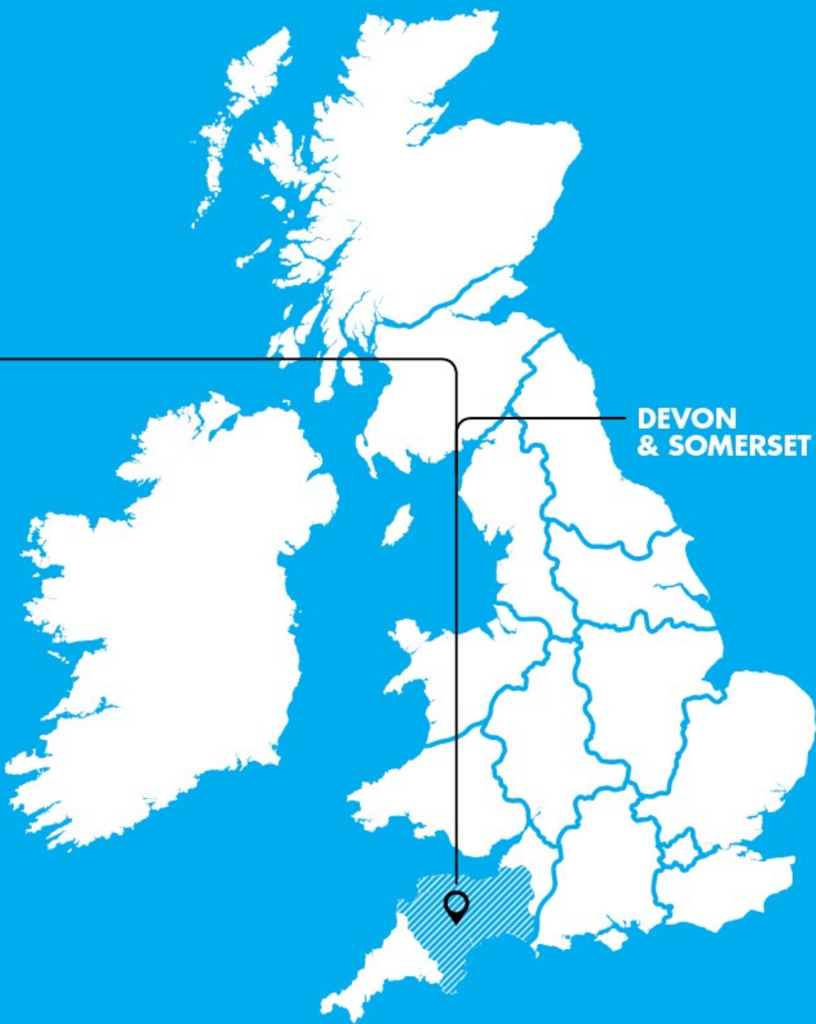
WESTERN POWER DISTRIBUTION

NETWORK EQUILIBRIUM

BALANCING GENERATION AND DEMAND



SDRC-8

Knowledge Capture and Dissemination

LCN Fund
Low Carbon Networks

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Contents

1.0 Introduction

1.1 Overview

Network Equilibrium is a Low Carbon Networks Fund (LCNF) project which aims to demonstrate how novel voltage and power flow management can release network capacity.

The project has three technical methods:

- The Enhanced Voltage Assessment (EVA) Method;
- The System Voltage Optimisation (SVO) Method; and
- The Flexible Power Link (FPL) Method.

The trial location for Network Equilibrium encompasses the 33kV and 11kV distribution networks in our South West area across the counties of Somerset and Devon.

This report focuses on the knowledge capture and dissemination activities as part of the project to ensure the learning and data has been appropriately shared as part of the project. This forms the Ofgem deliverable for Successful Delivery Reward Criteria (SDRC) 8: "Knowledge Capture and Dissemination".

1.2 Structure

This SDRC, 8, focuses on the knowledge dissemination, publication of reports and the generation of new policies produced as a direct consequence of the delivery of Network Equilibrium. The SDRC provides the details of specific knowledge dissemination in the form of:

- Network data and policies made available;
- Eight industry conferences attended and presented;
- LCNI conference presentations;
- Publication of comprehensive project reports;
- Detailed dissemination to other DNOs; and
- Six-monthly progress reports submitted to Ofgem and published throughout the project.

