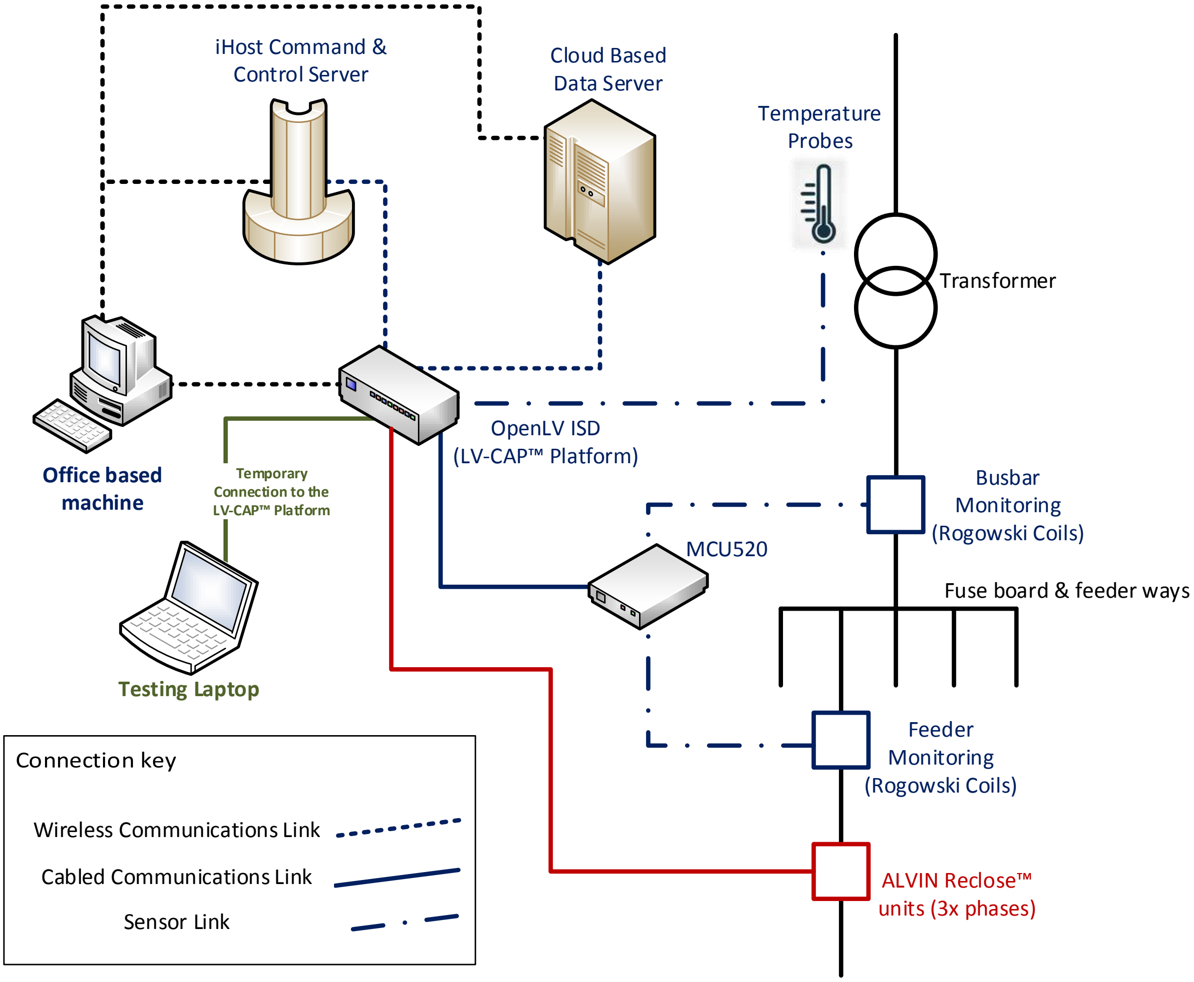


Figure 12: OpenLV Trial System Schematic

The Alvin Reclose™ units and associated communication link, shown in red in the above figure, demonstrate the ability of the system to autonomously affect the network through a controllable circuit breaker enabling automated network meshing within OpenLV.

The LV-CAP™ platform could have been utilised to control any other device capable of affecting the network, such as a battery storage system or management of EV charging; the OpenLV Project is demonstrating the 'proof of concept'.

2.5 Site selection

The process of selecting substations for the trials required a multi-stage process, detailed in **Error! Reference source not found.**.

The first stage consisted of **desktop surveys** utilising LV network data provided by WPD, to narrow down the number of potential sites to a manageable quantity. To do this, the following points were considered, and used together to either disregard a substation from consideration, or 'mark it' for a site survey.

1. Network location: Clusters of potential substations were prioritised over isolated locations in order to minimise installation and maintenance costs.
2. Transformer type: Pole-mounted substations were disregarded due to the added complexities involved with installation and maintenance at height.

3. Transformer rating: Transformers of rating between 200kVA and 500kVA were prioritised over higher ratings, in order to minimise fault levels (for the networks where automated meshing would be trialled),
4. Ratio of Transformer Rating vs Loading: Using WPD provided network data, substations were prioritised where the measured or predicted load meant the transformer was running at 50% or higher of the asset rating.
5. LV Network arrangement: Once a substation was identified as having 'passed through' the above steps, a check was performed on the LV network through WPD's Data Portal to determine if the substation connected to another, adjacent in the LV network, through a normally open point (NOP), enabling the potential for network meshing to be implemented.
6. LV Network Type: It was planned during the bid development process to cover the range of network types identified by WPD's Low Voltage Network Templates (LVNT) Project. The network analysis tool generated as part of the project was utilised to determine the specific network type of each substation.

The desktop surveys identified nearly 500 substations, giving approximately 250 potential substation pairs[3] in need of **site surveys** to select the locations for site trials.

These were predominantly located in the East and West Midlands Licence Areas, in part to simplify ongoing maintenance requirements within the project, although some surveys were also undertaken in the South Wales and South West Licence Areas where specific network types of interest were identified.

