WESTERN POWER DISTRIBUTION

OPEN LV

OPENING UP
THE SMART GRID

OPENLV SDRC 1

DETAILED DESIGN OF THE OVERALL OPENLV SOLUTION

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Contents

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Glossary

Term	Definition
ACL	Access Control List
API	Application Programming Interface
APN	Access Point Name
App	Software designed to run on smartphones and other mobile device
DSO	Distribution System Operator
DTR	Dynamic Thermal Rating
LV	Low Voltage
LV-CAP™	LV-CAP™ (Low Voltage Common Application Platform) is a hardware agnostic environment that in and of itself does not provide any direct functionality but instead makes available the environment in which various 'Apps', each designed to provide specific a network benefits (or benefits) can be deployed.
LV Feeder	The outgoing supply from the distribution substation.
LV Substation	LV substations step the electricity supply down from 11kV to 230 / 400V and distribute it along connected feeders.
Network Meshing	Joining adjacent normally separated networks by closing a Normally Open Point.
Normally Open Point	A Normally Open Point is generally located between two feeders, connected to different distribution substations. It allows the Distribution Network Operator (DNO) to reconfigure the network through closing the point to join the two networks together.
NIC	Network Innovation Competition
MQTT	MQ Telemetry Transport
Substation	A point on the network where voltage transformation occurs.
Successful Delivery Reward Criteria	The Project specific criteria set out in the Project Direction against which the Project will be judged for the Successful Delivery Reward.
Transformer	Device that changes the voltage of an a.c. current, without changing the frequency.
WPD	Western Power Distribution

1 Document Purpose

The OpenLV Project is funded by the Network Innovation Competition (NIC). The requirements for key project deliverables, as part of NIC Governance, are defined as Successful Delivery Reward Criteria (SDRC) and each SDRC has associated evidence criteria as defined in the Project Direction [Ref. 1].

It is confirmed that the SDRC and associated evidence requirements have been met and this is supported by the compliance matrix provided below:

Category	Detail	Criterion Met	Section(s)
Successful Delivery Reward Criterion	Detailed systems architecture	✓	Section 2
Successful Delivery Reward Criterion	Requirements specification for the OpenLV intelligent substation hardware	✓	Section 3.4 & Annex 2
Successful Delivery Reward Criterion	An assessment of the development of the intelligent substation control software to identify whether any changes are required to the planned deployment for the OpenLV project	✓	Annex 1
Successful Delivery Reward Criterion	Detail the approach for testing the overall solution ahead of wide scale deployment	✓	Section 3.3
Successful Delivery Reward Criterion	Factory and site acceptance test documentation	✓	Section 3.5 & Annex 3
Successful Delivery Reward Criterion	Factory testing results	✓	Section 3.5 & Annex 3
Evidence	the specification for the OpenLV solution	✓	Section 2 & Annex 2
Evidence	FAT and SAT documentation	✓	Annex 3 & Annex 4
Evidence	FAT test results	✓	Section 3.5 & Annex 3

2 Executive Summary

In this SDRC report we present the Specification, Design and Factory Testing results of the overall OpenLV solution.

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. The LV networks are expected to see radical change as we, as 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 Distribution Network Operator (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 ability to develop and deploy apps can provide benefits to the DNO, Community Groups and the Wider Industry (See Figure 1).

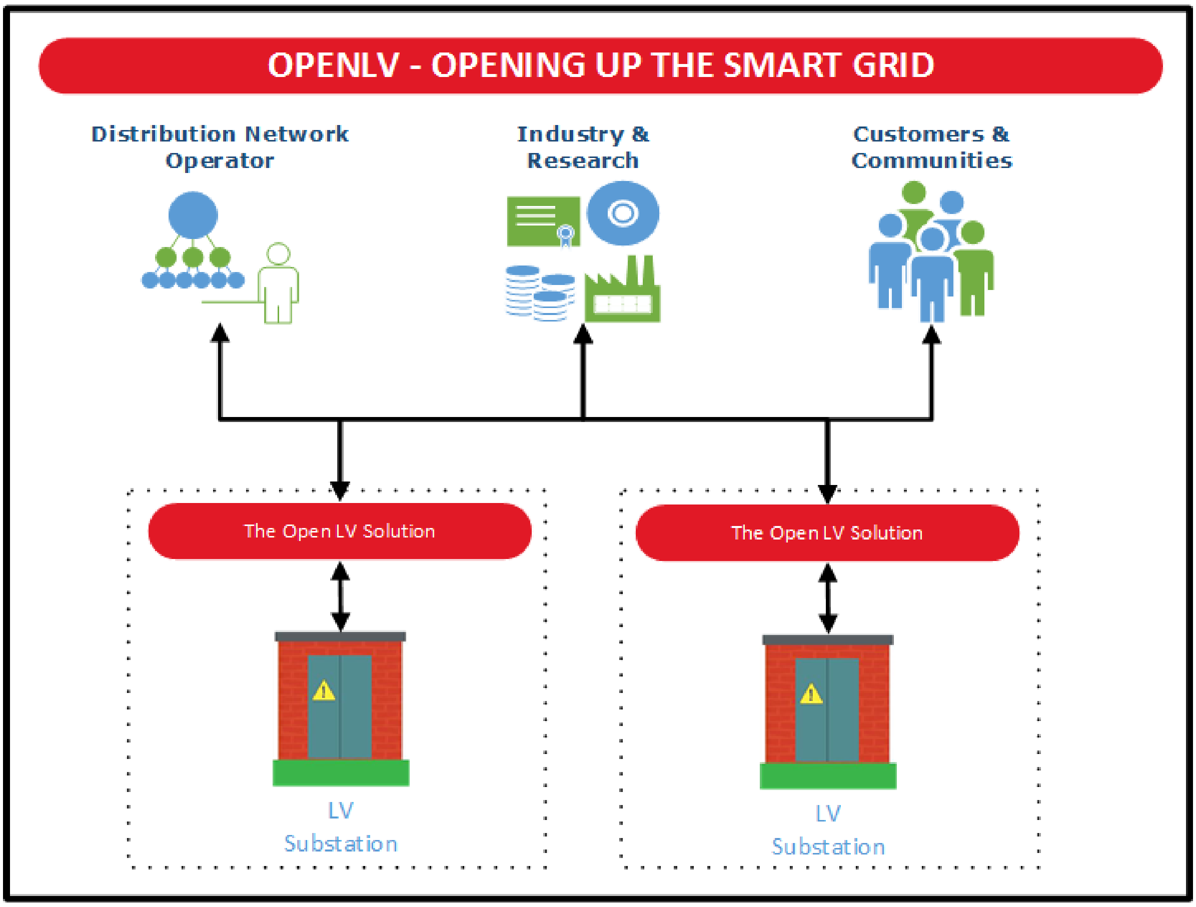


Figure 1: Overall OpenLV Solution

This report has been structured to meet the SDRC evidence criterion outlined in the OpenLV Project Direction [Ref. 1]. Chapter Two, Systems Architecture, outlines the design concepts for the overall OpenLV solution, the software components, the hardware components and associated central infrastructure and communications components.

