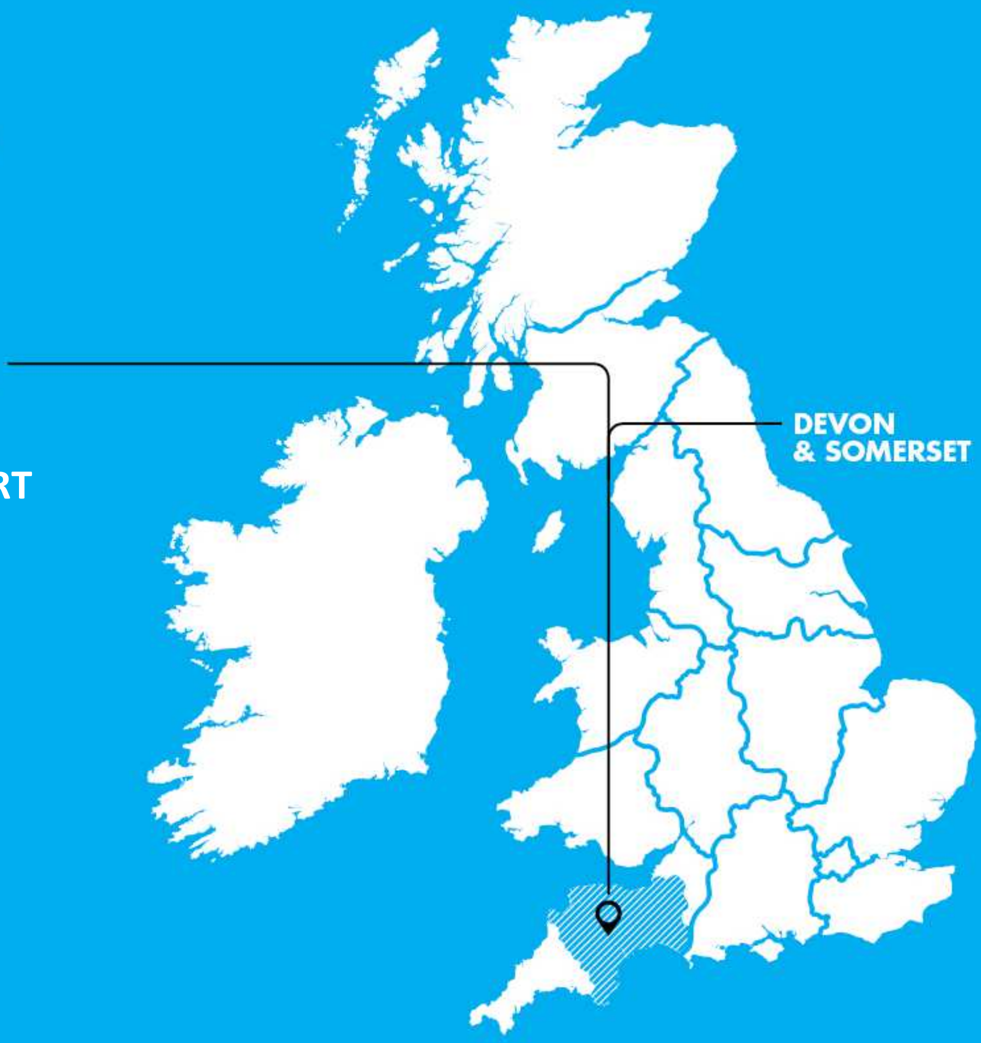
WESTERN POWER DISTRIBUTION

NETWORK EQUILIBRIUM

BALANCING GENERATION AND DEMAND



PROJECT PROGRESS REPORT

REPORTING PERIOD:
December 2017 to May 2018

LCN Fund
Low Carbon Networks

Report Title	:	Six Monthly Progress Report Reporting Period: December 2017 to May 2018
Report Status	:	FINAL
Project Ref	:	WPDT2006 - Equilibrium
Date	:	17.05.2018

Document Control

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Revision History

Date	Issue	Status
08.06.2018	V1.0	Released

Contents

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, December 2017 to May 2018.

Business Case

The business case for Network Equilibrium remains unchanged. The benefit of creating additional system capacity for the connection of load and generation, as well as the increases in security of supply to all customers is still valid.

Project Progress

This is the seventh progress report. The period covered in this report has focussed on the go-live operation of the System Voltage Optimisation (SVO) tool and the on-site commissioning of the Flexible Power Link (FPL). This work has enabled the project to move in to the trials phase to be reported in the next period.

Building on the testing and commissioning of the centralised and on-site equipment to support the SVO, this period has seen the Site Acceptance Testing (SAT) being carried out on the complete SVO system and has enabled the closed-loop operation to be demonstrated. This has enabled SDRC-5, Trialling and Demonstrating the SVO Method, to be completed within this reporting period.

Following the delivery of the FPL to site, the final device connection and commissioning activities have been completed in this period. The FPL is now energised and operating in a fixed power configuration to enable operational experience to be gathered and the full closed loop operation will commence in June, supporting the delivery of SDRC-6 in October 2018.

These activities described above have provided significant progress towards the completion of the next two SDRCs 6 and 7.

Project Delivery Structure

Project Review Group

The Network Equilibrium Project Review Group met once during this reporting period. The main focus of this meeting was the transition from the build and test phase to the trials phase.

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.

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	Completed
ABB	FPL	Exebridge	Completed

Installation

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

- 16 complete SVO relay site installation; and
- FPL device installed and commissioned.

Into the next reporting period additional monitoring equipment will be installed to optimise the operation of the SVO system and enable enhanced operational data to be gathered to benchmark performance.

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.

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 the now completed SDRC-5 and SDRC-6 due in October 2018.

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 will be investigated using three Methods, and their applicability to 33kV and 11kV distribution networks assessed. Each will involve 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 seventh progress report. The period covered in this report has focussed on the go-live operation of the System Voltage Optimisation (SVO) tool and the on-site commissioning of the Flexible Power Link (FPL). This work has enabled the project to move in to the trials phase to be reported in the next period. Site works for both the remaining SVO relay changes and FPL device integration have now been completed. The SVO has successfully undergone full end to end testing and is now operating in a closed-loop, real system environment, where it is running real-time system studies and updating the voltages at the 16 trial sites. Following the delivery of the FPL to site in the last reporting period the full device testing and commissioning has been completed .This has enabled the FPL to operate in fixed power transfer mode. During the next reporting the centralised FPL Control Module will be finalised and commissioned to enable full, dynamic, FPL control to be achieved.

A significant achievement in this reporting period has been the production and publication of SDRC-5, which details the design and installation process of the SVO along with the trialling and operation of the Method.

2.3 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 System Acceptance Testing (SAT), the commissioning of SVO at all sites and the commencement of the trials.

2.3.1 SVO Software System

2.3.1.1 Progress since previous reporting period

Following the completion of the Factory Acceptance Testing (FAT) and the System Integration Testing (SIT) in the previous reporting period, the System Acceptance Testing (SAT) was completed in this reporting period which enabled the commissioning of all SVO sites and the commencement of the trials.

In this report, the learning from the SAT is presented, showing how it shaped the commissioning process and making recommendations for the testing of such technologies. Additionally, the findings from the SVO commissioning are discussed which provide valuable knowledge on common commissioning issues and ways to prevent them. The operation of SVO in the trials so far has been analysed and its performance is also shown in this report. Finally, the results from the studies done using the SVO plugin are presented and provide a quantification of the expected benefits of the technology in terms of the capacity released.

2.3.1.2 System Acceptance Testing

The System Acceptance Testing (SAT) aimed to test the correct operation of the end-to-end SVO system and as part of this the first SVO sites were commissioned.

The preparations for the SAT included among other work, configuring the live NMS with the alarms and controls for the SVO sites, creating a commissioning plan with all the end-to-end tests that had to be carried out and ensuring SP5 was fully configured and ready to be commissioned. Also, the SVO control display in the NMS, which provides access to all SVO controls (to enable/disable SVO at each site), was updated for all SVO sites according to the requirements of the Control Engineers. Additionally, the commissioning procedure was agreed with the WPD Control Room ahead of the commissioning.

The sites that took part in these tests were Paignton BSP and Waterlake Primary and were chosen because they have different AVC relays and facilitate the testing of both substation types.

As part of the tests performed, all SVO Controls available in the NMS were tested to ensure that the correct actions are taken for each control. Additionally, repeating the FAT and SIT tests, all the network models in IMM and their displays were checked, the performance of DSSE was tested and the operation of VVC was confirmed.

After the initial tests verified the successful interaction between NMS and SP5 and the correct operation of the various SP5 modules, the end-to-end tests followed. During the end-to-end tests, manually entered set points were first sent from SP5 to each of the two sites that were tested. Figure 2-1 shows the SP5 window that was used to manually send set points to Waterlake Primary. In order to ensure that the tests had no operational impact on the network, the relays at each site were switched to Manual mode which prevented them from issuing any controls to the OLTCs on site. The successful application of analogue set points and group settings was proved in these first tests.

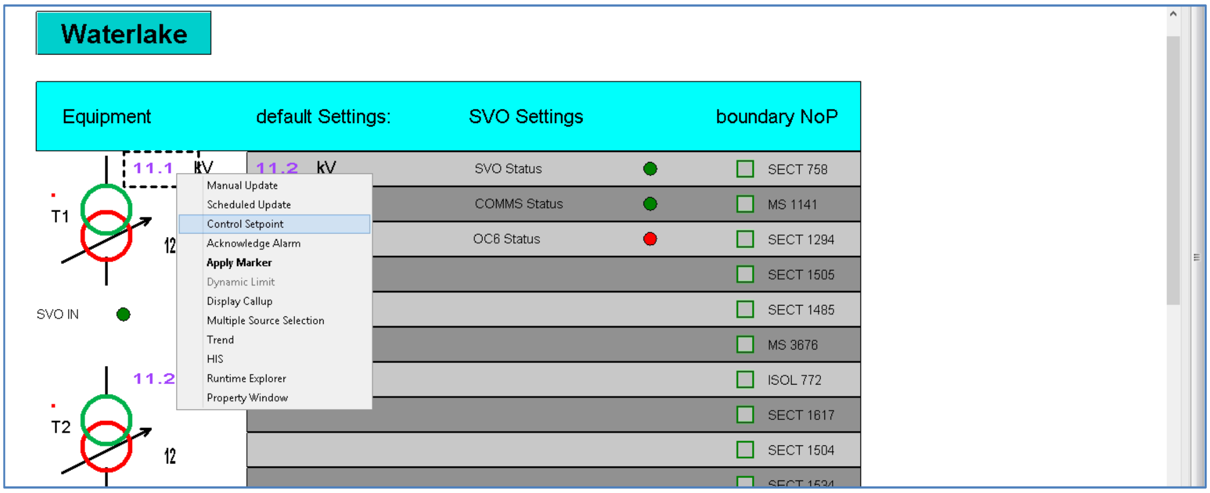


Figure 2-1 Manual Sending of Set Points through SP5

The final tests involved SVO being enabled at the two sites, performing a state estimation and sending target voltage set points. Figure 2-2 shows a screenshot from the NMS when SVO was enabled at Paignton BSP as part of the SAT, with all SVO indications shown as "IN".