The site survey teams were provided with guidance documentation (Appendix 1) and a corresponding checklist (Appendix 3) to be completed for each substation. Photographs of each element to be surveyed were required, as well as undertaking a mobile signal strength check to rule out any substations that didn't have multiple, usable networks[4]. A map detailing all substations surveyed as part of the project is available in Appendix 4.

Whilst most substations identified for use in the project were identified through the above process, to select the 5 pairs for trialling the automated network meshing process required additional checks.

The process of **Detailed Desktop Analysis** utilised data gathered during the site surveys relating to the transformer specification, and LV network data extracted from WPD's Data Portal. A detailed LV Network Study was undertaken on a number of networks until 5 usable pairs were identified and confirmed as suitable for use. This study calculated the fault levels, and network response times in the event of a fault, both when using standard fuses and Alvin Reclose™ units.

[3] A number of substations were potentially suitable for meshing with more than one other substation.

[4] It's noted that in some locations utilized for Method 2, it was necessary to rely on a single mobile network as the community group in question had limited scope for selecting alternative substation locations.

Some networks evaluated were deemed unsuitable for use in the project due to the highest, theoretical fault level exceeding P2/6 requirements, or the response time of a fuse / Alvin Reclose™ in the event of the lowest theoretical fault level exceeding one minute (60 seconds).

The full network evaluation of the five selected network pairs is provided in Appendix 5.

2.6 Learning Points

A number of learning points were identified, or confirmed during the process of specifying, designing and building the initial test systems; these have been detailed below and span three areas.

2.6.1 Technology & Equipment

- Specification: It is preferable to over-specify core components, for example the ruggedised PC, when trialling new systems, to ensure sufficient computational processing power and storage space to support project trials is available, given the uncertainties around computational resource requirements at the start of any trial.
- Specification: It is important to ensure the hardware specified fully supports the software you want to implement. In the case of LV-CAP™ operating system it is possible to run the software utilising an ARM chipset rather than an Intel chipset. However, the LV-CAP™ environment relies upon Docker, which at the time of system specification and design, was not fully supported on the (cheaper) ARM hardware. As a result, an Intel chipset was specified to reduce technical risks for implementation.
- Specification: It is important to utilise known, existing, tried and tested techniques to capture software requirements. For OpenLV we utilised the MSCW[5] approach.
- Specification: The sensors specified and the time intervals at which they are sampled will affect what applications are possible to run on the system. It may be desirable to over-specify sensors to provide for future application requirements, as well as providing additional 'stress-testing' of the trial system.
- Design: To reduce technical risks, 'off-the-shelf' hardware was used where possible. For example, the ruggedised PC and router is available from a number of suppliers. In addition, the LV monitoring hardware has already been deployed by WPD in a Business as Usual (BaU) scenario as have the Alvin Reclose™ devices.

[5] The term MSCW itself is an acronym derived from the first letter of each of four prioritization categories (Must have, Should have, Could have, and Won't have).

2.6.2 IT and Telecommunications

- The decision to utilise a dedicated private APN for the OpenLV Project trials was taken, rather than using a shared private APN. This improves the security of the overall solution.
- Establishing that there is adequate 3G/4G signal strength at a site to ensure reliable communications is essential. If in doubt, then deploy and outdoor antenna to improve signal strength.
- Monitoring of sites to ensure regular communications is occurring, with alarms to flag any issues, is invaluable. Hardware issues, particularly with routers have been detected and rectified.

2.6.3 Processes and Procedures

- Some community groups required more support to understand network configuration and terminology than was expected.
- Network topography meant that some community organisation required monitoring in more than one substation to be able to cover all the properties that they wanted data from (for example it was necessary to monitor four substations to get all the data from Marshfield village).
- Timescales can get pushed when dealing with community organisation. They generally are relying on volunteers so other priorities can take precedence.
- Extensive site surveys prior to site selection for use in the trials has greatly benefitted the installation process, with minimal problems encountered on-site.

The investment of undertaking these detailed surveys prior to installation resulted in a plug-and-play approach once installation was scheduled.

3. Installation Documentation

3.1 Overview of Project Method Statement

The suite of documentation created for installation of the OpenLV Project Trial hardware comprised method statements for installation of:

7. the LV-CAP™ enclosure;
8. associated thermal sensors;
9. Lucy Electric GridKey LV Monitoring platform;
10. Alvin Reclose™ units; and
11. deeper doors for close-coupled LV enclosures.

These were written such that the core trial hardware was detailed within the primary method statement document, applicable to all installations across Methods 1, 2 and 3, with the ‘optional’ elements, comprising the Alvin Reclose™ units and deeper LV enclosure doors, available in appendices for use when required.

The full suite of documentation is available in Appendix 6 and contains the most up-to-date version at the time of writing this SDRC.

Table 1: LV-CAP™ Method Statement Structure

Method Statement LV-CAP™	Appendix A - GridKey MCU520 Documentation	
	Appendix B - Sensor Installation Schematic	
	Appendix C - Site Acceptance Testing Schedule	Appendix A - Router / Modem Access Routine
	Appendix D - Method Statement - Alvin Reclose™	Blank Commissioning Records
		Alvin Reclose™ Quick Installation Guide
		Alvin Reclose™ Quick Removal Guide
		Fault Restoration Instructions - Stage 1
		Fault Restoration Instructions - Stage 2
		Fault Restoration Instructions - Stage 3
	Appendix E - Method Statement - Direct Coupled Door Replacement	

3.2 Illustrative Installation

The below figures provide an overview of the equipment installed as part of the trials. The images are not taken from a single substation, instead they have been selected from the 75 units installed at the time of writing as being the best suited for showing the equipment utilised.

The LV-CAP™ Enclosure and GridKey MCU520 were mounted using a temporary approach (magnetic or placement on top of the LV Enclosure) wherever possible, but where this proved impractical, direct wall mounting was used.

Figure 13: LV-CAP™ Enclosure wall mounted in Pilgrim Drive Substation

Figure 14: Lucy Electric GridKey MCU520 magnetically mounted in RR Wilmorton Substation

Alvin Reclose™ units used for the project are clearly labelled as such; it was decided that the unit's capability to 'auto-Reclose' would be disabled in substations utilised by the OpenLV Project in order to prevent any potential confusion in unit operation when connected to the LV-CAP™ control system.