As well as the knowledge dissemination described above, knowledge has also been disseminated in a variety of other formats, such as workshops., These workshops have expanded on the reports and described in more detail the analytical approach of the test results, and explained how we evaluated and quantified the benefits of each project solution. These workshops also allowed us to demonstrate the applicability to wider GB electricity networks, in the form of new policies.

This SDRC document will detail the format of each key element of project knowledge dissemination and its significant area of dissemination.

1.3 Project Background

The following section provides a brief overview of the three technical Methods delivered as part of the Network Equilibrium project.

1.3.1 Enhanced Voltage Assessment

The EVA Method has been tested as part of the project to understand the value in widening the statutory voltage limits on the 11kV and 33kV network as well as the technical impacts of such a change. The aim was to demonstrate the value of this Method to support the connection of additional distributed generation (DG) on to the system, whilst minimising the need to make any wider network changes.

To further explain how the statutory voltage limits can constrain the available network capacity, consider Figure 1-1, which shows the voltage rise caused by the connection of a new generator. If this voltage rise in any operational scenario exceeds the statutory voltage limit of 1.06 p.u in 11kV and 33kV networks, then the generator would not be able to connect.

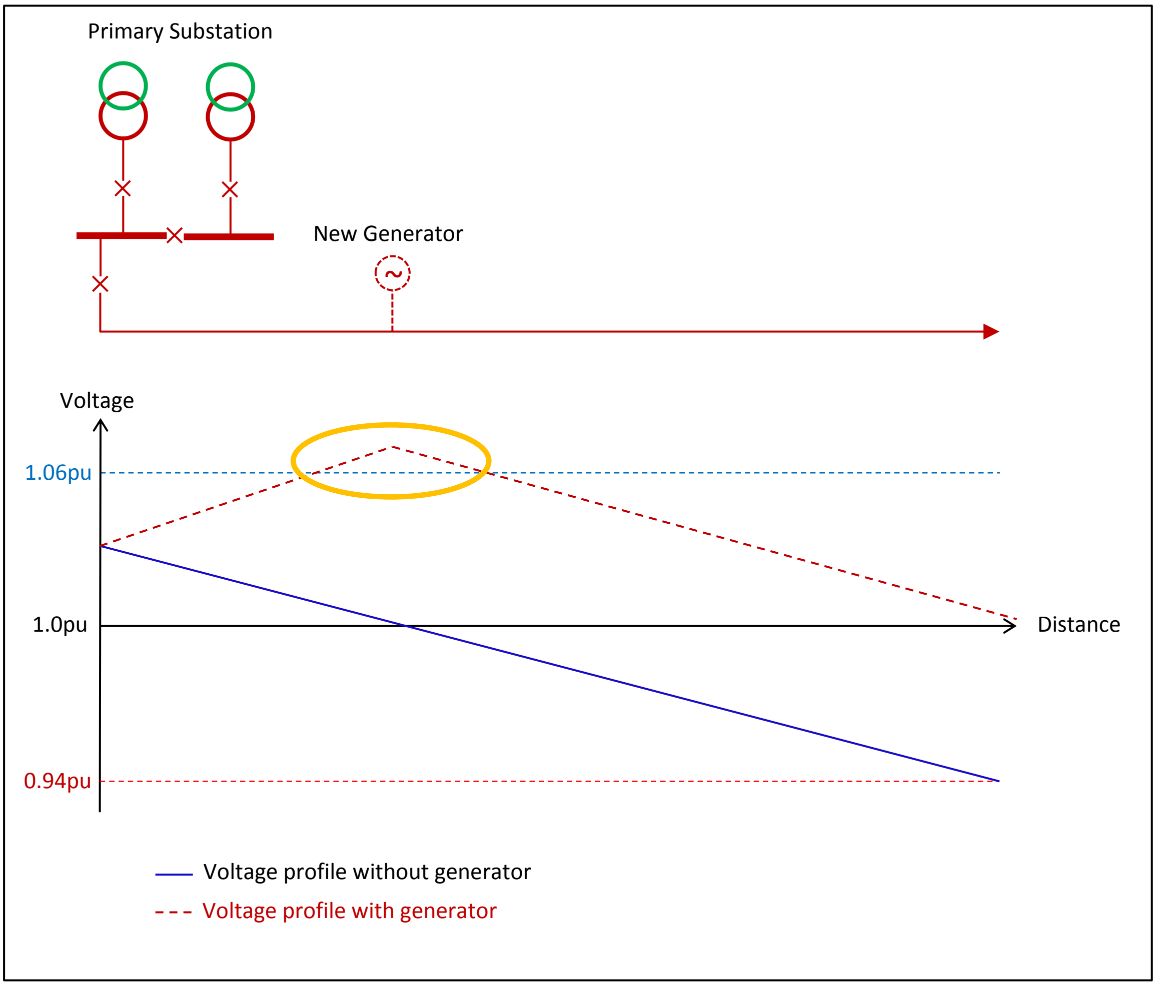

Figure 1-1 - Impact on voltage from new generation connection

If it was possible, however, to extend the high statutory voltage limit to 1.08p.u or 1.10 p.u, then the generation connection would be allowed without the need for network reinforcement.

Therefore, EVA explored the potential amendment of the statutory limits to release network capacity. This involved among others a number of power system studies, equipment investigations and consultation with the industry, with the full outputs of the study being presented in SDRC-1 previously.

1.3.2 System Voltage Optimisation

SVO is a novel voltage control system based on a completely different philosophy compared to traditional voltage control. It aims to release network capacity through intelligent voltage management, removing the constraints imposed by existing voltage control systems.

