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OPENLV

OPENING UP THE SMART GRID

Factory Acceptance Tests Stage 2

Results Documentation

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Document Control

	Name	Date
Prepared by:	Tim Butler	05.07.2018
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Recommended by:	Richard Potter	10.07.2018
Approved (WPD):	Mark Dale	11.07.2018

Revision History

Date	Issue	Status
11.07.2018	1.2	ISSUE FOR FATs
	1.3	ISSUED POST FATs

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Contents

Glossary

Term	Definition
DNO	Distribution Network Operator
DTR	Dynamic Thermal Rating
FAT	Factory Acceptance Test
GMT	Ground Mount Transformer
HV	High Voltage
LV	Low Voltage
LV-CAP™	Low Voltage Common Application Platform
NIC	Network Innovation Competition
NOP	Normally Open Point
RTTR	Real Time Thermal Rating
SAT	Site Acceptance Test
WPD	Western Power Distribution

1 Introduction

The testing of the OpenLV solution covers three distinct areas.

- **Factory Acceptance Tests** to verify the equipment meets the requirements detailed in the Requirements Specification.
- **Site Acceptance Tests** to verify the solution meets the requirements in realistic, non-laboratory / controlled environment conditions.
- **Cyber-security testing** to evaluate the cyber-security capabilities of the LV-CAP™ platform; these tests will be undertaken by a specialist provider.

This document details the Factory Acceptance Tests (FATs) for the overall OpenLV solution.

1.1 Scope

The tests in this document are based upon the functionality documented in the Loadsense Operational Logic document.

Factory Acceptance Testing (FAT) will be performed against the requirements outlined.

1.2 Environment

A representative setup of the OpenLV solution was established in the testing laboratories at EA Technology's Capenhurst offices.

This setup comprises two OpenLV solutions, set up such that demonstration of the functionality associated with the network meshing can be demonstrated. This includes 6x Alvin Reclose™ units, (3 per LV-CAP™ platform) in a test rig capable of simulating a low voltage (LV) network.

The test rig is also capable of simulating an LV network fault to demonstrate the overall trial system's ability to respond appropriately to a fault occurring during the project trials.

1.3 Test Data & Verification

Each test case lists the following:

- The objectives of the overall test;
- The initial conditions;
- Any necessary actions and anticipated result; and
- A test results record for the overall test including the result, date, name of the tester and name of the witness. White space is left after each test to allow for the recording of comments, issues, etc.

2 Factory Acceptance Tests (FATs)

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

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

Cyber-security testing is being undertaken separately to the FAT and SATs.

This final round of FATs is to test the following elements of the OpenLV Project's trial system:

- Profile predictor applications (load and ambient temperature);
- WeatherSense (transformer thermal state tracker and temperature predictor);
- LoadSense (network meshing control).

Each of these elements are intrinsically linked, with the output of the first feeding directly to the input for the second, and similarly, the output of the second feeding to the third.

The final (Part 3) FATs were conducted on July 12th, 2018.

2.1 Attendees

2.1.1 Western Power Distribution (WPD)

- Andrew Hood (AH)
- Chris Harrap (CH)
- Jake Ramsden (JR)

2.1.2 EA Technology

- Richard Ash (RA)
- Tim Butler (TB)

2.2 System deployed network configuration

The LoadSense software works with a pair of LV substations on the same 11kV feeder (with no normally open point between them), which are also interconnected at LV via a "meshing" feeder which has a link box on it. Traditionally this link box would be a normally open point with the links not fitted, except under fault conditions when a back-feed could be established.

For the OpenLV project the links will be permanently fitted to the link box, forming a continuous feeder between the two substations. ALVIN LV Circuit Breakers will be fitted in place of the LV board fuses at both ends of the feeder.

