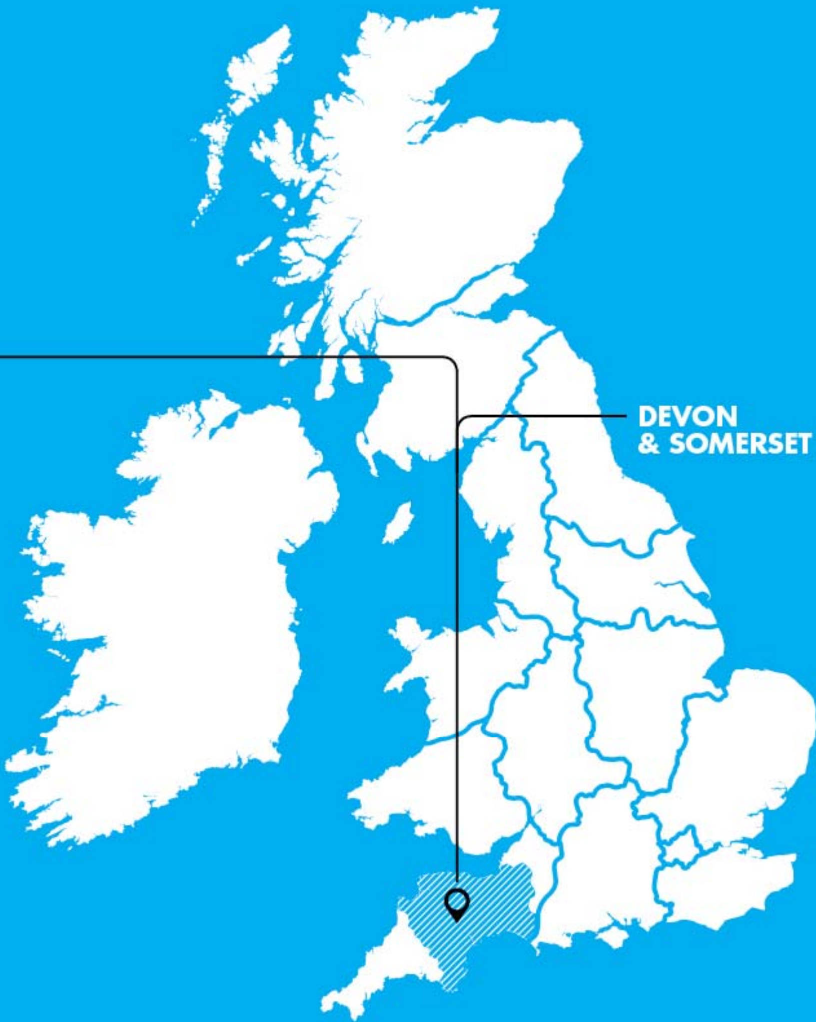
WESTERN POWER DISTRIBUTION

NETWORK EQUILIBRIUM

BALANCING GENERATION AND DEMAND



SDRC-7

Trialling and Demonstrating the Integration of the EVA, SVO and FPL Methods

LCN Fund
Low Carbon Networks

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Contents

Executive Summary

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, through the demonstration of three technical Methods; Enhanced Voltage Assessment, System Voltage Optimisation and a Flexible Power Link.

The report has been structured to provide an overview of the learning from the operation of each Method:

- Capacity release benefits of the Methods individually and the additional benefits of combining Methods;
- Wider system benefits of employing solutions; and
- Cost and carbon benefit analysis of the systems employed on the network.

Through the development and trialling of the Methods, (discussed in a number of previous project documents, principally, SDRCs 4, 5 and 6), a significant amount of learning has been shared on the implementation and performance of the Methods. This document focuses on the latest learning and moreover the benefits of implementing each of the Methods alone and combined.