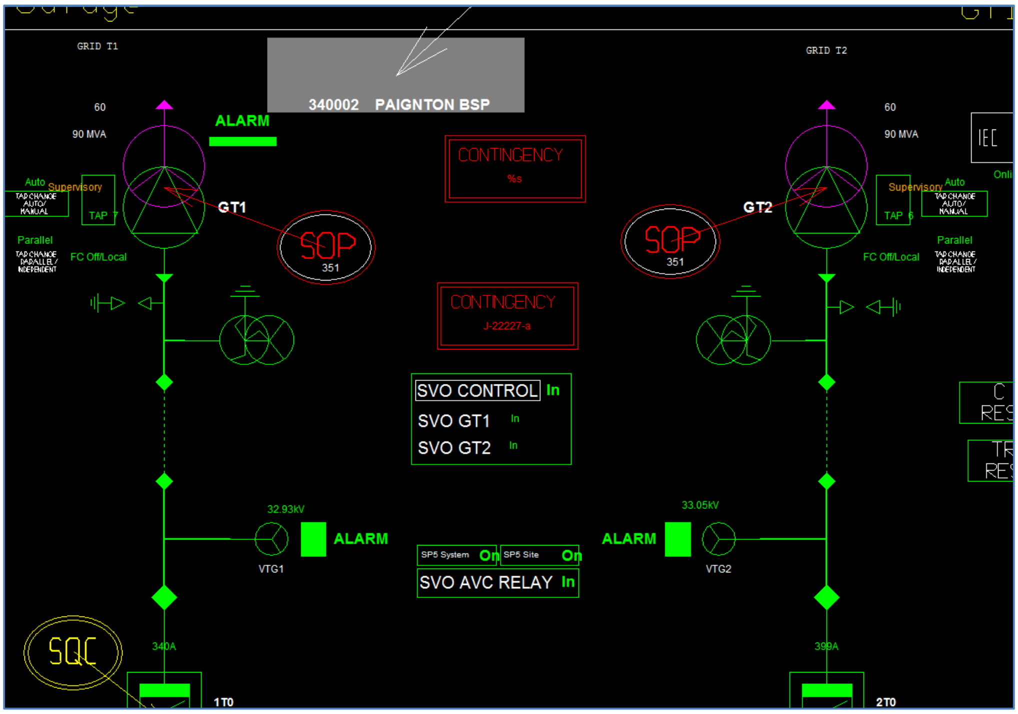


Figure 2-2 SVO Enabled at Paignton BSP in SAT

This final part of the testing offered significant learning on the RTU operation and the way it handles controls. It was found that when SP5 tried to send more than one set point to Paignton BSP, only the first set point was applied. This was because the RTU does not buffer controls; therefore if a second control is received when another control is being processed then the RTU discards the second control. This issue was successfully dealt with by configuring SP5 to wait for feedback from site on the previous control before sending a new one. The RTU and NMS configurations also had to be updated with the additional feedback points

2.3.1.3 SVO Commissioning

The commissioning of all 14 remaining SVO substations followed after the completion of the SAT. Incorporating the learning obtained from the SAT, the commissioning included the following tests:

- Testing of all NMS SVO controls to enable and disable SVO;
- Testing of manual sending of set points to site to ensure that set points are sent to all relays, applied correctly by the relay and the correct feedback is received back to the NMS; and
- Testing of back-to-back sending of set points to prove the correct RTU configuration and that SP5 waits for the feedback before sending any other set points.

The procedures that were followed in the commissioning are summarised in Figure 2-3. Following the successful completion of the commissioning, all sites were enabled for live operation as part of the commencement of the SVO trials.

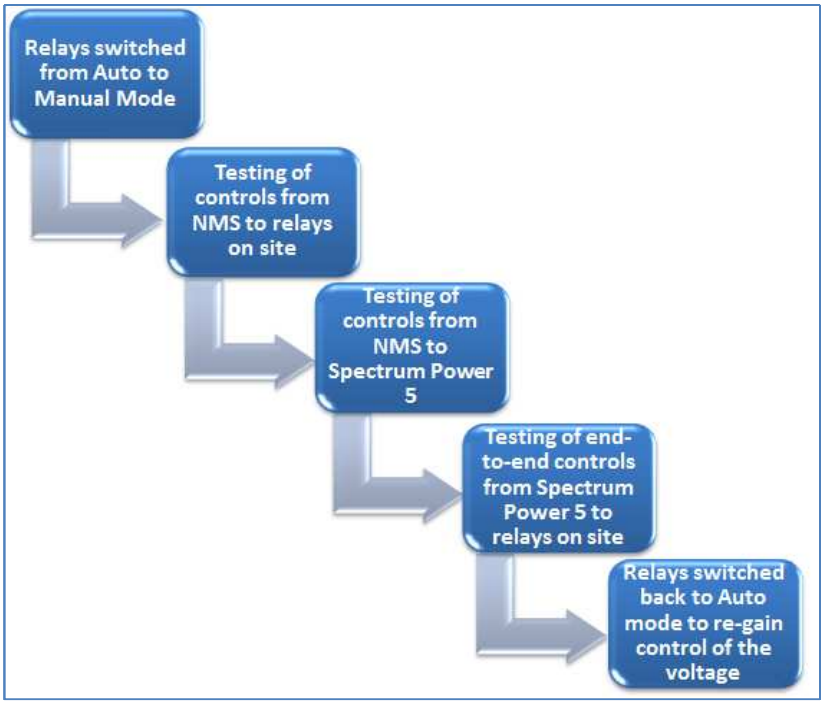


Figure 2-3 SV0 Commissioning procedures

2.3.1.4 SVO Trials

The trials of the SVO method have provided valuable learning on the operation of the SVO system.

Through the trials it was shown that overall it is possible to amend the target voltage at BSPs and Primary substations in real time and the amendment depends on the real time operating conditions.

For example, the target voltage set points at Paignton BSP between 03/04/2018 and 06/04/2018 are demonstrated in Figure 2-4. Paignton BSP has two 132/33kV Grid Transformers and SVO has been sending optimised target voltage set points to the AVC relays controlling the voltage at each of these two transformers.

During the period shown in the figure, SVO has been amending this target voltage and the set points applied are shown with the blue (Grid Transformer 1) and orange (Grid Transformer 2) lines. The figure shows that for the majority of the time that SVO was enabled, the target voltage was set to values lower than the traditional setting of 1 per unit which verifies that optimally, the target voltage should be set lower than what it has been set in Business As Usual operation. Enabling the reduction of the voltages in the network could allow generation, that would otherwise be constrained by high network voltages, to connect to the network.

Figure 2-5 shows how the voltage at the two Paignton transformers varied between 03/04/2018 and 06/04/2018. The variations in the 33kV voltages match the variations in the target voltage set points, proving the successful application of the optimised SVO set points.