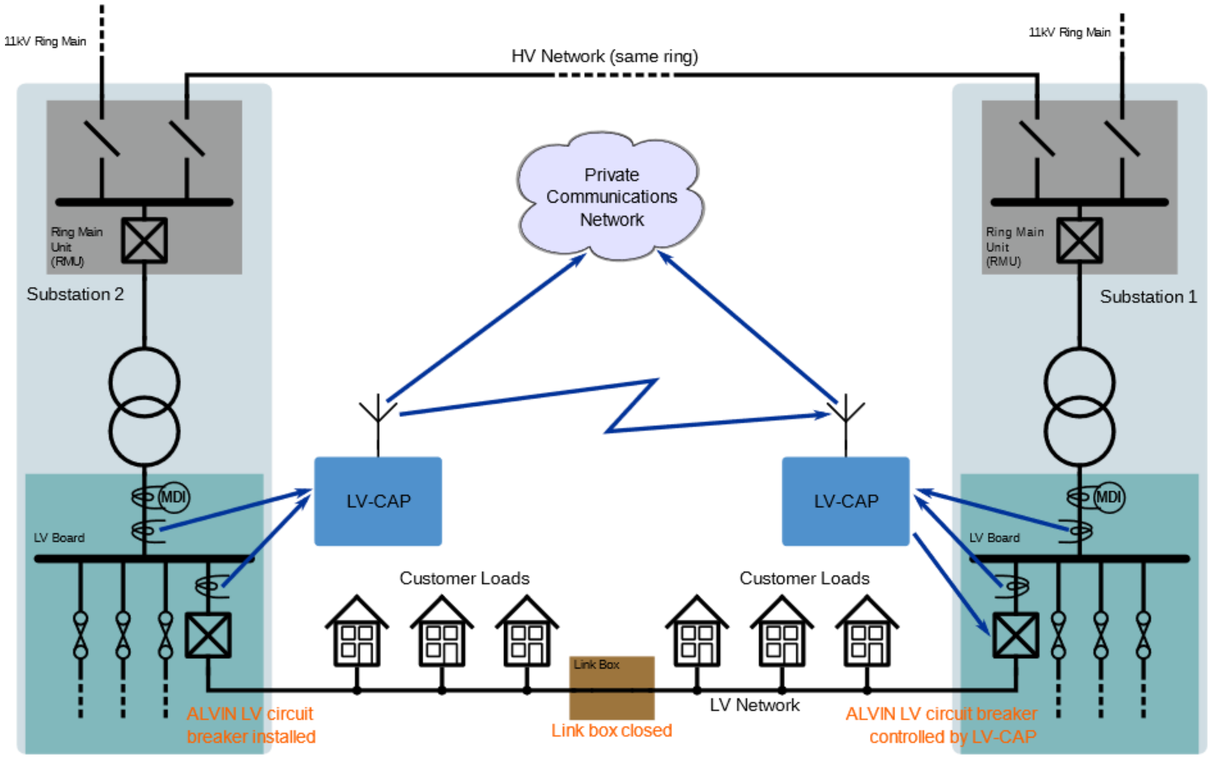

Figure 1: LV-CAP™ deployed on an LV Network

At substation Site 2, the Alvin Reclose™ Circuit Breaker will always be closed (unless there is a fault on the feeder, which will trip it) and so this substation will contribute to powering the meshing feeder. At substation Site 1, the Circuit Breaker will be controlled by LoadSense. If the Circuit Breaker at Site 1 is open, then the complete meshing feeder load will be supplied from Site 2. If the Circuit Breaker at Site 1 is closed, then the meshing feeder load will be shared between Sites 1 and 2.

The default state is to operate with the Circuit Breaker open. However, if this will cause an overload, then LoadSense may decide to close the Circuit Breaker. This will reduce the transformer load (and hence in time transformer temperature) at Site 2 but increase the load (and hence temperature) at Site 1.

The logic for the operation of the switch is shown in Figure 2.