Chapter Three, Building & Testing the OpenLV Solution, outlines the approach taken to build and test the OpenLV solution, outlines how the key requirements were captured and the results of the Factory Acceptance Tests (FAT) completed to date. It is confirmed that the OpenLV solution has passed the first two stages of FAT and that preparations are now being made to install the first 4 test units on WPD's LV network.

Chapter Four, Key Learning Points, outlines the key learning points recorded at this stage of the Project in relation to the specification, design, build and testing of the overall OpenLV solution.

Chapters Two and Three are supported by document annexes including: A1, the OpenLV Solution Requirements Specification, A2, the Factory Acceptance Test documentation along with the results of the tests completed at FAT and A3, the proposed Site Acceptance Tests (SAT) documentation.

The approach taken to building and testing the OpenLV solution is robust and is on track to enable initial installation of the first 4 devices in LV substations in 2017 with full roll out of 76 further devices in 2018 to support the trials for all 3 methods:

1. The network capacity uplift trials;
2. The community engagement trials; and
3. The OpenLV extensibility trials.

3 Systems Architecture

3.1 High Level Overview

The high-level architecture of the OpenLV solution is shown in Figure 2.

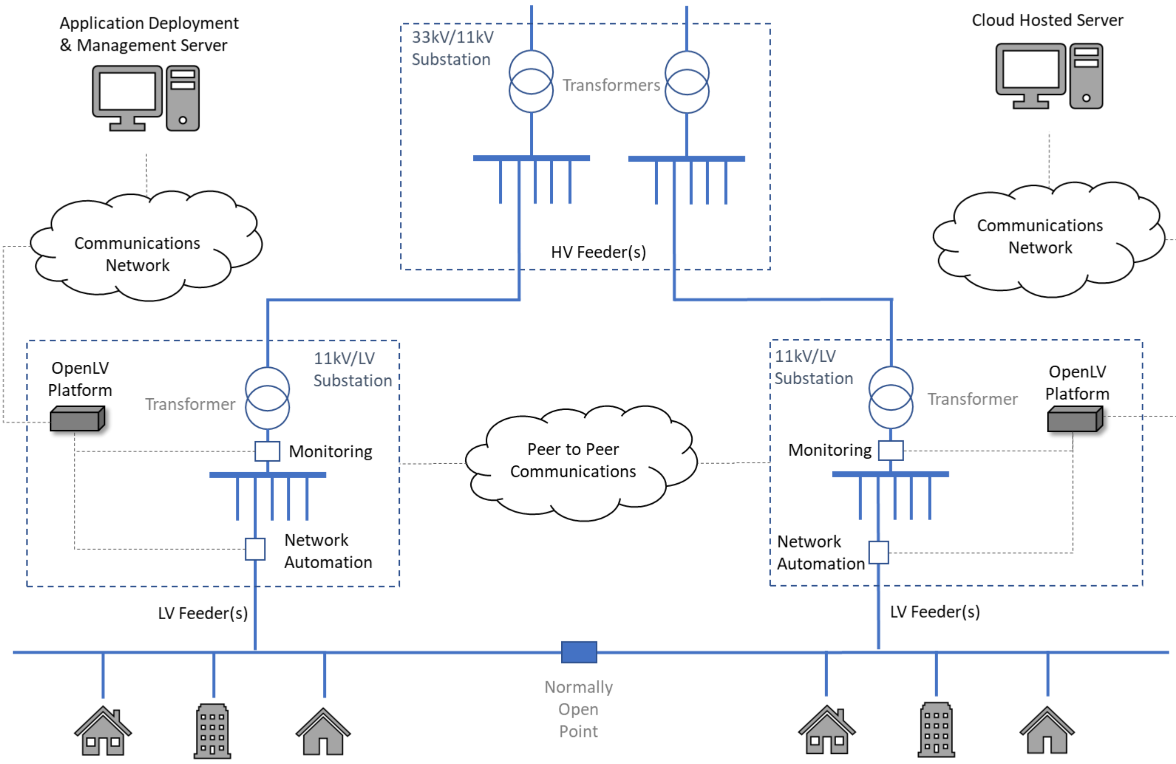


Figure 2: High Level Architecture

The key components of the solution are as follows:

- **LV Network Automation:** These devices enable automated meshing of the LV network via an app or app(s) installed on the platform.
- **LV Monitoring Equipment:** This monitoring equipment utilises sensors to take electrical measurements from the LV busbar, the transformer and the outgoing feeder(s). In addition, temperature measurements are also taken from the transformer, and inside and outside substation(s). The monitoring equipment provides this LV monitoring data to the OpenLV Platform.
- **OpenLV Platform:** Consists of a ruggedised PC with a Linux based operating system running the Low Voltage-Common Application Platform (LV-CAP™). This platform receives, stores and processes data from external LV monitoring equipment. These devices have sufficient computational power to store and run multiple apps and can provide relevant information out via a communications link to centralised server(s).

- **Application Deployment & Management Server:** Enables management of the OpenLV Platform(s) that will be installed as part of the project. This includes the deployment of app(s) to devices in the field. It will also be utilised to store relevant data to enable the OpenLV trials to be assessed.
- **Cloud Hosted Server:** Enables LV monitoring data to be collected, stored, shared and visualised to provide benefits to communities and the wider industry.

3.2 Design Concepts

The solution has been designed to be "open" in that it enables any individual or company to develop apps to be deployed on the platform. The OpenLV Platform is analogous to a smartphone. The LV-CAP™ software is analogous to an open operating system, for example Android, running on a smartphone.

The following key points should be noted regarding the systems architecture of the overall OpenLV solution. The solution, for the Project, has been designed to:

- Incorporate the LV-CAP™ platform;
- Interface to LV monitoring equipment to collect and share LV network data;
- Conform to a de-centralised systems architecture. This means that intelligence is built into the hardware that is installed in LV substations;
- Not to integrate with the Distribution Network Operator (DNO) Distribution Management System (DMS). This limits complexity of the Project trials;
- Provide data back to multiple vendor(s) back office systems; and
- Enable anyone to develop an app to run on the hardware installed in LV substations. Therefore, providing benefits to DNOs, community groups and the wider industry.