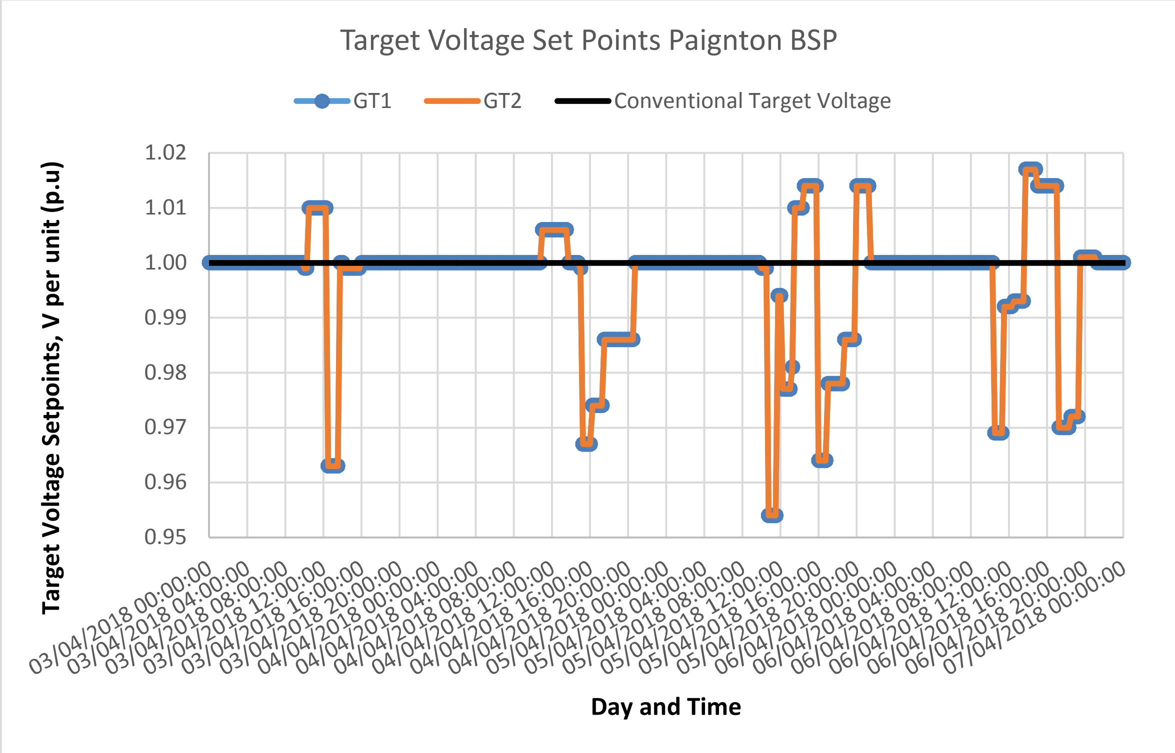


Figure 2-4 Paignton SVO set points

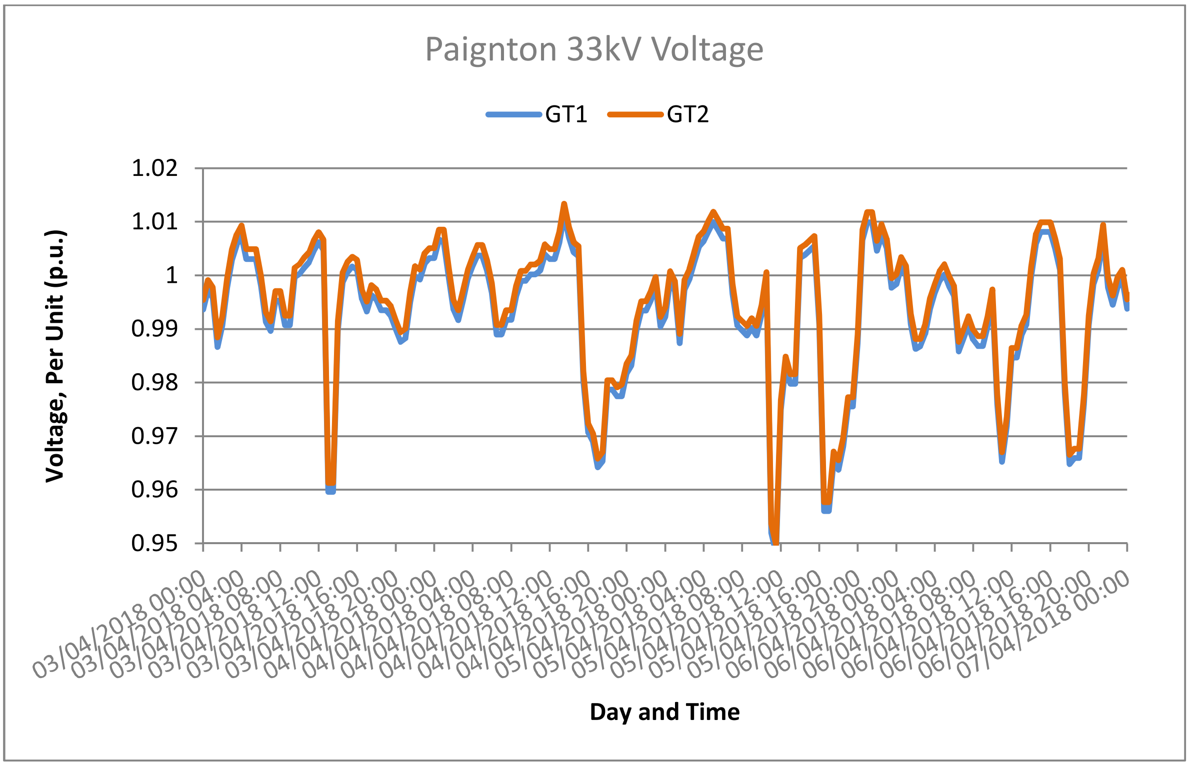


Figure 2-5 Paignton 33kV Voltage

The example of the operation of SVO at a different substation is shown in Figure 2-6. This figure demonstrates how the target voltage at Waterlake Primary substation varied between 03/04/2018 and 06/04/2018 when SVO was enabled during the daytime.

During the period shown in the figure, SVO has been amending this target voltage and the set points applied are shown with the blue (Transformer 1) and orange (Transformer 2) lines. Looking at how the voltage varies at each of the two Waterlake transformers in Figure 2-7, a different behaviour is observed compared to the variation of voltage at Paignton BSP. Even though in the example of Paignton BSP, the voltage at each transformer matched the optimised target voltages, this was not the case at Waterlake Primary. This is because Waterlake Primary operates with settings group control (MicroTAPP relays) while Paignton BSP can receive analogue set points (SuperTAPP SG relays). Since Paignton BSP can receive and apply any value of target voltage set point, the voltage at the substation is very close to the optimised target voltage it received from SVO. However, due to the operation of the settings group control, inaccuracies are introduced which cause variations between optimised target voltage sent by SVO and voltage at site.

Additionally, in Figure 2-7 it can be seen that there is no measurements for the voltage at T2 after the morning if the 5th of April 2018. This is because the local team were performing work at that part of the substation that day, which interrupted the transmission of the voltage measurements. During the time that the work was undertaken, the SVO operation was paused.

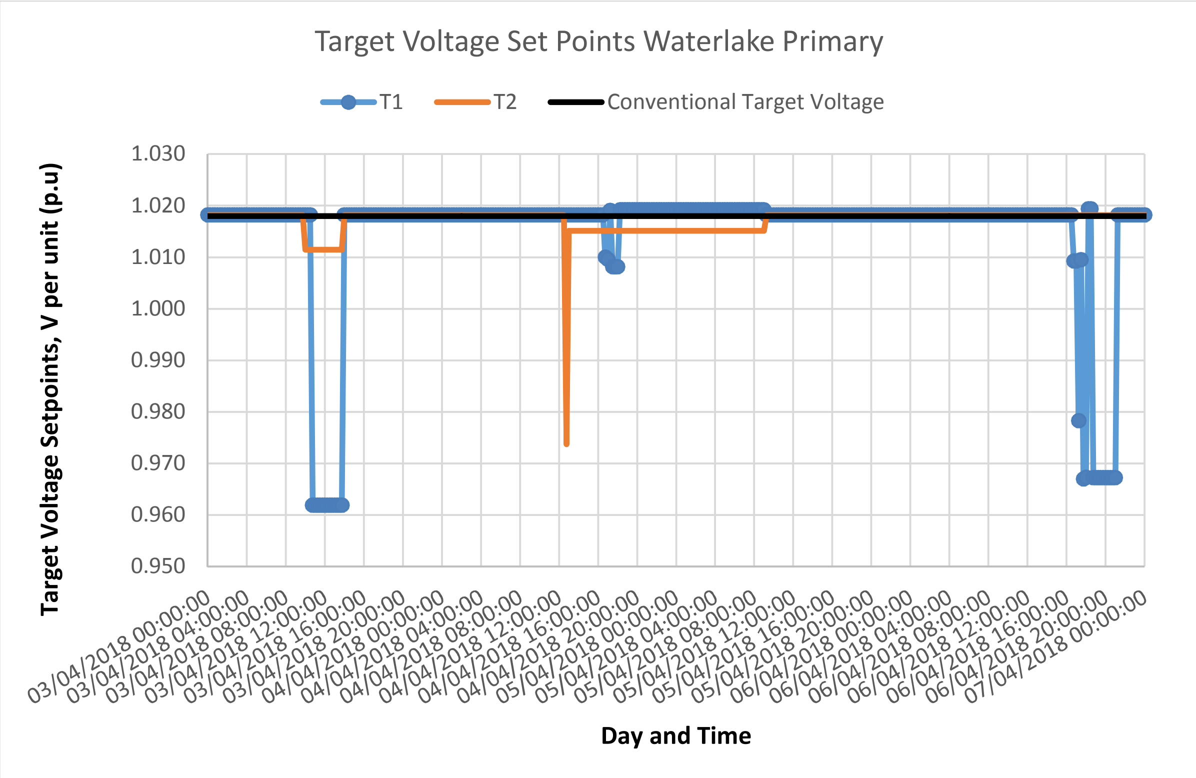


Figure 2-6 Waterlake SVO Set Points

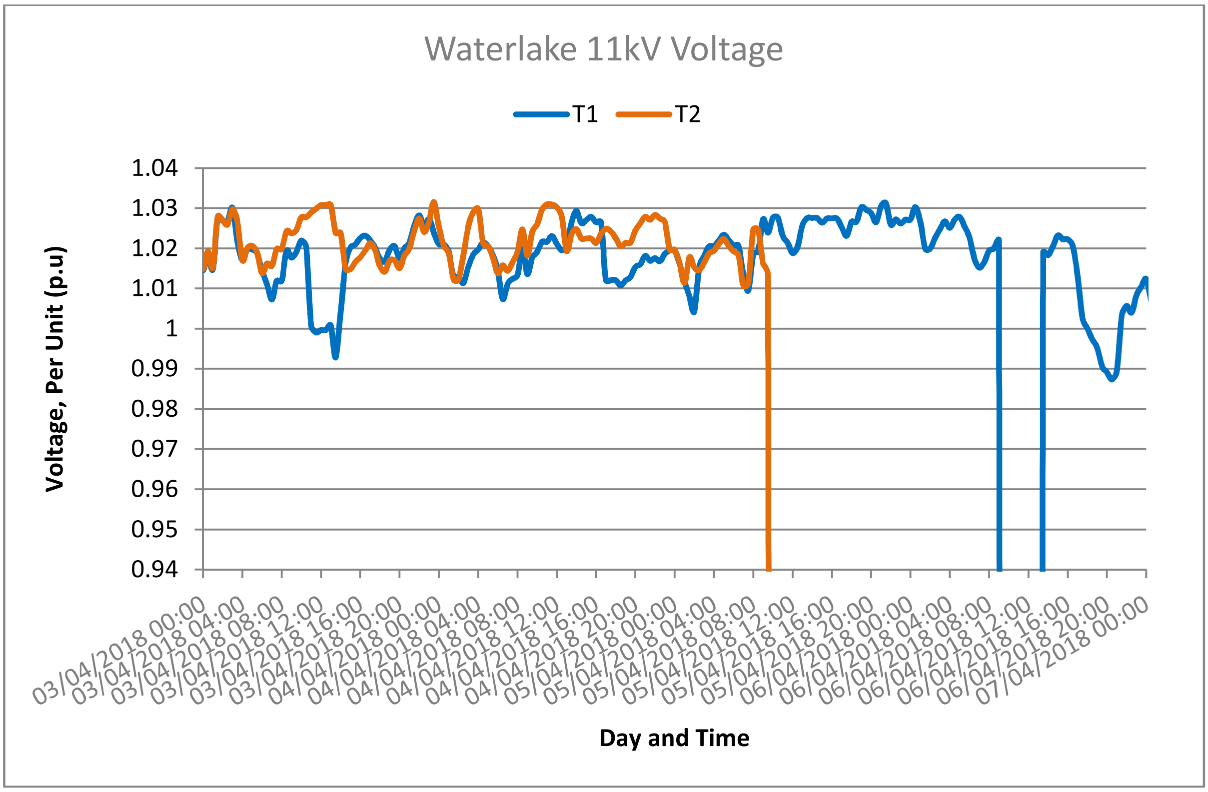


Figure 2-7 Waterlake 11kV Voltage

2.3.2 SVO Plugin

In the last reporting period, the SVO plugin tool was developed and handed over to WPD system planners for evaluation and feedback. During this reporting period, using the information gathered during testing of the tool by both the project team and WPD system planners, further development of the tools was carried out and the interface finalised. The final interface is shown in Figure 2-8 below:

Figure 2-8 SVO Plugin User Interface

2.3.2.1 Training

On 19th April 2018 a training course was delivered to a group of WPD Primary System Design Engineers with responsibility for network design for the substations affected by SVO. The training described the tools interface, interaction with the network model and interpretation of results. The training will enable planners to start incorporating SVO studies into the business as usual processes in preparation for the transition upon project closure.