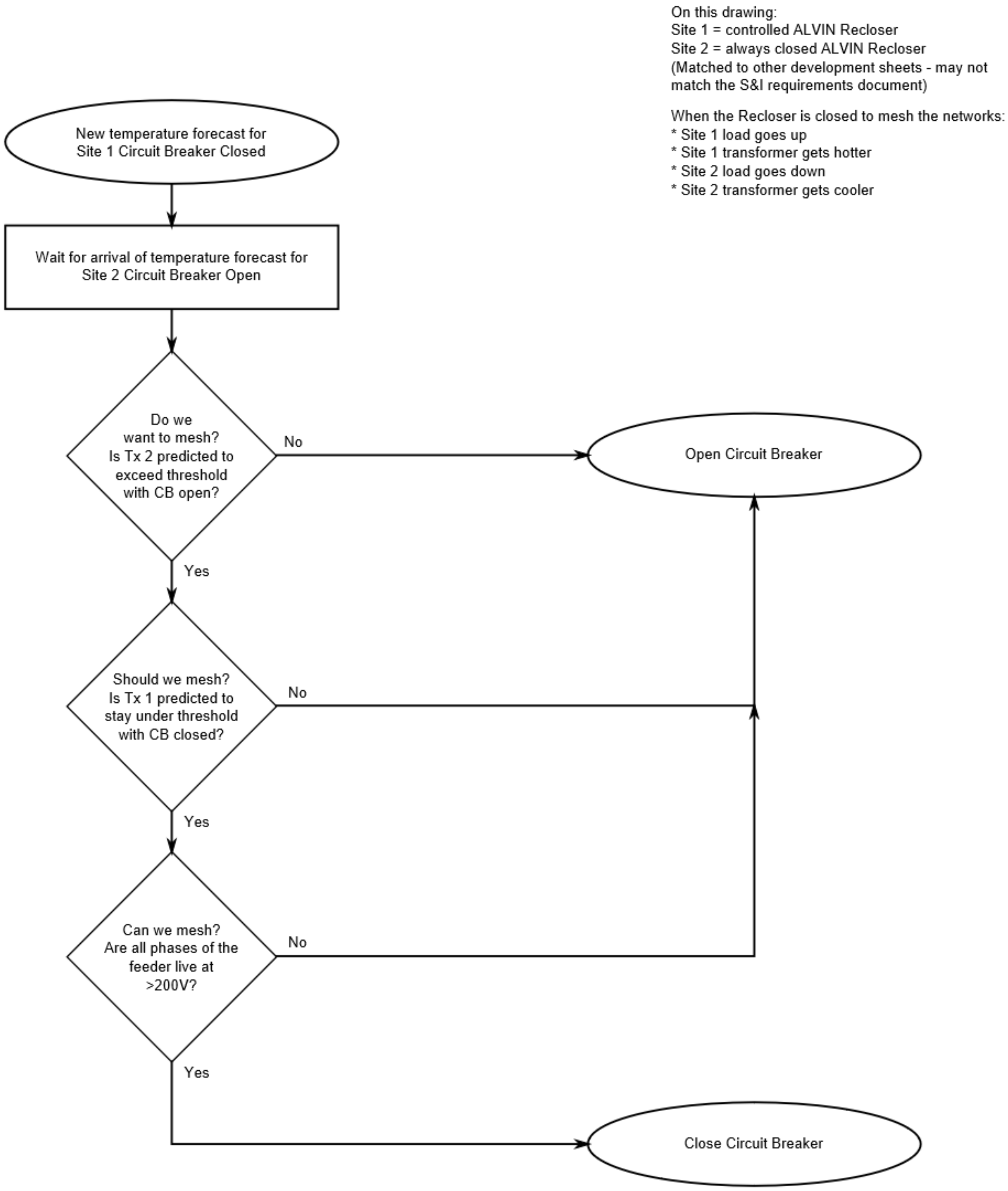

Figure 2: Loadsense Operational Logic

2.3 Setup Details

2.3.1 Test configuration

The test system will be installed in the Alvin Reclose™ demonstration laboratory at EA Technology's offices in Capenhurst and will comprise

- 2 x Intelligent Substation Devices (ISDs) with 4G SIMs as per substation installations;
    - "Substation (Site) 1" ISD is connected to three Alvin Reclose™ circuit breakers which will be controlled
    - "Substation (Site) 2" ISD will be connected to three Alvin Reclose™ circuit breakers which will not be controlled

Under normal circumstances, the profile predictors require several weeks of historical load to operate effectively. This is not possible to replicate correctly in the test environment and consequently the outputs of the monitoring hardware (Lucy Electric GridKey MCU520) will be simulated, allowing the test to be run faster (30x) than real-time.

As such, for the purposes of the tests, the Lucy GridKey Sensor and Modbus TCP Sensor Applications will be disabled, so that no real measurement inputs are produced and the Lucy GridKey hardware for the tests will not be set up.

The outputs of this hardware and the Sensor Applications will instead be simulated by playing back stimulus data calculated in advance and stored in CSV files.

The system to be tested will simulate the arrangement depicted above in Figure 1.

2.3.2 Software used

The following software versions were used in the FAT:

- Modbus RTU Sensor Application 2404-SWREL-S011-V03.07.00-production
- Transformer Thermal Ratings 2579-SWREL-S011-V00.02.01-production
- Peer to Peer communications 2661-SWREL-S011-V00.05.00-production
- Load Profiler 2662-SWREL-S011-V00.02.06-production
- OpenLV Operating System configuration 2826-SWREL-V00.01.08.

