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OPEN LV

OPENING UP THE SMART GRID

Site Acceptance Tests

ea technology

RIIO NIC NETWORK INNOVATION COMPETITION

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Contents

1 Introduction

1.1 Overall testing approach

The overall approach to testing the OpenLV solution has been defined in 'SDRC 1 – Specification Design & Testing'.

There are three distinct areas of testing for the OpenLV solution.

- **Factory Acceptance Tests** to verify the system and its components function correctly, including the operation and configuration of software components, and consequently that the overall system meets the requirements detailed in the Requirements Specification.
- **Site Acceptance Tests** to verify the solution meets the requirements in realistic, non-laboratory / controlled environment once the complete system has been installed on location in its final configuration. These tests verify that no damage occurred to the hardware during shipment and installation.
- **Cyber-security testing** to evaluate the cyber-security capabilities of the LV-CAP™ platform; these tests will be undertaken by a specialist provider.

The Factory Acceptance Tests (FATs) were undertaken in two stages and completed successfully, demonstrating the LV-CAP™ platform and ancillary equipment has been functionally tested and approved for deployment in the OpenLV Project trials.

As with the FATs, there will be two phases of Site Acceptance Tests (SATs), the first for the core OpenLV solution and the second to comprise the full solution, including the network automation elements; refer to Table 1 below for details of the components covered in each set of tests.

The current version of this document only details the tests for the Phase 1 SATs, and will be updated prior to the deployment of the network automation hardware.

SATs will only be undertaken on the first iterations of equipment installed for the project. For example, SATs for the 'Core System' will be undertaken for the first two pairs of systems deployed. The full solution SATs will only be undertaken on the first pair of sites upgraded to implement autonomous network control.

A set of detailed commissioning tests will be utilised on all site installations, including the sites where the SATs will also be undertaken.

Table 1 - Summary of Site Acceptance Testing

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

Cyber-security testing is a multi-phased process, and will not be completed until after the deployment of the trial hardware and a period of operation to evaluate performance. At the time of writing, prior to initial hardware deployment, a cyber-security evaluation has been undertaken to confirm the suitability of the LV-CAP™ platform for deployment as part of the trials.

NCC Group, the cyber-security specialised contracted to the Project have confirmed cyber-security tests and overall evaluation will be undertaken in parallel with the equipment deployment and will inform updates to the platform where necessary.

It is not intended to undertake tests relating to the cyber-security requirements as part of 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 requirements will be appraised separately by NCC Group, the OpenLV Project's cyber-security specialist.

2 Site Acceptance Tests Methodology

At the point of equipment deployment, elements of the overall OpenLV solution, (e.g. the LV-CAP™ platform code, the management and control server, and software containers), are unchanged from the testing undertaken within EA Technology's and project partner facilities to the point of deployment to site. Furthermore, with the majority of system components being software based, these are unlikely to be affected by a physical change in the hardware's location.

Therefore, the SATs detailed in this document focus on ensuring the system continues to operate as expected despite no longer being based in a controlled environment and following the disconnection, relocation and reconnection of the system's primary hardware and ancillary devices. The SATs therefore comprise a number of tests to verify the system's overall functionality is unaffected following transport and installation.

Due to the interconnected nature of the system and components, rather than replicating the full range of individual tests undertaken as part of the FATs, the SATs can be undertaken through a reduced number of tests by utilising targeted testing. This ensures the full process of operation, from the point of data gathering from the LV network to uploading the processed information, generated from the data, to the connected servers and therefore, that each individual component, comprising predominantly of software containers, is operating correctly.

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, and consequently multiple modules and software components are functioning as expected.

2.1 Setup Details

2.1.1 Login details

To undertake the tests detailed in this document, two forms of access to the Intelligent Substation Device (ISD) are required.

1. Local access via a laptop; and
2. Remote access via the modem within the ISD.

The local connection will be achieved through a laptop and a direct ethernet connection, that requires the use of a unique secure encryption key.

Remote access to the modem within the ISD, via a Virtual Private Network (VPN) connection, for staff based at EA Technology's offices will also be required.

To undertake the tests, the following additional computers, beyond the LV-CAP™ platform, will be required:

- 1x laptop on-site to provide direct access to and control the router modems within the enclosure.
- 1x computer in EA Technology offices to provide access to the iHost control server.

The tests will verify correct installation of monitoring sensors and consequently, the below devices will also be required:

- Handheld ammeter, appropriately rated to allow measurement of the LV network assets (busbar feed and individual feeder phases).
- Thermometer capable of undertaking ambient temperature readings.

2.2 Pre-deployment work

Prior to the deployment of equipment to the network for the trials, each set of hardware will be set-up and tested by EA Technology to confirm it is operating as expected. These tests will cover:

- Correct functionality of the LV-CAP™ platform;
- Correct functionality of the GridKey MCU520 platform;
- Connectivity between the MCU 520 and the LV-CAP™ platform;
- Connectivity between the LV-CAP™ platform and router modem;
- Successful bi-directional communications through the router modem;
- LV-CAP™ access to the iHost Command and Control Server; and
- LV-CAP™ access to the Lucy Electric Cloud Data Server.

All sets of LV-CAP™ equipment will be tested and verified as being fully operational before shipment to site, with the SATs and commissioning tests designed to verify the shipping and installation process have not inadvertently introduced issues.