Consequently, the Alvin Reclose™ units maintain the ability to detect faults, and operate as a smart fuse if required, but will require manual intervention to close the circuit-breaker following a network fault.

Figure 15: LV cabinet at Cosira Sleaford Substation

Figure 16: Alvin Reclose™ unit labelled for the OpenLV Project

As far as possible, taking into account best cable routes and available space within the enclosure, all cabling related to current sensors, communications and power for the trial equipment was routed such that it would not introduce an obstruction or trip hazard within the substation. Excess cable was coiled within the base of the enclosure.

Figure 17: Cable routing in Chapel Street Substation

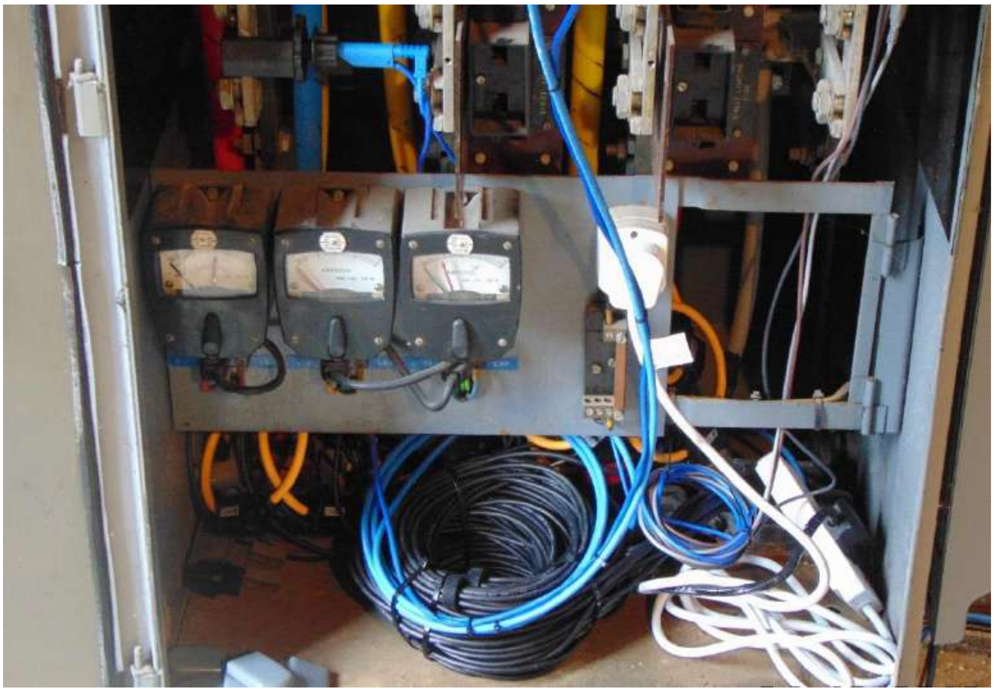


Figure 18: Securing excess cables in the LV cabinet at Pilgrim Drive substation

Temperature monitoring through the use of multiple thermocouples is shown below:

- Transformer top-oil temperature is monitored through inserting a thermocouple into the transformer oil pocket where present.

Figure 19: Thermocouple secured in Transformer Top-Oil pocket

- The external ambient air temperature thermocouple is mounted in a radiation shield, designed to ensure the correct temperature is recorded, without adverse influence of sunlight, wind or humidity.

Figure 20: External Temperature Sensor and Radiation Shield at Pilgrim Drive substation

- Where the LV-CAP™ trial equipment is installed indoors (either a building or GRP substation) the indoor air temperature is also monitored, although a radiation shield is not required in this instance.

Figure 21: Internal ambient Temperature Sensor at Nuns Road Substation

3.3 Learning Points

A number of learning points were identified, or confirmed during the installation of the equipment; these were:

3.3.1 Technology & Equipment

- Design: It is important to ensure that the hardware is designed to enable it to be installed in a number of different ways. The space available for hardware and the mounting requirements for the OpenLV Platform and associated LV monitoring hardware will vary on a site by site basis. As a result, the OpenLV Platform has been designed to be mounted in a number of different ways (magnetic, floor and wall mount).
- Design: Safety of on-site maintenance personnel is key and needs to be taken into account when designing new hardware to trial on innovation projects; with this in mind the OpenLV Platform enclosure has been designed to include an isolation switch for the Alvin Reclose™ devices. This ensures that on site personnel can isolate these devices locally when working on site.

4. Installation and Configuration Confirmation

The process of installing and commissioning the Alvin Reclose™ units comprised three stages:

- Stage 1 – Equipment installation, commissioning and initial data capture with normal network configuration
    - Installation of the Alvin Reclose™ devices.
    - Commissioning and functional testing of LV-CAP™ platform with Alvin devices.
    - Disabling of system control of Alvin devices.
    - Operation of the system in a ‘data capture only’ mode.
- Stage 2 (duration approximately 2 weeks) – Control simulation
    - Closing of the link box links to interconnect two LV feeders.
    - Operation of Alvin devices to supply the interconnect LV feeders from one substation only.
    - Enablement the Loadsense software without Alvin control capability, to simulate trial system operation, without any Alvin switching being undertaken.
- Stage 3 – Control implementation
    - Install links at the link box and enable full trial system functionality.

A blank set of commissioning documentation is provided in Appendix 7; this will be fully completed for each pair of Method 1, Phase 2 substations.

4.1 Fault Restoration Process

Due to the commissioning sequence outlined in section 4, it was possible, although unlikely, that an LV network fault could occur during the transition stages from current business-as-usual (BAU) operation until full trial automation was commissioned, or during the automation trials.

This multi-staged commissioning process required bespoke notices, detailing the process to be followed for post-fault supply restoration, specific to the substation in question and the commissioning stage currently in force.

The three stages are defined as:

- Stage 1: The LV-CAP™ platform and Alvin Reclose™ units are installed.
  The NOP has the links removed.
  The substations are not linked, and any network fault can be resolved through treating the Alvin Reclose™ units as a smart fuse.