Currently, the voltage on 33kV and 11kV networks is controlled using Automatic Voltage Control (AVC) relays that send signals to control On Load Tap Changers (OLTCs) to maintain the voltage at a particular target value. This target voltage is set to ensure that the network voltage is kept within the statutory limits of ±6% for 33kV and 11kV networks, as stated in the Electricity, Safety, Quality and Continuity Regulations (ESQCRs). As part of Business As Usual (BAU) voltage control, the static AVC target voltage set point is set relatively high to account for the voltage drop in the demand dominated networks it was designed for.

However, electricity distribution networks are no longer demand dominated. The increasing penetration of embedded generation, which is often intermittent in nature, causes the operating conditions of electricity distribution networks to vary significantly over time. During periods of low demand, for example, the high fixed target voltage value may set the network voltage unnecessarily high. This could prevent the connection of additional generation due to the lack of voltage headroom.

Therefore, instead of keeping the voltages as high as possible at all times, SVO continuously assesses the state of the network in real time and detects the changes in the network operation. It responds to these changes by calculating and sending optimised voltage set points to the voltage control relays.

The implementation of SVO consists of two critical parts:

- Part 1 is the implementation of a centralised voltage control system and its integration with WPD’s Network Management System (NMS); and
- Part 2 is the site implementation, including the work done on the AVC equipment of each SVO substation to support the dynamic target voltage set points sent by SVO.

This centralised system is based on Siemens’ SP5 technology which is able to estimate the real-time state of the network and perform complex optimisation calculations to find the best target voltage set points. It does that, by communicating with the NMS to receive real-time network operation and utilisation data. The received data is used in the estimation of the state of the network which then enables the calculation of the optimised target voltage set points. The calculated set points are sent by SP5 to the NMS, which then forwards them to the AVC relays in the network. The overall system architecture is shown in Figure 1-2.