Between testing at EA Technology and installation on-site, the following elements will be changed:

- **Location**: Whilst the LV-CAP™ platforms will communicate via the 3G / 4G network through the internal router modem, the units will be reactivated onsite for connection to different cell towers. This requires verification that the system can establish communication links to the rest of the Project systems.
- **Thermocouple sensors**: The thermocouples will be disconnected to ensure safe transit and will be installed and reconnected on-site. It will be necessary to verify that the thermocouples are still operating correctly, and have been connected to the correct inputs.
- **GridKey sensors**: the GridKey sensors will be disconnected for safe transit before being installed onsite and reconnected back to the LV-CAP™ platform. It will be necessary to verify that the sensors have been installed and reconnected correctly.
- **iHost Command and Control Server**: It is necessary to verify that the LV-CAP™ platform can connect to the iHost server and receive data from the server.
- **Lucy Electric Cloud Data Centre**: It is necessary to confirm that the LV-CAP™ platform can upload data to the cloud based server.

On completion of the pre-deployment testing process, the sensor container in the LV-CAP™ platforms will be configured to output data at ten-second intervals to expedite testing on-site once the equipment is energised and online. Once on-site testing, (SATs and commissioning as required) is complete, the rate of sensor reading will be reverted to one-minute intervals.

Some sites will require two rounds of SATs, with the second necessary at locations where ALVIN Reclose™ devices are to be installed. In these instances, when the ALVIN Reclose™ devices are deployed, they will have been fully tested prior to issuance from EA Technology, and will be tested with the LV-CAP™ platform in-situ to verify successful communications and relay operation.

2.3 Phase 1 Site Acceptance Tests – Initial deployment

For the avoidance of doubt, some sites in which the ISD enclosures and monitoring equipment are installed will be upgraded later in the project with the installation of ALVIN Reclose™ devices and separate SATs will be undertaken to verify the successful installation and operation of those components and associated software. This document will be updated to detail the Phase 2 tests in advance of the deployment of the ALVIN Reclose™ devices to implement the network automation functionality.

All equipment will be installed in accordance with the agreed method statements prior to commencing these tests.

Prior to commencing any SATs, the enclosure shall be installed in the location agreed during the site surveys, as will the MCU520 platform, and all ancillary equipment (Rogowski coils and thermocouples). All cables shall be routed using cable ducts or equivalent, as available, and appropriate within the substation in question.

The enclosure shall not be energised and made live until all work elements are complete. Once energised, the ISD will be fully connected and energised, being left for a period of at least several minutes to enable it to initialise all software applications and communication links in preparation for the tests to commence.

2.3.1 On-site testing approach

The on-site testing approach will demonstrate the following high-level capabilities of the system once installed.

A system overview, highlighting the key hardware elements and the interconnecting communication links is shown below.