The benefits of the EVA, which focussed on the widening of the existing voltage limits on the 11kV and 33KV from ±6% to ±8% and ±10%, respectively. Analysis has shown that the expansion of these limits could release over 380MVA of system capacity in a network the same scale as in the project. The implementation of the SVO on eight bulk supply point and primary substations has demonstrated that the real-time optimisation of the system voltage can deliver significant capacity release benefits. The modelled capacity released as part of the project is just under 200MVA. The FPL can facilitate up to 20MVA of additional capacity released based on the utilisation of both real and reactive power to solve power flow and voltage issues.

It has been demonstrated through detailed analysis that the optimal utilisation of multiple Methods is to implement the EVA and SVO on a single network; it has been demonstrated that this could release over 350MVA system capacity. The project has also shown that each of the project's Methods can be delivered at or lower than the bid phase post-trial implementation costs.

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 implementation and impact of the three project Methods, demonstrating the capacity released and the cost benefit analysis of the Methods. This forms the Ofgem deliverable for Successful Delivery Reward Criteria (SDRC) 7: “Trialling and Demonstrating the integration of the EVA, SVO and FPL Methods”.

1.2 Structure

The report has been structured as follows to provide an overview of the capacity release and financial benefits of each Method:

- Learning from the operation of each Method;
- Capacity release benefits of each Method in isolation and combinations of multiple Methods;
- Wider system benefits of employing Solutions; and
- Cost Benefit Analysis.

1.3 Background

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.

