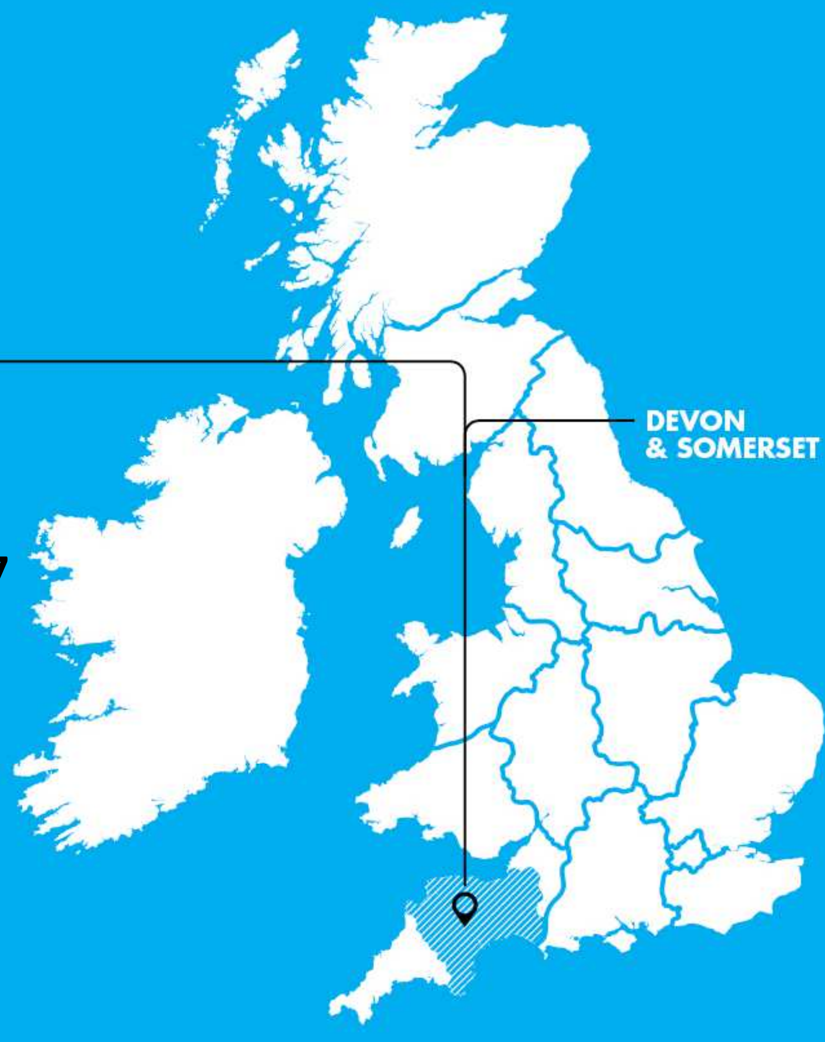
WESTERN POWER DISTRIBUTION

NETWORK EQUILIBRIUM

BALANCING GENERATION AND DEMAND



PROJECT PROGRESS REPORT

REPORTING PERIOD:

JUNE 2017 – NOVEMBER 2017

LCN Fund
Low Carbon Networks

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Contents

Glossary

Term	Definition
ABSD	Air Break Switch Disconnector
AC	Alternating Current
AIS	Air Insulated Switchgear
APT	Advanced Planning Tool
AVC	Automatic Voltage Control
BAU	Business as usual
BSP	Bulk Supply Point
CB	Circuit Breaker
CT	Current Transformer
DC	Direct Current
DG	Distributed Generation
DNO	Distribution Network Operator
EHV	Extra High Voltage
ENA	Energy Networks Association
ER	Engineering Recommendation
EU	European Union
EVA	Enhanced Voltage Assessment
FPL	Flexible Power Link
FTP	File Transfer Protocol
GB	Great Britain
GIS	Gas Insulated Switchgear
HSOC	High Set Overcurrent
HV	High Voltage
IDMT	Inverse Definite Minimum Time
IPR	Intellectual Property Register
ITT	Invitation to Tender
LCT	Low Carbon Technologies

LV	Low Voltage
LVAC	Low Voltage Auto Changeover
NMS	Network Management System
NOP	Normal Open Point
OCEF	Overcurrent Earth Fault
OHL	Overhead Line
OLTC	On Load Tap Changer
RTU	Remote Terminal Unit
SCADA	Supervisory Control and Data Acquisition
SDRC	Successful Delivery Reward Criteria
SLD	Single Line Diagram
SVO	System Voltage Optimisation
TSDS	Time Series Data Store
UK	United Kingdom
VLA	Voltage Level Assessment
VT	Voltage Transformer
WG	Working Group
WPD	Western Power Distribution

1 Executive Summary

Network Equilibrium is funded through Ofgem's Low Carbon Networks Second Tier funding mechanism. Network Equilibrium was approved to commence in March 2015 and will be complete by 14th June 2019. Network Equilibrium aims to develop and trial an advanced voltage and power flow control solution to further improve the utilisation of Distribution Network Operators' (DNO) 11kV and 33kV electricity networks in order to facilitate cost-effective and earlier integration of customers' generation and demand connections, as well as an increase an customers' security of supply.

This report details progress of the project, focusing on the last six months, June 2017 to November 2017.

1.1 Business Case

The business case for Network Equilibrium remains unchanged. The request for low carbon load and generation connections, as well as new storage connectors, in the project area, Somerset and Devon, continues to grow.

1.2 Project Progress

This is the sixth progress report. The period covered in this report is focussed on the completion of and testing of both the System Voltage Optimisation (SVO) tool and the Flexible Power Link (FPL). Site works of both Methods have continued to support the energisation of each Method in the next reporting period.

The Spectrum Power 5 (SP5) system, developed by Siemens, and the central controller of the SVO method has successfully undergone Factory Acceptance Testing (FAT) and System Integration Testing (SIT), where the system was successfully integrated and operated on our offline Network Management System (NMS). This is a significant operational and security milestone in transferring the SP5 system to our online NMS early in 2018.

The FPL designed and built by ABB, in this reporting period was successfully built and all FAT elements were completed. This enabled the delivery of the device and associated ancillary equipment to be delivered to Exebridge substation on the 15th November. This has enabled the work to fully install and commission the FPL system to start and energisation is planned, as previously, for March 2018.

These activities described above have provided significant progress towards the completion of the next two SDRCs 5 and 6.

1.3 Project Delivery Structure

1.3.1 Project Review Group

The Network Equilibrium Project Review Group met once during this reporting period. The main focus of this meeting was the resource and delivery requirements associated with the project as it transitions to the build and test phase.

1.3.2 Resourcing

The resourcing of the project remains as described in the previous reporting period, where the design team is led by WPD engineers and supported by WSP engineers.

1.4 Procurement

The procurement activities for Network Equilibrium focus on the SVO and FPL methods. Throughout the project supporting procurement activities will take place in order to facilitate the successful delivery of all project methods; however, there are two formal procurement activities as part of the project.

Table 1-1: Procurement Activities

Manufacturer	Technology	Applicable Substations	Anticipated Delivery Dates
Siemens	SVO System	16 Substations (Installed in 1 central location)	December 2017
ABB	FPL	Exebridge	April 2018

1.5 Installation

Construction and installation activities related to the SVO and FPL have continued in this reporting period:

- 11 complete SVO relay site installation;
- 1 remote end monitoring installation; and
- FPL compound civil works completed and delivery of device.

Into the next reporting period the change and upgrading of the Automatic Voltage Control (AVC) relays will be completed and the FPL will be installed, commissioned and energised.

1.6 Project Risks

A proactive role in ensuring effective risk management for Network Equilibrium is taken. This ensures that processes have been put in place to review whether risks still exist, whether new risks have arisen, whether the likelihood and impact of risks have changed, reporting of significant changes that will affect risk priorities and deliver assurance of the effectiveness of control.

Contained within Section 8.1 of this report are the current top risks associated with successfully delivering Network Equilibrium as captured in our Risk Register along with an update on the risks captured in our last six monthly project report. Section 8.2 provides an update on the most prominent risks identified at the project bid phase.

1.7 Project Learning and Dissemination

Project lessons learned and what worked well are captured throughout the project lifecycle. These are captured through a series of on-going reviews with stakeholders and project team members, and will be shared in lessons learned workshops at the end of the project. These are reported in Section 6 of this report.

A key aim of Network Equilibrium is to ensure that significant elements of the work carried out for network modelling, monitoring, design and installation are captured and shared within WPD and the wider DNO community. During this period the main focus has been to capture the learning of all three methods' progress to report in SDRCs 5 and 6.

In addition to this we have shared our learning (where applicable), through discussions and networking at a number of knowledge sharing events hosted by other organisations.

2 Project Manager's Report

2.1 Project Background

The focus of Network Equilibrium is to balance voltages and power flows across the distribution system, using three Methods to integrate distributed generation within electricity networks more efficiently and delivering major benefits to distribution customers.

The Problem that Network Equilibrium addresses is that electricity infrastructure in the UK was originally designed and developed for passive power distribution requirements. As a result, the integration of significant levels of low carbon technologies (LCTs) within our present electricity networks can cause voltage management and thermal issues. For business as usual (BAU) roll-out we need to develop solutions, which take a strategic engineering approach, considering the whole system and not solving constraints on a piecemeal basis. The Problem is being investigated using three Methods, and their applicability to 33kV and 11kV distribution networks assessed. Each involves testing within South West England:

(1) Enhanced Voltage Assessment (EVA);
(2) System Voltage Optimisation (SVO); and
(3) Flexible Power Link (FPL).

The aims of Equilibrium are to:

- Increase the granularity of voltage and power flow assessments, exploring potential amendments to ENA Engineering Recommendations and statutory voltage limits, in 33kV and 11kV networks, to unlock capacity for increased levels of low carbon technologies, such as distributed generation (DG);
- Demonstrate how better planning for outage conditions can keep more customers (generation and demand) connected to the network when, for example, faults occur. This is particularly important as networks become more complex, with intermittent generation and less predictable demand profiles, and there is an increased dependence on communication and control systems;
- Develop policies, guidelines and tools, which will be ready for adoption by other GB DNOs, to optimise voltage profiles across multiple circuits and wide areas of the network;
- Improve the resilience of electricity networks through FPL technologies, which can control 33kV voltage profiles and allow power to be transferred between two, previously distinct, distribution systems; and
- Increase the firm capacity of substations, which means that the security of supply to distribution customers can be improved during outage conditions, leading to a reduction in customer interruptions (CIs) and customer minutes lost (CMLs).

2.2 Project Progress

This is the sixth progress report. The focus of this reporting period has been finalising the build elements of both the SVO and FPL systems. The build of the Siemens SP5 system, as part of SVO, was successfully built, FAT and SIT tested. The site works to enable the dynamic voltage settings to be realised on site has continued with 12 of the 16 sites now complete. This period has also seen the design, build and installation of the first remote end monitoring system, which enables the SVO system to ensure that at no point on the network is the voltage outside of statutory limits. Previously the FPL's power electronics had been built and tested; this reporting period has seen the successful build and testing of the FPL transformer and software system. These successful tests, along with the completion of the FPL compound site works enabled the delivery of the complete device to site on the 15th November. In order to maximise the value of the two methods and ensure that a reduced period of project trials to business as usual operation is possible the plugin development has continued. The SVO plugin, built within PSS/e, has been built and tested, which will enable system planners to benchmark the benefits of the SVO over traditional network planning and reinforcement requirements. This will be finalised, trialled and reported in the next period and will form a key part of the learning to be captured in SDRC 5.

2.3 Voltage Limit Assessment

During this reporting period, a desktop study was carried out to assess the potential gains in network capacity for generation from the adjustment of the statutory voltage limits on the 33kV network from ±6% to ±10%. This analysis was carried out for the eight Bulk Supply Points (BSPs) with SVO being applied to them and was carried out on a model with demand at 30% of its maximum and no existing generation, to ensure worst case scenarios were used.

2.3.1 Methodology

The chosen method for determining the additional capacity released was to add a single generator on the 33kV network at each primary substation. All the generators would then be increased until a voltage or thermal constraint was found on any feeder or BSP transformer. The generator within the network that triggered the constraint was then locked and the remaining generators increased. This process was then repeated until all generators were locked.

This methodology may not identify the absolute maximum generation capacity of the network being studied, however, by using the same methodology at both voltage limits it was suitable for identifying the additional capacity that could be released in each network.

2.3.2 Results

A summary of the results for each substation is shown in Table 2-1 below.

Table 2-1: Summary of VLA Results

Substation	±6% Voltage Limit	±10% Voltage Limit	% Capacity Increase
Bowhays Cross	118.5	129.5	9.28%
Bridgwater	145.5	149.5	2.75%
Exeter City	159.5	158.5	-1.00%
Exeter Main	74.0	74.0	0.00%
Paignton	158.0	158.0	0.00%
Radstock	147.5	147.5	0.00%
Taunton Main	130.0	130.0	0.00%
Tiverton	81.5	81.5	0.00%

With the chosen methodology it was found that across all the networks it was more likely that the thermal limit of a circuit or transformer was reached before a voltage limit. This led to many networks showing no capacity increase when voltage constraints are relaxed. It should be noted that this is specifically when the network is in its in-tact arrangement rather than being in N-1 configuration, whereby voltage is often the limiting factor to connection. This will be further investigated in the next reporting period.

The results for Exeter City show a reduction in capacity of 1MW when the voltage limits are increased. On analysing the details of the studies it was shown that this was caused by modelling variations in the transformer voltage profiles. The limiting factor in this network is the thermal capacity of the BSP transformers; therefore this reduction was deemed not significant and was treated as a zero difference.

Analysis of the networks studied showed that Bowhays Cross and Bridgwater networks were the most radial in nature with relatively high impedance circuits, causing higher voltage rise. BSPs with mainly ring circuits or short, low impedance radial feeders did not benefit from a change in voltage limits.

2.4 SVO Studies Plugin

In order to access the impact of the SVO system and to begin the transition to business as usual, plugin tools are being developed to replicate the behaviour of the SVO system within WPD's current power system studies software. The aim is to enable planning engineers to benchmark the benefits of SVO whilst it's in the trials phase against traditional network reinforcement options.

During this period the SVO plugin tool was developed and a soft handover of the tool to WPD system planners for assessment carried out.

2.4.1 Tool Interface

The tool has been developed with its own Graphical User Interface (GUI) within the PSS/e operating environment for ease of use by the end user. In this regard many functions of the tool have been automated to minimise the risk of user error and running time. Many of the inputs are populated with data, with the user able to adjust several configurable parameters to manipulate the operation of the SVO. These include the upper and lower voltage limits and the number of spare taps to remain at both the top and bottom of the tap changer range.