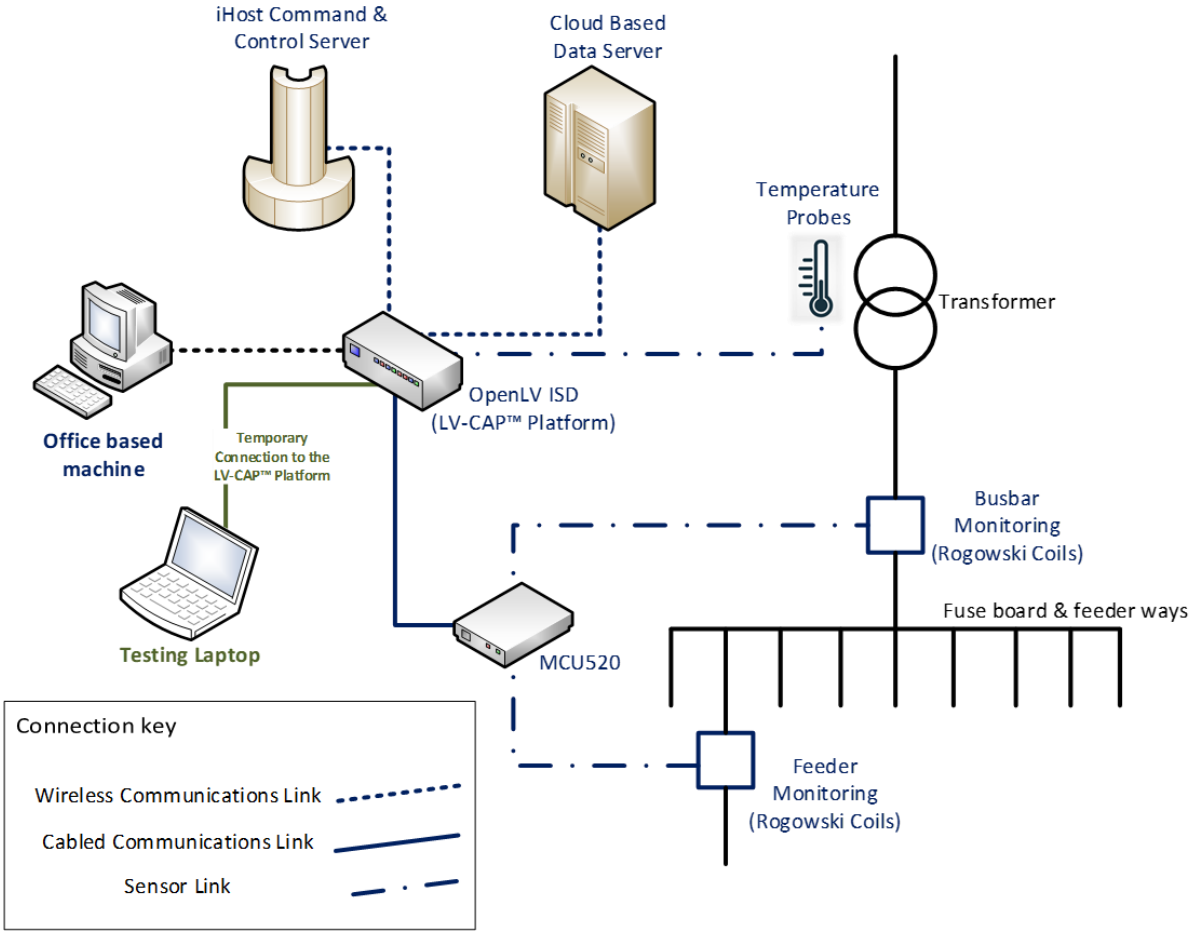


Figure 1 – OpenLV Trial System Overview

Each sequence of tests detailed in Section 3 are designed to test a specific part of the system shown above: either individual components, or interconnections between them, and outline:

- The objectives of the overall test sequence;
- The initial required conditions; and
- A list of numbered actions with their corresponding expected results.

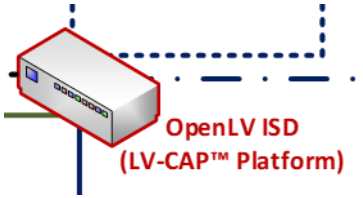
If successful, these sequence of tests, demonstrate the hardware, communication links and associated software containers previously verified as operational in the FATs and pre-deployment tests, continue to operate as expected in the new location of the equipment.

Consequently, successful completion of the FATs confirms that:

1. The system has been successfully energised with the LV-CAP™ platform running as expected;
2. The GridKey MCU520 has successfully energised and is communicating with the LV-CAP™ platform;
3. The sensors have been installed correctly and are successfully communicating with the MCU520;
4. The thermocouples have been installed correctly and are providing accurate data to the LV-CAP™ platform;
5. The router / modem is operational and communicating successfully to both the LV-CAP™ platform and the mobile data network;
6. That remote access can be achieved directly to the router / modem;
7. That remote access can be achieved to the LV-CAP™ platform through the router / modem;
8. That the LV-CAP™ platform is successfully transmitting data to the iHost and the Cloud Data Servers; and
9. That the LV-CAP™ platform can be updated remotely using the router / modem mobile data connection.

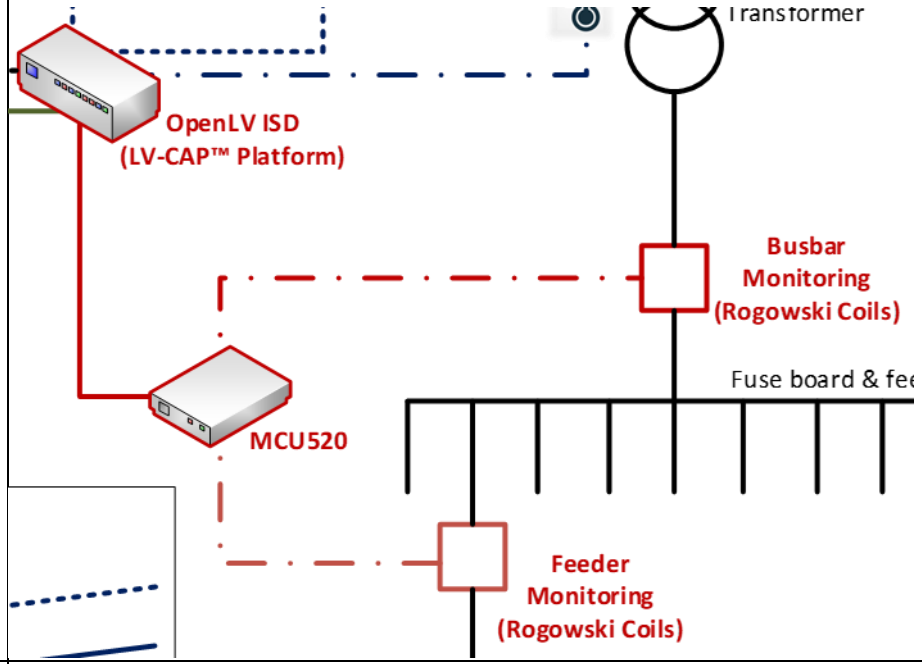
3 Site Acceptance Tests

Test: SAT 1.01

Objective:	To confirm the industrial PC is operational, has activated successfully and that the LV-CAP™ platform is operational.			
Elements under test:	 This test sequence is concerned with verifying the Ruggedised PC within the Intelligent Substation Device remains operational. In order to be successful, the following elements must be functioning correctly: • Nortech Communications Container • Load Profile Predictor • CSV Data Recorder • Lucy Electric Sensor Container • Lucy Electric Communications Container • Temperature Sensing Application			
Starting condition:	The ISD enclosure shall be installed in line with the method statement and specific on-site requirements. It will have been energised and left for a period of several minutes to enable the system to start-up without interference.			
Test sequence:		***Action***	***Expected result***	***Pass / Fail***
	1	Open the enclosure and connect the testing laptop to an ethernet port on the industrial PC.		
	2	Log into the LV-CAP™ platform.	A secure connection should be established. If the system is not online, disconnect the testing laptop, restart the ISD enclosure then restart this test sequence.	Pass ☐ Fail ☐