The core aim of the project is to prove the open nature of the platform through three core Methods:

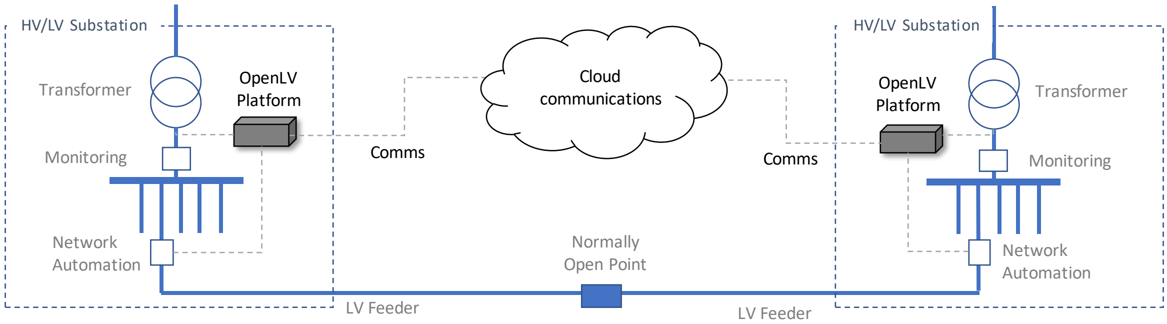
1. Network Capacity Uplift;
2. Community Engagement; and
3. OpenLV Extensibility.

These Methods are outlined in the following sub-sections of this report.

3.2.1 Method 1: Network Capacity Uplift

Figure 3 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.



<u>What</u>

- 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

<u>How</u>

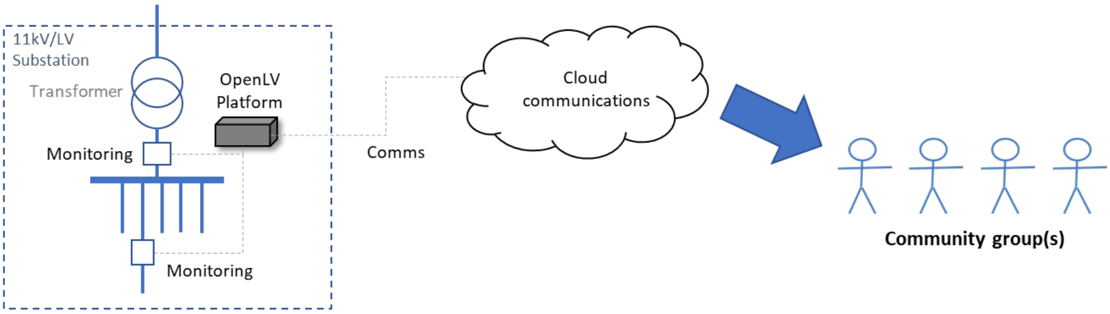
- Assess WPD’s network to identify candidate circuits
- Deploy LV-CAP™ to 60 substations
- Monitor how the solution would operate over several months
- Install actuators on 5 circuits (2 ends each) to prove end-to-end control
- Assess and report on performance

Figure 3: Method 1 – Network Capacity Uplift

3.2.2 Method 2: Community Engagement

Figure 4 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.



<u>What</u>

- 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

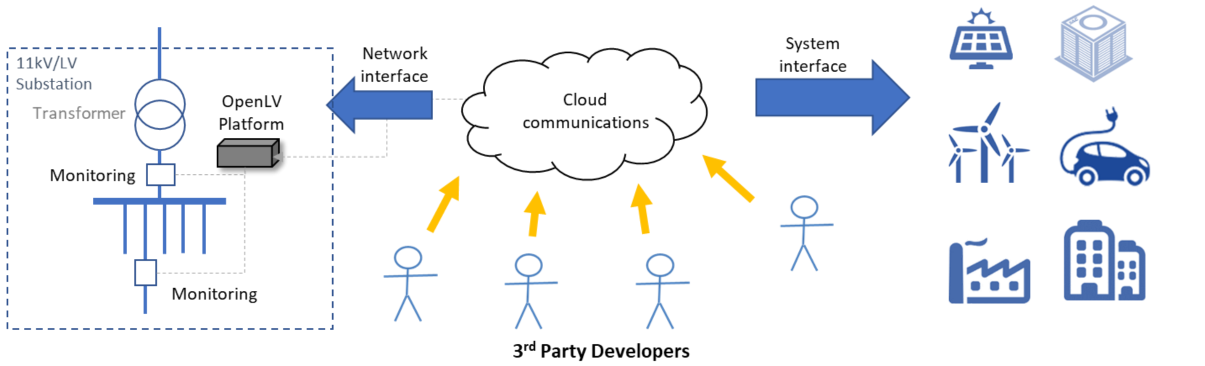
<u>How</u>

- 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 4: Method 2 – Community Engagement

3.2.3 Method 3: OpenLV Extensibility

Figure 5 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 5: Method 3 – OpenLV Extensibility

3.3 Software Components

3.3.1 High Level Software Flow

The LV-CAP™ is a hardware agnostic operating system that enables cost effective deployment of smart grid products from multiple suppliers on a single set of hardware, the OpenLV Platform, as shown in Figure 6.

Apps can be developed by multiple manufacturers and generate bespoke datasets and/or control various unrelated network assets without any application being influenced or affected by another, although outputs can be shared. For example, data can be transmitted back to multiple vendor back office systems.

The apps that are being deployed have been coded in C++, Go and Java. It is also expected that Python will also be utilised for further apps.