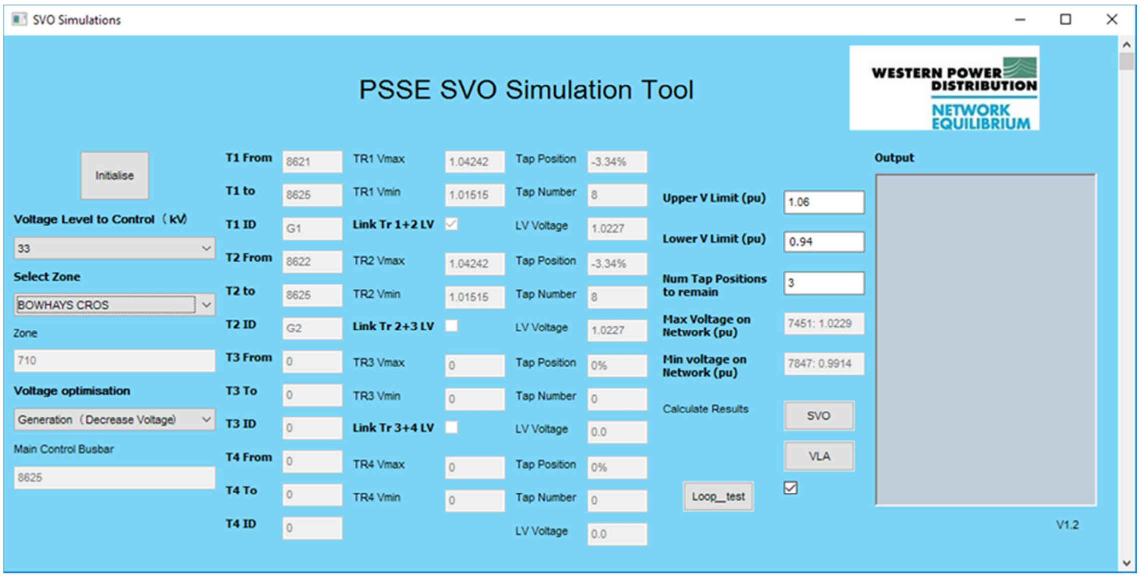

Figure 2-1: SVO Simulation Tool Input Window

Following the completion of a study the results are shown in the output window within the tool interface and exported in spreadsheet format for further analysis if desired.

2.4.2 User Manual and Operation

To assist end users with the operation of the plugin tools, a manual has been created for the plugin tool. This provides a detailed walkthrough of the interface including each user selectable input field. The manual also provides an overview of the algorithms used to carry out the various studies and the known limitations of the current tool.

The tool is designed to import data from the network model after a click on the initialise button. Following this the user is able to select the voltage level and then substation that SVO is to be applied via drop down boxes. Once the optimisation target and limits are confirmed it is then possible to run the required studies using the various buttons within the interface. A file input box is also available for the loading of network data for time series studies.

The tool will import network data from the pre-loaded model allowing the user to apply SVO at any substation. The tool is able to optimise for both generation and load connections either minimising or maximising the network voltage respectively. Once a study has been completed the data is outputted in a spreadsheet format for further detailed analysis.

Through modification of the original PSS/e system save case it is possible to run the same studies on various network topologies to assist with all aspects of planning. For example, N-1 contingency scenarios or the transfer of loads between BSP's during outage conditions.

2.4.3 Studies

The SVO tool has been developed to carry out a variety of static, single studies and dynamic time series studies, using historical network data.

Static

For the static SVO studies, the tool will complete a voltage optimisation based on the user defined model loaded into PSS/e. The tool will run reducing the transformer target voltage either up or down as required. This is ideal for carrying out studies for worst case scenarios for a fast analysis of potential SVO performance.

Dynamic

By utilising historic time series network data, the tool can operate in a more dynamic nature; calculating set points based on actual network load and generation data. This can then be used to verify the operation of the live SVO system and also enable system planners to analyse the effect of SVO when carrying out studies for customer connections. Figure 2-2 below shows the variation in the calculated SVO target voltage compared to the existing static voltage set point.

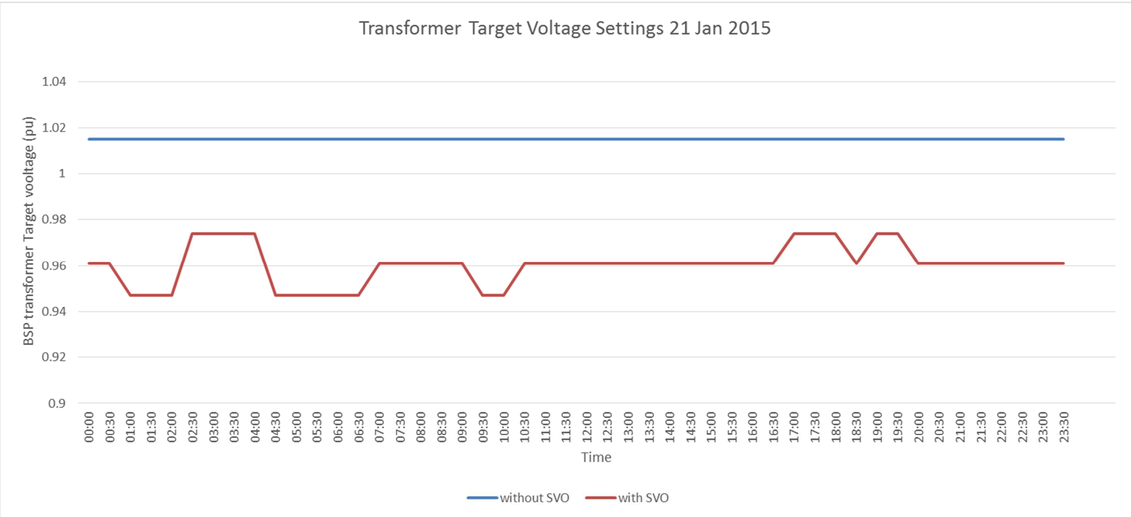

Figure 2-2: Existing Tapchanger Set point vs. SVO set point for a 24hr Period

Voltage limit assessment (Network capacity)

For both static and dynamic SVO, it is possible to carry out a Network Capacity assessment studies to estimate the additional generation capacity released at a substation from the deployment of SVO. This study utilises the same base methodology as the Voltage Limit Assessment work described above. The study is run with and without SVO operating to enable a direct comparison. Figure 2-3 below shows a comparison for a single day of the current available capacity and the potential capacity with SVO enabled.

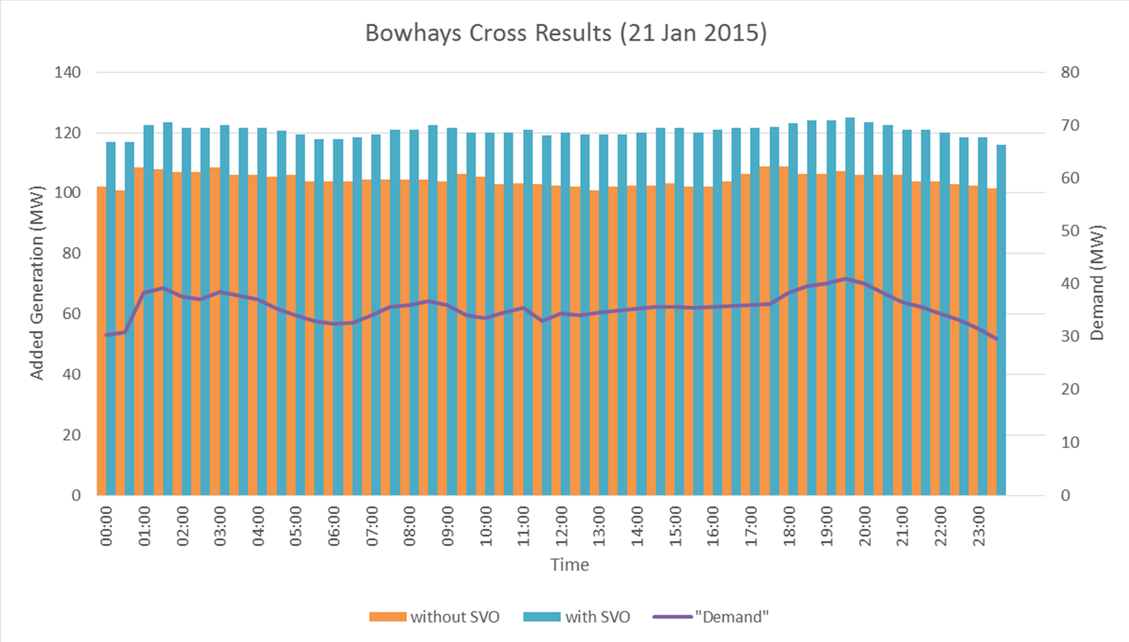

Figure 2-3: Comparison of Generation Capacity with and without SVO enabled

In this example, it can be seen that deployment of SVO increases the network capacity for generation by almost 20MW. As expected the total capacity released value is proportional to the demand, reflecting the fluctuations over time. A key element of SDRC 5 will be to determine if this initial learning is represented when utilising the live and dynamic system over a number of sites.

2.5 System Voltage Optimisation

The SVO method of Network Equilibrium aims to dynamically manage the voltages in the network to maximise the level of Low Carbon Technologies (LCT) that can be connected to network while maintaining statutory limits.

In this reporting period work has focused on the creation of the new IPSA network models, the Factory Acceptance Testing (FAT), the Spectrum Power 5 installation and the System Integration Testing (SIT).

2.5.1 SVO Software System

Progress since previous reporting period

After the import of the APT IPSA network models into Spectrum Power 5 during the previous reporting it period has shown that the models required refinement, the IPSA models were re-created using data from WPD’s Geographical Information System (GIS). Additionally, the SP5 system installation was successfully completed following the previous preparations of the hardware. In July 2017, the FAT took place in Nuremberg, Germany, and in October the SIT was held at WPD’s NMS testing facility.

In this report, the methodology followed to re-create the IPSA models and the learning obtained from the process is discussed. WPD’s installed Spectrum Power 5 system is presented and an overview of the planning and preparations completed for the FAT and SIT is provided with recommendations about the best approaches to ensure successful testing and system integration.

Network Model Creation from GIS

Spectrum Power 5 requires 16 network models, one for each of the 16 SVO controlled substations. These electrical network models are necessary for the state estimation that will be performed in order to estimate the power flows and voltages at the points in the network where there are no real-time measurements.

Continuing from the work completed in the previous reporting period, the plan originally was to update the APT IPSA models which were imported into Spectrum Power 5 to perform corrections and refinements. Due to the complexity in correcting them and the criticality of the models in the successful system operation, it was decided to instead re-build them.

The network model creation process involved using WPD's GIS to obtain information about the electrical connectivity of each network (feeder impedances, demand and generation connection points) and then using a conversion tool, which was developed as part of the previous FlexDGrid project, to build a network model in PSS/e. Since SP5 supports the import of IPSA models, the PSS/E models were first converted in that format. All switching components (circuit breakers and isolators) were manually added to the converted IPSA models and the schematic representation of the models was arranged to match the representation of the models in the NMS. The NMS and IPSA model representation is shown in Figure 2-4.

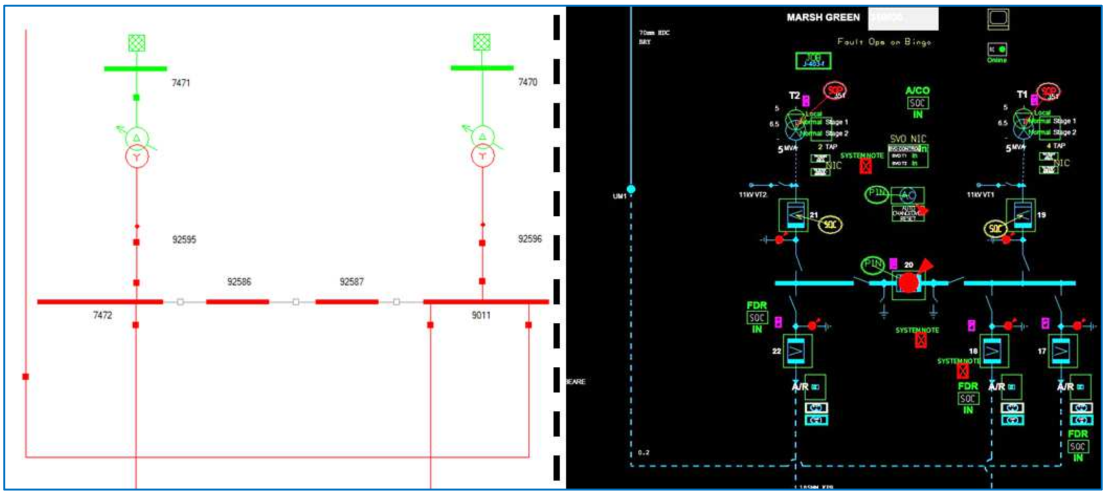

Figure 2-4 IPSA model (left) and NMS (right) representation

The naming of the components (switches, transformers) in the IPSA model was done in such a way to match the NMS. This enabled the mapping of the Supervisory Control And Data Acquisition (SCADA) data points between the NMS and network models to be done efficiently, producing one SCADA mapping table for each network model.

All 16 models were completed in September and provided to Siemens for the SP5 import. The entire model creation process is summarised in Figure 2-5.

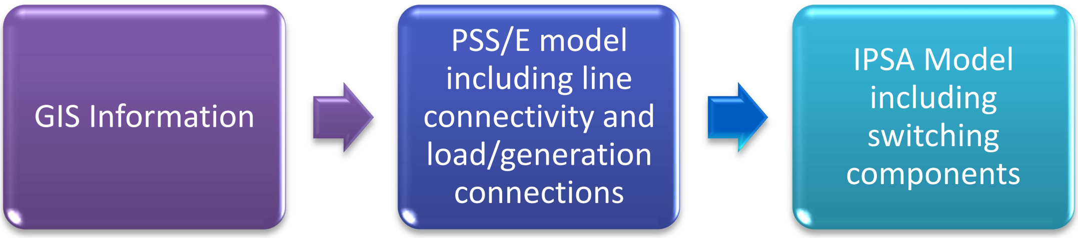

Figure 2-5 Network Model Creation Process

All the models have now been successfully integrated in to SP5. The validation of the models involved:

- Confirming that the IPSA and SP5 diagrams were identical by performing visual checks;
- Comparing the power flow results of the two models and calculating the variance; and
- Running the state estimation in SP5 using a 2-hour capture of instantaneous SCADA analogues to ensure that the SCADA data points were mapped to the model correctly.