	3	Access the management console for the LV-CAP™ platform and verify that expected software containers are operational.	The following software containers should be active: • Nortech Communications Container • Load Profile Predictor • CSV Data Recorder • Lucy Electric Sensor Container • Lucy Electric Communications Container • Temperature Sensing Application	Pass ☐ Fail ☐
Comments:				

Test: SAT 1.02

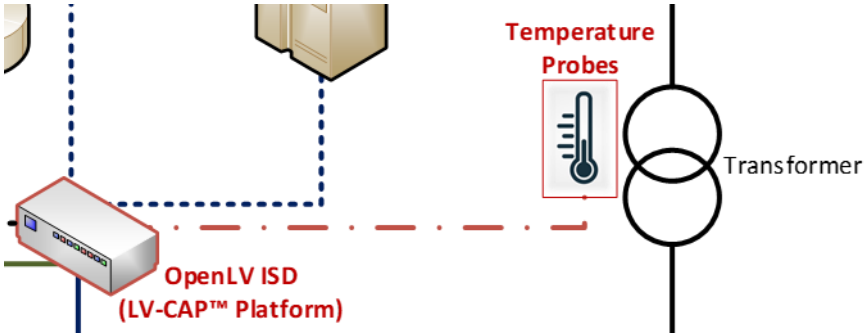
Objective:	To verify the MCU520 is communicating successfully with the LV-CAP™ platform and that the sensors providing data to the MCU520 have been installed correctly.
Elements under test:	 This test sequence is concerned with verifying the MCU520 and associated monitoring devices (Rogowski Coils) are operational and correctly installed. In order to be successful, the following elements must be functioning correctly: • Rogowski Coils; • MCU520; • Wired communications link between the MCU520 and the LV-CAP™ platform; and • MCU520 Sensor Container.
Starting condition:	The ISD enclosure shall be installed in line with the method statement and specific on-site requirements. This test sequence shall follow from the previous test, 1.01, and consequently, the testing laptop shall be already connected. If for any reason the testing laptop is not connected, follow step 1 of Test SAT: 1.01 before commencing the steps of Test SAT: 1.02.

Test sequence:		*Action*	*Expected result*	*Pass / Fail*
	1	Using the testing laptop, monitor the MQTT message broker and confirm data readings are provided by the MCU520 platform at 10-second intervals.	Data should be published onto the message broker at 10-second intervals, providing the voltage at the busbars and current readings from both the Rogowski coils.	Pass ☐ Fail ☐
	2	Identify a suitable approach to use the portable ammeter to measure the current in each phase on the connection to the busbars.		
	3	Using the portable ammeter, monitor the current in the first phase of the power connector from the transformer and compare this reading against the equivalent reading published to the message broker.	The two readings should be the same, within a reasonable margin for error. If not, verify that the busbar Rogowski Coils are installed correctly (right direction) and connected to the correct terminal on the MCU520.	Pass ☐ Fail ☐
	4	Using the portable ammeter, monitor the current in the second phase of the power connector from the transformer and compare this reading against the equivalent reading published to the message broker.	The two readings should be the same, within a reasonable margin for error. If not, verify that the busbar Rogowski Coils are installed correctly (right direction) and connected to the correct terminal on the MCU520.	Pass ☐ Fail ☐
	5	Using the portable ammeter, monitor the current in the third phase of the power connector from the transformer and compare this reading against the equivalent reading published to the message broker.	The two readings should be the same, within a reasonable margin for error. If not, verify that the busbar Rogowski Coils are installed correctly and connected to the correct terminal on the MCU520.	Pass ☐ Fail ☐

	6	Identify a suitable approach to use the portable ammeter to measure the current in each phase on the feeder being utilised in the project.		
	7	Using the portable ammeter, monitor the current in the first phase of the feeder cable and compare this reading against the equivalent reading published to the message broker.	The two readings should be the same, within a reasonable margin for error. If not, verify that the feeder Rogowski coils are installed correctly (right direction) and connected to the correct terminal on the MCU520.	Pass ☐ Fail ☐
	8	Using the portable ammeter, monitor the current in the second phase of the feeder cable and compare this reading against the equivalent reading published to the message broker.	The two readings should be the same, within a reasonable margin for error. If not, verify that the feeder Rogowski coils are installed correctly (right direction) and connected to the correct terminal on the MCU520.	Pass ☐ Fail ☐
	9	Using the portable ammeter, monitor the current in the third phase of the feeder cable and compare this reading against the equivalent reading published to the message broker.	The two readings should be the same, within a reasonable margin for error. If not, verify that the feeder Rogowski coils are installed correctly (right direction) and connected to the correct terminal on the MCU520.	Pass ☐ Fail ☐
	10	Compare the three phase angles reported to the message broker.	The three phases should be separated by approximately 120 degrees, within the margins of reasonable monitoring error.	Pass ☐ Fail ☐