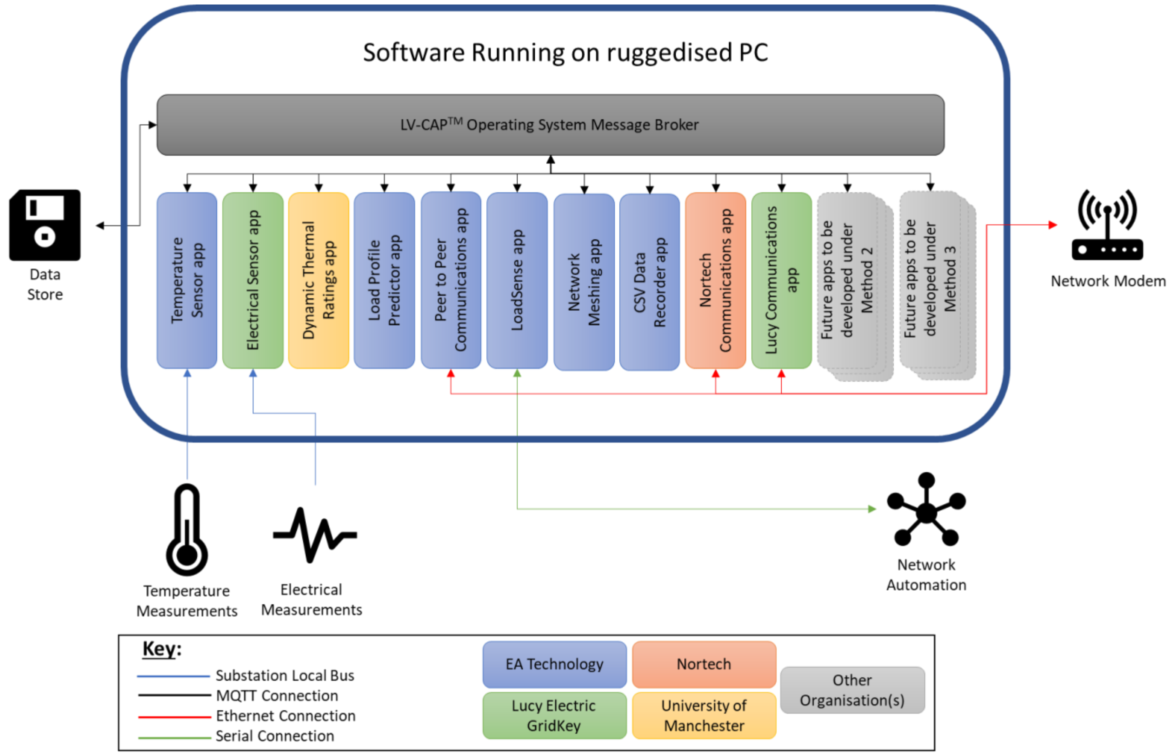


Figure 6: OpenLV Software Stack

3.3.2 Apps to be deployed

The solution has been designed to enable the deployment of apps developed by multiple companies. The apps to be deployed are as follows:

- **EA Technology:** The following apps developed by EA Technology will be deployed:
    - A 'Temperature Sensor' app to receive and process temperature measurement points from the transformer and within and outside the substation.
    - A 'Load Profile Predictor' app to assess historic load and predict the load profile of the LV transformer in the future.
    - A 'Peer to Peer Communications' app to enable load and capacity forecasts to be shared between 'adjacent' LV substations.
    - A 'LoadSense' app that, directly or indirectly, utilises the end outputs of the above elements to inform the decision of whether to mesh or de-mesh the network, or to leave it in the current state.
    - A 'Network Meshing' app to respond to the commands from the LoadSense app and sends commands to the automated network circuit breakers.
    - A 'CSV Data Recorder' app to enable storage of all data captured by the system, information generated by any applications and a record of any actions implemented.
- **University of Manchester:** A 'Dynamic Thermal Ratings' app utilising underlying IP owned by the University of Manchester will be deployed. This app enables dynamic rating rather than static rating of the LV transformer enabling additional capacity to be made available on the LV network.
- **Nortech:** A 'Nortech Communications' app that enables communications to the application deployment & management server will be deployed.
- **Lucy Electric GridKey:** The following apps developed by Lucy Electric GridKey will be deployed:
    - An 'Electrical Sensor' app that enables LV monitoring data to be transmitted from the LV monitoring hardware to the OpenLV Platform.
    - A 'Lucy Electric Gridkey Communications' app that enables communications to a server hosted in the cloud.

In addition to the apps listed above the Project will seek 3rd parties to develop new apps to be deployed as part of the trials to support community energy schemes and the wider industry (Methods 2 and 3).

3.4 Hardware Components

The following sub-sections provide technical information regarding the core hardware components.

3.4.1 LV Network Automation

EA Technology's ALVIN Reclose™ devices (see Figure 7) will be utilised to provide the 'network meshing' functionality. The Network Meshing app will be deployed on the LV-CAP™ platform allowing control of individual connected ALVIN Reclose™ devices. ALVIN Reclose™ devices can be deployed in place of 315A and 400A fuses on the LV network and operate automatically to protect the network in the event of a fault.

The devices monitor the voltage on either side of the LV fuse board and current passing through them, and can relay this information back to the LV-CAP™ platform. The LV-CAP™ platform is also able to control the relay within the ALVIN Reclose™ devices, enabling autonomous reconfiguration of the network.

Figure 7: ALVIN Reclose™ devices

3.4.2 LV Monitoring Hardware

The LV monitoring equipment, installed in each LV substation, consists of a Lucy GridKey MCU520 LV monitoring system (see Figure 8). This device utilises sensors to measure the Voltage and Current and pass this data on to the OpenLV Platform through an Ethernet connection.

Figure 8: GridKey MCU520

3.4.3 OpenLV Platform

The OpenLV Platform consists of the Following:

- **Temperature Sensors:** Temperature measurements of the connected transformer is achieved through the use of an Ethernet to 8 Channel Isolated Thermocouple Input / 8 Channel Digital Output Module with Modbus TCP. In addition, temperature sensors will be deployed to provide temperature both inside and outside the substation (see Figure 9). The temperature data will be utilised by the DTR app and will also be made available to potential apps to be developed as part of Methods 2 and 3.
- **Intelligent Substation Devices:** The Intelligent Substation Devices consist of a ruggedised PC with a Linux based operating system running the LV-CAP™ software platform. These devices have sufficient computational power to run the LV-CAP™ operating system and multiple apps. These devices provide the capability to receive, store and process data being gathered by the monitoring sensors, and relay all, or part of the information back to a centralised location if required (see Figure 10 and Figure 11).
- **GSM Modem:** The GSM modem provides the LV-CAP™ platform access to the management and data servers via a dedicated private mobile network. Through this, the platform is able to receive over-the-air updates, signal alerts and transmit data and processed application outputs to designated storage servers (see Figure 10).