2.4 Automated reclose operation

EA Technology's Alvin Reclose™ units are being utilised to provide network meshing functionality. These units normally operate as an automatic recloser in the event of a transient LV fault, restoring supply to customers without requiring a site visit by DNO staff.

To meet WPD's request that such automatic operation is disabled, the Alvin Reclose™ units to be deployed by the OpenLV Project will be reprogrammed such that reclosing after a fault will require manual intervention.

This change from normal functionality will also be demonstrated as part of the FATs.

3 System tests

The threshold temperatures for the two substations (sites) will be set such that the demonstration system initiates meshing at least once per 'day', (every 72 minutes within the testing period).

IHost will be utilised to demonstrate the pre-loaded 'network data' and subsequent calculated load and temperature profiles. This data will show a 'history period' of 5 weeks, and the early weeks of the calculated values will be of insufficient confidence to generate meshing commands.

This data will be visualised through iHost to show the following information:

- The transformer load at each site, for each circuit breaker position;
- The transformer actual temperatures achieved under current operating conditions (be that breaker open or closed);
- The 4-hours-ahead predicted maximum temperature of Substation 2 transformer if the circuit breaker remains open[1];
- The 4-hours-ahead predicted maximum temperature of Substation 1 transformer if the circuit breaker is closed[1];
- Whether (based on thermal considerations only) the networks should be meshed;
- The final Circuit Breaker state decision (open or closed) also considering the network voltage and not closing onto a fault.

Once the data has sufficient historical information and subsequent 'confidence' in the load profile to enable network meshing, the Loadsense Application will commence decision making.

This will initiate a link of the LV network when Substation 2 transformer is forecast to exceed the assigned threshold and Substation 1 has spare capacity.

[1] Calculation starts from the present state of the transformers at each site

3.1 Testing

Test	1	
Requirement No.	Must: 047, 048, 049, 050	Should:
Objective	Demonstrate the load profile and temperature profile prediction applications are operating as expected. The predicted transformer temperature for Substation 1 will always be higher than the actual temperature when the LV network is meshed.	
System Area	ISD	iHost Control Server
	Lucy Data Server	LV-CAP™ Platform
	LV Monitoring	Thermal Monitoring
	LV Meshing	Load Profile Predictor ✓
	CSV Data Recorder	Loadsense
	Dynamic Thermal Rating ✓	Management Communications
	Data Upload Communications	Peer-to-peer Communications
	Cyber-Security	Overall System
Initial condition	LV network un-meshed. Test system is running, utilising the 5-week historical data set.	
Action(s)	Inspect graphs produced by the iHost server.	
Expected Result	When the LV circuit is meshed, and the two substations are linked, the 'predicted temperature' at Substation 1 is higher than the 'actual temperature' as the currents used to calculate the prediction are those from the non-meshed scenario.	
Pass / Fail	Pass. • Pass - Load profile prediction application • Pass – Agreed retrospectively following the publication of the Post-FAT Analysis report.	
Comments	The load profile prediction application was demonstrated in previous tests and remains operational. It was agreed by all witnesses to the tests that the load profile prediction application was operating as expected. The data available from the temperature profile prediction application was insufficient to verify correct operation of the software. It appeared that the application may be utilising incorrect inputs to generate a load profile, or the wrong field had been plotted in the visualisation plots. Action: EA Technology to verify the data inputs utilised for the temperature profile prediction application and that the correct outputs are used for redrawing the data plots and provide revised version to WPD once complete. WPD will verify acceptance of the temperature profile prediction application from the revised plots. Reference report 'Factory Acceptance Tests Stage 2 – Post-FAT Loadsense Analysis' for the detail required.	