2.3.2.2 Estimated Capacity Benefits – SVO Plugin Studies

The operation of SVO was simulated in the PSS/E plugins that were developed as part of the project. The plugins also calculate an estimate of the available network capacity when running SVO compared to normal running (no SVO), enabling the quantification of the technology benefits.

The analysis performed provides estimates of the capacity released at each of the SVO BSPs and Primaries for a Winter Day and a Summer Day.

For example, the available network capacity in Exeter City BSP with SVO enabled (blue line) and without SVO (brown line) during a winter day is shown in Figure 2-9. The average capacity of the network without SVO enabled for the 24hr period is 224 MW of generation. With SVO enabled this average increases to 236 MW unlocking an additional 12 MW of generation capacity at this BSP.

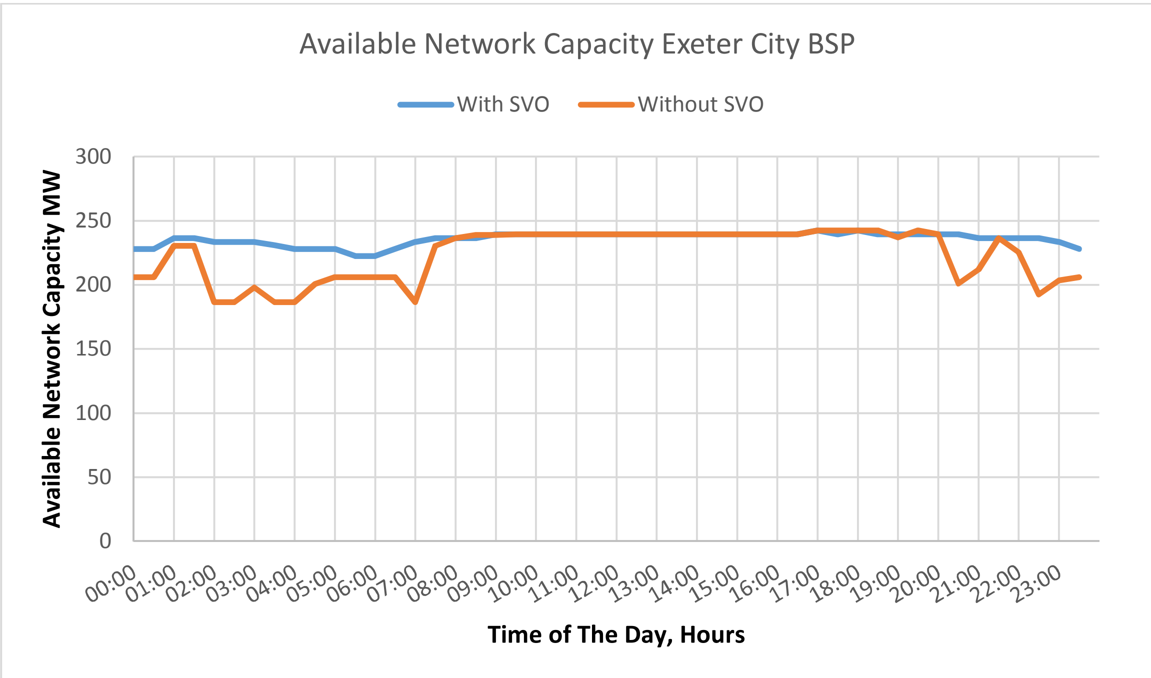


Figure 2-9 Available Network Capacity Exeter City BSP Winter Day

To gain an appreciation of the capacity benefits SVO can introduce over all eight BSPs, Figure 2-10 shows how the average network capacity over the 8 SVO BSPs varies in a winter day when SVO is enabled (blue line). As can be seen in the figure, the average existing network capacity (brown line) is lower than the capacity when SVO is enabled, showing that SVO overall provides additional network capacity at all times. By calculating the difference of the two capacities (with and without SVO), it is found that at least 20 MW of average capacity at each of the eight BSPs is released using SVO in winter, giving a total capacity release of 160 MW. This provides a capacity increase of 15%.

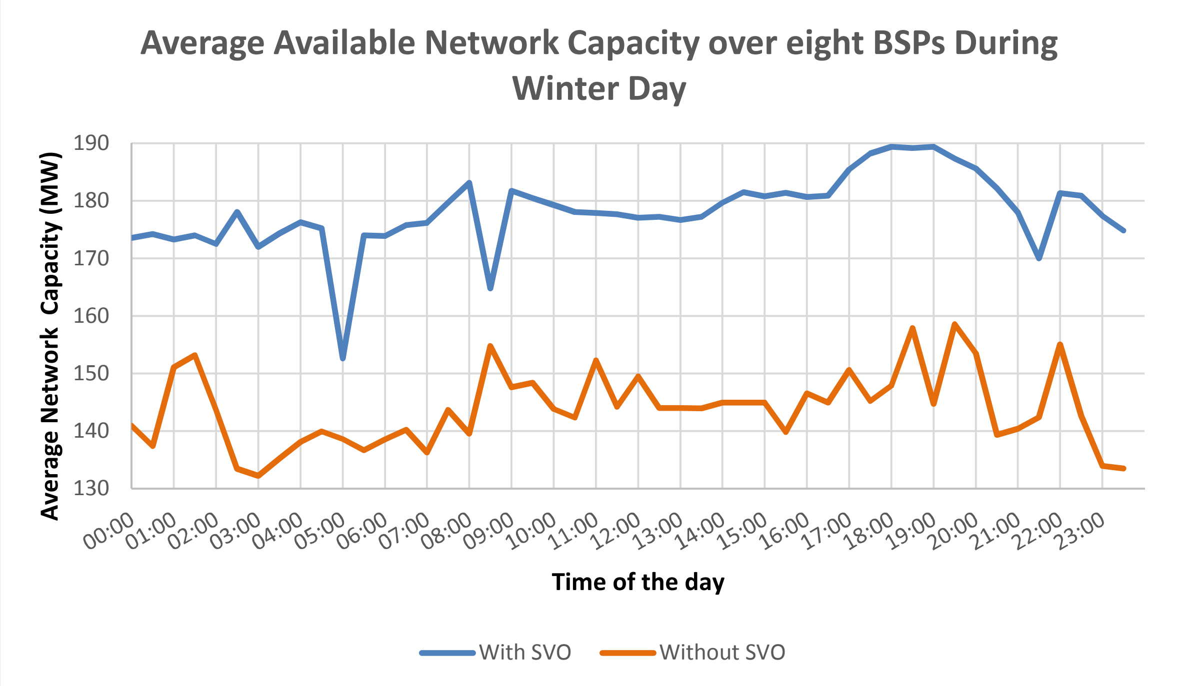


Figure 2-10 Winter Day Average Available Network Capacity over eight SVO BSPs – With and without SVO

Similarly, Figure 2-11 shows the average network capacity over the eight BSPs in a summer day, with and without SVO enabled. Again, SVO is shown to provide additional network capacity at all times. The minimum capacity release by SVO in summer is found to be 20 MW average at each BSP, releasing 160 MW in total and providing 15% increase in capacity.

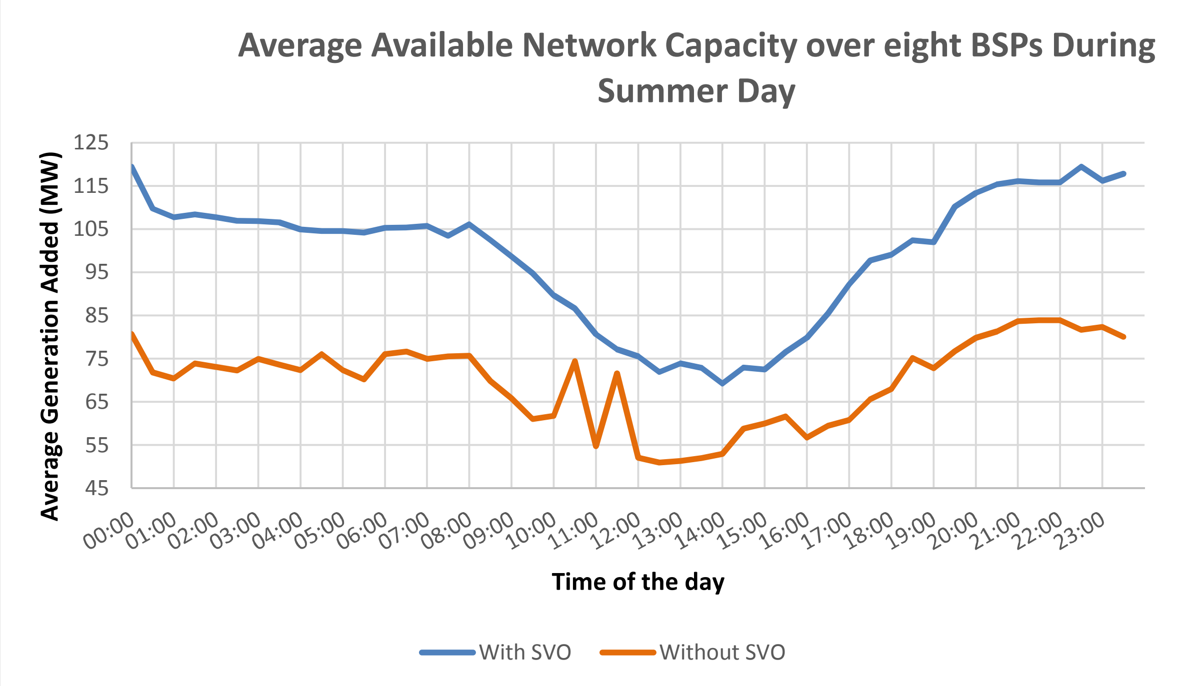


Figure 2-11 Summer Day Average Available Network Capacity over eight SVO BSPs – With and Without SVO

Figure 2-12 and Figure 2-13 demonstrate how the average network capacity over the eight SVO Primaries varies in a Winter Day and a Summer Day with and without SVO. By considering the difference between the two lines, it is calculated that with SVO enabled the average capacity over the eight Primaries increases by at least 9 MW in winter and 6 MW in summer. This provides a total capacity release of 72 MW (75% increase) in winter and 48 (60% increase) MW in the summer across the eight Primaries.