WPD's SP5 System

WPD's Information Resource (IR) team and Siemens performed the installation of SP5 on WPD's hardware in June 2017. As part of this, the first SP5 users were configured and the SVO/NMS teams were able to start familiarising with the system. The successful remote access to the system over the Virtual Private Network (VPN) connection configured in the previous period was also confirmed and used numerous times as part of the installation activities.

User Interface and System Access

The User Interface of SP5 allows access to the different modules of the software and displays the status of the different alarm categories.

As shown in Figure 2-6, the SP5 Toolbar is displayed at the top of the User Interface, allowing access to any other applications on the virtual machine while still providing visibility of the system status.

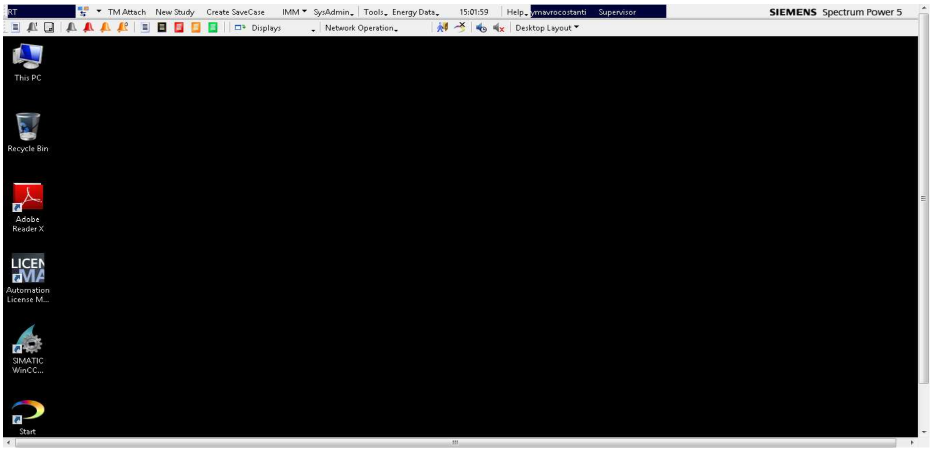

Figure 2-6 SP5 User Interface

From the main toolbar, the user can also open the SVO network model displays through the Displays menu shown in Figure 2-6. An example of the network models is demonstrated in Figure 2-7 where the SP5 model of one of the SVO controlled primary substations is compared to the IPSA model. As can be seen, the models are identical, confirming the successful import of the model.

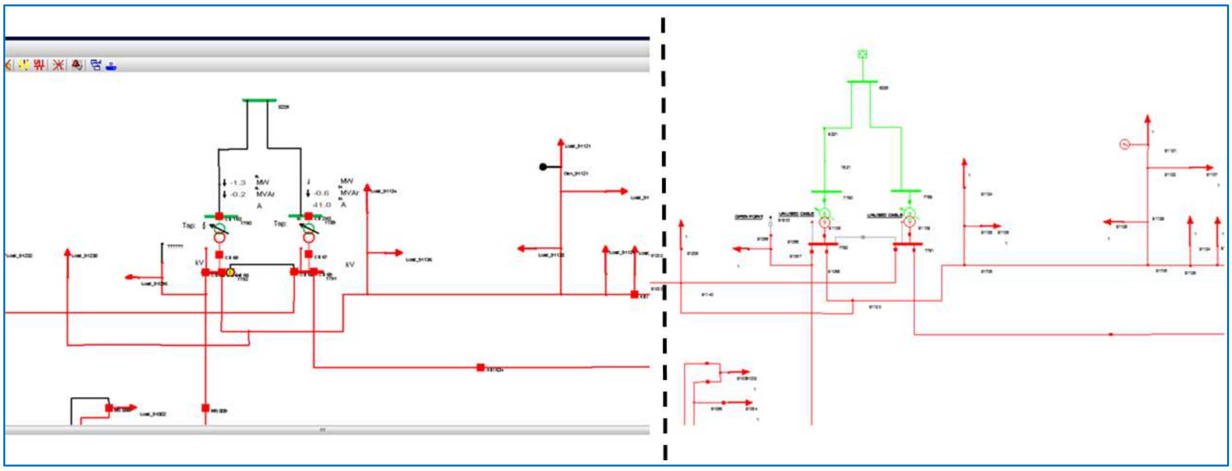

Figure 2-7 SP5 Model Display (left) and IPSA model (right) for an SVO controlled Primary substation

The access the user has available to the different parts of the system depends on their user type. The user types of “Control Engineer”, “Administrator”, “Viewer” and “Updater” have been configured on SP5, enabling the access to be confirmed by Administrator users.

FAT – Preparations and testing

The FAT involved the testing of SP5, with the aim to prove the correct functionality of the different software modules. It took place at Siemens’ offices in Nuremberg, Germany, in July 2017.

The testing setup involved Siemens’ SP5 system which was a replication of WPD’s SVO SP5 system, connected to a simulation tool representing the NMS side and the Inter-Control Centre Communications Protocol (ICCP) link.

In order to ensure that the testing would be done under realistic conditions, it was planned for all of the tests to be performed using real SCADA data. Therefore, as part of the preparations for the FAT, an extract of 2-hours instantaneous SCADA data was captured and exported from the NMS. During the testing, this data was fed into the simulation tool which was sending the data to SP5 over ICCP. The FAT test setup is shown in Figure 2-8.

Figure 2-8 FAT Test Setup

In order to test specific operating conditions, the data in the simulation tool was manually changed at different points during the testing to reflect the scenario that had to be tested.

SIT – Preparations and testing

The SIT took place at WPD's Bristol office in October 2017 and aimed to test the integration of SP5 with the offline NMS, the ICCP communications, the correct operation of each part of the SVO system and the functionality of SP5 when interacting with the NMS.

As part of the pre-SIT work, each system (SP5 and NMS) was prepared separately but the configuration of both systems was very closely coordinated.

The establishment of the ICCP link is the most important part of the integration works, therefore it was prioritised and efforts were made to ensure it is completed before the commencement of the SIT. This was achieved by ensuring that both sides (SP5 and NMS) have the same understanding of the agreed ICCP parameters and Bilateral Table.

One of the main learning points gained as part of the ICCP work, is that it is important to ensure not only that the ICCP Bilateral tables agree but also that both sides interpret the ICCP values in the same way. For example, a value of "Closed" for the "SVO IN" indication could be interpreted as the indication being on but it could also be interpreted as the indication being off depending on the point of view of each person. To ensure that both parties communicating over ICCP have the same interpretation, the meaning of each value of each point should be documented and mutually agreed.

The ICCP link between the NMS and SP5 was successfully established before the commencement of the SIT. An extract from SP5 demonstrating the data exchange over ICCP is shown in Figure 2-9.

ICCP Name	ICCP Type	ICCP Value	ICCP Quality	ICCP Timestamp (UTC)	Value	Local Timestamp
A10264	Analog Quality Timestamp	84	Valid | Telem | Norm	27/10/2017 15:05:07	84	27/10/2017 16:05:07 - 0...
A10265	Analog Quality Timestamp	11.32871	Valid | Telem | Norm	27/10/2017 12:42:11	11.32871	27/10/2017 13:42:11 - 0...
A10267	Analog Quality Timestamp	106	Valid | Telem | Norm	26/10/2017 13:08:13	106	26/10/2017 14:08:13 - 0...
A10268	Analog Quality Timestamp	11.32871	Valid | Telem | Norm	27/10/2017 12:43:56	11.32871	27/10/2017 13:43:56 - 0...
A10278	Analog Quality Timestamp	31.64239	Valid | Telem | Norm	27/10/2017 15:13:46	31.64239	27/10/2017 16:13:46 - 0...
A10279	Analog Quality Timestamp	33.04863	Valid | Telem | Norm	27/10/2017 12:50:42	33.04863	27/10/2017 13:50:42 - 0...
A11464	Analog Quality Timestamp	10.09824	Valid | Telem | Norm	27/10/2017 15:13:30	10.09824	27/10/2017 16:13:30 - 0...
A11467	Analog Quality Timestamp	3.353984	Valid | Telem | Norm	27/10/2017 15:14:15	3.353984	27/10/2017 16:14:15 - 0...
A11468	Analog Quality Timestamp	-0.5398911	Valid | Telem | Norm	27/10/2017 15:14:15	-0.5398911	27/10/2017 16:14:15 - 0...
A11469	Analog Quality Timestamp	197	Valid | Telem | Norm	27/10/2017 15:13:38	197	27/10/2017 16:13:38 - 0...
A11833	Analog Quality Timestamp	158	Valid | Telem | Norm	27/10/2017 15:14:13	158	27/10/2017 16:14:13 - 0...
A11834	Analog Quality Timestamp	11.23105	Valid | Telem | Norm	27/10/2017 15:04:10	11.23105	27/10/2017 16:04:10 - 0...
A11837	Analog Quality Timestamp	3.018633	Valid | Telem | Norm	27/10/2017 15:14:29	3.018633	27/10/2017 16:14:29 - 0...
A11838	Analog Quality Timestamp	-0.6003018	Valid | Telem | Norm	27/10/2017 15:14:29	-0.6003018	27/10/2017 16:14:29 - 0...
A12228	Analog Quality Timestamp	0	Valid | Telem | Norm	26/10/2017 07:19:33	0	26/10/2017 08:19:33 - 0...
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A12248	Analog Quality Timestamp	-0.9356526	Valid | Telem | Norm	27/10/2017 15:00:33	-0.9356526	27/10/2017 16:00:33 - 0...
A14282	Analog Quality Timestamp	0	Valid | Telem | Norm	26/10/2017 07:19:24	0	26/10/2017 08:19:24 - 0...
A14283	Analog Quality Timestamp	11.09434	Valid | Telem | Norm	27/10/2017 12:32:54	11.09434	27/10/2017 13:32:54 - 0...

Figure 2-9 Data Exchange over ICCP

The SVO Operational Scenarios specified in the previous reporting period identified the work required to configure the NMS to support its interaction with SP5. Therefore, as part of the preparations for the system integration, a detailed plan was created for the completion of that work and a testing schedule was put in place to ensure that each required functionality is supported by the NMS. The entire process proved to be an efficient way of preparing the integration of the NMS with another system and minimised the risk of having integration issues. This work has confirmed the fact that in sophisticated systems like SVO, where the successful operation of the entire system requires actions from different parts of the system and their coordination, it is crucial to ensure that the actions each system needs to take in all possible conditions are clearly documented and agreed as part of the design process. In this case, it has enabled both sides (PowerOn and SP5) to be fully configured and ready for a successful integration with no issues and is therefore recommended for similar implementations.

The SIT was done with WPD's SP5 system connected to the offline NMS over ICCP as shown in Figure 2-10. The offline NMS was then connected to two test set-ups consisting of a Remote Terminal Unit (RTU) and a relay, each representing the two different SVO site types. The first SVO site type represents the sites that have a MicroTapp relay installed and the second SVO site type represents the sites that have the SG relay installed.

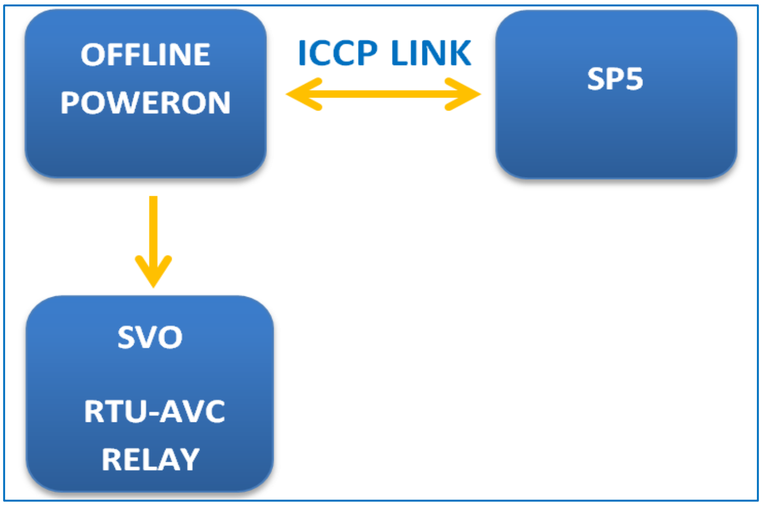
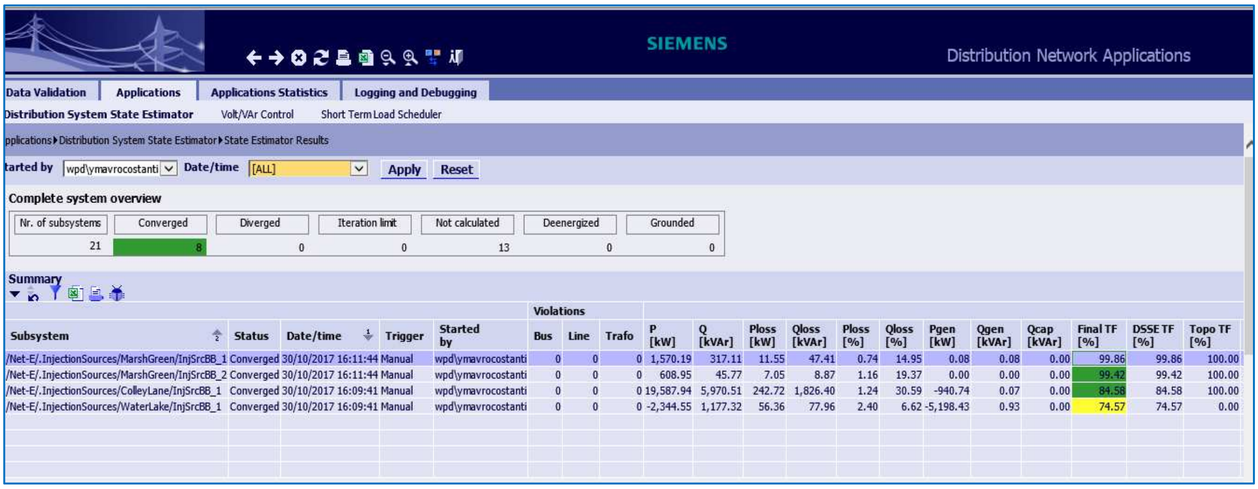


Figure 2-10 SIT Test Setup

The testing demonstrated among others the successful operation of:

- The ICCP link;
- Both systems (SP5 and PowerOn) under all operating scenarios;
- The SP5 alarms;
- PowerOn when handling SP5 alarms;
- SP5 when performing a state estimation on an SVO Primary substation network using the SCADA data received over ICCP. An example of the state estimation results is shown in Figure 2-11; and
- SP5 when performing the voltage optimisation on an SVO Primary substation network.