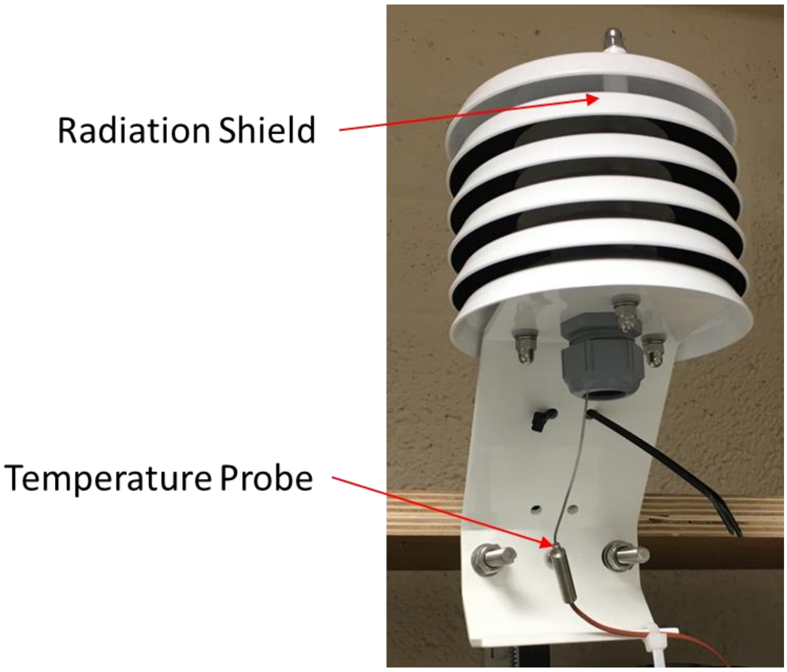


Figure 9: Temperature Sensor

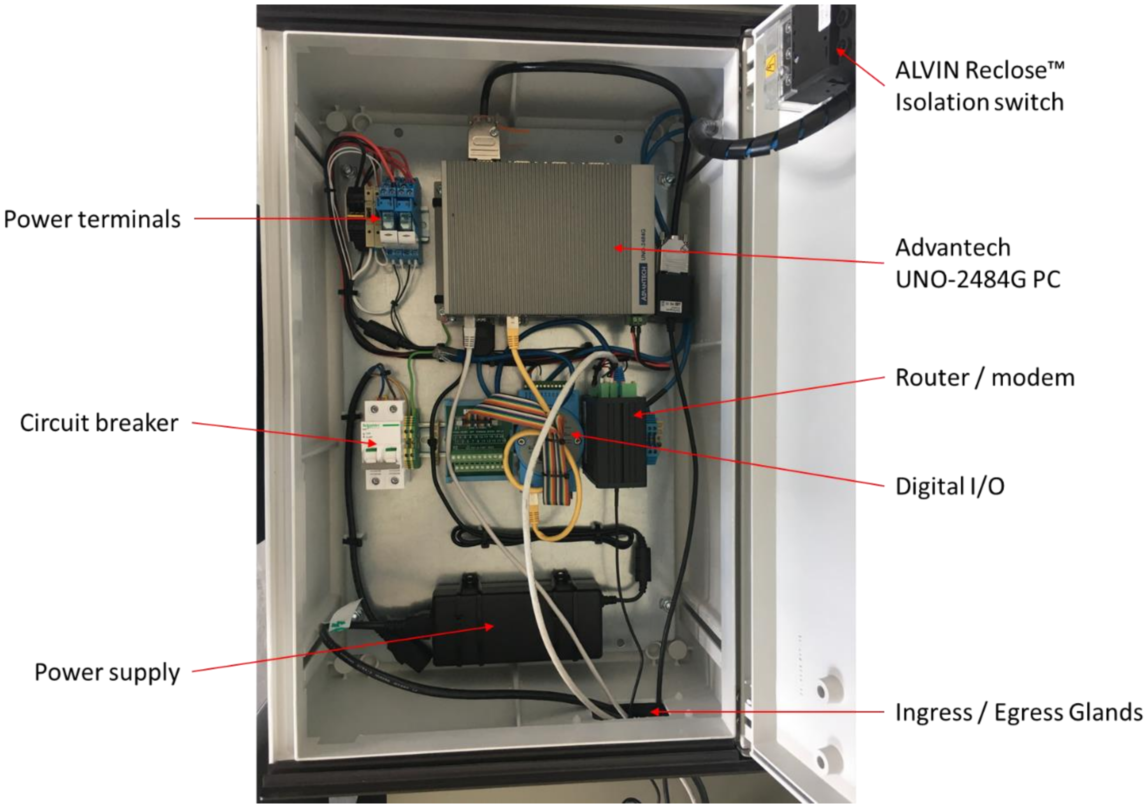


Figure 10: OpenLV Platform (inside)

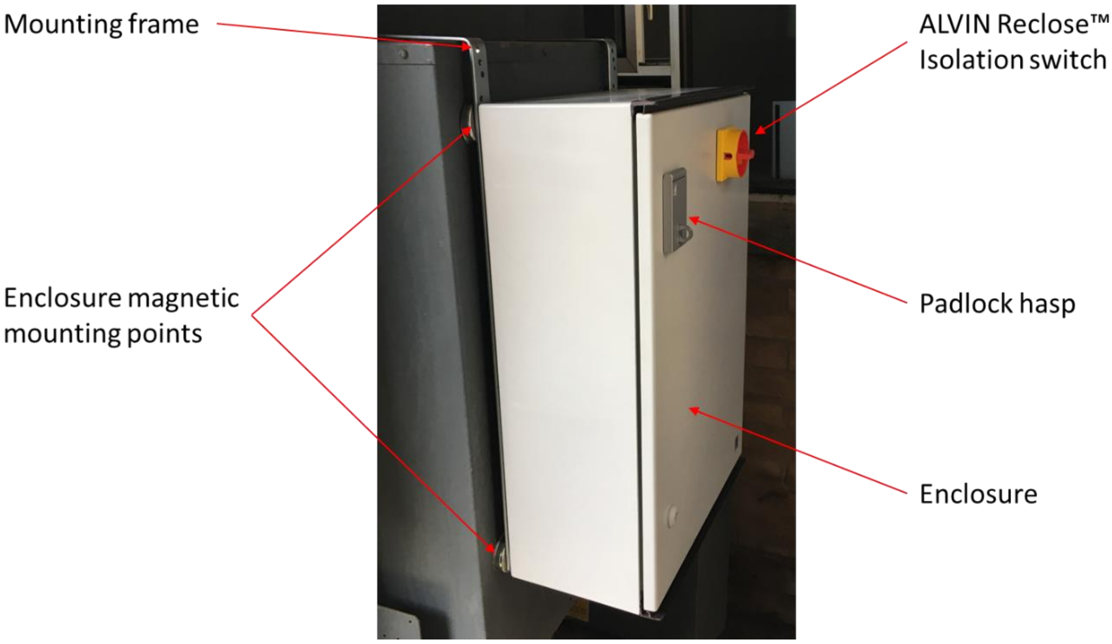


Figure 11: OpenLV Platform (outside)

3.4.4 Application Deployment & Management Server

The Application Deployment and Management Server is an iHost server (see Figure 12), provided by Nortech and provides the LV-CAP™ platform management services as well as receiving the data gathered by all sensors connected to the deployed devices. This provides a secure, reliable central host platform, receiving and storing data from any number of remote sites using a variety of communication channels and, as part of the OpenLV solution the iHost system will enable the deployment and management of apps on the Intelligent Substation Devices and will store data to support the Project trials for Method 1 – Network Capacity Uplift.