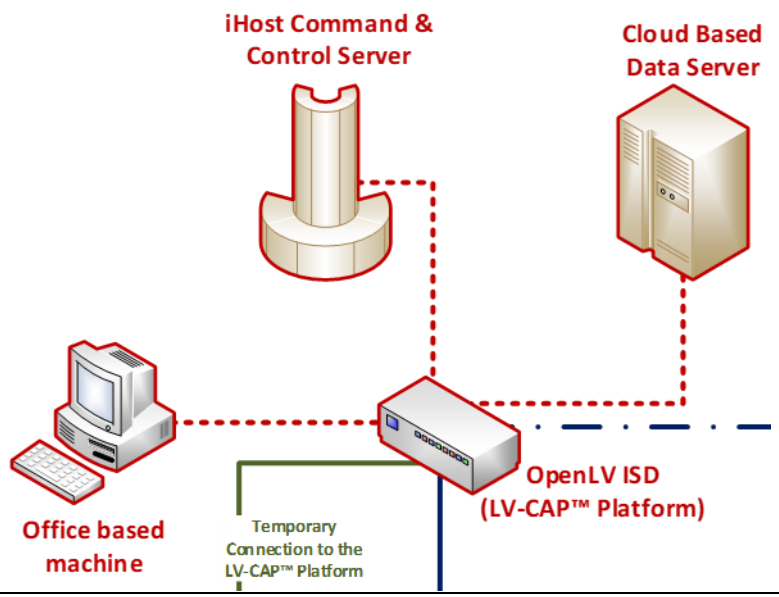
	11	The ability to complete the above tests provides assurance that the sensors, connections to the MCU520 platform and communication link between the MCU520 and LV-CAP™ platform are operating correctly.	It is expected that LV network readings will be published to the message broker allowing the previous stages to be successfully completed.	Pass ☐ Fail ☐
Comments:				

Test: SAT 1.03

Objective:	To verify that the thermocouples are providing reasonably accurate data into the LV-CAP™ platform.		
Elements under test:	 This test sequence is concerned with verifying the thermocouples are connected correctly to the LV-CAP™ platform and are functioning as expected. In order to be successful, the following elements must be functioning correctly: • Thermocouples (multiple, but quantity site dependent); • Digital I/O module; and • Thermal monitoring software container.		
Starting condition:	The ISD enclosure shall be installed in line with the method statement and specific on-site requirements. This test sequence shall follow from the previous test, 1.01, and consequently, the testing laptop shall be already connected. If for any reason the testing laptop is not connected, follow step 1 of Test SAT: 1.01 before commencing the steps of Test SAT: 1.03.		
Test sequence:		***Action***	***Expected result***	***Pass / Fail***
	1	Using the testing laptop, monitor the MQTT message broker and confirm data readings are provided by the thermal monitoring software at 10-second intervals.	Data should be published onto the message broker at 10-second intervals, providing temperature readings for each connected thermocouple.	Pass ☐ Fail ☐
	2	Using the handheld thermometer, determine the outdoor air temperature of the substation in close proximity to the location of the thermocouple installed within the radiation shield.	The reading provided by the thermocouple should be reasonably close to the separately monitored value.	Pass ☐ Fail ☐

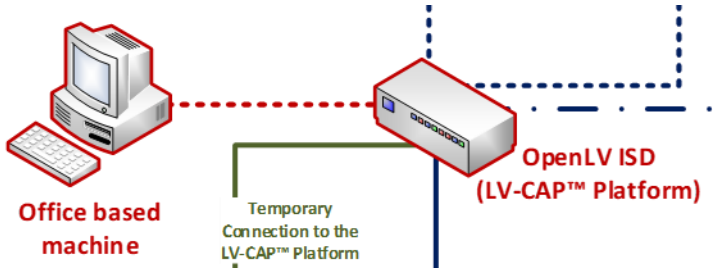
	3	If installing in an indoor substation: Using the handheld thermometer, determine the ambient air temperature of the substation in close proximity to the location of the thermocouple installed within the substation.	The reading provided by the thermocouple should be reasonably close to the separately monitored value.	Pass ☐ Fail ☐ N/A ☐
	4	In comparison to the temperature readings determined in steps 3 and 4 above, determine if the measured reading from the transformer thermocouple appears reasonable.	The reading provided by the transformer thermocouple should be warmer than the ambient air temperatures, although site specific conditions will determine by how much.	Pass ☐ Fail ☐
Comments:				

Test: SAT 1.04

Objective:	To verify that that data is being received by the iHost control server and the Cloud Data Server.		
Elements under test:	 This test sequence is concerned with verifying the router / modem is correctly recorded as being installed at the location in question and that the mobile data connection is capable of allowing remote access to the unit. In order to be successful, the following elements must be functioning correctly: • Router / modem module; • Mobile data network; • Connection to iHost Command and Control Server; and • Connection to Cloud Based Data Server.		
Starting condition:	The ISD enclosure shall be installed in line with the method statement and specific on-site requirements. This test does not require the use of the testing laptop, if it is still connected from the previous test sequence, disconnect it from the LV-CAP™ platform but do not close and seal the enclosure.		
Test sequence:		***Action***	***Expected result***	***Pass / Fail***
	1	On-site testing crew to telephone a designated, office-based colleague.		