The testing of the end-to-end operation of the entire system was proved, with SP5 performing a state estimation, then calculating a set point and sending it to the NMS over ICCP to be finally sent and applied to the relay.



Nr. of subsystems	Converged	Diverged	Iteration limit	Not calculated	Deenergized	Grounded
21	8	0	0	13	0	0

Subsystem	Status	Date/time	Trigger	Started by	Violations Bus	Violations Line	Violations Trafo	P [kW]	Q [kVAr]	Ploss [kW]	Qloss [kVAr]	Ploss [%]	Qloss [%]	Pgen [kW]	Qgen [kVAr]	Qcap [kVAr]	Final TF [%]	DSSE TF [%]	Topo TF [%]
/Net-E/.InjectionSources/MarshGreen/InjSrcBB_1	Converged	30/10/2017 16:11:44	Manual	wpd\ymavrocostanti	0	0	0	1,570.19	317.11	11.55	47.41	0.74	14.95	0.08	0.08	0.00	99.86	99.86	100.00
/Net-E/.InjectionSources/MarshGreen/InjSrcBB_2	Converged	30/10/2017 16:11:44	Manual	wpd\ymavrocostanti	0	0	0	608.95	45.77	7.05	8.87	1.16	19.37	0.00	0.00	0.00	99.42	99.42	100.00
/Net-E/.InjectionSources/ColleyLane/InjSrcBB_1	Converged	30/10/2017 16:09:41	Manual	wpd\ymavrocostanti	0	0	0	19,587.94	5,970.51	242.72	1,826.40	1.24	30.59	-940.74	0.07	0.00	84.58	84.58	100.00
/Net-E/.InjectionSources/WaterLake/InjSrcBB_1	Converged	30/10/2017 16:09:41	Manual	wpd\ymavrocostanti	0	0	0	-2,344.55	1,177.32	56.36	77.96	2.40	6.62	-5,198.43	0.93	0.00	74.57	74.57	0.00

Figure 2-11 SP5 State Estimation Results Extract

2.5.2 System Voltage Optimisation (Site Works)

In the last reporting period, installation works had commenced with four sites commissioned and ready for SVO. In this reporting period installation and commissioning works continued with a total of 11 sites now ready for SVO.

Site Installation Progress

During this reporting period, the offline manufacture of panels for ease of installation was completed for the required sites and installation and commissioning of these continued. It was originally planned that all installation works would be completed within this reporting period, however, due to operational constraints installation works at three sites has been moved into next period. These sites will be commissioned by the end of February 2018. Details of actual and planned commissioning dates are shown in Table 2-2.

Table 2-2: Commissioning dates for SVO Substations

Substation	SVO Site Commission Date
Colley Lane	24/02/2017
Waterlake	24/02/2017
Lydeard St Lawrence	03/03/2017
Paignton	26/05/2017
Bridgwater	09/06/2017
Exeter City	13/10/2017
Tiverton Moorhayes	27/10/2017
Taunton	18/08/2017
Dunkeswell	11/12/2017
Bowhays Cross	20/10/2017
Tiverton BSP	03/11/2017
Millfield	26/01/2018
Exeter Main	10/11/2017
Nether Stowey	09/02/2018
Marsh Green	01/12/2017
Radstock	02/03/2018

Lessons learnt

Following installation and operation of the SuperTAPP SG relay since February last year there has been many lessons and minor changes that have occurred to increase reliability and performance.

Relay Mode Changes

It was noted by site teams that when visiting site the AVC relays were in Local/Manual mode instead of the usual SCADA/Auto mode. This led to an issue at one site where control engineers were unable to issue commands to the relay. On investigation, it was confirmed that on the loss of supply voltage to the relay control panel, the relays have a built in safety feature to automatically change operating mode. This feature is based on the assumption that the loss of supply has been caused by a person switching the tapchanger to “Local” at the transformer.

However, this feature does not exist on any other AVC relay and as such, WPD have well developed and understood operational policies for local operation of tapchangers that stipulate that the relay automatic control must be disabled before approaching the tapchanger. Fundamentals have developed a firmware upgrade to change the relay behaviour and this is currently undergoing bench and field testing before it is rolled out to all SVO sites.

Lockout Relays

Current WPD policy is for each transformer to be fitted with a lockout relay to cut supplies to the tapchange motor if an issue is detected by the AVC relay. Due to the age of existing relay and transformers, where at the time of installation the lockout facility wasn't available this hadn't been installed. The only major issue experienced was with a tapchanger that utilised a separate DC circuit for the control circuits. This meant that the relay was unable to detect a local operation correctly, locking out for a tapchange runaway.

RTU Communications Fail Switch

For each SVO enabled site, the substation RTU was configured to issue a communications fail command to each relay once the connection with the NMS is down for four minutes. Following testing and analysis of data logs it was discovered that there was a bug in the main RTU code that would trigger a fail command every 6-8 weeks even if there was no loss of connectivity. The decision was made by the WPD team responsible for the RTU's to disable this feature until such a time that the bug is patched and its reliability is confirmed.

To minimise the risk of being at the wrong voltage set point, it was decided that under a communications lost scenario the relays would be reset to their default values. Without the feature enabled there is an increased risk, however, this is still a lower risk then having no visibility for the whole substation. To manage this in the short term, once a communications lost situation has reached a critical point and an engineer is sent to site to investigate, an additional procedure will be added to manually disable the SVO system on site.

Remote End Network Monitoring

Following the design and development of a monitoring panel alongside the radio network survey in the previous reporting period, testing has been carried out on the prototype panel and the deployed to a site for evaluation. This system will enable us to accurately measure the LV voltage and communicate this back to PowerON and through to SP5, to ensure that no part of the primary network is below the statutory voltage limits allowed.

Panel Testing

In August, a prototype panel was delivered to WPD for offline testing and to confirm its suitability. Testing showed that changes were required to the panel power supplies due to a change in specification of the radio being used and adjustment to the location of some fixing points and openings. Figure 2-12 shows the inside of the panel during the offline testing process.

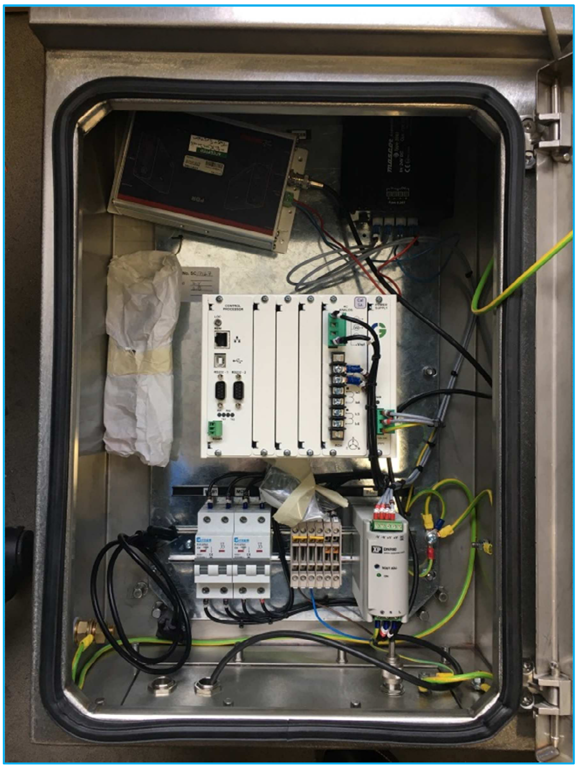


Figure 2-12: Inside of Monitoring panel during testing

2.5.1 Policies

In this reporting period, the first drafts of the SVO Engineering Specification, the SVO Operations and Control Policy and the SVO Model Update Guidance were produced.

The way Control Engineers will be interacting with the SVO system through WPD's current NMS, is explained and demonstrated in the SVO Operations and Control Policy. This document among others, also includes information about all the alarms that will be received by the NMS from SP5 and the actions that need to be taken when alarms are raised.

The SVO Model Update Guidance captures all procedures that will be followed to update the SP5 network models and ensure they are synchronised with the NMS. This includes step by step instructions on how to make changes to the models in SP5 but also the way that the network changes will be recorded and assigned to the SP5 updaters as jobs. The overall creation process of SP5 Updating jobs is shown in Figure 2-13.

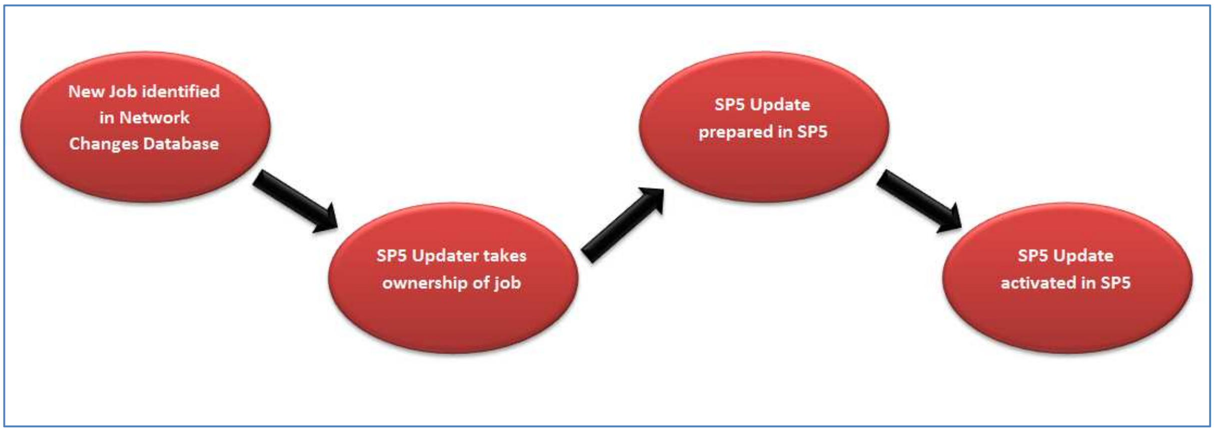


Figure 2-13: Overall process for creation of SP5 Updating Jobs

2.5.2 Training

In November 2017, the SVO Administrator and Updater training took place at WPD's Bristol Office, where Siemens provided the final rounds of training to the Distribution System Operator (DSO) Technology team in preparation for the system handover.

The Administrator training covered all tasks required to manage the SP5 system including backup and restore procedures, system troubleshooting and user administration.

In the Updater training (Figure 2-14) the DSO Technology team initially received a detailed demonstration of the SP5 network model structures and graphical representation which was then followed by a series of practical exercises which gave the team hands-on experience with the system. As part of this, the DSO technology engineers created templates of typical network changes including new switches, new substations and new generation connections but also implemented a number of updating jobs, bringing the network models up to date.

Figure 2-14 SVO Updater Training

2.5.3 Next Steps

After the successful integration of SP5 with the offline NMS and the completion of SIT in this reporting period, the next reporting period will focus on the integration of SP5 with the online NMS, the Site Acceptance Testing (SAT) and the first trials of the technology. This will involve configuring the online system to ensure it is ready to interface with SP5, calibrating the SCADA data of each SVO site to ensure that the SP5 state estimator can successfully converge and setting up the ICCP link between online NMS and SP5. Once SP5 is successfully integrated with NMS, SVO will be commissioned on each site and the trials will officially begin.

2.6 Flexible Power Link

2.6.1 Overview

During the previous reporting period construction works had started at Exebridge 33/11kV substation in preparation for the FPL installation. The new 33kV indoor switchgear had been installed and was ready to be energised as part of the plan to remove the 33kV outdoor compound to create space for the FPL equipment. WPD has also witnessed the FAT for the FPL converter frame which was the first in a series of tests for the FPL device.

In this reporting period the majority of the construction work at Exebridge 33/11kV substation has been completed and the new 33kV switchboard has been energised. All of the FPL components have successfully undergone FAT and the equipment has now been delivered to site. Work is currently underway to complete the installation works and prepare for commissioning and energisation within the next reporting period. Further details of the progress can be found in the following sections.

2.6.2 Technology

The following sections detail how the FPL technology has transitioned from the design phase into the construction phase during this reporting period. Robust planning has ensured that all component testing was completed to schedule facilitating the delivery of equipment in November 2017. A detailed FAT procedure for the FPL software identified several issues that could have resulted in delays to commissioning on site. Sufficient time had been allocated in the design and delivery programme which allowed ABB, the FPL manufacturer, to rectify the issues and perform a second FAT which was successful.

FPL Design

Detailed Design Stage 2 was finalised in the last reporting period which led to the final designs being issued by ABB in this reporting period. Finalising the design of the FPL enabled the final site layout and interface drawings, which would be required for the FPL installation, to be completed.

Equipment Testing

During this reporting period the FPL components were undergoing a number of tests prior to delivery of all the equipment in November 2017. The ABB FPL software FAT on 27th October was the last test to be conducted and signified the successful completion of all

FATs. Further site tests will be carried out on the FPL when all the components are delivered to Exebridge and installation works are completed.

Container Testing

In May 2017 the FPL converter frame underwent FAT to confirm various parameters of the power electronic modules before the frame was installed into the main FPL container. The tests on the converter frame were successful and the fit out of the FPL container took place over two months. WPD stipulated that the FPL container should be tested in its finished state and therefore all wiring inside the container was completed (including power electronic modules, controllers, protection relays, transducers, small power and lighting etc.) and all the final components were installed (HMI, UPS, cooling system etc.). Carrying out rigorous testing on the completed container meant that any issues could be resolved in the factory rather than on site. Figure 2-15 to Figure 2-17 show the container ready for testing in the ABB's factory in Turgi, Switzerland during August 2017.

Figure 2-15: FPL container in ABB factory

Figure 2-16: FPL cooling system

Figure 2-17: Inside the FPL converter room

The list below details the critical tests that were carried out to verify the performance of the container:

- Insulation Test – this was performed on the 3.25kV AC and 2500V DC connections on the converter to ensure there were sufficient levels of insulation following installation into the container. The control cabinets inside the container also underwent insulation tests.
- Control Devices – verification that all the individual control devices operate in the correct manner from protection relays to pump controllers.
- Cooling System – the functionality of the cooling system was tested. This included checking the pumps and controllers, system redundancy, presence of leaks and operation of the by-pass valve.
- Pre-charger – the pre-charger transformer and rectifier that supply the DC link were tested to verify that the correct voltage would appear during energisation.
- Power loss – the losses associated with the container, including all auxiliaries, were measured and added to the converter frame losses to establish the total figure for the FPL. Additional losses associated with the heat exchanger and transformer would be added to these at a later date once tested.