- Stage 2: The links in the NOP have been inserted.
  The Alvin Reclose™ units at one end are open, with the other end closed.
  The corresponding LV feeder is now fed from the substation with the 'closed' circuit breaker; this is where any network fault restoration work should commence.

- Stage 3: The links in the NOP remain in place.
  The Alvin Reclose™ unit 'opened' in Stage 2, is placed into a state of automation, under the control of the LV-CAP™ platform.
  Any fault may occur when the feeder is energised from one, or both substations.
  The process of supply restoration must verify the status of both substation systems prior to work commencing.

A 'blank' set of restoration notices are provided in Appendix 8.

4.2 Learning Points

The following learning point was identified, or confirmed during the installation and configuration of the Alvin Reclose™ units; this was

- When installing equipment that can affect the LV network it is necessary to consider all possible situations the system may instigate, and the actions required to manage or mitigate them.

  Where actions may be required outside of normal operating practices, training must be provided to staff who may be affected, and on-site reminders / documentation also provided.

5. Training Overview

The use of Alvin Reclose™ units in multiple WPD depot areas necessitated training of WPD Fitting Teams in their installation and operation.

This was undertaken through a series of four separate training sessions, held in WPD's Grantham Depot on:

- November 19^{th}, 2018;
- November 20^{th}, 2018;
- December 3^{rd}, 2018; and
- December 4^{th}, 2018.

The training provided an overview of the Alvin Reclose™ equipment, and associated product capabilities, before giving practical demonstrations of the installation and commissioning process, prior to the units being installed on-site.

The presentation provided to WPD staff is included in Appendix 9.

6. Acceptance Tests

Early in the project, a detailed Requirements Specification document was created (Appendix 10) and formed the basis for the subsequent Factory Acceptance Tests (FATs) and Site Acceptance Tests (SATs).

Testing of the deployed OpenLV solution, covered three distinct areas:

- FATs to verify the equipment met the requirements detailed in the Requirements Specification;
- SATs to verify the equipment met the requirements detailed in the Requirements Specification in non-laboratory / controlled environment conditions;
- Cyber-security testing to evaluate the cyber-security capabilities[6].

6.1 Summary of Factory Acceptance Test

The FATs were separated into discrete areas, those that tested the OpenLV solution (the LV-CAP™ platform and associated hardware) and those that tested the applications to be deployed for the provision of trial functionality.

The tests were scheduled to minimise repeated tasks and wherever possible, enable a single action, or sequence of actions to demonstrate multiple requirements are met where appropriate to do so.

Each test clearly detailed which requirement(s) is tested, and the relevant system area(s) (defined below).

1. Intelligent Substation Device (ISD)
2. IHost Control Server
3. LV-CAP™ Platform
4. Lucy Data Server
5. Thermal Monitoring
6. LV Meshing
7. Load Profile Predictor
8. CSV Data Recorder
9. Loadsense
10. Dynamic Thermal Rating
11. Management Communications
12. Data Upload Communications
13. Peer-to-peer Communications
14. Cyber-Security
15. Overall System

[6] The Cyber-Security testing is not covered further in this report although verification of security hardware was included in the FATs; further details on the OpenLV Project Cyber-Security details and associated learning are scheduled for publication later in the OpenLV Project.

It was not intended to undertake significant testing relating to the cyber-security requirements at the same time as the hardware and functionality tests. Due to the nature of cyber-security testing, particularly penetration testing, the duration required for effective evaluation, and the potential conflict of simultaneous tests being undertaken, these were appraised separately by NCC Group, the OpenLV Project's cyber-security specialist and will be covered in a later project publication.

Testing was separated into two sessions due to the availability of some testing elements. Not all tests undertaken in Part 1 were repeated in Part 2 as there was no requirement to do so, given that nothing had changed within that part of the solution in the interim period.

Where further work on the solution between Part 1 and Part 2 FATs had the potential to affect the results, individual FATs were repeated for assurance purposes.

The FATs are detailed in Appendix 11.

6.1.1 Factory Acceptance Test – Part 1

The Stage 1 FATs comprised 28 individual tests, demonstrating the overall system meets specific requirements defined in the Requirements Specification Document.

Of these 28 tests:

- 27 passed;
- 1 was unable to be tested due to minor issues experienced with the test rig a few days earlier. This prevented sufficient data being gathered to enable profile forecasting to be demonstrated; the test was subsequently scheduled to be repeated during the Stage 2 FATs.

The FATs were signed off by representatives of all key equipment providers to the OpenLV Project, and by WPD.

6.1.2 Factory Acceptance Test – Part 2

The Stage 2 FATs comprised 7 individual tests, demonstrating the overall system meets specific requirements defined in the Requirements Specification Document.

- 7 passed (including the test deferred from FATs Part 1);
- 1 test, despite passing the criteria assigned, identified unexpected behaviour relating to the loss of power of the router without a similar loss of power to the LV-CAP™ platform.
    - Repeating the test through simply disconnecting the network communications cable enabled the test to pass.
    - The settings responsible for the issue were identified and corrected preventing a reoccurrence.

In support of the Part 2 tests, specifically relating to the interaction between the of the load profile prediction application, the transformer temperature modelling application, and the Loadsense control software, a supporting document was published. 'Post-FAT Stage 2 – Loadsense Analysis', located in Appendix 12, details the operation of the Loadsense software at both substations in the pair, and clarifies how the control decisions are reached.

6.2 Summary of Site Acceptance Test

The SATs comprised 7 tests. designed to demonstrate that the complete system was functioning as it was in the laboratory and all the tests were successful when the firsts systems were deployed.

The SATs are detailed in Appendix 13.

6.3 Learning Points

A number of learning points were identified, or confirmed during the Acceptance Tests; these were:

- Test: Formally defining the requirements for the overall solution is key to ensure that the FAT and SAT documents test each of the individual project requirements. Both the FAT and SAT documents refer back to the specific requirements to ensure relevant tests are completed at each stage.
- Test: A dedicated test rig was built to enable testing of two development OpenLV Platforms. This test rig includes relevant sensors (temperature, voltage and current) to provide data inputs to the test system. This test rig was built as early as possible within the programme to enable components to be soak tested for as long as possible prior to installation.
- Test: Having a controlled test rig in a laboratory environment allows defined inputs (currents, voltages and temperatures in this case) to be applied and the outputs verified. Where necessary scaling and unit issues can be resolved under laboratory conditions. This would be very difficult to achieve in a field situation on a live network.