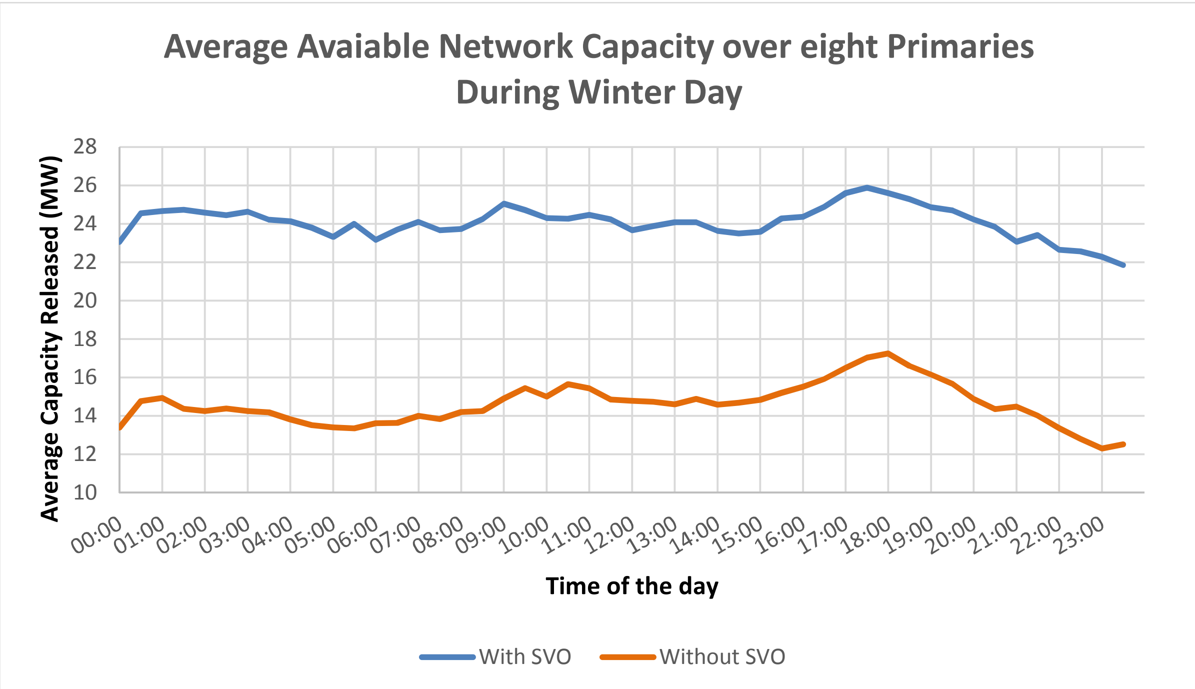


Figure 2-12 Winter Day Average Available Network Capacity over eight SVO Primaries – With and Without SVO

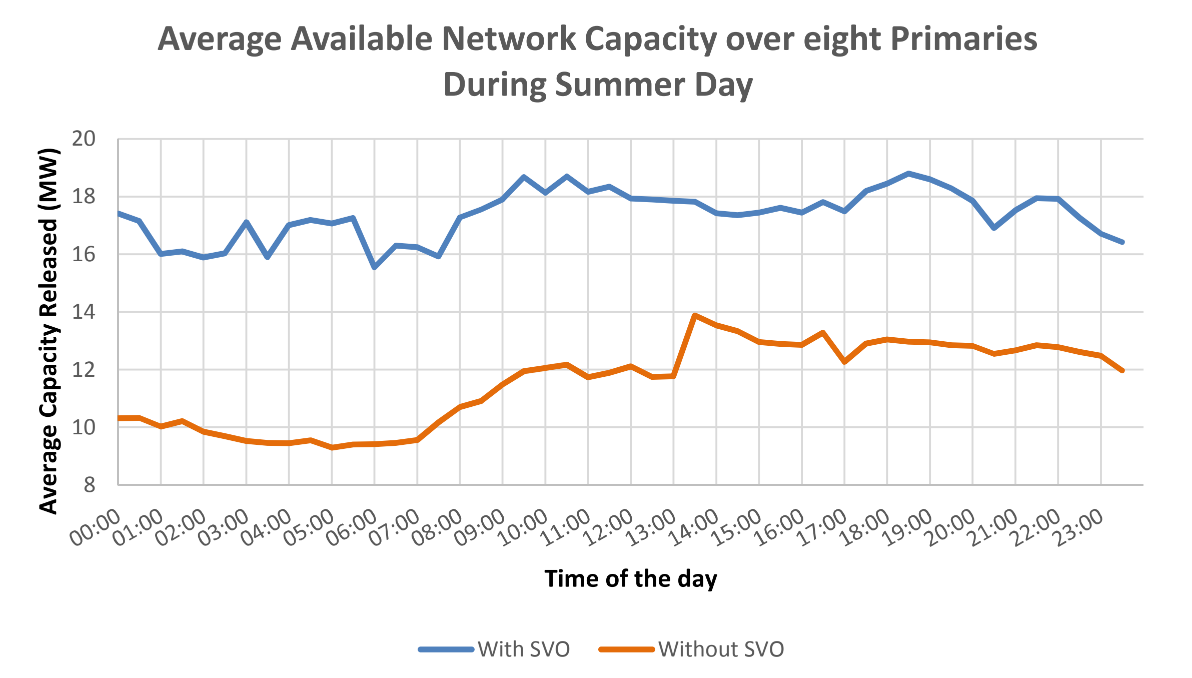


Figure 2-13 Summer Day Average Available Network Capacity over eight SVO Primaries – With and Without SVO

2.3.3 Policies

In this reporting period, the SVO Operation and Control Policy (Operation and Control of System Voltage Optimisation – Standard Technique ST:OC1AB) has been finalised and issued for usage by WPD staff before the commencement of the live trials. WPD's Control Engineers were involved in all stages of the review process of the document and received detailed briefings of the final document, ensuring the successful implementation of the policy.

The SVO Engineering Equipment Specification (EESPEC), provides the detailed specification of the SVO technology and as part of the work completed in this reporting period, the first draft has been finalised and will be updated as required at the end of the SVO trials.

The first draft of the SVO Applications and Connections Policy has also been finalised. This document includes the requirements for the application and connection of SVO in 33kV and 11kV networks. It demonstrates all considerations that need to be taken into account when implementing SVO and the required works that need to be completed. It will be finalised at the end of the SVO trials.

2.3.4 SVO Site Works

2.3.4.1 Site Installation

In the previous reporting period, installation works were ongoing with a total of 11 sites commissioned for SVO. In this reporting period installation and commission works at the remaining five substations was completed with the final substation commissioned on 23rd February 2018. A list of all substations and their energisation dates are shown in Table 2-1 below.

Table 2-1 SVO Site Installation dates

Substation	Energisation Date
Bowhays Cross	20/10/2017
Bridgwater	09/06/2017
Colley Lane	24/02/2017
Dunkeswell	08/12/2017
Exeter City	13/10/2017
Exeter Main	10/11/2017
Lydeard St Lawrence	03/03/2017
Marsh Green	02/02/2018
Millfield	26/01/2018
Nether Stowey	09/02/2018
Paignton	26/05/2017
Radstock	23/02/2018
Taunton	18/08/2017
Tiverton	03/11/2017
Tiverton Moorhayes	27/10/2017
Waterlake	24/02/2017

2.3.4.2 Colley Lane Relay Failure

On the 1st March 2018, one of the SuperTAPP SG relays installed at Colley Lane experienced a critical failure, entering into an infinite loop attempting to reboot. The transformer remained operational throughout and was placed onto a fixed tap and controlled manually. Investigations by the relay manufacturer, Fundamentals, discovered that the issue was caused by a memory overload of the built in storage. On reboot of the relay, the memory would fail to respond causing the reboot to fail and the cycle to repeat.

2.3.4.3 Relay Upgrades

Following the lessons previously reported and the memory issue experienced at Colley Lane, an updated firmware and software was developed and released by Fundamentals to resolve the issues experienced and to increase the overall stability of the relay. This upgraded relay was soak tested on the bench to ensure stability and compatibility with WPD's systems before installation onto the system.

Following successful testing, a roll out plan was developed to replace the relays at each substation. Due to the replacement of internal cards within the relay, it was decided that the upgrade works should be carried out in the manufacturer's factory rather than on site. This would remove the risk of issues arising on site meaning the relays could not be recommissioned. The relay changes took place at all sites between January and April 2018 with each relay requiring basic recommissioning once installed.

2.4 Flexible Power Link

2.4.1 Overview

During the last reporting period the FPL equipment had successfully passed factory acceptance tests and most of the major components had been delivered to the 33/11kV Exebridge substation. The new 33kV switchboard had been energised and the necessary enabling works were underway. In this reporting period, the FPL equipment has been installed at the 33/11kV Exebridge substation. In addition, it has been commissioned and demonstrated through a programme of site acceptance tests. On-site training has been conducted and the Operation, Control and Maintenance policies have been agreed and implemented.

2.4.2 Technology

The following sections detail how the FPL technology has been integrated into the live network.

2.4.2.1 FPL Design

There were no changes to the FPL design during this reporting period. The emphasis in this reporting period was the installation and commissioning. However in February 2018, WSP held an internal workshop to discuss the lessons from the FPL design phase and capture improvements for future work.

2.4.2.2 FPL Network Integration

The new 33kV switchboard was fully tested and commissioned during this reporting period. The project provided interface schematics and a cable schedule to allow LV supplies, control and protection wiring and communications to integrate directly with the existing network.

This included the intertripping protection scheme associated with substations at South Molton and Wiveliscombe substations.

2.4.2.3 FPL Installation

ABB UK and the installation contractor HET Hanseatische completed the installation of the FPL equipment. Under the management of ABB; specialist sub-contractors were used for both the transformer installation (doble) and transformer noise enclosure (dBA).

The FPL installation work was conducted under the management of the Senior Authorised Person (SAP) according to schedule and the commissioning work took less than four weeks to complete keeping disruption to the WPD network and customers to a minimum. The final week was disturbed by a weather event known as '*the Beast from the East*' and it was necessary to halt work for three days, however, the installation works were completed on time and successfully.

Installation activities included the following detail as described below.

FPL Transformer

The FPL transformer manufacturer by Koncar contains two three phase transformers within a single tank. The lifting arrangements were carefully planned early in the installation since the transformer tank is larger than usual and the mass of the transformer is 50t before an additional 10.5t of oil is added. All lifting activities (requiring an 80t mobile telescopic crane) were carried out early in the installation work. Thereafter, a smaller telehandler and MEWP remained on site for movement of small equipment and unloading deliveries.

A specialist contractor (dBA ltd.) then assembled a noise enclosure around the transformer tank in order to attenuate the sound during operation.

Figure 2-14: Transformer Noise Enclosure

A small amount of remedial work was required following transport damage to ensure the equipment is properly protected against corrosion. This work had to be completed before the busbar connections could be installed between the transformer and FPL container.

The transformer was filled with 15,800 litres of insulating oil. Samples were tested for water content, breakdown voltage and then returned to a lab for gas testing.