<table>
<tr><td>Test</td><td colspan="2">2</td></tr>
<tr><td>Requirement No.</td><td>Must: 047, 048, 049, 050</td><td>Should:</td></tr>
<tr><td>Objective</td><td colspan="2">Demonstrate the load profile predictor and temperature profile prediction applications are operating as expected.
The predicted transformer temperature for Substation 2 will always be higher than the predicted temperature when the LV circuit is un-meshed.</td></tr>
<tr><td rowspan="8">System Area</td><td>ISD</td><td>iHost Control Server</td></tr>
<tr><td>Lucy Data Server</td><td>LV-CAP™ Platform</td></tr>
<tr><td>LV Monitoring</td><td>Thermal Monitoring</td></tr>
<tr><td>LV Meshing</td><td>Load Profile Predictor ✓</td></tr>
<tr><td>CSV Data Recorder</td><td>Loadsense</td></tr>
<tr><td>Dynamic Thermal Rating ✓</td><td>Management Communications</td></tr>
<tr><td>Data Upload Communications</td><td>Peer-to-peer Communications</td></tr>
<tr><td>Cyber-Security</td><td>Overall System</td></tr>
<tr><td>Initial condition</td><td colspan="2">LV network un-meshed.
Test system is running, utilising the 5-week historical data set.</td></tr>
<tr><td>Action(s)</td><td colspan="2">Inspect graphs produced by the iHost server.</td></tr>
<tr><td>Expected Result</td><td colspan="2">When the LV circuit is un-meshed, separating the two substations, the ‘predicted temperature’ at Substation 2 is always higher than the ‘actual temperature’ as the currents used to calculate the prediction are those from the meshed scenario.</td></tr>
<tr><td>Pass / Fail</td><td colspan="2">Pass.
• Pass - Load profile prediction application
• Pass – Agreed retrospectively following the publication of the Post-FAT Analysis report.</td></tr>
<tr><td>Comments</td><td colspan="2">The load profile prediction application was demonstrated in previous tests and remains operational. It was agreed by all witnesses to the tests that the load profile prediction application was operating as expected.
The data available from the temperature profile prediction application was insufficient to verify correct operation of the software. It appeared that the application may be utilising incorrect inputs to generate a load profile, or the wrong field had been plotted in the visualisation plots.
Action: EA Technology to verify the data inputs utilised for the temperature profile prediction application and that the correct outputs are used for redrawing the data plots and provide revised version to WPD once complete.
WPD will verify acceptance of the temperature profile prediction application from the revised plots.
Reference report ‘Factory Acceptance Tests Stage 2 – Post-FAT Loadsense Analysis’ for the detail required.</td></tr>
</table>

Test	3		
Requirement No.	Must: 044, 046	Should:	
Objective	Demonstrate the ability of the Loadsense application to initiate a meshing request.		
System Area	ISD	iHost Control Server	
	Lucy Data Server	LV-CAP™ Platform	
	LV Monitoring	Thermal Monitoring	
	LV Meshing ✓	Load Profile Predictor ✓	
	CSV Data Recorder	Loadsense ✓	
	Dynamic Thermal Rating ✓	Management Communications	
	Data Upload Communications	Peer-to-peer Communications ✓	
	Cyber-Security	Overall System	
Initial condition	LV network un-meshed. Test system is running, utilising the 5-week historical data set.		
Action(s)	Verify that the LV network is meshed when expected as the daily load profile repeats every 48 minutes.		
Expected Result	When the ‘predicted temperature’ for Substation 2 exceeds the assigned threshold, but simultaneously, when the prediction for Substation 1 is below its assigned threshold, a request to mesh the LV circuits will be made.		
Pass / Fail	Pass		
Comments	The LV-CAP™ platform demonstrated the ability to ‘close’ the Alvin Reclose™ circuit breaker when required. This requirement is determined within the platform, and no manual intervention was required to enable the breaker to close and ‘mesh’ the adjacent circuits.		

<table>
<tr><td>Test</td><td colspan="4">4</td></tr>
<tr><td>Requirement No.</td><td colspan="2">Must: 045, 046</td><td colspan="2">Should:</td></tr>
<tr><td>Objective</td><td colspan="4">Demonstrate the ability of the Loadsense application to initiate a de-meshing request.</td></tr>
<tr><td rowspan="8">System Area</td><td>ISD</td><td></td><td>iHost Control Server</td><td></td></tr>
<tr><td>Lucy Data Server</td><td></td><td>LV-CAP™ Platform</td><td></td></tr>
<tr><td>LV Monitoring</td><td></td><td>Thermal Monitoring</td><td></td></tr>
<tr><td>LV Meshing</td><td>✓</td><td>Load Profile Predictor</td><td>✓</td></tr>
<tr><td>CSV Data Recorder</td><td></td><td>Loadsense</td><td></td></tr>
<tr><td>Dynamic Thermal Rating</td><td>✓</td><td>Management Communications</td><td></td></tr>
<tr><td>Data Upload Communications</td><td></td><td>Peer-to-peer Communications</td><td>✓</td></tr>
<tr><td>Cyber-Security</td><td></td><td>Overall System</td><td></td></tr>
<tr><td>Initial condition</td><td colspan="4">LV network meshed.
Test system is running, utilising the 5-week historical data set.</td></tr>
<tr><td>Action(s)</td><td colspan="4">Verify that the LV network is de-meshed when expected as the daily load profile repeats every 48 minutes.</td></tr>
<tr><td>Expected Result</td><td colspan="4">When the ‘predicted temperature’ for Substation 2 falls below the assigned threshold, the LV network will be un-meshed.</td></tr>
<tr><td>Pass / Fail</td><td colspan="4">Pass</td></tr>
<tr><td>Comments</td><td colspan="4">The LV-CAP™ platform demonstrated the ability to ‘open’ the Alvin Reclose™ circuit breaker when required. This requirement is determined within the platform, and no manual intervention was required to enable the breaker to open and ‘de-mesh’ the adjacent circuits.</td></tr>
</table>