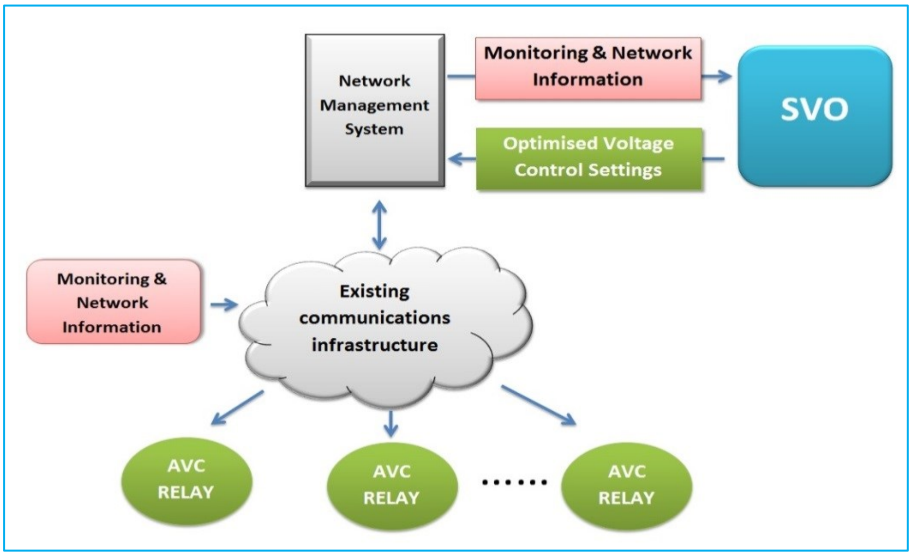

Figure 1-2: SVO Block Diagram

1.3.3 Flexible Power Link

Where possible it is advantageous to operate power networks in large groups whereby the load and generation can be equally distributed across that group. Distribution networks are typically operated in separate, smaller, network groups defined by connections to Grid Supply Points (GSPs) from National Grid (NG). The main reason for this is that paralleling or connecting network groups between different GSPs is likely to result in:

i. Abnormal power flows due to differences in network impedance between the two sources; and
ii. Higher fault levels due to the interconnection of sources from the GSPs.

Our network in the South West typically comprises multiple 132/33kV Bulk Supply Points (BSPs) fed from 400/275/132kV GSPs. The individual BSPs supply many 33/11kV primary substations through an interconnected 33kV network. A typical arrangement is shown in Figure 1-3.

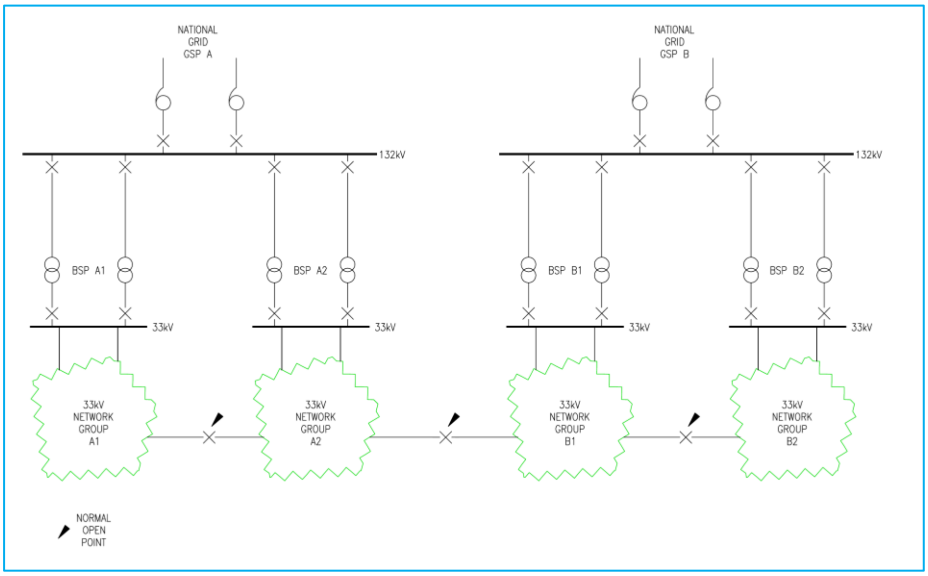

Figure 1-3: Typical Arrangement of a DNO Network

The 33kV networks are then often run as an interconnected system in rural areas as is the case in some elements of the South West distribution area. The interconnected network will generally be fed from a single BSP to ensure that power flow and voltage are not affected should a BSP transformer trip or another network fault occur.