7. Standard App Development Guidelines

EA Technology has developed a suite of information aimed at helping app developers to design their applications following certain common rules. These rules were set to ensure compliance to allow multiple "Smart" applications to be deployed on a single set of hardware and sensors.

Details of these guidelines are provided in the subsections below.

7.1 Description of the Guidelines provided by EA Technology to 3rd Party Organisations

7.1.1 Support Documentation: OpenLV Business and Academia Trials – Guidance for Applicants

This document provides generic information about the OpenLV project; what the project is looking for, what the project offers to the participants, what support is provided for the development and deployment of applications, project timescales, etc.

In terms of the app development and deployment support, this document specifies the offer provided by the project team as defined below:

- The Application Programming Interface (API) for developers intending to write applications to run on the OpenLV Platform (See Annex 4 of the document);
- A testing environment for third parties that develop apps to enable them to be tested before they are deployed;
- A skeleton app that provides base code for third parties to utilise to speed up app development;
- A description of the available OpenLV measurement points;
- The option to attend workshop(s) to provide further information on the development of apps for the OpenLV Platform;
- Technical support to answer any questions participants may have regarding app development;
- Testing of the app(s) developed by applicants;
- Working with trial participants to select a suitable LV substation to install the OpenLV Platform;
- The installation of the OpenLV Platforms and associated LV monitoring hardware;
- The provision of the communications infrastructure to support the project trials;
- Maintenance of the OpenLV Platforms and associated LV monitoring hardware throughout the project trials;
- Decommissioning of equipment at the end of the trials; and
- Covering the costs of the above including the on-going communication costs for transferring data from the OpenLV Platform(s) for the trial time period.

This document titled "OpenLV Business and Academia Trials – Guidance for Applicants" is available in Appendix 14.

7.1.2 Third-party Application Information Form

This form details all the information EA Technology requires to test each application before deployment at WPD's substation(s). It was created in the form of a test specification / procedure sheet that contains sequential questions participants need to test themselves before submitting. This was done to ensure developers test their apps themselves first to ensure they comply with the set rules. In this way developers can find non-compliant cases before submission and can address them within shorter timescales.

This document titled "OpenLV Third-party Application Information Form" is available in Appendix 15. This template includes all the information a third-party must provide to EA technology so tests can be run to confirm the app is sufficiently robust prior to be deployed (please refer to Appendix 16 and 17 for further information on EA Technology's test procedures).

7.2 Feedback Documentation: Feedback on Standard Guidelines for App Development

Centre for Sustainable Energy (CSE) are the project contractor who have responsibility for recruiting and mentoring the seven community organisations participating in Method 2 of the project. They were the first organisation to use the guidelines developed by EA Technology to develop an app and they produced a document critiquing the app development documentation provided by the project. The following documentation was included on their feedback:

- Developing with the LV-CAP™ Virtual Machine, Version 2622-MANUL-S0001-V02.03.01;
- LV Common Application Platform, Public API;
- OpenLV Measurement Points (pdf) and 2689-PUBLC-S002-V01.01.00 OpenLV Data Point List.xlsx; and
- GridKey OpenLV Data centre System Overview.

The CSE document was reviewed by EA Technology and suggestions were implemented/actions taken where required. The reviewed document titled "Feedback on Standard Guidelines for Application Development" is available in Appendix 18.

7.3 Learning Points

A number of learning points were identified together with third-party organisations during the development of new applications; these were:

- Some organisations outlined that they would like to gather more information before making a commitment to develop an app and commit resources to this purpose. The Guidance for Applicants documentation was therefore created to provide potential participants with further information on the project.
- Asking commercial organisations to develop apps with their own funding for a research and innovation project was challenging as there was no certainty around the commercial viability of LV-CAP™ at the start of the project. Most organisations have a set development programme that is flexible, but companies are resistant to change unless they really justify it with a valid business case. This was challenging

given the research/innovation status of the OpenLV project but direct contact to speak to representatives to sell the concept and gain buy in to the project has proved to be successful.

- A number of organisations expressed concerns about giving up their ideas for potential apps. As a result, a Non-Disclosure Agreement (NDA) has been utilised where applicable.
- Community organisations tend to have less resources available and technically capable of developing software applications for their communities. The OpenLV project realised of this barrier early in the process and appointed the Centre for Sustainable Energy (CSE) to support these projects and the development of the app technology to assist in visualising the OpenLV data through the trial period.
- It is envisaged that Community Groups may require external support for the development of software applications. It is to be noted, however, that the application being developed for the Community Groups in the OpenLV project will be freely available for public use at the end of the trials. This will certainly reduce the complexity of the technical development of apps, since only small configuration changes are expected to be required to fit the needs of future Community Groups.
- Some community organisations have required more support than was expected to configure the web app developed by CSE, and to understand the data that they are receiving via it.
- There are also 3rd parties (although a minority) that would have reduced availability to develop their own apps due to lack of internal skill sets. This can be seen as a business opportunity for other organisations that could assist with the development of applications.
- Clarifications were made regarding EA Technology not requiring the actual app source code to test applications as part of the approval process. EA Technology needs a fully built app and a set of test inputs, and sufficient information about the application's outputs so that correct operation can be confirmed. The purpose of these tests is to confirm that the application integrates into the LV-CAP™ platform correctly. The EA Technology tests are not designed to determine whether the application outputs are correct, or to demonstrate that it meets the customer's requirements. As such EA Technology only checks for the presence of the declared outputs, not whether their values are correct.
- Likewise, this ensures that EA Technology doesn’t have any conflict of interests with potential app development organisations since access to the source code is not required.

8. App Development Kit

Several tools and documents were made available for the Method 2 and 3 participants wanting to develop applications. These included:

- The Node-RED application and application manual;
- The Virtual Machine Developer Guide;
- The C++ Skeleton code and everything required to build it on the development Virtual Machine.