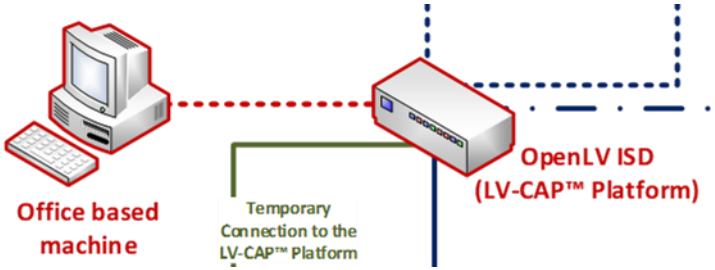
	2	Office-based test crew to login to the iHost Command and Control Server and verify that the LV-CAP™ platform in question has connected to the server and transferred data, at 10-second intervals.	iHost server contains data from the system having been uploaded since installation.	Pass ☐ Fail ☐
	3	Office-based test crew to login to the iHost Command and Control Server and verify that the LV-CAP™ platform in question has connected to the server and transferred data, at 10-second intervals.	Cloud based data server contains data from the system having been uploaded since installation.	Pass ☐ Fail ☐
Comments:				

Test: SAT 1.05

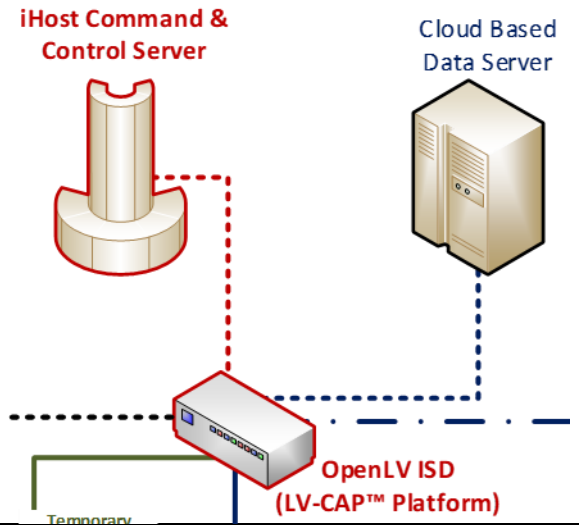
Objective:	To verify that: 1. The router – modem and SIM card combination installed within the ISD is correctly recorded; 2. The router – modem can be remotely accessed; and 3. That data transfer to the servers resumes after a system restart.		
Elements under test:	 This test sequence is concerned with verifying the router / modem is correctly recorded as being installed at the location in question and that the mobile data connection is capable of allowing remote access to the unit. In order to be successful, the following elements must be functioning correctly: • Router / modem module; and • Mobile data network.		
Starting condition:	The ISD enclosure shall be installed in line with the method statement and specific on-site requirements. This test does not require the use of the testing laptop, if it is still connected for any reason, disconnect it from the LV-CAP™ platform but do not close and seal the enclosure.		
Test sequence:		***Action***	***Expected result***	***Pass / Fail***
	1	On-site testing crew to telephone a designated, office-based colleague if not still connected to them from previous test-sequence.		
	2	Office-based testing crew to access the router / modem using the process detailed in 0.	Office-based crew should be able to access the router / modem command console.	Pass ☐ Fail ☐

	3	Whilst the on-site test crew watch the console, the office-based test crew should trigger a hard-rest of the platform.	If successful, the power relay for the LV-CAP™ platform will illuminate, confirming the correct modem was being communicated with and that remote reset capability is available for the site. Site-based test crew will confirm successful shutdown of the unit through lack of LED activity on network ports.	Pass ☐ Fail ☐
	4	Office-based test crew to re-energise the LV-CAP™ platform.	Site-based crew, will observe the relay light deactivate, demonstrating power has been restored the LV-CAP™ platform. Network ports on the platform will begin flashing signifying restoration of power to the unit.	Pass ☐ Fail ☐
	5	Site-based test crew to seal and lock the enclosure.		
Comments:				

Test: SAT 1.06

Objective:	To verify that the LV-CAP™ platform resumes communication with the iHost and Cloud Data Servers following a system restart.		
Elements under test:	 This test sequence is concerned with verifying the router / modem is correctly recorded as being installed at the location in question and that the mobile data connection is capable of allowing remote access to the unit. In order to be successful, the following elements must be functioning correctly: • Router / modem module; and • Mobile data network.		
Starting condition:	The ISD enclosure shall be installed in line with the method statement and specific on-site requirements. This test does not require the use of the testing laptop, if it is still connected for any reason, disconnect it from the LV-CAP™ platform then close and seal the enclosure.		
Test sequence:	***Action***	***Expected result***	***Pass / Fail***
1	Office-based test crew to login to the iHost Command and Control Server and verify that the LV-CAP™ platform in question has re-connected to the server and is transferring data, at 10-second intervals.	System will restart following the restoration of power and following a period of a few minutes, recommence uploading data to the servers.	Pass ☐ Fail ☐
Comments:			

Test: SAT 1.07

Objective:	To verify that remote update capability of the LV-CAP™ platform configuration can be achieved.
Elements under test:	 This test sequence is concerned with verifying the router / modem is correctly recorded as being installed at the location in question and that the mobile data connection is capable of allowing remote access to the unit. In order to be successful, the following elements must be functioning correctly: • IHost Command & Control Server; • Router / modem module; and • Mobile data network.
Starting condition:	The ISD enclosure shall be installed in line with the method statement and specific on-site requirements. This test does not require the use of the Testing Laptop; if it is still connected for any reason, disconnect it from the LV-CAP™ platform then close and seal the enclosure. The LV-CAP™ platform shipped following testing with the sensors configured for 10-second reporting and the outputs of those sensors assigned for upload to the iHost and Cloud Based Data Servers.