In general, paralleling the 33kV network within the same network group (a single BSP) is achievable assuming power flow, voltage and fault levels are within thermal and voltage limits. However, connecting two separate network groups, at BSP level, in parallel through the 33kV network is not usually possible due to the issues explained.

The connection of DG and Low Carbon Technologies (LCTs) has a direct effect on the voltage and power flows within a network group. The voltage for a whole network group is regulated by transformers via their built-in On-Load Tap Changer (OLTC) to maintain the voltage at any point in the network within statutory limits (±6% at 11kV and 33kV). The connection of DG generally causes voltage rise issues and the connection of load customers often causes the voltage to drop. The network is configured such that in a minimum generation, maximum demand scenario, the voltage will remain above the minimum statutory limit. This leaves a limited capacity for DG to connect before the existing transformers can no longer successfully regulate the voltage, for conditions such as minimum load and maximum generation.

Generation also causes changes to the flow power within the network group. As the levels of DG connecting to the network begin to exceed the demand at certain times of the day, reverse power flows occur, which is where power is exported through the 33kV network onto the 132kV system for the instance a generator is connected to the 33kV network. The rating of parts of the upstream network, such as transformers and overhead circuits are increasingly becoming a limiting factor to the connection of DG as the network.

Due to the varying types of demand and generation connected at increasingly disparate points of the network, substations and network groups can have significantly different demand and generation profiles. Often sections of the network with high demand could be physically, or geographically, close to sections with high generation but cannot be connected due to the engineering constraints described. The FPL Method aimed to provide a solution to facilitate the connection between these networks. This would efficiently and controllably transfer active power (P) between the two networks to ensure dynamic and balanced control of the power flows and also facilitate the provision of independent reactive power (Q) on each side of the FPL to provide voltage control to the connected network.

2.0 Details of Knowledge and Learning Dissemination Reports and Presentations

The knowledge and learning dissemination of the project focussed on the six monthly reports and successful delivery reward criteria documents, however, an important part of the dissemination activities has been through actively sharing learning at industry conferences. Throughout the project lifetime a number of conferences and dissemination events have been attended by members of the Network Equilibrium project team, where project knowledge and learning has both been formally and informally shared with the industry. Below is a summary of eight key industry conferences that have contained formal Network Equilibrium dissemination and presentations as well as further dissemination and reporting activities.

2.1 Industry Conference Presentations

2.1.1 Balancing Act 2016 – London, 8th September 2016

The Balancing Act conference was organised by WPD and focussed on how the changing nature of the electricity grid is transforming the role of DNOs, demanding intelligent ways of controlling power flows and voltages, a higher level of interaction with customers and more advanced methods of network management and planning.

The presentation focussed on outlining the aims and objectives of the project as well as the design activities to date of the three key Methods. It demonstrated the requirements and needs of the Methods to develop a more flexible and adaptive network to facilitate additional load and generation connections.

2.1.2 Smart Distribution Networks: Technologies and Business Models – London, 10th April 2017 – circa 50 attendees

The Smart Distribution Networks Workshop was organised between the H2020[1] and PF7[2] mechanisms. It focused on the changing need of electricity networks as generation, energy storage and new low carbon loads connect to the system and how disruptive technologies and business models for distribution networks can be used to facilitate these changing requirements.

The presentation centred on the technical methods of Network Equilibrium and the potential value the SVO and FPL methods can have on the networks to deliver significant additional capacity to connect new generation and load.

2.1.3 CIRED – Glasgow, 12-15th June 2017 – circa 1500 attendees

International Conference on Electricity Distribution (CIRED) is widely considered to be the world's largest technical international conference focussed on distribution electricity networks. Dissemination at CIRED enables peer review, comparison with international projects and information gathering on the latest products and techniques from leading manufacturers as soon as relevant learning is gathered.

[1] https://ec.europa.eu/programmes/horizon2020/en

[2] https://ec.europa.eu/research/fp7/index_en.cfm

As part of this event two technical papers were presented:

- Steady-State Modelling for the Integration of a Bi-Directional AC-DC-AC Flexible Power Link; and
- Real-Time, Centralised Voltage Control in 33kV and 11kV Electricity Distribution Networks.