  The Skeleton Application for the Low Voltage Common Application Platform (LV-CAP™) is an algorithm application which provides an environment for the easy integration of new algorithms into LV-CAP™ compatible software containers. It is written in C++ and comes with example configuration files and information on how to run and deploy.

Supporting documents are outlined below.

8.1 Support Document 1: LV-CAP™ Node-RED Application Developer Guide

The LV-CAP™ platform is a hardware agnostic software environment designed to allow multiple “Smart” applications to be deployed on a single set of hardware and sensors, which all share data on an internal Data Marketplace. In order to allow rapid prototyping of algorithms and to encourage partners without software development resource to use the data available on the platform, EA Technology have developed an application which packages Node-RED for deployment to LV-CAP™ compatible platforms.

This document details how to deploy and configure the LV-CAP™ Node-RED application (although it is important to mention that the Node-RED app has already been deployed on the Virtual Machine to assist with its development) and documents an example flow developed allowing email notification when a measurement passes a defined threshold.

This document titled “LV-CAP™ Node-RED Application Developer Guide” is available in Appendix 19.

8.2 Support Document 2: Developing with the LV-CAP™ Virtual Machine

The LV-CAP™ platform was designed to accelerate the deployment of the Smart Grid on electricity networks by:

- Allowing multiple "Smart" applications to be deployed on a single set of hardware and sensors, eliminating costly duplication.
- Decoupling the challenging but agnostic areas of communications and data storage from the development of innovative monitoring and control algorithms.
- Making it easy to deploy new and updated algorithms to existing equipment without expensive field visits.
- Providing a common software abstraction for a range of hardware implementations, so that the optimum hardware and software can be procured separately, rather than as a compromise bundle.
- Allowing a wide range of parties to compete to supply applications to run on a single set of hardware owned by the system operator.

The interface to LV-CAP™ and the standards required are set out in the LV Common Application Platform Public API document referred on section 8.3.

This document (Developing with the LV-CAP™ Virtual Machine) details how to start developing for the LV-CAP™ platform using a Virtual Machine image supplied by EA Technology. This Virtual Machine image gives developers a representative environment on which to test and debug their applications on and ensure their application integrates with the rest of the system.

This document titled "Developing with the LV-CAP™ Virtual Machine" is available in Appendix 20.

8.3 Support Document 3: LV Common Application Platform: Public API

The Common Application Platform for LV Networks (LV-CAP™) is a software environment which facilitates the implementation of the Smart Grid at the lower distribution voltages. To drive down the cost of deploying Smart Interventions, the platform allows multiple algorithms to be deployed to one set of measurement and data processing hardware. The platform allows these algorithms to be designed and produced by independent third-party developers and packaged as stand-alone applications which can be easily deployed by the distribution network operator without requiring bespoke software development.

This document details the Application Programming Interface (API) for developers intending to write applications to run on LV-CAP™. LV-CAP™ uses Docker to overcome dependency problems for third-party developers and helps to maintain and manage containers. It uses a MQTT messaging system for the communication of running containers and has a data storage functionality to persist data. This document has details on how a third-party application can be set-up, run and interact with the core services on the platform.

This document titled "LV Common Application Platform Public API" is available in Appendix 21.

8.4 Support Document 4: OpenLV Measurement Points

This document lists the measurements which are made by the OpenLV hardware and published on the LV-CAP™ Data Marketplace so that applications running in the substation can make use of them. This data can also be used by those organisations intending to access historic data on a monthly basis.

This document titled "OpenLV Measurement points" is available in Appendix 22.

8.5 Support Document 5: GridKey OpenLV Data Centre System Overview

This document was created by Lucy Electric with the purpose to provide a description of the various components that make up the OpenLV Data Centre used by third parties in support of project Methods 2 and 3. Each part of the Data Centre solution is presented in separate sections covering, amongst others:

- Data processing/storage;
  - Directory Scanning - to allow for validation of the uploaded data as part of FAT activities, or for debug purposes should the transfer of data or its contents need to be verified;
  - Backlog Processing – to avoid problems uploading data when a communications outage occurs;
  - Database Schema - designed so that there is a logical breakdown of data, to ensure colocation and ensure that queries execute in a timely manner;
  - Data Storage;
- API - as part of Methods 2 and 3 there is a requirement to be able to extract data in a usable format. Therefore, an API has been provided to meet this need; and
- A demonstration web server to show how to visualise data stored in the database.

This document titled "GridKey OpenLV Data Centre System Overview" is available in Appendix 23.

8.6 Learning Points

A number of learning points were identified together with third-party organisations from the use of the app development kit; these were:

- The OpenLV project facilitated the development of new applications providing third parties with:
  - A development tool to allow easy connection of data, web services and hardware in a visual format using pre-defined blocks of functionality called nodes. This tool is called Node-RED. It allows simple drag and drop elements allowing data from one source to be passed onto another, with the ability to write complex functionality using the JavaScript programming language. Having Node-RED on the LV-CAP™ platform allows the rich data sets available from the Data Marketplace to be made available to users and third parties who may now have the resource to develop a packaged application or instead might want to quickly prototype a concept.
  - The 'development skeleton App' - this was designed and created to help speed up development.

    The API document shows all the interactions an app needs to just run on the system. The Skeleton app already achieves all of this. For example:
    - Responds to status requests;
    - Responds to commands sent from the Container Manager;
    - Deals with requesting and processing the response of a Configuration;
    - Provides a way for the app to subscribe to known data points (provided within the Data Points Document)

- Offers a way to collect these data points, add algorithms to calculate set outputs and publish these to the Marketplace;
- Provides a way to compile, build and export their app ready for deployment on the system.

This is a quick overview of what the Skeleton provides. Much the same as the Node-RED app but with more control and freedom.