The tests were witnessed by WPD experts and the container successfully passed all the tests detailed in the specification.

Software Testing

One critical part of the FPL design is the software that controls, monitors and operates all the components of the FPL. The software for the FPL was built upon the hardware design requirements that were finalised between WPD and ABB during Detailed Design Stage 2.

A separate FAT was proposed to verify the performance of the software and this was scheduled to be carried out in parallel with the FPL container testing in August 2017. The main areas that would be tested were the local SCADA system, open loop control, closed loop control and protection functions. The tests were carried out in ABB's test laboratory in Turgi, Switzerland. Figure 2-18 and Figure 2-19 show the ABB simulator setup used to test the software. The system can be configured to simulate the various scenarios that can occur during FPL operation and is an efficient way to check the performance of the software before finalising and uploading into the container.

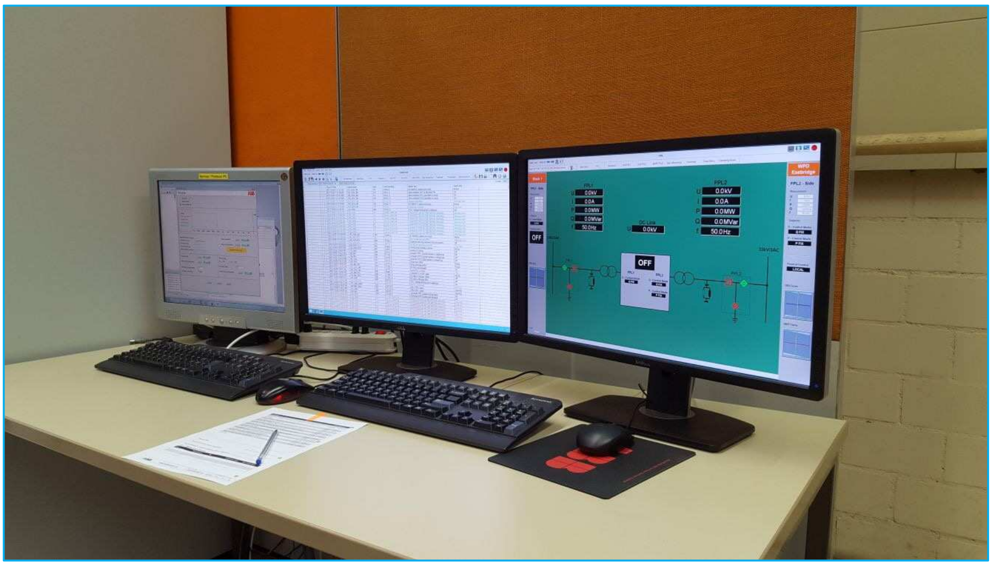


Figure 2-18: FPL software on ABB simulator

Figure 2-19: FPL software undergoing closed loop tests

A detailed testing specification was requested by WPD prior to the FAT so that all key functions could be witnessed and verified. When WPD were witnessing the software FAT in August 2017, it was observed that the software was not fulfilling the test requirements in a number of different areas. After consultation with the ABB management team it was decided that due to the number of issues, further time would be required to re-design the software to resolve the issues resulting in the FAT having to be postponed. The main cause of the issues stemmed from the specific FPL software changes not being properly tested by ABB prior to the FAT occurring. It would have been possible to resolve the issues on site after delivery; however, this would have required a significant extension of time for site based activities resulting in additional costs to WPD.

A list of actions was prepared after the initial FAT failed and these were used to form the new plan for the re-test. ABB performed pre-FAT checks in early October 2017 and the software successfully met all the FAT criteria when WPD witnessed the tests again during 24 to 27 of October.

Transformer Testing

ABB sourced the FPL transformer from Končar DS&T, Croatia, who were familiar with providing specialist transformers for this type of application and had previously supplied several converter transformers for ABB.

The design of the FPL transformer was completed in the last reporting period and manufacturing started in July 2017. The completed transformer was ready for testing in mid-September 2017. Before tanking the transformer and filling with oil a number of pre-checks were carried out on the windings to check that the resistances were symmetric and within tolerances.

The transformer underwent FAT from 3 to 6 October at Končar's dedicated transformer test facility in Zagreb, Croatia. The standard procedures detailed in the IEC 60076 suite of standards were used as the basis for testing with additional modifications to account for the special design of the FPL transformer (two active parts in a single tank). The list below details the main tests from the FPL transformer testing specification:

- <u>Impedance Voltage and Load Losses</u> – the LV windings of T1 and T2 were short circuited and current was injected on the HV terminals at three different levels (corresponding to the three operating ratings: 12.42MVA (ONAN), 15.24MVA (CMR) and 20.2MVA (CER)). Measurements were taken to determine the losses and impedances for T1 and T2 at the three ratings.
- <u>Sound Level</u> – although the FPL transformer will be installed within a noise enclosure, it was important to measure the sound power level in laboratory conditions so that the noise enclosure design could be verified. Measurements were taken around the transformer tank and cooler to establish the sound power levels at both ONAN and CER ratings.
- <u>Applied Voltage</u> – the insulation level of the two transformer was checked by applying an AC 50Hz voltage for one minute on each terminal. HV terminals were subjected to 70kV whereas the LV terminals were subjected to 20kV.
- <u>Lightning Impulse</u> – the basic insulation level (BIL) of the transformers were also tested to ensure that it could withstand a lightning impulse. A test voltage of 170kV in various configurations (both full wave and chopped wave as per the standards) was applied to each HV terminal to verify that no breakdown would occur.
- <u>Temperature Rise Test</u> – this test involved short circuiting the LV windings and injecting the rated current into the each transformer. The transformer top oil and

ambient temperatures were recorded and monitored until the temperatures would stabilise. This often takes a number of hours due to the mass of the transformer and variations in ambient temperature. The results from the test are used to verify that the maximum hot-spot temperature does not exceed the design limits.

- Induced Voltage with PD – the last test in the sequence was an induced voltage test with partial discharge measurement. A test voltage of 66kV at 200Hz was applied to the HV windings to check for any signs of breakdown or variation in partial discharge over the test period of one hour. The partial discharge test can often detect very minor faults in the transformer before they escalate into more serious problems.

The FPL transformer successfully passed all tests on 27 October 2017. A snagging list was prepared to address minor issues that were observed with the transformer during testing and these were rectified prior to delivery. Figure 2-20 to Figure 2-23 show a range of photographs that were captured during testing.

Figure 2-20: Assembled FPL transformer

Figure 2-21: 70kV applied voltage test

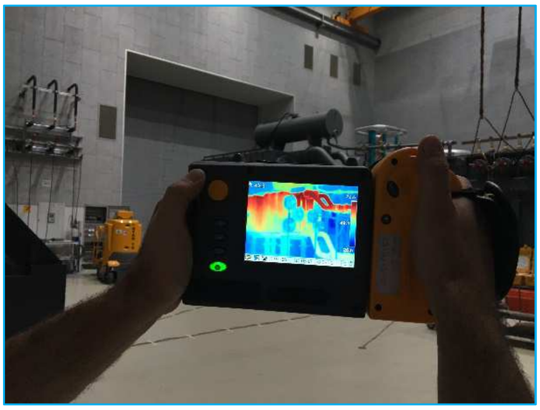


Figure 2-22: Temperature rise test

Figure 2-23: Winding resistance test

2.6.3 FPL Network Integration

Site works have been progressing according to the project plan during this reporting period with all major construction work complete in time for the FPL equipment delivery which occurred in November 2017. Installation work is ongoing to prepare the FPL for commissioning and energisation within the next reporting period.

Site Progress

The completion of the final FPL layout instigated the next stage of civil works at Exebridge substation. A tender meeting was held in July 2017 and work began on preparing compound for the installation of the FPL equipment in August 2017. The work involved extending the 33kV compound, installing new 33kV cable structures, installing new foundations for the FPL equipment, construction of a new access road and installation of a new compound security fence.

Figure 2-24 and Figure 2-25 show some of the construction works that were carried out during the reporting period.

Figure 2-24: Rebar for transformer plinth

Figure 2-25: Installation of plinths

The new 33kV indoor switchboard was successfully energised in July 2017. All the 33kV feeder circuits and transformers were transferred over from the old outdoor compound which allowed the compound area to be completely cleared. Figure 2-26 shows the newly energised 33kV indoor switchboard.

Figure 2-26: 33kV switchboard being commissioned

Equipment Delivery

The three main components of the FPL (transformer, container and heat exchanger) were delivered to Exebridge on week commencing 13 November 2017. ABB contracted Ainscough to offload the items and it was determined that a 250T mobile crane should be used due to the mass and position of the components on the site. The size and load of the crane required a 12m x 12m crane pad to be provided on site. The crane was setup on 15 November and all equipment was offloaded by 17 November. Figure 2-27 and Figure 2-28 show the delivery of the components in progress.

Figure 2-27: Delivery of container

Figure 2-28: Delivery of transformer

FPL Installation

The installation contractor appointed by ABB, HET Hanseatische, is carrying out the installation of the FPL transformer and are in the process of installing the FPL harmonic filters and FPL container. In parallel, WPD are installing the 33kV cables that feed the FPL transformer. The 33kV cables will be terminated once the FPL filter has been assembled and the FPL system is ready to be connected to the WPD network. A separate working area was defined in the CDM plan for use by HET staff which avoided the need for them to access WPD operational areas.

Figure 2-29 shows the installation works in progress.

Figure 2-29: Installation work at Exebridge

Policy Documentation

Prior to connecting the FPL equipment to the network it was important the sufficient policy documentation was prepared to allow WPD engineers to gain familiarity with the equipment and its operation. Two separate policies have been produced during this reporting period and are currently under review by WPD management.

Standard Technique : OCXXX - Operation and Control of ABB 33kV Flexible Power Link
This policy document provides the reader with the information to carry out the safe operation and control of the FPL. The document includes a description of the FPL and associated components, what measures must be in place to safely operate and control the FPL, how the FPL is connected to the network, the operational and control procedures and a list of alarms and trips that the FPL can generate.

<u>Standard Technique : SPXXX – Inspection and Maintenance of ABB 33kV Flexible Power Link</u>
This policy document is tailored towards WPD engineers who will be carrying out inspection and maintenance of the FPL on a regular basis. The structure of the document is similar to the operation and control policy, but also includes a detailed list of maintenance activities that need to be carried out along with explanatory notes on how to perform them.


WESTERN POWER DISTRIBUTION
Serving the Midlands, South West and Wales

Company Directive

STANDARD TECHNIQUE : OCXX

Operation and Control of ABB 33kV Flexible Power Link installed at Exebridge Primary Substation for use on the Network Equilibrium project

Policy Summary

This document covers Western Power Distribution's requirements for the operation and control of the ABB 33kV Flexible Power Link (FPL) as part of the Low Carbon Networks Fund (LCNF) tier-2 Project, Network Equilibrium.

Author:	
Implementation Date:	October 2017
Approved by:	
	Approver
	Job Title
Date:	

ST:OCXX October 2017 - 1 of 26 -

Figure 2-30: Operation and Control Policy


WESTERN POWER DISTRIBUTION
Serving the Midlands, South West and Wales

Company Directive

STANDARD TECHNIQUE : SPXX

Inspection and Maintenance of ABB 33kV Flexible Power Link installed at Exebridge Primary Substation for use on the Network Equilibrium project

Policy Summary

This document covers Western Power Distribution's requirements for the inspection and maintenance of the ABB 33kV Flexible Power Link (FPL) as part of the Low Carbon Networks Fund (LCNF) tier-2 Project, Network Equilibrium.

Author:	
Implementation Date:	October 2017
Approved by:	
	Approver
	Job Title
Date:	

ST:SPXX October 2017 - 1 of 27 -

Figure 2-31: Inspection and Maintenance Policy

These two policies can be read in conjunction with ABB's Installation and Operation Manual and Local SCADA Manual to resolve any issues or queries following installation. ABB will also be providing on-site training to WPD engineers in the next reporting period as part of the commissioning process.

2.7 Flexible Power Link Control Module

2.7.1 Overview

During the last reporting period work was focussed on the preparation of the FPL control module design and how this would be integrated into WPD's NMS. The initial detailed design documents had been submitted by Nortech and WPD had prepared the first version of the IPSA model to be implemented within the Control Module.

In this reporting period the build of the FPL CM has been completed and it has successfully passed its FAT. The FPL CM is due to begin SIT to ensure that the software is suitable to interface with the NMS. Further details of the progress can be found in the following sections.

2.7.2 Detailed Design

In the last reporting period Nortech had submitted the detailed design documentation for the FPL CM. The detailed design was split into two main sections:

- The FPL CM Functional Specification D6. This set of documents defines the system layout and the functional and the interfacing specification/requirements of the systems that constitute the FPL CM.
- The FPL Control Module logic D5. This is a design report and flow chart describing the logic design of the FPL CM. It describes how the FPL CM calculates set points for the FPL as well as how the module reacts to various network and FPL scenarios.

During this reporting period the detailed design underwent a design review process. The design submissions were reviewed and after several iterations these were approved in mid-August 2017. In addition to Nortech's detailed design, a number of designs were also completed to enable a common understanding between the project interfaces, namely: Nortech, WPD NMS and ABB. The documents that were produced were as follows:

- <u>NMS Logic Configuration Requirements</u> – This document lists each of the signals in the ICCP bilateral table and the corresponding action to be taken by the NMS upon receipt of each signal. This allows the interface between the FPL CM and the NM to be configured correctly.

Point Name	Point Type	Scope	Units	Description	NMS Action	Comment
FPL_ICCP_Heartbeat	Real Q Timetag	ICC			NMS to interface with Nortech ICCP heartbeat. Further information to be provided.	
FPL_Module_Enabled	State Q Timetag	ICC	N/A	Indication from the FPL CM that the FPL CM is enabled	NMS to add as an attribute	Not currently displayed on the NMS symbol
FPL_Module_Enable	Command	ICC	N/A	Commmand to enable the FPL CM after is has been disabled either manually, or by a Stage 2 alarm condition	This command is not anticipated to be updated via ICCP. It is to be treated as a settings change and manually updated by NMS via Nortech iHost's web interface.	
FPL_Logic_Error_Code	Real Q Timetag	ICC		Inidcation from the FPL CM of the logic error code associated with the last logic run. It could either be a Stage 1 or Stage 2 error. The list of error codes are described in design document (doc ref. D_002242)	NMS to display the Stage 1 error code on the control engineer event/alarm list	
FPL_Constraint_Violation_Alarm	State Q Timetag	ICC	N/A	This is an indication from the FPL CM that a constraint violation has been on the system for more than the maximum allowable time. The FPL CM is automatically disabled after issuing this alarm to PowerOn	NMS shall issue a NOSOFF signal to the FPL. This will cause the FPL to ramp down its power output and turn off. NMS to display that a constraint violation alarm has occurred on the control engineer event/alarm list	

Figure 2-32: Extract from NMS Logic Configuration Requirements

- <u>NMS Sign Convention Diagram</u> – This diagram documents the sign convention for power flow analogue quantities in the NMS. It was created to ensure that both Nortech and ABB had a clear understanding of how the direction of power flows was interpreted by the NMS.