These papers disseminated the latest learning of the FPL and SVO methods respectively.

2.1.4 ENA SHE Conference – Newcastle, 25th May 2018- circa 150 attendees

This conference is organised by the Energy Networks Association (ENA) and is the energy industry's Safety, Health and Environment (SHE) Management Conference. The conference provides a forum for all stakeholders – employees, employers, trade unions and regulators – to network, share best practice and review SHE challenges and concerns. It aims to foster co-operation and improve contact between and within the organisations and companies that comprise the energy industry.

The presentation centred on the integration of the FPL in to an existing substation and how this is achieved safely. It demonstrated the need and value for documented processes in the form of policies and procedures as well as sufficient training to enable operatives to work safely and successfully.

2.1.5 CIGRE – Paris, 26-31st August 2018 – circa 1000 attendees

CIGRE is a bi-annual conference based in Paris, France. It brings together over 1250 members from 90 countries to share eminent learning and innovation in the power engineering environment.

Members of the project team presented the FPL and on the wider topic of DC technologies in an otherwise AC network. The presentation focussed on the need for distribution networks to take learning from transmission DC operating principles and how these have been demonstrated as part of trials including Network Equilibrium, projects in Indonesia and Netherlands.

2.1.6 International Forum on DC Technologies and Renewable Energy Integration – Birmingham, 5th February 2019 – circa 30 attendees

This event was organised by Professor Xiao-Ping Zhang of the University Birmingham and brought together international experts from China, USA, Canada and the UK to discuss in detail their experiences and achievements in the world of HV and MV DC installations. The day focussed on the technical need and capability of the physical technology and the control systems required to facilitate the dynamic control of DC systems.

The FPL was presented and the presentation focussed on the design and implementation of the control system to operate the FPL.

2.1.7 IET ACDC Conference – Coventry 6-7th February 2019 – circa 150 attendees

The IET ACDC Conference is an annual event, which alternatives between the UK and China. It provides an opportunity to showcase the very latest developments and implementation in DC technology.

The FPL was presented and the focus of the presentation was the technical considerations and design required to successfully integrate a DC device within an otherwise AC network. This focus was on protection, earthing and power quality issues.

2.1.8 CIRED – Madrid, 3-6th June 2019 – circa 1500 attendees

As described in Section 2.1.3 CIRED is a bi-annual conference providing an opportunity to disseminate the latest in distribution network technical and operational innovations.

As part of this event two technical papers will be presented:

- The Operational Performance and Benefits of an MVDC Device Integrated Within A 33kv Distribution Network; and
- Implementation and Trial of Centralised Voltage Control in 33kV and 11kV Electricity Distribution Networks.

The technical papers will be released once the event has taken place.

2.2 LCNI Conferences

The project has been presented at each of the LCNI Conferences, 2015, 2016, 2017 and 2018. The presentations have taken the form of either formal events or regular informal presentations at the WPD stand to enable detailed technical discussions to take place. The wider project learning, in terms of procurement, project management and delivery of innovation projects was also shared. Detail on the presentations can be found in Appendix 6.

2.3 Publication of other SDRC Reports

This SDRC, 8, represents the final SDRC required as part of the project. The previous seven have been submitted, either on time or early, as set out in the Project Direction document. These SDRCs have provided valuable learning throughout all aspects of the project and importantly have documented the clear decision making and optioneering for all elements of the project.

All these reports are available on the ENA's Smarter Networks Portal and WPD's Innovation website through the links below:

SDRC-1 – Detailed Design of the Enhanced Voltage Assessment Method;
SDRC-2 – Detailed Design of the SVO Method;
SDRC-3 – Detailed Design of the FPL Method;
SDRC-4 – Trialling and Demonstrating the EVA Method;
SDRC-5 – Trialling and Demonstrating the SVO Method;
SDRC-6 – Trialling and Demonstrating the FPL Method; and
SDRC-7 – Trialling and Demonstrating the Integration of the EVA, SVO and FPL Methods.