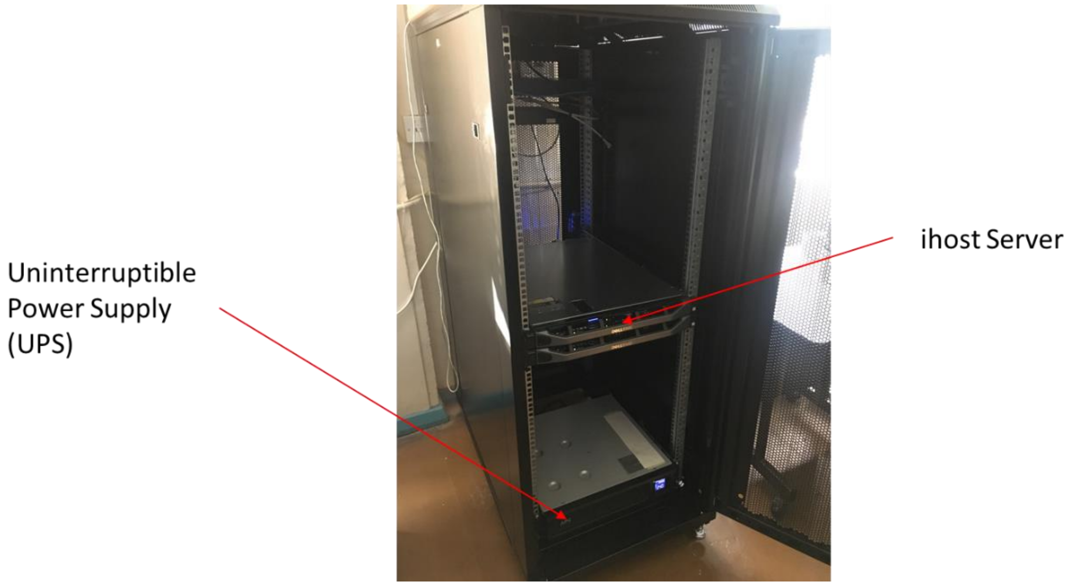


Figure 12: Nortech iHost Server & UPS

3.4.5 Cloud Hosted Server

This Server is a cloud based data storage and processing platform, provided by Lucy Electric GridKey. This provides a secure, reliable central host platform, receiving, and storing data from any number of remote sites using a variety of communication channels and protocols. As part of the OpenLV solution Lucy Electric's cloud storage system will store data to support the Project trials for Method 2 – Community Engagement and Method 3 – OpenLV Extensibility, providing community groups, academia and third-party companies access to data gathered by the deployed platforms. The platform will be separated, both physically and via firewalls, from Lucy Electric's BAU data provision systems.

3.5 Communications

The wide area communications links for the project will be provided over 3G / 4G mobile data networks. A dedicated private Access Point Name (APN) will be set up for the project trials, supporting roaming between three of the four UK Mobile Operators. Using a dedicated APN separates the project equipment from other mobile network users and provides secure communications between the OpenLV Platforms deployed in LV substations and both the Application Deployment & Management Server and Cloud Hosted Server.

4 Building & Testing the OpenLV Solution

4.1 Background

The core element of the OpenLV solution is the LV-CAP™ environment. The development of the LV-CAP™ was joint-funded by InnovateUK under the project name "Common Application Platform for Low Voltage Network Management".

This project involved the formation of a SME-led collaboration between EA Technology, Nortech and the University of Manchester to develop a novel, common, low cost, robust monitoring and management system for the LV network. As part of this project LV-CAP™ was tested in a laboratory environment.

The OpenLV project builds on this work, taking the platform out of the laboratory and into a real-world controlled trial, with a total of 80 devices to be installed as part of the Project trials. Information on the changes made to the LV-CAP™ environment, for implementation on the OpenLV project, is provided in Appendix 1 below.

4.2 Requirements Specification

The OpenLV Requirements Specification is provided in Annex 1. This document provides a record of the requirements for the overall OpenLV solution that will be utilised to support Project trials for the three Methods outlined in the Full Submission Process (FSP) [Ref. 3].

4.2.1 Capturing & Prioritising Requirements

In order to define the requirements for the overall OpenLV Solution, the key hardware and software components were defined, and then the requirements for each component were identified.

In order to prioritise requirements, the MoSCoW approach was utilised. This approach is a well-known technique used in business analysis and software development to reach a common understanding with stakeholders on the importance they place on the delivery of each requirement.

Each requirement has been identified and prioritised using the MoSCoW approach, that stands for Must, Should, Could and Will not:

- M – Must have this requirement to meet the business needs;
- S – Should have this requirement if possible, but project success does not rely on it;
- C – Could have this requirement if it does not affect anything else in the project; and
- W – Will not deliver this requirement at the current time, but it could be delivered at a later date.

In addition to the above requirements the OpenLV Requirements Specification also includes a number of Information Statements that provide relevant context.

4.3 Building the OpenLV solution

The overall approach for building and implementing the OpenLV solution is outlined in Figure 13. The green boxes represent stages that are complete, the orange boxes represent stages that are currently being completed and the grey boxes represent stage(s) that have not started yet.