Test sequence:		*Action*	*Expected result*	*Pass / Fail*
	1	Office-based test crew to login to the iHost Command and Control Server and change the configuration settings for the site in question such that sensor reporting is only required at one-minute intervals.		Pass ☐ Fail ☐
	2	Office-based test crew to verify that data reporting back to the iHost and Cloud Based Data Servers reduces from a rate of once every ten seconds to once every minute.	The LV-CAP™ platform will reduce the rate of data capture and this will be reflected in a reduction in the data uploaded to the two servers.	Pass ☐ Fail ☐
Comments:				

OpenLV system tested elements

The below diagram, shows each element, (highlighted in red) of the deployed system that has been tested, as part of the Phase 1 SATs.

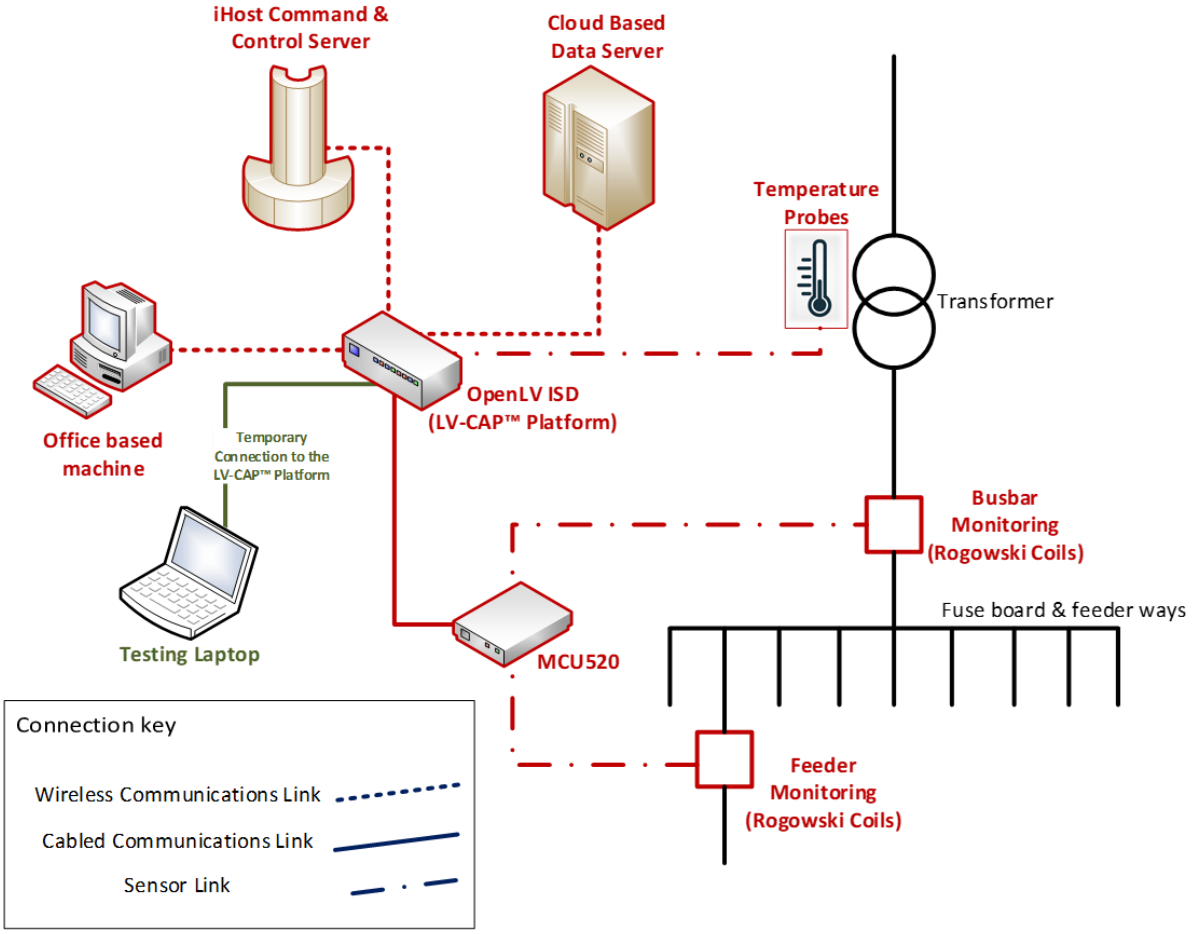
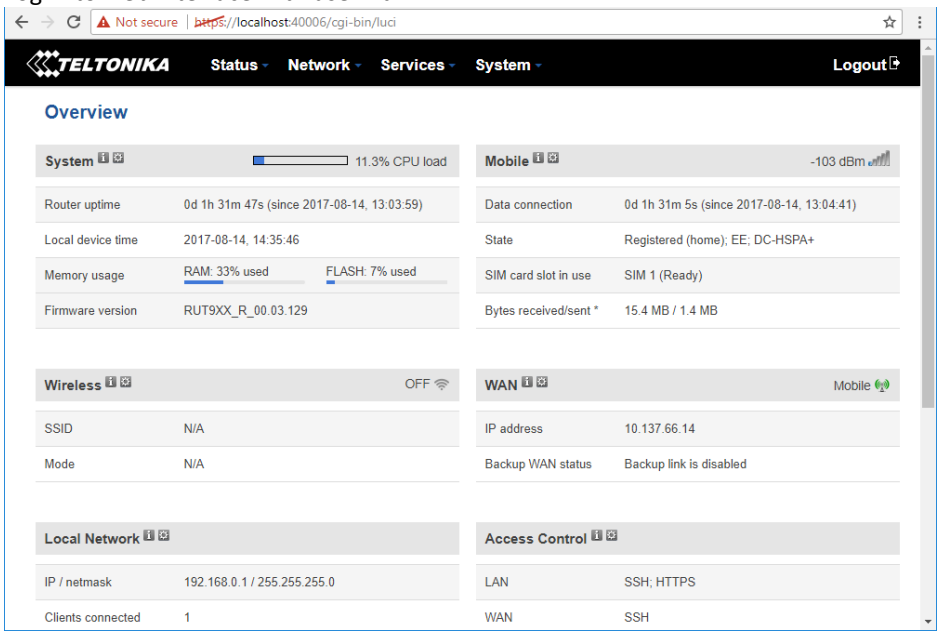