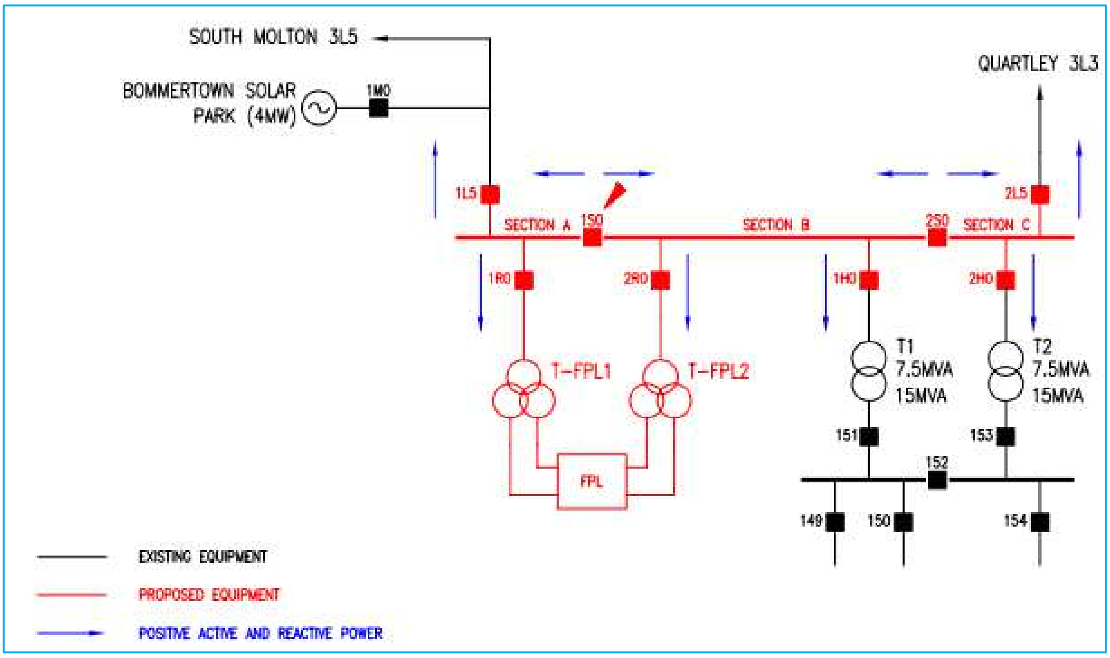


Figure 2-33: Extract from Power flow Sign Convention Drawing

- End-to-End Sign Convention Flow Chart – This diagram was created to show how the sign and scaling factor applied to a set point sent from the FPL CM is interpreted by the NMS and the FPL at site. The same was shown for feedback signals sent in the reverse direction: from the FPL to the FPL CM via the NMS. This is a critical document to ensure all parties are aware of the format of the messages being passed between the interfaces.

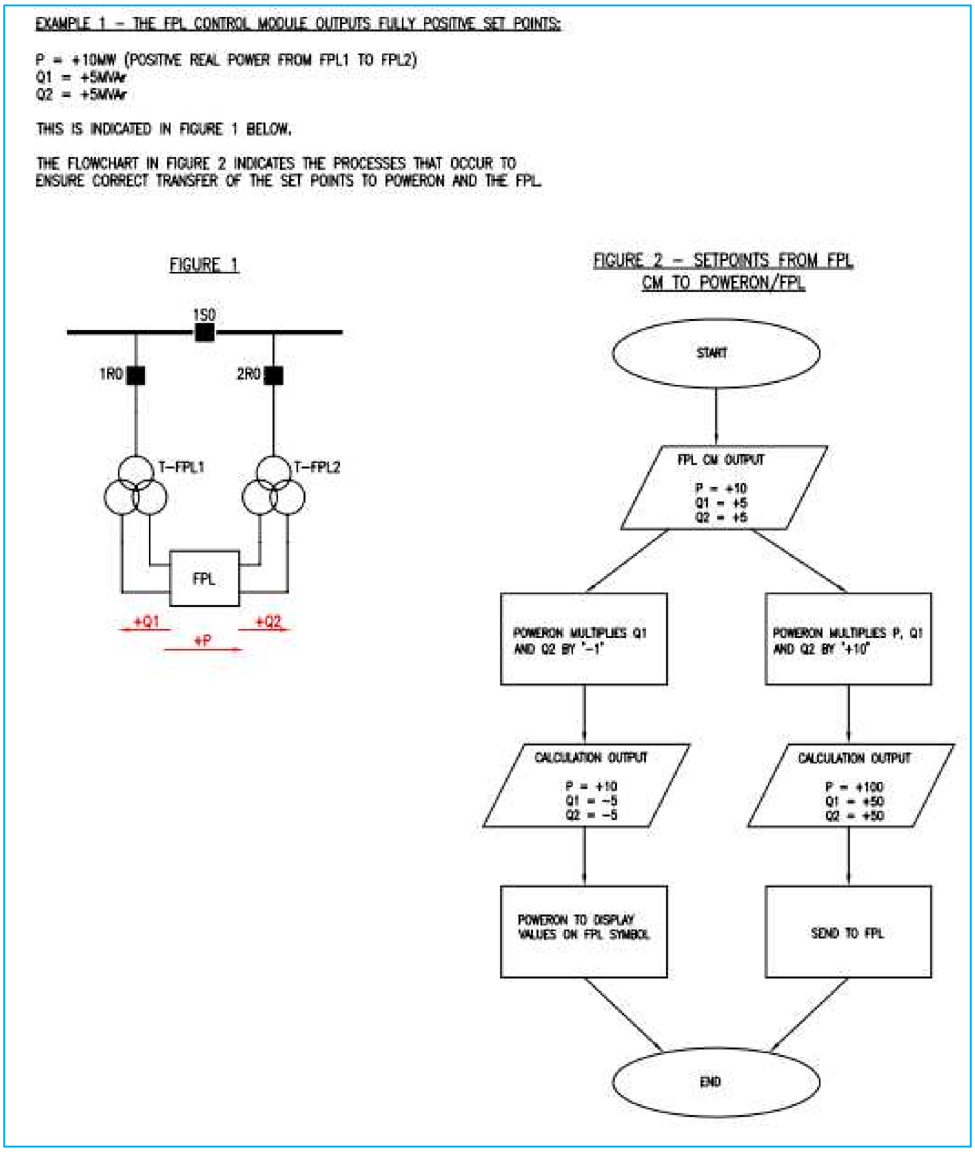


Figure 2-34: Extract of End-to-End Sign Convention Flow Chart

- Operational Scenarios Document – This document lists all the network scenarios that could occur while the FPL CM is operating and how the module should react in each case. This document was used as an input to Nortech's logic documentation and also to inform the FAT and SIT testing specifications.

2.7.3 Operation Manual

During this reporting period Nortech have submitted the first draft of the FPL CM Operation Manual. This has now been reviewed by WPD and comments issued to Nortech to allow them to resubmit the document. The manual has been submitted and reviewed by WPD prior to the FAT to ensure that all relevant tests are incorporated into the FAT test specification.

2.7.4 Model

In this reporting period a validation of the IPSA network model produced in the last reporting period was undertaken. This validation found that there were a number of modifications that could be carried out to improve the reliability and 'future proofing' of the model. These were implemented and the model was finalised on 05th September 2017. A summary of the changes are as follows:

- Extension of the 132kV network at Barnstaple BSP to incorporate the feeders from Alverdiscott GSP;
- The inclusion of all switches and disconnectors along the 132kV and 33kV feeders between Barnstaple BSP and Taunton BSP;
- The 11kV incomer circuit breaker MW and MVar aliases were mapped to the respective busbar loads; and
- The naming convention was reassigned and applied consistently to all components in the model.

A selection of snapshots of the final IPSA model is shown below in to Figure 2-38.