FPL Container

The FPL container underwent final assembly on site with external fittings and grounding connections being completed after delivery.

Most of the components within the FPL container are pre-installed in the factory. This dramatically reduced the amount of time taken carrying out installation work on site. Therefore, the remaining installation work is mostly associated with pulling, glanding and terminating of multicore and small power cables.

Figure 2-15: FPL Container

Grid Filter

The grid filter is a tuned HP filter (2nd order damped) connected at 33kV on the grid side of the FPL transformer. The grid filter equipment is all mounted on support structures using the larger telescopic mobile crane and the mechanical assembly was inspected.

Finally, the electrical properties of each component were checked, (i.e. Resistance, Capacitance) to ensure all remains within tolerance.

Figure 2-16: Grid Filters

Heat Exchanger

The FPL has a dedicated external heat exchanger which carries heat away from the FPL container via a monoethylene glycol and distilled water mixture. A run of external pipework was installed between the container to the heat exchanger. This was then inspected to ensure flange connections and steel supports were properly tightened and earthed.

Figure 2-17: FPL Cooling System

2.4.2.4 Commissioning

In accordance with WPD Safety Rules, the commissioning programme comprised of two parts;

- Pre-Commissioning (or Cold Commissioning)
- Hot Commissioning

The cold commissioning tests were equipment checks and tests using low power and standalone test equipment. This testing commenced on 6th March 2018 and was completed by 20th March 2018.

The hot commissioning tests were conducted over a nine day programme. The first six days to undertake the standard tests mandated by ABB for the FPL equipment and three further days to demonstrate the full performance of the FPL (i.e. active and reactive power transfer). Following this, a series of measurements were taken relating to audible noise, harmonics and EMC.

Cold Commissioning

During the cold commissioning tests the FPL was completely isolated from the WPD 33kV network via the two dedicated circuit breakers (designation 1RO and 2RO).

The cold commissioning tests were mostly routine check and tests that would be carried out for all equipment installed on the distribution network by WPD. This includes visual checks of wiring, proving the earth connections to equipment and measurement of the auxiliary supply (low voltage).

Testing of particular interest include;

FPL Transformer

- Sweep Frequency Response Analysis (SFRA)
- Insulation Resistance
- Transformation ratio within ±0.5% in accordance with IEC 60076-1.
- Magnetising current (at low voltage)

All tests passed successfully, there was some difficulty repeating the factory test results for transformation ratio. This was due to damage to one of the measurement cables.

FPL Converter

- Overcurrent protection (blocking) on each phase
- Energise the DC link with ±25V_{DC}
- Check all IGCT pulse patterns (low voltage) and measure primary voltage on FPL transformer VT.
- Charge DC link and measure frequency spectrum on HP filter using Rogowski coil.

All tests passed successfully.

Hot Commissioning

In order to carry out the hot commissioning tests on the live WPD network, a number of local network configurations were agreed, illustrated in Figure 2-18. For much of the testing, a 'bypass' configuration was used allowing power to circulate from one side of the FPL to the other without significant impact to the live network. The performance of the FPL in this arrangement is shown in Figure 2-19.

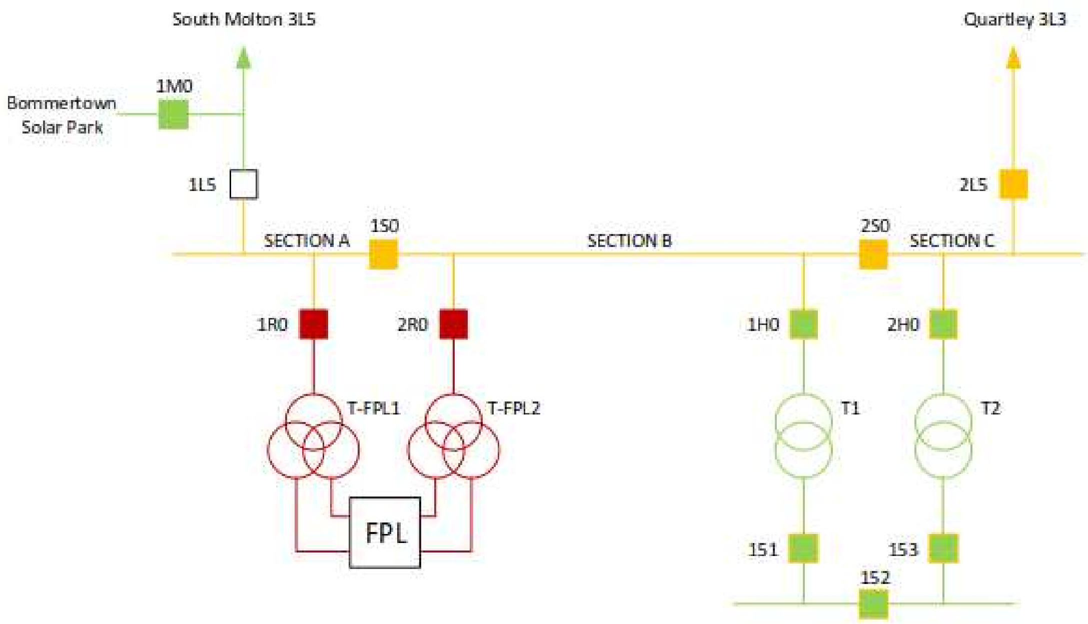


Figure 2-18: Configuration for Hot Commissioning

Other special configurations were developed for the single purpose of conducting voltage measurements as each side of the FPL was energised on the live network for the first time.

Once all main circuit components had been energised and synchronised on the 33kV network, the local and remote control inputs were tested before a full load test for 30 minutes. The hot commissioning tests were passed successfully without incident.

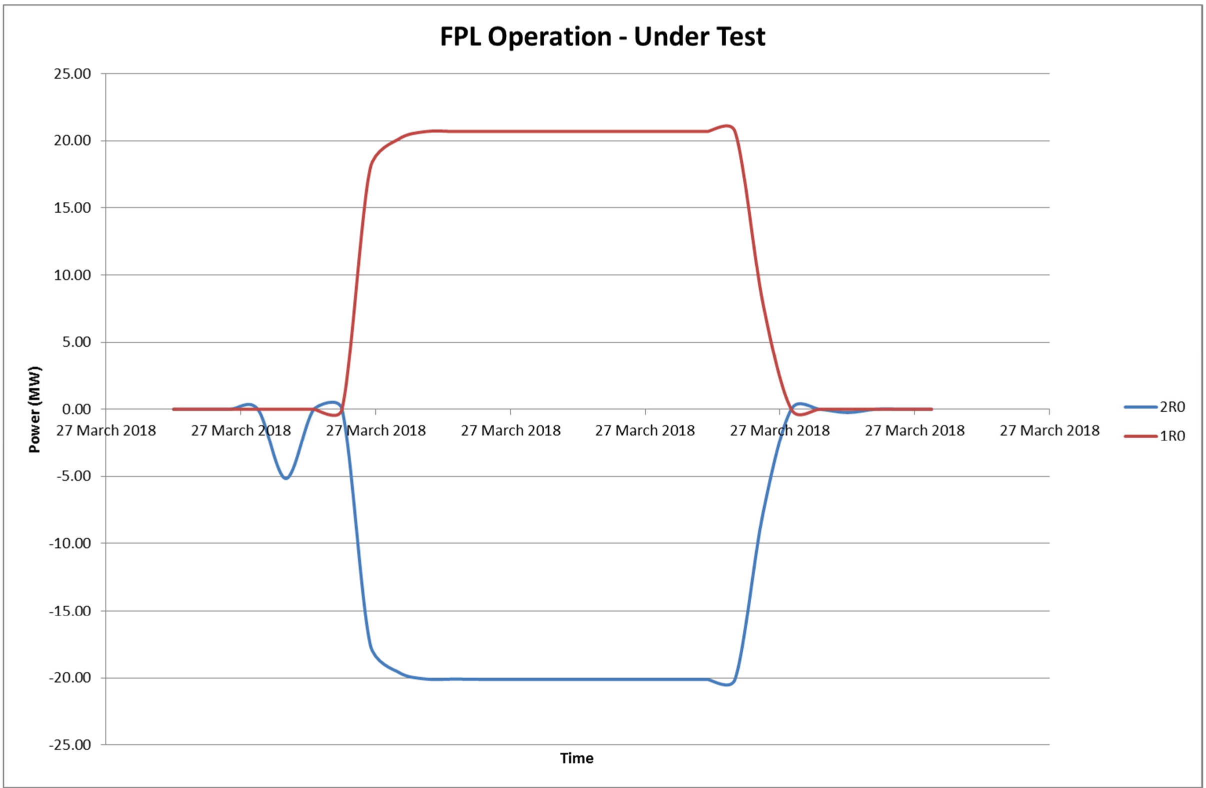


Figure 2-19: FPL Real Power Transfer Under Test

2.4.2.5 Acceptance Tests

In order to fully demonstrate the performance of the equipment provided by ABB, a set of contractual acceptance tests were conducted. These addressed;

- Power loss determination
- A heat run
- Active and reactive power capability

And, a programme of emissions tests to ensure that the system was operating within planning and safety limits;

- Electromagnetic Field limits according to ICNIRP 2010[1]
- Audible noise to local planning requirements
- Harmonic distortion and modification within planning levels according to ER G5/4[2] methodology

[1] Guidelines for limiting exposure to time-varying electric and magnetic fields (1Hz – 100kHz)
[2] Planning Levels for Harmonic Voltage Distortion and the connection of Non-Linear Equipment to Transmission and Distribution Networks in the UK