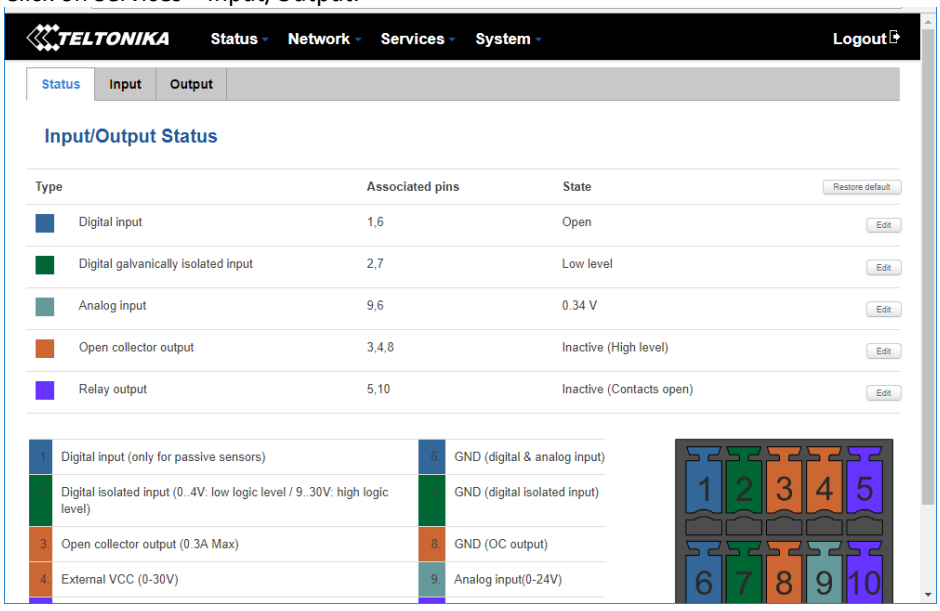
Figure 2 - OpenLV Trial System - Tested Elements

Appendix A. Router / modem access routine

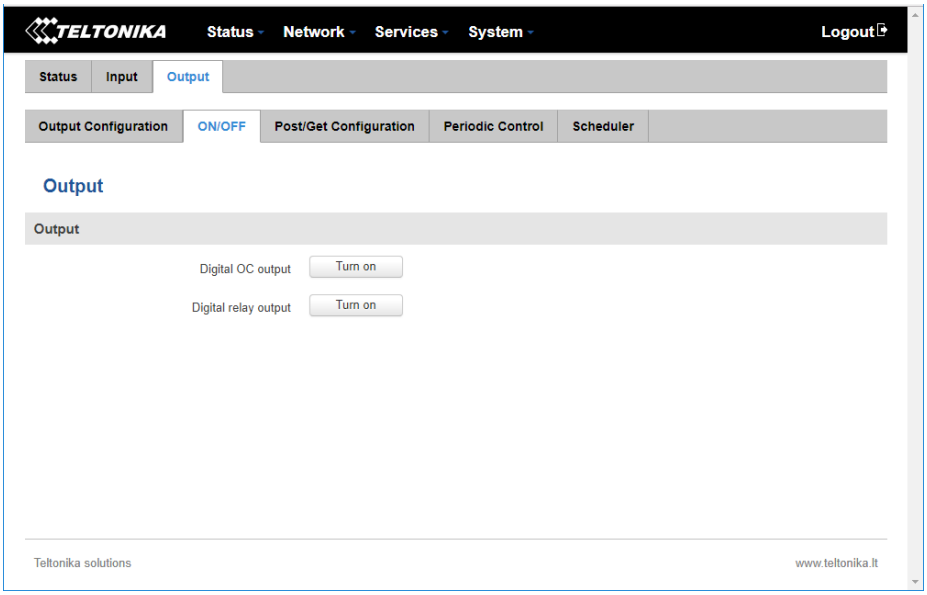
1. Connect to Wireless Logic SSL VPN (NetExtender) using user ssl_lv
2. Connect SSH session to 4G router using Putty:
   a. IP: see SIM records (10.x.x.x)
   b. Port: 8192
   c. Username: root
3. Forward local port “40006” (e.g.) to “localhost:443”
4. Open a web browser and connect to https://localhost:40006
5. Accept the security error for the self-signed router SSL certificate
6. Log in to web interface with user Admin



7. Click on Services > Input/Output.



8. Click on the Output sub-tab and then the ON/OFF sub-tab.



9. Click the “Digital OC output” Turn On button. This will remove power from the PC.

After the required delay, click the Turn Off button. This will re-apply power to the PC and allow it to start up.