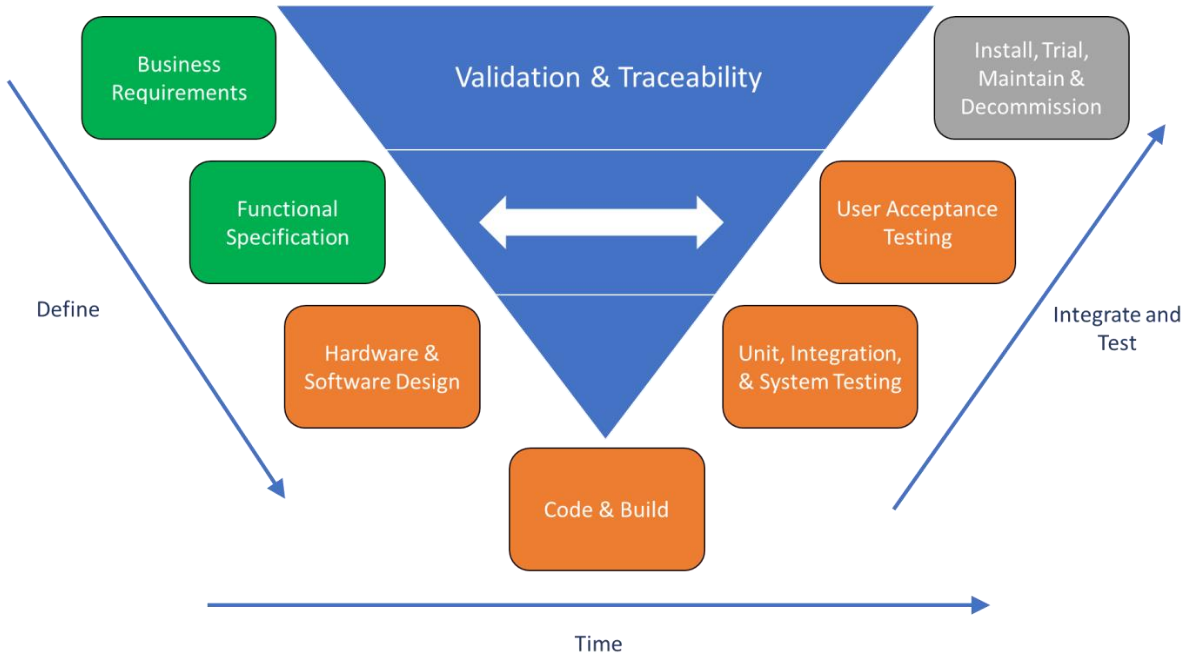


Figure 13: Building the OpenLV solution

An overview of each stage and associated key documentation are outlined below:

- **Business Requirements:** In this stage, the business requirements were defined. The business requirements for the OpenLV solution are outlined in the Initial Screening Process (ISP) and FSP documents [Ref. 2 and Ref. 3]. These documents were completed in line with NIC Governance Document [Ref. 4]. This stage is complete.
- **Functional Specification:** In this stage, the requirements for the overall solution were defined. Requirements are documented in the OpenLV Requirements Specification. This document is provided in Annex 1. This stage is complete.
- **Hardware & Software Design:** This stage entailed the hardware design for the equipment to be installed in LV substations and the software design for each of the software components that runs on the OpenLV Platform. This stage is currently being completed.
- **Code & Build:** This stage includes coding the individual software components and building the Intelligent Substation Devices to be installed in LV substations. This stage is currently being completed.

- **Unit Integration & System Testing:** This stage includes testing individual hardware and software components and also testing the overall system. System testing ensures that the individual hardware and software components work together. This stage is currently being completed.
- **User Acceptance Testing:** This stage includes testing the overall solution. The key tests that are completed in this stage are Factory Acceptance Tests (FAT), that are completed in a laboratory environment and Site Acceptance Tests (SAT), that are completed on equipment installed in the field. In both cases the tests defined in the test documents are traceable, in that they link back directly to each requirement. In both cases the tests are formally signed off by EA Technology and WPD representatives. This stage is currently being completed.
- **Install, Trial, Maintain & Decommission:** This stage includes the installation of 80 OpenLV Platforms in WPD's licence area(s), trials to prove the overall solution, maintenance of the devices and finally de-commissioning the devices at the end of the project. This stage has not started.

4.4 Approach to Testing

Testing the overall OpenLV solution has been completed through: 1) Unit Integration & System Testing and 2) User Acceptance Testing.

A staged approach has been taken to the development and testing of the overall OpenLV solution. This has enabled the project team to focus on building and deploying the core solution and then adding additional functionality.

As a result, the approach to testing has been to hold multiple formal acceptance testing FATs and multiple SATs have also been scheduled. The core components tested at each stage are outlined in the core component test matrix sub-section (below) and the dates for completed and scheduled acceptance testing are outlined in the timeline sub-section (below).

4.4.1 Core Component Test Matrix

The core components tested or scheduled to be tested at each formal test stage are shown in Table 1.

Component	Category	FAT 1 OpenLV Core System	FAT 2 OpenLV Network Meshing & Cloud Hosted Server	FAT3 OpenLV LoadSense & DTR app tests	SAT 1 OpenLV Core System	SAT 2 OpenLV Full Solution
LV Network Automation Hardware	Hardware	No	Yes	Yes	No	Yes
LV Monitoring Hardware	Hardware	Yes	Yes	Yes	Yes	Yes
OpenLV Platform	Hardware	Yes	Yes	Yes	Yes	Yes
Application Deployment & Management Server	Hardware	Yes	Yes	Yes	Yes	Yes
Cloud Hosted Server	Hardware	No	Yes	Yes	Yes	Yes
Communications Infrastructure	Hardware	Yes	Yes	Yes	Yes	Yes
LV-CAP Operating System	Software	Yes	Yes	Yes	Yes	Yes
Temperature Sensor app	Software	Yes	Yes	Yes	Yes	Yes
Load Profile Predictor app	Software	No	Yes	Yes	Yes	Yes
Peer to Peer Communications app	Software	Yes	Yes	Yes	Yes	Yes
LoadSense app	Software	No	No	Yes	No	Yes
Network Meshing app	Software	No	Yes	Yes	No	Yes
Dynamic Thermal Ratings app	Software	No	No	Yes	No	Yes
Nortech Communications app	Software	Yes	Yes	Yes	Yes	Yes
Electrical Sensor app	Software	Yes	Yes	Yes	Yes	Yes
Lucy Electric Gridkey Communications app	Software	Yes	Yes	Yes	Yes	Yes

Table 1: Core Component Test Matrix

4.4.2 Timeline

The high-level test and build timeline for the overall OpenLV Solution is outlined in Table 2.

Title	Task	Start Date	End Date	Status
Build & Install Hardware	Build Hardware	Sep-17	Jan-18	In Progress
	Install & Field Test First (4) Devices	Oct-17	Feb-18	Not Started
	Install Method 1 Devices (56)	Jan-18	Mar-18	Not Started
	Install Method 2 Devices (10)	Feb-18	Aug-18	Not Started
	Install Method 3 Devices (10)	Feb-18	Aug-18	Not Started
Central Infrastructure	Install & Set Up - Application Deployment & Management Server	Jun-18		Complete
	Set Up - Cloud Hosted Server	Sep-17	Oct-17	In Progress
	Set Up Communications Infrastructure	Aug-17	Oct-18	In Progress
Test	FAT 1 - OpenLV Core System	Aug-17		Complete
	FAT 2 - OpenLV Network Meshing & Cloud Hosted Server	Sep-17		Complete
	FAT 3 - OpenLV LoadSense & DTR app tests	Dec-17	Jan-18	Not Started
	SAT 1 - OpenLV Core System	Nov-17		Not Started
	SAT 2 - OpenLV Full Solution	Jun-18	Jul-18	Not Started
Trial	Method 1 Trials	Mar-18	Mar-19	Not Started
	Method 2 Trials	Sep-18	Jun-19	Not Started
	Method 3 Trials	Sep-18	Jun-19	Not Started

Table 2: High Level OpenLV Test & Build Timeline

4.5 Factory & Site Acceptance Testing

The tests completed and associated results from FAT 1 and FAT 2 are provided in Annex 2. It is confirmed that both FAT's were successful, and the work required to install the initial 4 OpenLV Platforms is being completed. Once these initial devices are installed exact SAT dates will be scheduled and completed. The proposed tests to be completed at SAT are provided in Annex 3.