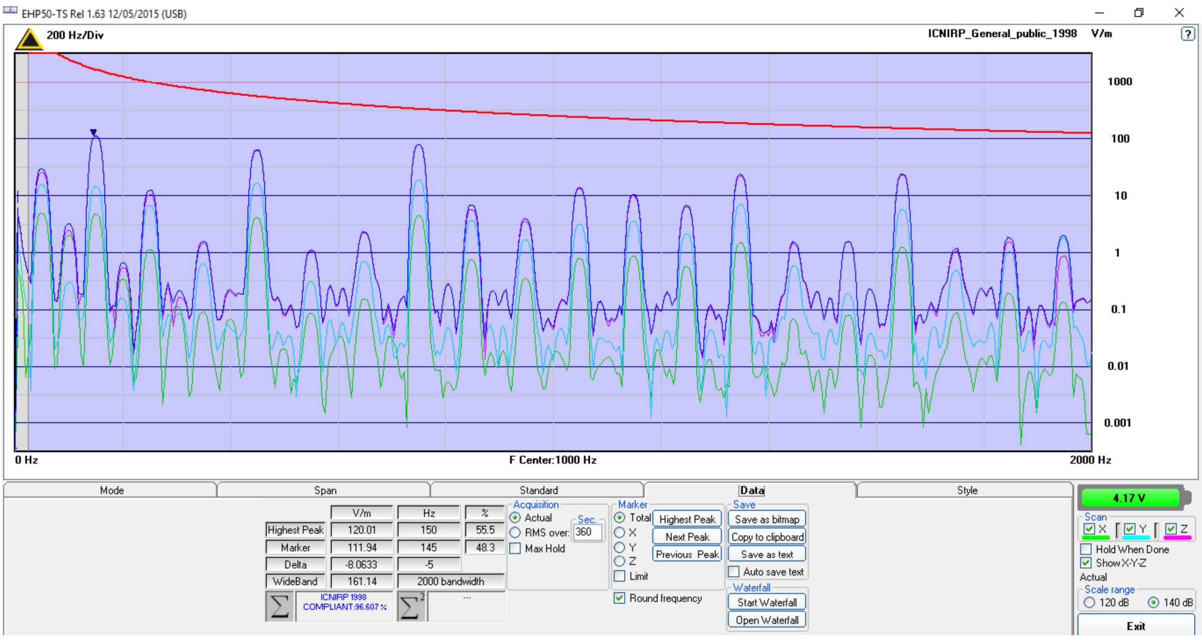


Figure 2-20: FPL EMF Levels

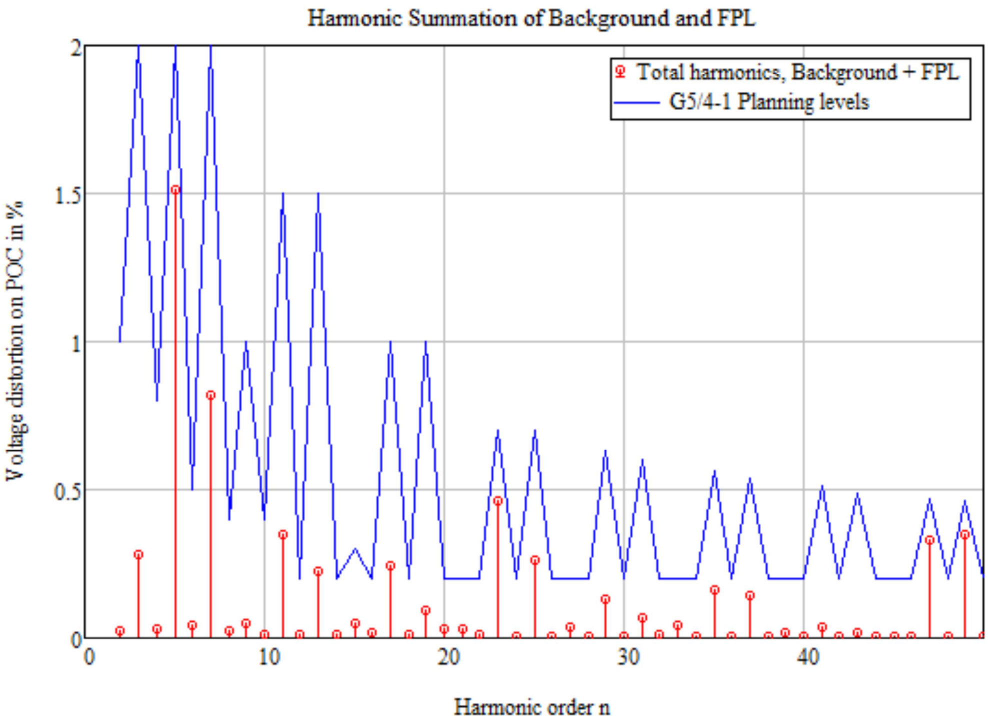


Figure 2-21: FPL Harmonic Performance against G5/4

Power Loss Determination

Losses were calculated by transferring power through the FPL in both directions and then taking an average of the two results. This method (proposed by ABB) was reviewed and approved by the project team prior to testing. Figure 2-22 shows the results for this test and it can be seen that the loss measurements fall within expectations.

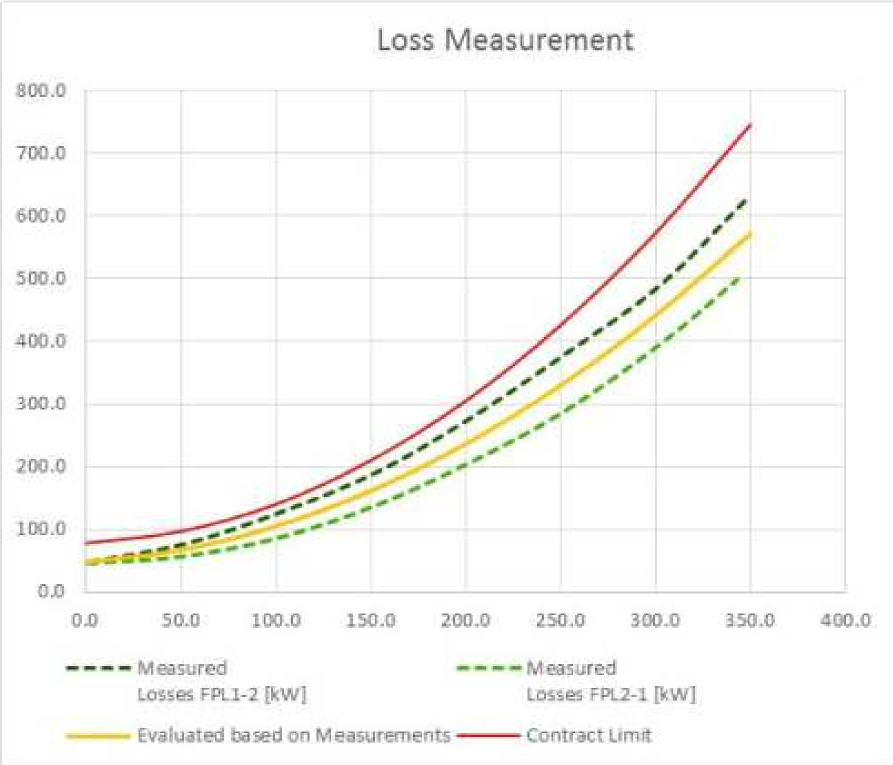


Figure 2-22: FPL Loss Measurement under Test

Active and Reactive Power Capability

Figure 2-23 was produced from data taken during the acceptance testing for the FPL. It shows that the system is achieving the full P-Q capability required. The blue line indicates the nominal voltage of 33kV and performance of 20MW, 5MVar is demonstrated where the two orange lines intersect.

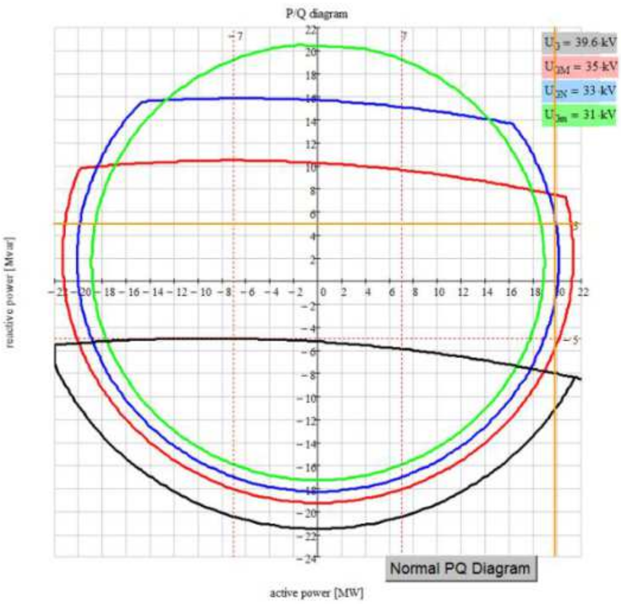


Figure 2-23: FPL1 20MW, 5MVar (@ 34kV)

2.4.2.6 Policy Documentation and Training

The Operation and Control and Inspection and Maintenance policies developed for the FPL were formally reviewed and approved by WPD management prior to commissioning of the FPL.

This was supported by a training course provided by ABB at Exebridge for our operational engineers and operatives so that they would become familiar with the local user interface and maintenance requirements of the device described in the associated policies.

The final ABB's Installation and Operation Manual and Local SCADA Manual was also provided and reviewed by the project team. Whilst some irregular maintenance tasks will be undertaken by specialist service providers it is expected that our staff will conduct the majority of inspection and maintenance tasks on the site.

2.4.3 FPL Plugin

In order to access the impact of the FPL at Exebridge and to also provide tools to WPD system planners to begin the transition to business as usual, a plugin tool was developed to replicate the FPL operation. During this reporting period the FPL plugin was developed and a soft handover of the tool to WPD system planners for assessment carried out.

2.4.3.1 Tool Interface

Similar to the tool developed for SVO, the FPL tool has a dedicated Graphical User Interface (GUI) within the PSS/e operating environment for ease of use by the end user. Many functions of the tool have been automated to simplify operation and minimise the risk of user error. Once a suitable network model is selected by the user, the tool will insert the FPL at the defined location. It is also possible to select two BSP's with the tool then selecting appropriate connection points between the two. Other user defined parameters include loading factor, Maximum and minimum voltage limits and thermal limit plus additional user target voltage limits and thermal limit. The user interface developed is shown in Figure 2-24 below.