3.0 Details of Network Equilibrium Data

3.1 Network Data

A key part of the project has been the generation of new data, which has been in the form of:

- Plugins to facilitate the modelling of both the SVO and FPL to understand their impacts and benefits on the wider distribution network;
- SVO voltage data and supporting data to facilitate the SVO state estimation activities; and
- FPL power data and the wider network input to the FPL Control Module.

3.1.1 PSS/E Plugins

As part of the SVO and FPL method, as well as being supported by the EVA method two specific plugins were created, which enable the SVO and FPL to be accurately and robustly modelled in WPD's standard power system analysis software, PSS/E[4]. This means that engineers can easily understand the operation and performance of existing SVO and FPL's installed on the system and examine and quantify the benefit of a new implementation to facilitate new connections or operational changes as required. A user interface has been created for both, seen in Figure 3-1, which ensures that the plugins are easy to use and provide the required data to inform decisions.

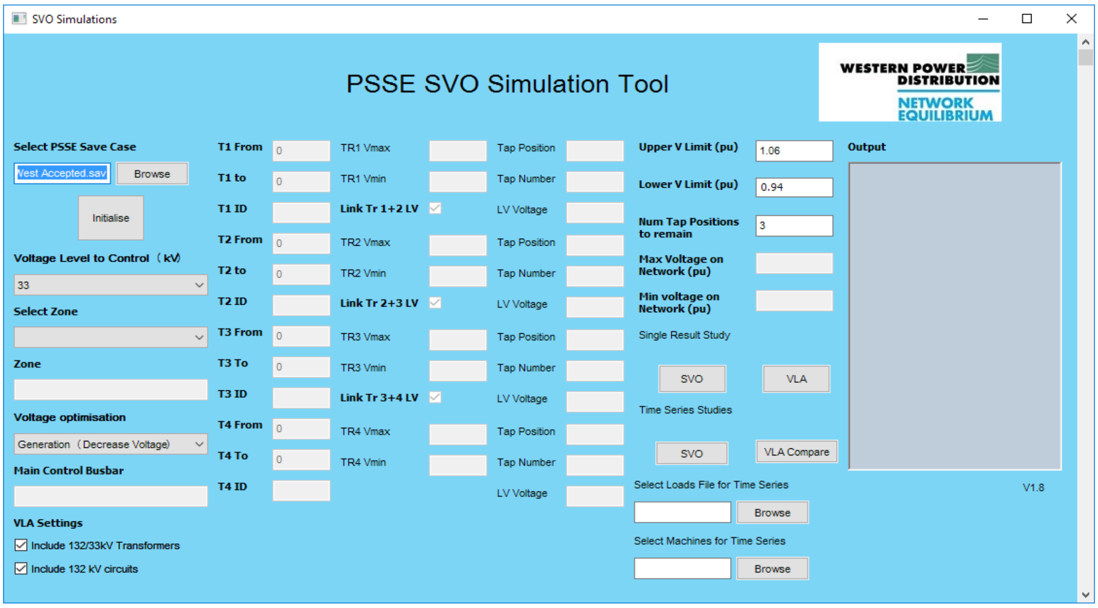

Figure 3-1: SVO Plugin User Interface

Both plugins have been made available to all DNOs, through the ENA's sharing platform hosted by Huddle, where the tools can be used directly or the source code for adaption for use with different software platforms is also available. User guides are also available to support their use.

[4] Siemen's Power System Analysis Tool

3.1.2 SVO

The learning demonstrated in SDRCs 5 and 7 relating to the operational performance of the 16 SVO implementations came from a significant amount of data. This data centres on the voltage calculation detail in the state estimation system, the operating voltage on site and critically the load and generation on the wider network at an instant in time affecting the voltage changes.

This data for the 16 SVO has been made available and is contained within Appendix 2. The selection page of the SVO database is shown in Figure 3-2.

Figure 3-2: SVO Data Hub

3.1.3 FPL

As part of the operation of the FPL and the learning to support the production of SDRC 6 and 7 a substantial level of data was used and stored. This data centres on the wider system voltage and power levels, the decisions from the central FPL Control Module and the real and reactive power provided by the device itself.