5 Key Learning Points

The key learning points regarding the specification, design, build and testing of the overall OpenLV solution, to date, are outlined in the below sub-sections.

5.1.1 Specification

The key learning points regarding the specification of the OpenLV solution are as follows:

- 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.
- 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.
- What is seen as a single, simple, requirement from an end user perspective may require more than one Application to deliver it, and so trigger numerous technical requirements which must be cross-referenced.
- It is important to utilise known, existing, tried and tested techniques to capture software requirements. For OpenLV we utilised the MoSCoW approach.
- The sensors specified and the time intervals at which they are sampled will affect what applications it is possible to run on the system. It may be desirable to over-specify sensors to provide for future Application requirements.

5.1.2 Design

The key learning points regarding the design of the OpenLV solution are as follows:

- It is important to ensure that the systems deployed for innovation trials are sufficiently secure. In the case of OpenLV, NCC Group were awarded this role and part of their scope of works is to ensure that the cyber security elements of the proposed trial solution are fit for purpose.
- 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).
- 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.

- 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.
- 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.

5.1.3 Build

The key learning points regarding building the OpenLV solution are as follows:

- The approach to building the overall OpenLV solution was to focus on building the core functionality first and then adding additional functionality later. This is reflected in the approach to testing and implementation. This enabled the Project team to focus on delivering core functionality, testing it and then building on this foundation. This approach gets a core system built earlier which means testing can also start earlier in the programme reducing the technical risks of deployment.
- The LV-CAP™ operating system is based on a Docker systems architecture. This enables flexibility when building the overall solution. This architecture means that software, or in the case of OpenLV, Apps, from multiple vendors can be packaged into separate 'containers'. The core advantage of this is that the containers are designed to run on a shared operating system.
- 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.
- Prior to the deployment of any trial system of this nature it is critical to complete a cyber security review of the proposed solution prior to installation. In the case of OpenLV, NCC Group has completed an assessment of the proposed solution and has confirmed that the OpenLV Platform can be deployed for field trials.

5.1.4 Test

The key learning points regarding testing the OpenLV solution are as follows:

- 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.
- 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.
- 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.

6 Summary

This SDRC report has presented the Systems Architecture for the overall OpenLV solution outlining the design concepts, key hardware components, key software components and associated central infrastructure and communications components.

The approach taken to build and test the overall OpenLV Solution has been outlined and supported by the provision of the OpenLV Requirements Specification, FAT documentation, and the associated results of the FAT tests completed to date. The approach to testing the overall solution has been outlined and this will enable the OpenLV Platforms to be tested in the field in late 2017 and rolled out at scale in 2018. This approach will ensure relevant learning can be generated from the Project trials under the 3 methods: 1) The network capacity uplift trials, 2) The community engagement trials and 3) The OpenLV extensibility trials.

In addition, the key learning points recorded at this stage of the Project in relation to the specification, design, build and testing of the overall OpenLV solution have also been recorded. It is confirmed that the SDRC and associated evidence requirements have been met and this is supported by the compliance matrix provided in Section 1.

7 References

1. OpenLV Project Direction, 16th December 2016, https://www.ofgem.gov.uk/system/files/docs/2017/02/open_lv_formal_project_direction.pdf
2. OpenLV Initial Screening Pro-forma, https://www.ofgem.gov.uk/system/files/docs/2016/04/electricity_isp_proforma_nic_wpd_openlv_pdf_0.pdf
3. OpenLV Full Submission Pro-forma, https://www.westernpower.co.uk/docs/Innovation/Current-projects/Open-LV/NON-CONFIDENTIAL-OpenLV-NIC-Bid-2016-WPD_EN_NIC_02.aspx
4. NIC Governance Document, Version 2.1, https://www.ofgem.gov.uk/publications-and-updates/version-2-1-network-innovation-competition-governance-documents
5. LV Common Application Platform Public API, July 2017, V04.03.00.

8 Annexes

1. SDRC 1 A1:OpenLV Solution Requirements Specification
2. SDRC 1 A2: Factory Acceptance Test (FAT) Documentation & Results
3. SDRC 1 A3: Site Acceptance Test (SAT) Documentation

Appendix 1. Assessment of the LV-CAP™ operating system for the OpenLV Project

An assessment of LV-CAP™ operating system developed as part of the "Common Application Platform for Low Voltage Network Management", InnovateUK project, was undertaken. The purpose of this assessment was to identify what changes were required to the LV-CAP™ operating system to enable the deployment of the overall OpenLV solution required to complete Project trials. This assessment identified four security improvements that needed to be made each of which have been addressed. The four security improvements that have been made are as follows:

- **MQTT Broker Authentication:** The MQTT broker did not check whether application containers connecting to it supplied a username and password, i.e. anonymous connections are permitted. Therefore, any attacker would have been able to send network traffic to the MQTT broker, monitor the communication activity of the other operating applications, and impersonate them on the broker.
- **Shared MQTT Authentication Credentials:** The username and password for all application containers within the InnovateUK trials were the same. Consequently, any container could connect as though it was any other container. In the event the system was breached then every container would be impacted and would have required an update to restore system operation.
- **Symmetric MQTT Authentication Credentials in Mosquitto:** MQTT Broker connections are protected using a username and password, the password must be stored both in the container and in the authentication data for the MQTT Broker. In the Mosquitto implementation used as part of the InnovateUK trials, the Broker on the LV-CAP™ platform held the password text for all users. Although this was encrypted, there was a risk that theft of, or other unauthorised access to, an individual LV-CAP™ platform could provide an attacker with the passwords for all container users.
- **No Access Control Lists on MQTT Broker:** The MQTT Broker did not implement Access Control Lists (ACLs) controlling which topics a given user can publish on or subscribe to. Once connected to the MQTT Broker any container was able to view the topics published to by any other container and was able to impersonate any of them.

In addition the following changes were identified and have been amended in the latest revision of the Application Programming Interface (API) documentation [Ref. 5]:

- Changes to the software to enable performance issues with the database to be resolved; and
- Changes to the software to support multiple communication containers, as the OpenLV solution requires communication with multiple servers from independent suppliers to be supported.