- These development tools are being used by a big proportion of the participants on the trials suggesting they have been useful to organisations.
- The LV-CAP™ environment enables developers to write apps in any programming language. This has enabled the overall platform to be built up quickly and easily utilising apps developed by multiple vendors using various programming languages (C++, Java and Go).
- Although LV-CAP™ allows the use of a wide range of programming languages, it still imposes restrictions on the memory usage, processor usage and storage space available to applications. These restrictions must be clearly communicated to developers at an early stage.
- The main limit on the storage size of applications is the reliability and cost of deploying them to all required sites over mobile data networks.
- A Measurement Points spreadsheet including the full list topic names and units was separately provided to app developers. This was well received, and suggestions were made to include this spreadsheet as part of the main OpenLV Measurement Points document.
- There was confusion over the name to be used for applications (Docker Image and Running Container). In some cases, the version number does need to be added to the end of the string and in other cases it is not needed, leading to confusion.
- This was addressed setting a conference call with the relevant parties to clarify the naming structure. For the future, ensuring consistency and clarity, especially around 'Application version' and 'Instance number' within the documentation and providing examples, where possible, will also benefit app developers.
- Questions were raised regarding the extraction of data via the API call to Lucy Electric Cloud server (e.g. it's not explained how to convert a username and password into the string). A separate email is now sent to app developers with clarifications and command examples that help with the interpretation of the instructions. It is recommended that Lucy Electric update the GridKey OpenLV Data Centre System Overview document to include examples and ensure all the strings, filepaths and instructions are consistent.
- An issue was found when connecting the Virtual Machine to a third-party hardware via the network. It was found that an anti-virus on the computer running the Virtual Machine set the firewall to block this connection.
- A third-party highlighted that Node-RED wasn't working on the Virtual Machine. This was due to app permissions that had run out. Certificates were remade and distributed.
- What is seen as a single, simple, requirement from an end user perspective may require more than one software application to deliver it, and so trigger numerous technical requirements which must be cross-referenced.

The learning points detailed in the previous sections are collated here.

- Specifying the Overall OpenLV Solution Specification: It is better to over specify core components, for example the ruggedised PC, when trialling new systems to ensure you have sufficient computational processing power and storage space to support project trials.
- Specification: It is important to ensure the hardware specified fully supports the software you want to implement. In the case of LV-CAP™ operating system it is possible to run the software utilising an ARM chipset rather than an Intel chipset. However, the LV-CAP™ environment relies upon Docker, which is not yet fully supported on the (cheaper) ARM hardware. As a result, an Intel chipset was specified to reduce technical risks for implementation.
- Specification: It is important to utilise known, existing, tried and tested techniques to capture software requirements. For OpenLV we utilised the MoSCoW approach.
- Specification: The sensors specified and the time intervals at which they are sampled will affect what applications are possible to run on the system. It may be desirable to over-specify sensors to provide for future application requirements.
- Design: To reduce technical risks, off the shelf hardware has been used where possible. For example, the ruggedised PC is an off the shelf piece of hardware that is available from a number of suppliers. In addition, the LV monitoring hardware has already been deployed by WPD in a Business as Usual (BaU) scenario as have the Alvin Reclose™ devices.
- The decision to utilise a dedicated private APN for the OpenLV Project trials was taken, rather than using a shared private APN. This improves the security of the overall solution.
- Establishing that there is adequate 3G/4G signal strength at a site to ensure reliable communications is essential. If in doubt, then deploy and outdoor antenna to improve signal strength.
- Monitoring of sites to ensure regular communications is occurring, with alarms to flag any issues, is invaluable. Hardware issues, particularly with routers have been detected and rectified.
- Some community groups required more support to understand network configuration and terminology than was expected.
- Network topography meant that some community organisation required monitoring in more than one substation to be able to cover all the properties that they wanted data from (for example it was necessary to monitor four substations to get all the data from Marshfield village).
- Timescales can get pushed when dealing with community organisation. They generally are relying on volunteers so other priorities can take precedence.
- Extensive site surveys prior to site selection for use in the trials has greatly benefitted the installation process, with minimal problems encountered on-site.
- The investment of undertaking these detailed surveys prior to installation resulted in a plug-and-play approach once installation was scheduled.
- Installation Documentation Design: It is important to ensure that the hardware is designed to enable it to be installed in a number of different ways. The space available for hardware and the mounting requirements for the OpenLV Platform

and associated LV monitoring hardware will vary on a site by site basis. As a result, the OpenLV Platform has been designed to be mounted in a number of different ways (magnetic, floor and wall mount).

- Design: Safety of on-site maintenance personnel is key and needs to be taken into account when designing new hardware to trial on innovation projects; with this in mind the OpenLV Platform enclosure has been designed to include an isolation switch for the Alvin Reclose™ devices. This ensures that on site personnel can isolate these devices locally when working on site.

8.7 Configuration

- When installing equipment that can affect the LV network it is necessary to consider all possible situations the system may instigate, and the actions required to manage or mitigate them.
- Where actions may be required outside of normal operating practices, training must be provided to staff who may be affected, and on-site reminders / documentation also provided.

8.8 Acceptance Testing

- Test: Formally defining the requirements for the overall solution is key to ensure that the FAT and SAT documents test each of the individual project requirements. Both the FAT and SAT documents refer back to the specific requirements to ensure relevant tests are completed at each stage.
- Test: A dedicated test rig was built to enable testing of two development OpenLV Platforms. This test rig includes relevant sensors (temperature, voltage and current) to provide data inputs to the test system. This test rig was built as early as possible within the programme to enable components to be soak tested for as long as possible prior to installation.
- Test: Having a controlled test rig in a laboratory environment allows defined inputs (currents, voltages and temperatures in this case) to be applied and the outputs verified. Where necessary scaling and unit issues can be resolved under laboratory conditions. This would be very difficult to achieve in a field situation on a live network.

8.9 Standard Application Development Guidelines

- Some organisations outlined that they would like to gather more information before making a commitment to develop an app and commit resources to this purpose. The Guidance for Applicants documentation was therefore created to provide potential participants with further information on the project.
- Asking commercial organisations to develop apps with their own funding for a research and innovation project was challenging as there was no certainty around the commercial viability of LV-CAP™ at the start of the project. Most organisations have a set development programme that is flexible, but companies are resistant to change unless they really justify it with a valid business case. This was challenging

given the research/innovation status of the OpenLV project but direct contact to speak to representatives to sell the concept and gain buy in to the project has proved to be successful.