This data, as with the SVO, has been made available in a raw format to enable further third party analysis of the FPL's performance to be undertaken and is included in Appendix 3.

3.2 Policies

As part of the project, to ensure that technology and solutions were appropriately and safely connected to the system, controlled, operated and maintained correctly a number of WPD policies were created. This is of fundamental importance when considering a new technology or operational regime and therefore the following suite of policy documents as part of this project were produced:

ST:OC1AB - Operation and Control of System Voltage Optimisation (SVO) for the Network Equilibrium Project

This document describes the standard operation and control procedure for SVO on WPD's 11 and 33kV network, as part of Network Equilibrium.

ST:OC1AC - Operation and Control of ABB 33kV Flexible Power Link installed at Exebridge Primary Substation for use on the Network Equilibrium project

This document describes the standard operation and control procedure for an FPL on WPD's 33kV network, as part of Network Equilibrium.

ST:SP2CAD - Inspection and Maintenance of ABB 33kV Flexible Power Link installed at Exebridge Primary Substation for use on the Network Equilibrium project

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

These policies are now part of WPD's wider portfolio and are updated at a regular interval, or as required with the learning from the operation of new technologies.

All policies created as part of the project have been made available to all other DNOs via ENA's Huddle.

4.0 Details of Six-Monthly Progress Reports Submitted

Throughout the delivery of the project the regular reporting to Ofgem has been in the form of Six-Monthly Progress Reports (6MPR). These documents have contained key project management detail, risks, actions and cost profile and forecasting. As well as the direct project management detail a robust commentary on the project delivery activities over the six month reporting period were captured. This focussed on the design, installation and operational activities of the three project methods with significant focus on the learning and dissemination activities.

The 6MPRs submitted as part of Network Equilibrium have been:

- December 2014 to May 2015;
- June 2015 to November 2015;
- December 2015 to May 2016;
- June 2016 to November 2016;
- December 2016 to May 2017;
- June 2017 to November 2017; and
- December 2017 to May 2018.

All these reports are available on the ENA's Smarter Networks Portal and WPD's Innovation website.

5.0 Conclusion

Throughout the delivery of Network Equilibrium there has been a significant amount of learning generated and this has been robustly captured and disseminated in a number of formats as discussed in this document, specifically learning logs for each element of the project that is captured in the other, Method related, SDRCs.

This learning has been captured and disseminated in a way the enables all GB DNOs to have access to the data and information they need in order to determine the suitability and viability of any of the project's solutions their own network. It also provides third parties, such as academics, equipment suppliers and customers to understand the project's aims, process, and outputs and utilise the raw data to carry out further research.

The future learning and data will continue to be captured and shared until the end of the project and beyond, where appropriate.

Appendices

Appendix 1 - Details of Equilibrium Project Presentations

Presentation File

Appendix 2 - SVO Data

SVO Data Hub

Appendix 3 - FPL Data

FPL Data Hub

Appendix 4 – LCNI Conference Detail

Conference Detail

Glossary

Term	Definition
AVC	Automatic Voltage Control
BAU	Business As Usual
BSP	Bulk Supply Point
CBA	Cost Benefit Analysis
CM	Control Module
DG	Distributed Generation
DNO	Distribution Network Operator
DSO	Distribution System Operator
EVA	Enhanced Voltage Assessment
FPL	Flexible Power Link
GSP	Grid Supply Point
LCNF	Low Carbon Networks Fund
LCT	Low Carbon Technology
LV	Low Voltage
LVAC	Low Voltage Alternating Current
MVA	Mega Volt Ampere
MVAR	Mega Volt Ampere Reactive
MVDC	Medium Voltage Direct Current
MW	Mega Watt
NG	National Grid
NMS	Network Management System
OLTC	On-Load Tap Changer
PSS/E	Siemens Power System Analysis Tool
RTU	Remote Terminal Unit
SCADA	Supervisory Control And Data Acquisition
SDRC	Successful Delivery Reward Criteria
SVO	System Voltage Optimisation
WPD	Western Power Distribution