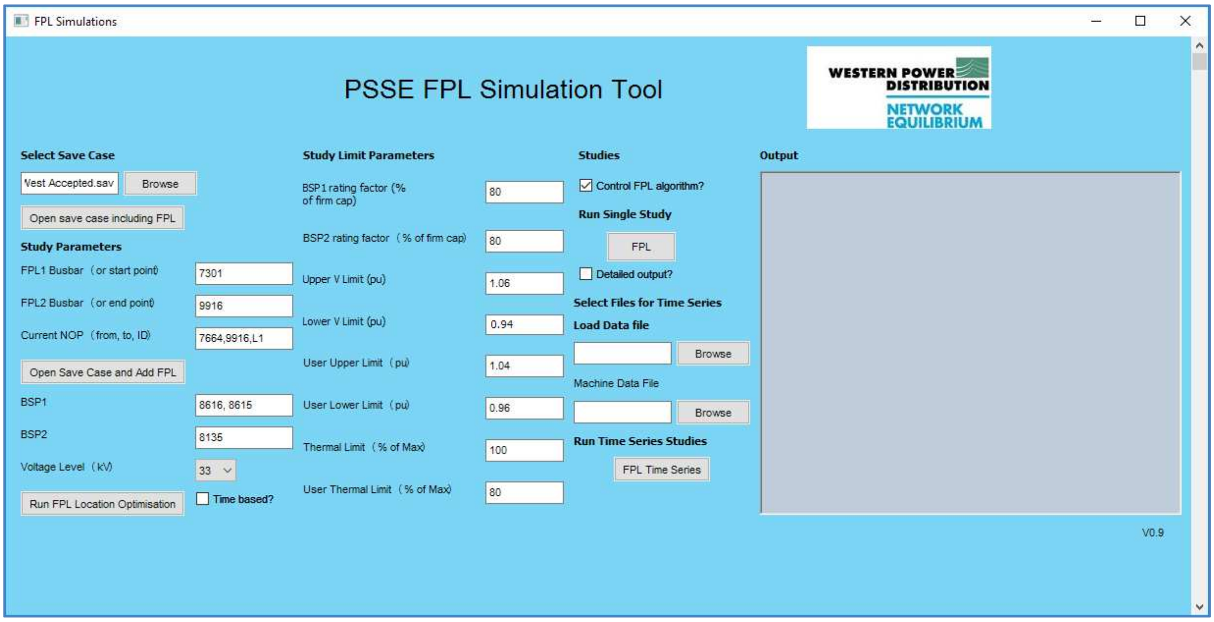


Figure 2-24 FPL Plugin User Interface

Following completion of a study the results are shown in the output window within the GUI and also exported in spreadsheet format for further analysis.

2.4.3.2 Tool Operation Modes

The tool is designed to operate in two modes; using the FPL Control Module Algorithm or in the default studies mode. The FPL Control Module Algorithm, due to the being in control of the actual device on the network, is programmed to fail safe if it is unable to find a suitable operating condition that meets all the user defined limits. The studies mode developed for the tool is based on the Control Module Algorithm, however if it is unable to find an operating condition to meet all the user defined limits, it will work to minimise the number of violations and find the closest solution while ensuring all upper limits are adhered to. This mode is designed to enable system planners to tune the FPL Control Module and to find suitable user limits.

2.4.3.3 FPL Location Optimisation

The tool is also able to carry out an FPL Location Optimisation algorithm that will aim to find the optimum FPL connection point between two BSPs. The user is required to select the busbars of each BSP to parallel and the Normally Open Point between them both. With this information, the tool will place the FPL at viable connection points between the two, determining the optimum point based on the FPL capacity required.

2.4.3.4 Studies

The FPL tool has been developed to carry out either static, single studies or dynamic time series studies using historical network data.

For static FPL studies, the tool will determine the optimum FPL operating set point based on the user defined model loaded into PSS/e. This is ideal for carrying out studies for worst case scenarios and for determining the FPL capacity required to solve network voltage or power flow issues at these extremes.

By utilising historical network data collected for a period of time, it is possible for the tool to operating in a more dynamic mode; generating FPL operating set points based on actual network load and generation conditions. This will be used to verify the operation of the FPL installed at Exebridge and to inform the user defined limits programmed into the FPL Control Module. For system planners the dynamic study will allow them to see the affect the FPL could have over time when additional load or generation is added to the network.

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 May 2018	Actual Spend to date	Variance £	Variance %
Labour	**1262**	**753**	**716**	**(37)**	**-5%**
WPD Project Management & Programme office	510	345	329	(15)	-4%
Project Kick Off & Partner / Supplier Selection	33	33	33	-	0%
Detailed design & modelling	101	101	92	(9)	-9%[1]
Installation of Equipment - 11kV & 33kV	290[2]	56	53	(3)	-5%
FPL Technologies - Substation Installation 33kV	241[2]	180	172	(9)	-5%
Capture, analyse & verify data for EVA, SVO & FPL	58	24	23	(1)	-3%
Dissemination of lessons learnt	29	14	13	(0)	-3%
Equipment	**6691**	**5,563**	**5,599**	**37**	**1%**
Project Kick Off & Partner / Supplier Selection	2	2	2	-	0%
Procurement of SVO Equipment	1540	940	959	19	2%
Procurement of FPL Technologies 33kV	4550	4,022	4,022	(0)	0%
FPL Technologies - Substation equipment 33kV	599	599	616	17	3%
Contractors	**3339**	**2,297**	**2,222**	**(75)**	**-3%**
Detailed design & modelling	804	804	765	(38)	-5%
Delivery of SVO Technique - 11kV & 33kV	392	292	285	(7)	-2%
Installation of Equipment - 11kV & 33kV	650[3]	120	116	(4)	-3%
Implementation of Solution	46	46	46	0	0%
Implementation of Solution	139	67	65	(2)	-3%
FPL Technologies - Substation	740[3]	680	663	(18)	-3%

Installation 33kV					
Capture, analyse & verify data for EVA, SVO & FPL	445	266	261	(5)	-2%
Dissemination of lessons learnt	123	22	21	(1)	-4%
IT	**396**	**317**	**307**	**(11)**	**-3%**
1. WPD - Advanced Network Modelling and Data Recovery	130	125	114	(11)	-9%[4]
1. WPD - Procurement of SVO Equipment	60	38	37	(1)	-2%
Installation of Equipment - 11kV & 33kV	60	8	8	0	2%
6. WPD - Implementation of Solution	46	46	46	0	0%
FPL Technologies - Substation Installation 33kV	100	100	100	0	0%
Travel & Expenses	**159**	**119**	**115**	**(4)**	**-4%**
Contingency	**1190**	**-**	**-**	**-**	**0%**
Other	**53**	**26**	**25**	**(1)**	**-4%**
TOTAL	**13091**	**9,075**	**8,984**	**(92)**	**-1%**

Notes on line item changes and variations

1 – Efficiencies in detailed design and the production of standard designs enabled savings.

2 – £100k has been transferred from the labour costs of the SVO Method to the FPL Method. There is no material change in the delivery of either of the two Methods through this budget line change.

3 - £200k has been transferred from the contractor costs of the SVO Method to the FPL Method. There is no material change in the delivery of either of the two Methods through this budget line change.

4 – Cost savings were enabled through the use of an existing advanced network modelling methodology created as part of the previous FlexDGrid project.

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
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 capturing in this reporting period, specifically in SDRC-5 regarding the optimised design, installation and operation of the SVO system. Several key learning elements have also been generated during the installation, commissioning and operation of the FPL that will be robustly reported in SDRC-6.

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 28 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
Analogue data is not suitable to support the SVO and FPL real-time system decisions	MAJOR	Ensure that quality and quantity of analogue data is suitable for the project	All available analogues have been ratified and their granularity of data reporting has been increased to support the project. Trialling of the system will reduce this risk
Design and Protection methodology employed for FPL is unsuitable	MAJOR	Ensure standardised protection is employed where possible and run extensive models prior to commissioning	First of a kind installation and this risk will reduce when the protection has proved successful under live trial
Optimal FPL violation limits for operation cannot be determined	MAJOR	Robust cold-commissioning and testing of the system and its suitability	Risk will reduce when the FPL CM is commissioned and the trials commence
Voltage complaints	MAJOR	Carry out detailed analysis of data retrieved during trial phase of the FPL / FPL CM to establish credible violation limits that can be implemented after trial phase.	SVO affects voltage at a large number of substations. This risk will reduce from further system operation
Correct level of network data can't be gathered to benchmark SVO and FPL performance	MAJOR	Carry out detailed analysis of data retrieved during trial phase of the FPL / FPL CM to establish credible violation limits that can be implemented after trial phase.	Pre-trial data has been gathered but as network operation and arrangements change this will be monitored

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

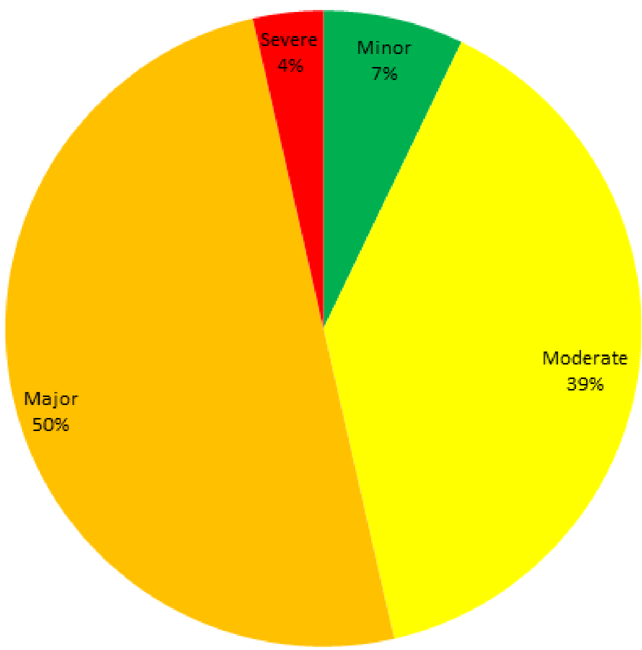
Table 8-2 - Graphical view of Risk Register

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	1	0
	50/50 chance of occuring/ Mid to short term (11-15)	0	0	2	4	0
	Less likely to occur/Mid to long term (6-10)	0	0	7	7	1
	Very unlikely to occur/Far in the future (1-5)	0	0	2	1	3
		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	11	14	1	No of instances
Total	28				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
Cost of site works and implementation of FPL are greater than budgeted	SEVERE	MINOR	Ensure that the project is delivered as efficiently as possible	FPL site activities are nearly finalised as only minor snagging work is to be completed
Analogue data is not suitable to support the SVO and FPL real-time system decisions	SEVERE	MAJOR	Ensure the FPL and SVO analogues are fixed as a priority over other analogues	All available analogues have been ratified and their granularity of data reporting has been increased to support the project. Trialling of the system will reduce this risk
Design and Protection methodology employed for FPL is unsuitable	MAJOR	MAJOR	Robust cold-commissioning and testing of the system and its suitability	First of a kind installation and this risk will reduce when the protection has proved successful under live trial
Technologies/Solutions do not deliver the anticipated network benefits by unlocking expected capacity	MAJOR	MODERATE	Ensure that the scope and specification of the technologies and solutions is clearly designed and tested prior to implementation	Learning reported in SDRC-5 has shown the benefits of SVO reducing this risk
Internal resource constraints mean that technologies cannot be installed on time	MAJOR	CLOSED	Continued engagement with the teams and progress tracking	Technologies are now installed and operation

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 operation of SVO and FPL is now in place.
No SVO available from the contracted supplier	Closed	Closed	The SVO system procurement activity is now complete
Project cost of high cost items are significantly higher than expected	Minor	Closed	All major items are now procured
No FPL available from the contracted supplier	Minor	Closed	FPL is now live and operational
Selected sites for technology installations become unavailable	Minor	Closed	Construction activities on all sites are now complete

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.

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