<table>
<tr><td>Test</td><td colspan="2">5</td></tr>
<tr><td>Requirement No.</td><td>Must: N/A
This requirement was specified by WPD later in the OpenLV Project and hence was not included within the original Requirements Specification.</td><td>Should: N/A</td></tr>
<tr><td>Objective</td><td colspan="2">To demonstrate the Alvin Reclose™ units will not attempt to reclose after a fault without manual intervention. (The Alvin Reclose™ units will operate as a simple fuse, rather than a smart recloser.)

It is also noted that the Alvin Reclose™ units will only respond to a meshing instruction from the LV-CAP™ platform in the event that the LV feeder has a voltage reading and hence confirms the feeder is live. This will prevent the LV-CAP™ platform initiating a breaker closure onto a feeder that has experienced a fault.

It is not possible to demonstrate this additional functionality within the Alvin Reclose™ test environment at EA Technology due to the on-site connection arrangements.</td></tr>
<tr><td rowspan="8">System Area</td><td>ISD</td><td>iHost Control Server</td></tr>
<tr><td>Lucy Data Server</td><td>LV-CAP™ Platform</td></tr>
<tr><td>LV Monitoring</td><td>Thermal Monitoring</td></tr>
<tr><td>LV Meshing ✓</td><td>Load Profile Predictor</td></tr>
<tr><td>CSV Data Recorder</td><td>Loadsense</td></tr>
<tr><td>Dynamic Thermal Rating</td><td>Management Communications</td></tr>
<tr><td>Data Upload Communications</td><td>Peer-to-peer Communications</td></tr>
<tr><td>Cyber-Security</td><td>Overall System</td></tr>
<tr><td>Initial condition</td><td colspan="2">LV Network energised.
Test system is running, utilising the 5-week historical data set.</td></tr>
<tr><td>Action(s)</td><td colspan="2">Trigger a ‘fault’ on the Alvin test rig LV network.</td></tr>
<tr><td>Expected Result</td><td colspan="2">Alvin Reclose™ units will open to protect the network and will not attempt to automatically reclose.
Manual intervention will be required to reclose the breakers.</td></tr>
<tr><td>Pass / Fail</td><td colspan="2">Pass</td></tr>
<tr><td>Comments</td><td colspan="2">The Alvin Reclose™ units opened as required on the implementation of a network fault and did not attempt to reclose to restore connection until a manual trigger was initiated, instructing the units to close and restore supply.</td></tr>
</table>

4 Additional information provided post FAT's

Following the partial pass of both Test 1 and Test 2, demonstrating the ability of the LV-CAP™ platform to control the Alvin Reclose™ devices additional information was requested by WPD to allow a deeper understanding of the operation of the Loadsense software operation.

This information is provided in the separate document "Factory Acceptance Tests Stage 2 - Post-FAT Loadsense Analysis".

5 Sign-off and acceptance

It is acknowledged by all those in attendance at the Factory Acceptance Tests (FATs) undertaken on the OpenLV LV-CAP™ Trial system at EA Technology's Capenhurst offices on September 21st, 2017, that the results and comments detailed against each test in this document are a true record of the tests outcome and subsequently, the Loadsense application and Alvin Reclose™ units are approved for installation as part of the OpenLV Project trials.

The tests were witnessed by representatives of the below companies:

- Western Power Distribution
- EA Technology

Name	Company & Role
Andrew Hood	Technical Policy Manager Western Power Distribution
Christopher Harrap	Project Manager Western Power Distribution
Jake Ramsden	Operational Safety Adviser Western Power Distribution
Richard Ash	Senior Consultant EA Technology
Tim Butler	Senior Consultant EA Technology