- A number of organisations expressed concerns about giving up their ideas for potential apps. As a result, a Non-Disclosure Agreement (NDA) has been utilised where applicable.
- Community organisations tend to have less resources available and technically capable of developing software applications for their communities. The OpenLV project realised of this barrier early in the process and appointed the Centre for Sustainable Energy (CSE) to support these projects and the development of the app technology to assist in visualising the OpenLV data through the trial period.
- It is envisaged that Community Groups may require external support for the development of software applications. It is to be noted, however, that the application being developed for the Community Groups in the OpenLV project will be freely available for public use at the end of the trials. This will certainly reduce the complexity of the technical development of apps, since only small configuration changes are expected to be required to fit the needs of future Community Groups.
- Some community organisations have required more support than was expected to configure the web app developed by CSE, and to understand the data that they are receiving via it.
- There are also 3rd parties (although a minority) that would have reduced availability to develop their own apps due to lack of internal skill sets. This can be seen as a business opportunity for other organisations that could assist with the development of applications.
- Clarifications were made regarding EA Technology not requiring the actual app source code to test applications as part of the approval process. EA Technology needs a fully built app and a set of test inputs, and sufficient information about the application's outputs so that correct operation can be confirmed. The purpose of these tests is to confirm that the application integrates into the LV-CAP™ platform correctly. The EA Technology tests are not designed to determine whether the application outputs are correct, or to demonstrate that it meets the customer's requirements. As such EA Technology only checks for the presence of the declared outputs, not whether their values are correct.
- Likewise, this ensures that EA Technology doesn’t have any conflict of interests with potential app development organisations since access to the source code is not required.

8.10 Application Development Kit

- The OpenLV project facilitated the development of new applications providing third parties with:
  - A development tool to allow easy connection of data, web services and hardware in a visual format using pre-defined blocks of functionality called nodes. This tool is called Node-RED. It allows simple drag and drop elements allowing data from one source to be passed onto another, with the ability to

write complex functionality using the JavaScript programming language. Having Node-RED on the LV-CAP™ platform allows the rich data sets available from the Data Marketplace to be made available to users and third parties who may now have the resource to develop a packaged application or instead might want to quickly prototype a concept.

- The 'development skeleton App' - this was designed and created to help speed up development.
  The API document shows all the interactions an app needs to just run on the system. The Skeleton app already achieves all of this. For example:
  - Responds to status requests;
  - Responds to commands sent from the Container Manager;
  - Deals with requesting and processing the response of a Configuration;
  - Provides a way for the app to subscribe to known data points (provided within the Data Points Document)
  - Offers a way to collect these data points, add algorithms to calculate set outputs and publish these to the Marketplace;
  - Provides a way to compile, build and export their app ready for deployment on the system.

  This is a quick overview of what the Skeleton provides. Much the same as the Node-RED app but with more control and freedom.

- These development tools are being used by a big proportion of the participants on the trials suggesting they have been useful to organisations.
- The LV-CAP™ environment enables developers to write apps in any programming language. This has enabled the overall platform to be built up quickly and easily utilising apps developed by multiple vendors using various programming languages (C++, Java and Go).
- Although LV-CAP™ allows the use of a wide range of programming languages, it still imposes restrictions on the memory usage, processor usage and storage space available to applications. These restrictions must be clearly communicated to developers at an early stage.
- The main limit on the storage size of applications is the reliability and cost of deploying them to all required sites over mobile data networks.
- A Measurement Points spreadsheet including the full list topic names and units was separately provided to app developers. This was well received, and suggestions were made to include this spreadsheet as part of the main OpenLV Measurement Points document.
- There was confusion over the name to be used for applications (Docker Image and Running Container). In some cases, the version number does need to be added to the end of the string and in other cases it is not needed, leading to confusion.
- This was addressed setting a conference call with the relevant parties to clarify the naming structure. For the future, ensuring consistency and clarity, especially around 'Application version' and 'Instance number' within the documentation and providing examples, where possible, will also benefit app developers.
- Questions were raised regarding the extraction of data via the API call to Lucy Electric Cloud server (e.g. it's not explained how to convert a username and

password into the string). A separate email is now sent to app developers with clarifications and command examples that help with the interpretation of the instructions. It is recommended that Lucy Electric update the GridKey OpenLV Data Centre System Overview document to include examples and ensure all the strings, filepaths and instructions are consistent.

- An issue was found when connecting the Virtual Machine to a third-party hardware via the network. It was found that an anti-virus on the computer running the Virtual Machine set the firewall to block this connection.
- A third-party highlighted that Node-RED wasn't working on the Virtual Machine. This was due to app permissions that had run out. Certificates were remade and distributed.
- What is seen as a single, simple, requirement from an end user perspective may require more than one software application to deliver it, and so trigger numerous technical requirements which must be cross-referenced.

Appendix 1. Site Selection

Appendix 2. Site Survey Guidance

Appendix 3. Site Survey Checklist

Appendix 4. Locations of Site Surveys

Appendix 5. Fault Protection Studies (Method 1 – Phase 2 locations)

Appendix 6. Method Statement

Appendix 7. Alvin Reclose™ Commissioning Documentation

Appendix 8. Fault Restoration Process

Appendix 9. Alvin Installation Training Presentation

Appendix 10. Requirements Specification

Appendix 11. Factory Acceptance Tests (FATs)

Appendix 12. Post-FAT Stage 2 Loadsense Analysis

Appendix 13. Site Acceptance Tests (SATs)

Appendix 14. OpenLV Business and Academia Trials – Guidance for Applicants

Appendix 15. OpenLV Third-party Application Information Form

Appendix 16. OpenLV Third-party Supporting Test Document

Appendix 17. OpenLV Third-party Test Results Document

Appendix 18. Feedback on Standard Guidelines for Application Development

Appendix 19. LV-CAP™ Node-RED Application Developer Guide

Appendix 20. Developing with the LV-CAP™ Virtual Machine

Appendix 21. LV Common Application Platform – Public API

Appendix 22. OpenLV Measurement Points

Appendix 23. GridKey OpenLV Data Centre System Overview