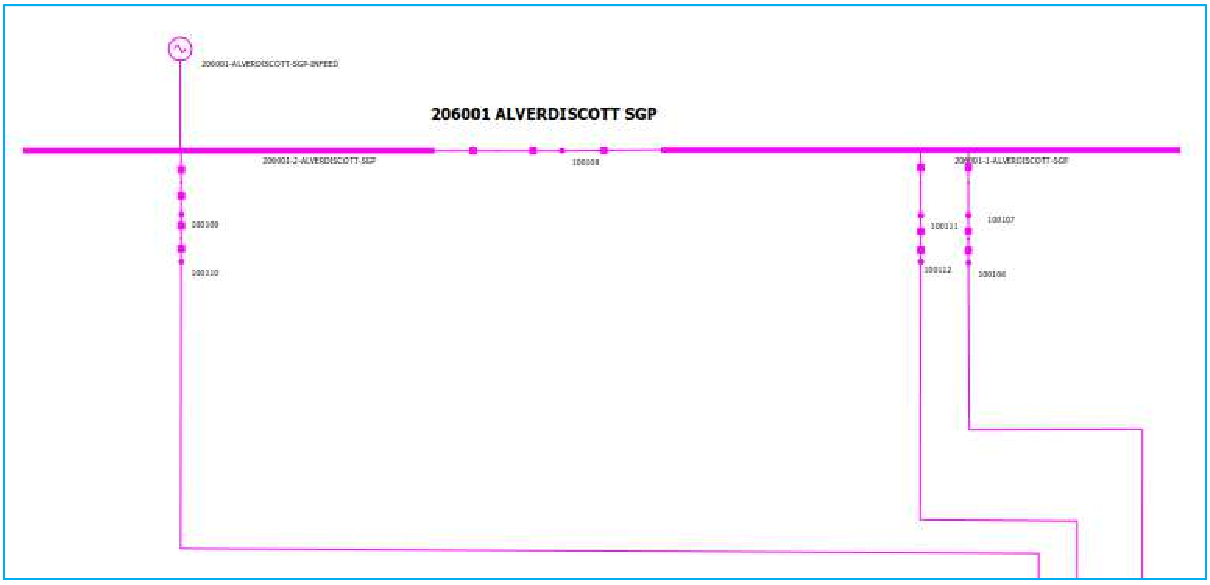


Figure 2-35: Snapshot of Alverdiscott SGP in final IPSA model

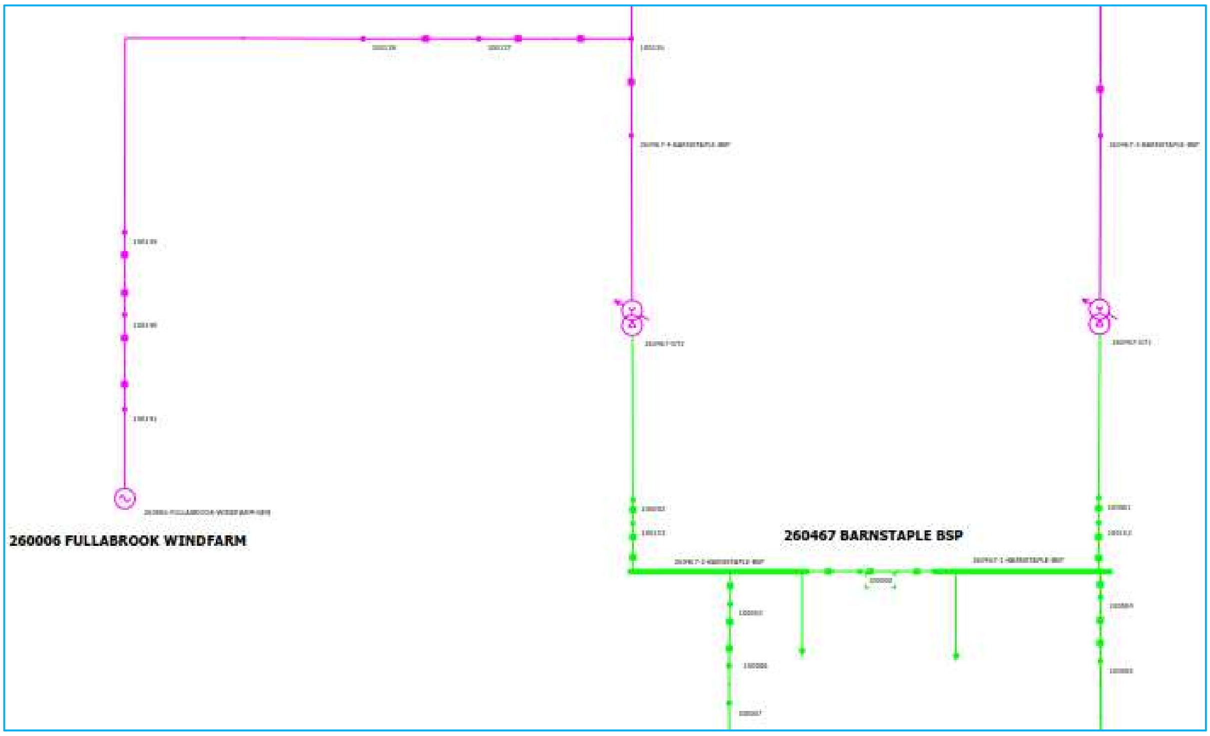


Figure 2-36: Snapshot of Barnstaple BSP in final IPSA model

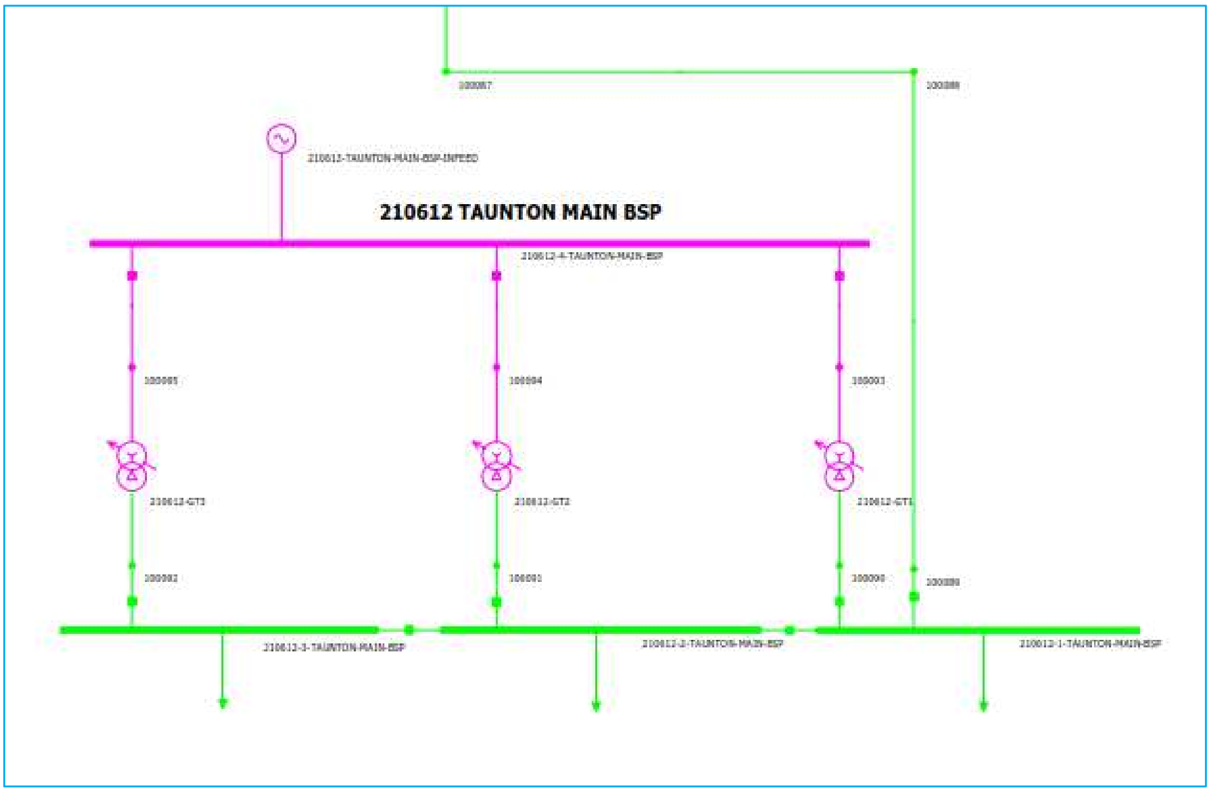


Figure 2-37: Snapshot of Taunton Main BSP in final IPSA model

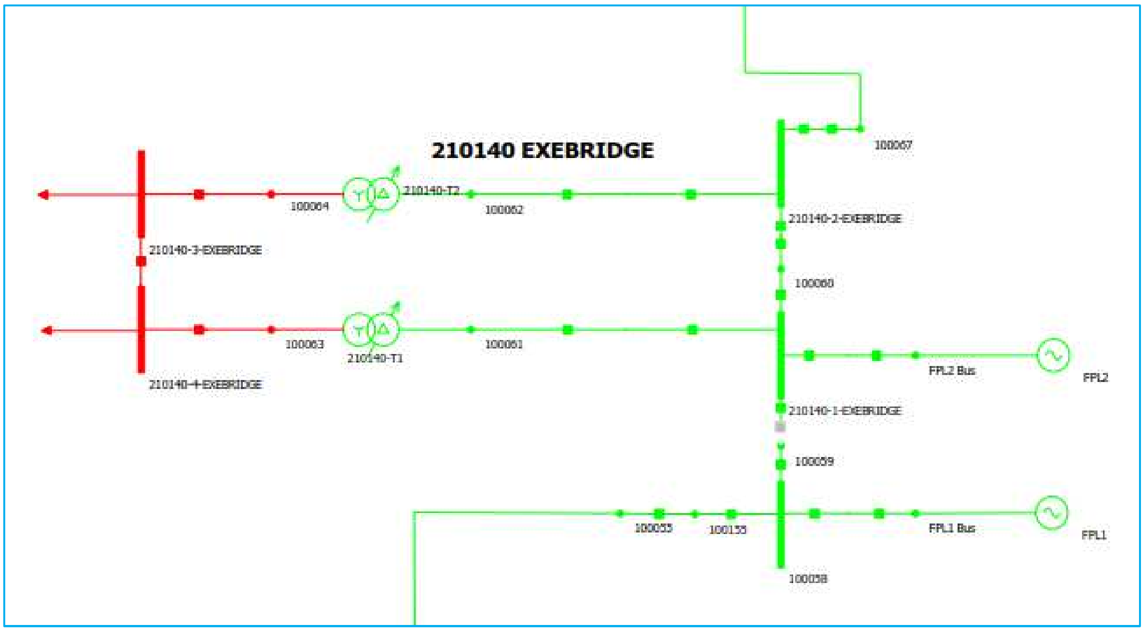


Figure 2-38: Snapshot of Exebridge Primary in final IPSA model

The ICCP bilateral table was finalised after the model was frozen and all the associated aliases were validated. The bilateral table allows the correct communication of network information to/from the FPL CM.

2.7.5 NMS Interfaces

The FPL CM communicates to WPD's NMS via an ICCP link. This link transfers information to/from the FPL CM to allow calculation of the FPL set points that are sent to the FPL at site. The link is also used to communicate alarms from the CM to the NMS and to instruct the NMS to shut down the FPL if an error occurs in its internal logic.

During this reporting period Nortech have successfully incorporated ICCP functionality into their iHost software. This was rolled out as a new revision (v2.38) and the ICCP link was successfully tested with NMS on 14 July 2017. The ICCP link was then successfully soak tested to ensure it operated in a stable manner. The latest version of iHost and all other software required for the operation of the FPL CM was successfully installed on the FPL CM servers on 4 September 2017.
In this reporting period the interface logic in the NMS has been progressing. This logic ensures the following:

- Set points (P, Q1 and Q2) are sent to the FPL in the correct format and sign convention;
- Set points (P, Q1 and Q2) are displayed correctly on the NMS symbol for the FPL;
- The logic error alarms and alarm codes from the FPL CM are displayed on the WPD Control Engineer Alarm/Event Screen;
- The FPL shut down signal from the FPL CM is sent to the FPL; and
- The FPL CM receives the FPL feedback signals in the correct format and sign convention.

Work has been carried out to manually simulate the various output signals of the FPL CM. This simulation has allowed the point-to-point testing between the FPL CM and the NMS to validate the interface logic before the formal System Integration Testing (SIT). Some screenshots of these tests are shown below:

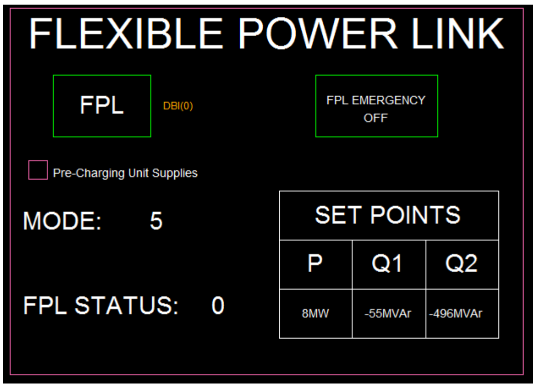


Figure 2-39: PowerOn FPL representation

SP Value	55.32
SP Value Int	553
Q1 SP Display Value	-55.32
Q1 SP Readback Value	6

Figure 2-40: Example of setpoint values

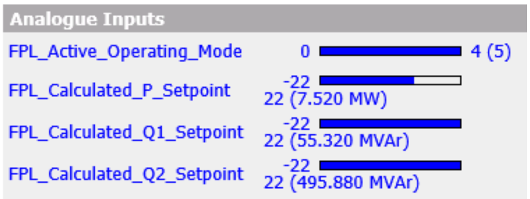


Figure 2-41: Testing analogue inputs

2.7.6 Factory Acceptance Testing (FAT)

The FAT for the FPL CM was carried out in Nortech's offices in Birmingham, UK, over the period 13 to 17 November. A test system was developed by Nortech for the purposes of the FAT. The test system consisted of an ICCP simulator that mimicked the WPD NMS. A range of program scripts were developed that simulated various network measurements. These scripts were then used as an input to the ICCP simulator which communicated this data to the FPL CM over ICCP for processing by the internal logic. A schematic view of the test system is shown in Figure 2-42 and a photograph of the actual system is shown in Figure 2-43.

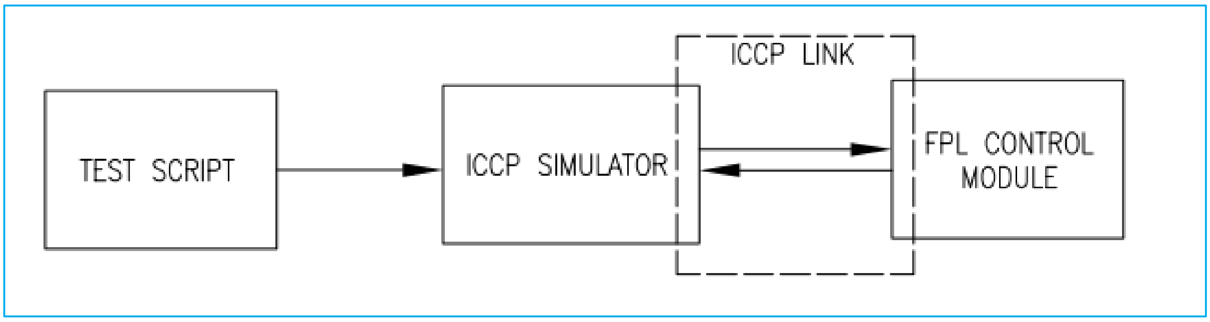


Figure 2-42: Schematic showing the Nortech test system developed for FAT

Figure 2-43: Photograph of Nortech's Test System during FAT

A test specification was developed to ensure that the CM was tested thoroughly. The testing specification was divided into six main sections described as follows:

1. User Interface Tests – In this group of tests the various menu systems and user interface functionality was tested and checked against the user manual and design specification. In addition, the user login and user rights functionality was also tested to ensure the software was secure.
2. Violation Tests – Nortech simulated various network operating conditions and violation limits on different network components for each of the CM's operational modes. A hand calculation was done for each test to show the expected behaviour of the FPL CM. The results of the CM's logic calculations were compared with the hand calculation to check if the test had passed successfully. The model was loaded with the calculated set points from the CM to show that the violation was removed correctly.
3. Open Loop Logic Tests – This section of the test specification proceeded to test the logic of the FPL CM in detail. Each logic component described in the design documentation D5 was tested in turn to ensure that the CM responded in the correct manner.
4. Closed Loop Logic Tests – For these tests Nortech simulated the response of the FPL to set points issued by the CM. The reaction of the CM to the simulated feedback was validated against the logic specification in the D5 design documentation.
5. Data Quality Tests – Various tests were applied in this section to validate the behaviour of the CM in response to poor data quality. This included tests to simulate the loss of critical measurements/analogues, a mismatch of measured data

compared with the state estimated values and the corruption of the model and/or ICCP bilateral table.

6. User Defined Tests – In this section a range of tests were applied that were added to the test specification by WPD during the course of the FAT. Particular emphasis was made to implement spot checks by simulating different network conditions and violations that had not been tested in the preceding sections of the test specification.

The FPL CM successfully passed the FAT on 17th November 2017. A screenshot of the FPL CM dashboard display within Nortech's iHost platform is shown below in Figure 2-44. The screenshot is displaying the calculated set point for violations detected on both Barnstaple and Taunton sides of the FPL.

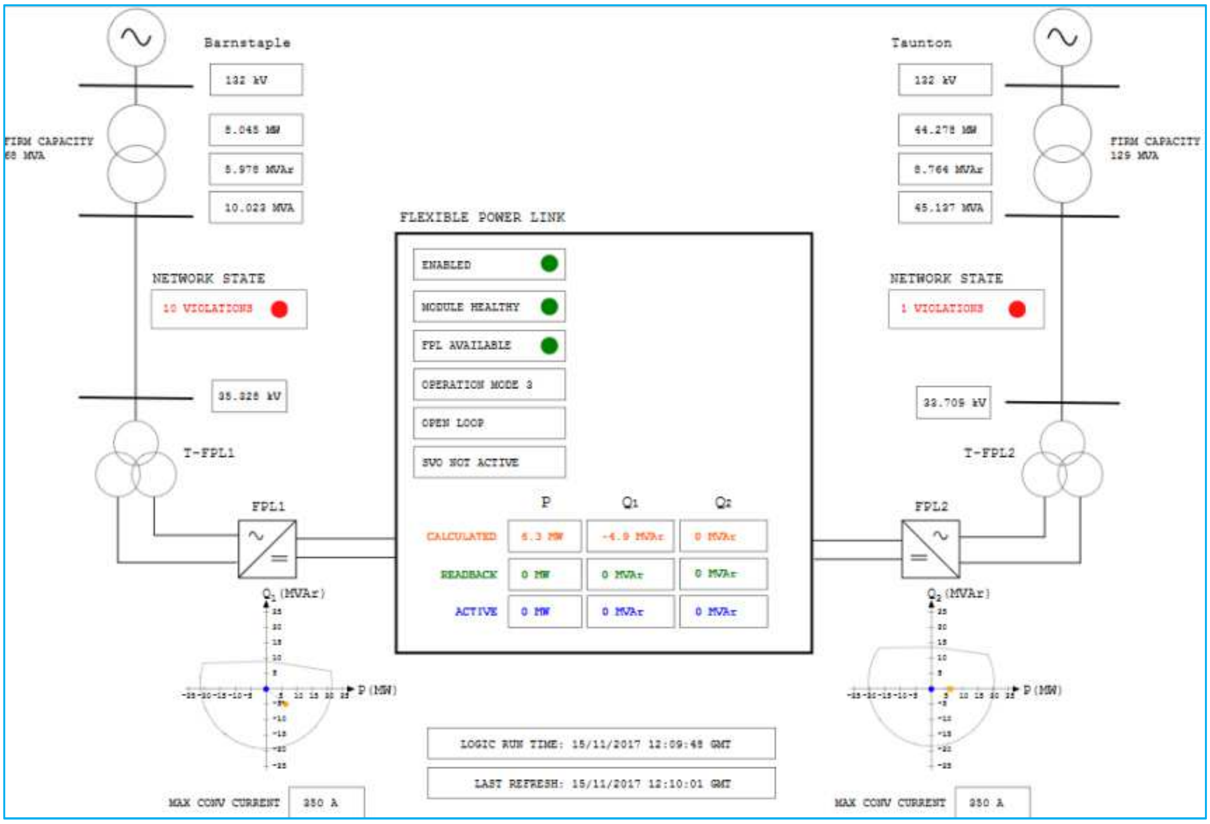


Figure 2-44: Screenshot of the FPL CM dashboard display in iHost

2.7.7 System Integration Testing (SIT)

During this reporting period there has been significant progress to prepare the infrastructure required to perform the FPL CM SIT. The SIT is due to be carried out in the next reporting period. The purpose of the SIT is to ensure that the FPL CM can successfully perform set point calculations whilst interfacing with an 'offline' version of the WPD NMS. WPD's philosophy for the SIT is to simulate as much of the final 'real world' system as possible before the FPL CM begins the Site Acceptance Testing (SAT).

To this effect a full end-to-end test system has been built. The test system is shown schematically in Figure 2-45.

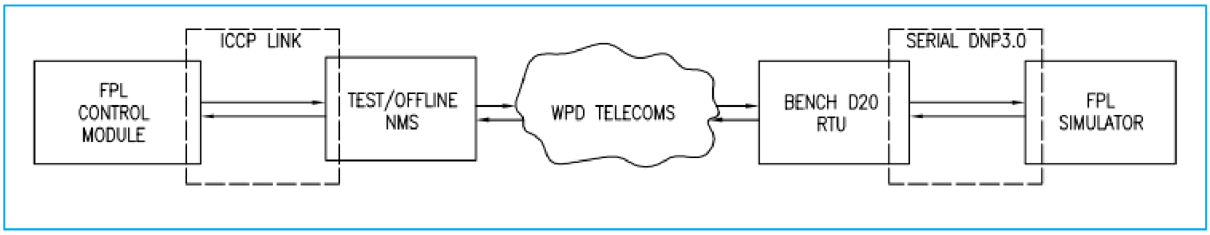


Figure 2-45: End-to-end test system for SIT

The FPL CM will interface with a test version of the NMS which is ‘offline’. The test NMS system is configured with ICCP and the complete interface logic to communicate correctly with the FPL CM. Real time network data is then fed into the test NMS system and communicated to the FPL CM over ICCP.

The RTU at Exebridge and the FPL have been simulated for the SIT. A D20 RTU has been set-up on a test bench and has been configured with the same RTU configuration as will be loaded on the real RTU at site. In addition, an FPL simulator has been developed by Nortech. This is a piece of software that interfaces with the bench RTU over serial DNP3.0. The aim of this set-up is to test that the FPL CM and the NMS correctly issue commands to the FPL simulator and also react correctly to feedback signals from the FPL simulator.

3 Business Case Update

There is no change to the business case. The business case to further facilitate the connection of low carbon loads and generation in the project area, on both the 11kV and 33kV are still applicable.

4 Progress against Budget

Table 4-1: Progress against budget

	Total Budget	Expected Spend to Date Nov 2017	Actual Spend to date	Variance £	Variance %
Labour	**1262**	**644**	**612**	**-31**	**-5%**
WPD Project Management & Programme office	510	325	292	-33	-10%
Project Kick Off & Partner / Supplier Selection	33	33	33	0	0%
Detailed design & modelling	101	101	92	-9	-9%
Installation of Equipment - 11kV & 33kV	390	35	33	-2	-6%
FPL Technologies - Substation Installation 33kV	141	128	140	12	9%[1]
Capture, analyse & verify data for EVA, SVO & FPL	58	9	8	-1	-9%
Dissemination of lessons learnt	29	12	13	1	8%[2]
Equipment	**6691**	**4440**	**4434**	**-6**	**0%**
Project Kick Off & Partner / Supplier Selection	2	2	2	0	0%
Procurement of SVO Equipment	1540	480	478	-2	-1%
Procurement of FPL Technologies 33kV	4550	3458	3458	0	0%
FPL Technologies - Substation equipment 33kV	599	500	496	-4	-1%
Contractors	**3339**	**1892**	**1868**	**-24**	**-1%**
Detailed design & modelling	804	804	732	-71	-9%
Delivery of SVO Technique - 11kV & 33kV	392	250	245	-5	-2%
Installation of Equipment - 11kV & 33kV	850	75	72	-3	-4%
Implementation of Solution	46	46	46	0	0%
Implementation of Solution	139	40	38	-2	-6%
FPL Technologies - Substation	540	490	536	46	9%[3]

Installation 33kV					
Capture, analyse & verify data for EVA, SVO & FPL	445	165	178	13	8%[4]
Dissemination of lessons learnt	123	22	21	-1	-5%
IT	**396**	**286**	**271**	**-15**	**-5%**
1. WPD - Advanced Network Modelling and Data Recovery	130	125	114	-11	-9%
1. WPD - Procurement of SVO Equipment	60	20	19	-1	-7%
Installation of Equipment - 11kV & 33kV	60	5	5	0	1%
6. WPD - Implementation of Solution	46	46	46	0	0%
FPL Technologies - Substation Installation 33kV	100	90	87	-3	-3%
Travel & Expenses	**159**	**100**	**103**	**3**	**3%**
Travel & Expenses	159	100	103	3	3%
Contingency	**1190**	**0**	**0**	**0**	**0%**
Contingency	1190	0	0	0	0%
Other	**53**	**23**	**25**	**2**	**8%[5]**
Other	53	23	25	2	8%
TOTAL	**13091**	**7385**	**7313**	**-72**	**-1%**

1- ***Installation activities brought forwards compared to original schedule to de-risk construction work;***
2- ***Increase on workshop costs to date – this will be managed in respect of complete budget;***
3- ***As per note 1;***
4- ***Additional resource required to ensure inputs to SVO were of suitable quality for implementation – this will be managed in respect of complete budget; and***
5- ***These are costs associated with dissemination of lessons learnt as per note 2.***

5 Successful Delivery Reward Criteria (SDRC)

5.1 Future SDRCs

Table 5-1 captures the remaining SDRCs for completion during the project life cycle.

Table 5-1 - SDRCs to be completed

SDRC	Status	Due Date	Comments
5 - Trialling and demonstrating the SVO Method	Green	20/04/2018	On track
6 - Trialling and demonstrating the FPL Method	Green	05/10/2018	On track
7 - Trialling and demonstrating the integration of the EVA, SVO and FPL Methods	Green	28/12/2018	On track
8 - Knowledge capture and dissemination	Green	12/04/2019	On track

Status Key:	
Red	Major issues – unlikely to be completed by due date
Amber	Minor issues – expected to be completed by due date
Green	On track – expected to be completed by due date

6 Learning Outcomes

Significant learning has been generated and captured throughout this reporting period and has been robustly documented to support the delivery of SDRCs 5 and 6. The learning has also been captured within policies produced in this reporting period for both the SVO and FPL systems. The policies, when internally approved by WPD, will be made to all other DNOs on request or through ENA's ENACT Portal.

7 Intellectual Property Rights

A complete list of all background IPR from all project partners has been compiled. The IP register is reviewed on a quarterly basis.

No relevant foreground IP has been identified and recorded in this reporting period.

8 Risk Management

Our risk management objectives are to:

- Ensure that risk management is clearly and consistently integrated into the project management activities and evidenced through the project documentation;
- Comply with WPD's risk management processes and any governance requirements as specified by Ofgem; and
- Anticipate and respond to changing project requirements.

These objectives will be achieved by:

- ✓ Defining the roles, responsibilities and reporting lines within the Project Delivery Team for risk management
- ✓ Including risk management issues when writing reports and considering decisions
- ✓ Maintaining a risk register
- ✓ Communicating risks and ensuring suitable training and supervision is provided
- ✓ Preparing mitigation action plans
- ✓ Preparing contingency action plans
- ✓ Monitoring and updating of risks and the risk controls

8.1 Current Risks

The Network Equilibrium risk register is a live document and is updated regularly. There are currently 64 live project related risks. Mitigation action plans are identified when raising a risk and the appropriate steps then taken to ensure risks do not become issues wherever possible. In Table 8-1, we give details of our top five current risks by category. For each of these risks, a mitigation action plan has been identified and the progress of these are tracked and reported.

Table 8-1 - Top five current risks (by rating)

Details of the Risk	Risk Rating	Mitigation Action Plan	Progress
Cost of site works and implementation of FPL are greater than budgeted	SEVERE	Ensure that the project is delivered as efficiently as possible	Work is being closely managed and monitored to minimise any additional costs
Analogue data is not suitable to support the SVO and FPL real-time system decisions	SEVERE	Ensure the FPL and SVO analogues are fixed as a priority over other analogues	Updating and review of analogues is in process
Design and Protection methodology employed for FPL is unsuitable	MAJOR	Robust cold-commissioning and testing of the system and its suitability	Offline testing and modelling is being undertaken
Technologies/Solutions do not deliver the anticipated network benefits by unlocking expected capacity	MAJOR	Ensure that the scope and specification of the technologies and solutions is clearly designed and tested prior to implementation	De-risked due to testing and modelling. Plugins will provide further confidence to reduce risk
Internal resource constraints mean that technologies cannot be installed on time	MAJOR	Continued engagement with the teams and progress tracking	Deliveries are delayed but planned in line with project timescales

Table 8-2 provides a snapshot of the risk register, detailed graphically, to provide an on-going understanding of the projects' risks.

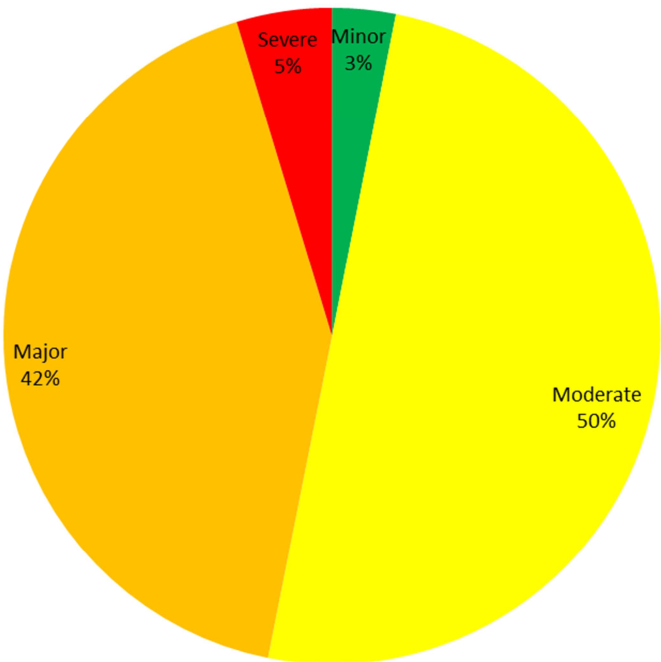
Table 8-2 - Graphical view of Risk Register

Likelihood = Probability x Proximity						
	Certain/Imminent (21-25)	0	0	0	0	0
	More likely to occur than not/Likely to be near future (16-20)	0	0	0	2	0
	50/50 chance of occuring/ Mid to short term (11-15)	0	0	5	0	1
	Less likely to occur/Mid to long term (6-10)	0	0	12	15	7
	Very unlikely to occur/Far in the future (1-5)	0	0	2	11	9
		1. Insignificant changes, re-planning may be required	2. Small Delay, small increased cost but absorbable	3. Delay, increased cost in excess of tolerance	4. Substantial Delay, key deliverables not met, significant increase in time/cost	5. Inability to deliver, business case/objective not viable
		Impact				

	Minor	Moderate	Major	Severe	
Legend	2	32	27	3	**No of instances**
Total	64				No of live risks

Table 8-3 provides an overview of the risks by category, minor, moderate, major and severe. This information is used to understand the complete risk level of the project.

Table 8-3 - Percentage of Risk by category



8.2 Update for risks previously identified

Descriptions of the most significant risks, identified in the previous six monthly progress report are provided in Table 8-4 with updates on their current risk status.

Table 8-4 - Risks identified in the previous progress report

Details of the Risk	Previous Risk Rating	Current Risk Rating	Mitigation Action Plan	Progress
The full and final APT will not be available to support the delivery of SDRC-4	Major	Closed	Ensuring appropriate plan is in place and resource.	SDRC-4 was successfully delivered whilst also highlighted areas of the APT and wider that would benefit from additional development
Key personnel leave the project	Major	Moderate	Rigorous and robust documentation of work. Induction Package to aid new starters	This risk continues to be actively managed
Correct level of network data can't be gathered to benchmark SVO and FPL performance	Major	Severe	Ensure the FPL and SVO analogues are fixed as a priority over other analogues	Updating and review of analogues is in process
Required data from several WPD systems in to the Siemens SVO system to enable it to function is unmanageable and non-updatable	Major	Closed	Develop a team structure and a process to enable the required timely updates to be carried out	All data is now gathered and integrated in to the system
SVO method is delivered behind schedule	Moderate	Minor	Ensure all elements of the method and communications interface are understood	All testing on track to date

Descriptions of the most prominent risks, identified at the project bid phase, are provided in Table 8-5 with updates on their current risk status.

Table 8-5 - Risks identified at the Bid Phase

Risk	Previous Risk Rating	Current Risk Rating	Comments
Project team does not have the knowledge required to deliver the project	Minor	Minor	Risk is being tracked but testing of systems has been successful further reducing the risk
No SVO available from the contracted supplier	Major	Closed	The SVO system procurement activity is now complete
Project cost of high cost items are significantly higher than expected	Major	Minor	All major items are now contracted and the state of these will be robustly monitored
No FPL available from the contracted supplier	Major	Minor	An FPL supplier has been contracted (ABB). Awaiting energisation
Selected sites for technology installations become unavailable	Moderate	Minor	Works have started a significant number of project site locations and suitable reserve sites have been selected as documented in SDRCs 2 and 3

9 Consistency with Full Submission

During this reporting period a core team of both WPD and WSP|PB engineers has been formed, which has and will continue to ensure that there will be consistency and robust capturing of learning moving forwards. This has ensured that the information provided at the full submission stage is still consistent with the work being undertaken in the project phase.

The scale of the project has remained consistent for all three methods:

- **EVA** – Develop and demonstrate an Advanced Planning and Operational tool for 33kV and 11kV networks;
- **SVO** – Install and trial advanced voltage control schemes at 16 substations; and
- **FPL** – Install and trial a Flexible Power Link at a 33kV substation.

10 Accuracy Assurance Statement

This report has been prepared by the Equilibrium Project Manager (Jonathan Berry), reviewed by the Future Networks Manager (Roger Hey), recommended by the Network Strategy and Innovation Manager (Nigel Turvey) and approved by the Operations Director (Philip Swift).

All efforts have been made to ensure that the information contained within this report is accurate. WPD confirms that this report has been produced, reviewed and approved following our quality assurance process for external documents and reports.