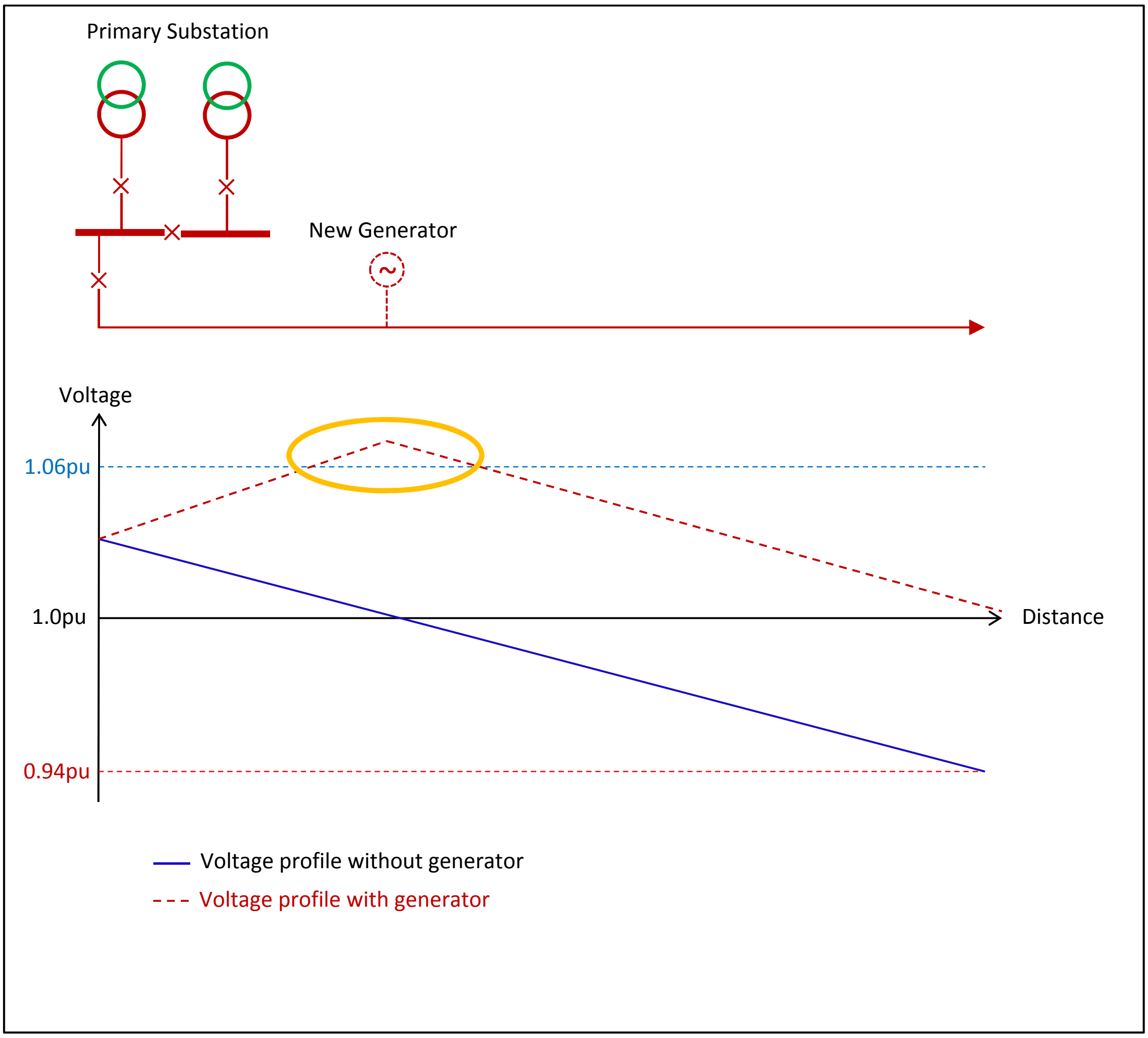

Figure 1-1 - Impact on voltage from new generation connection

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.

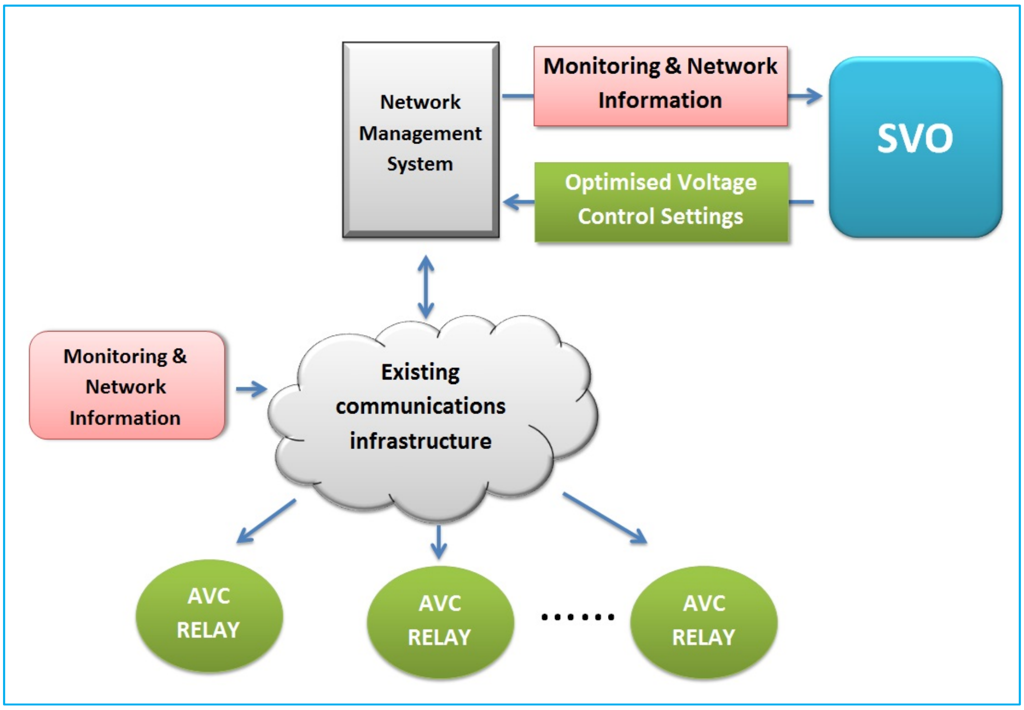

Figure 1-2: SVO Block Diagram

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.

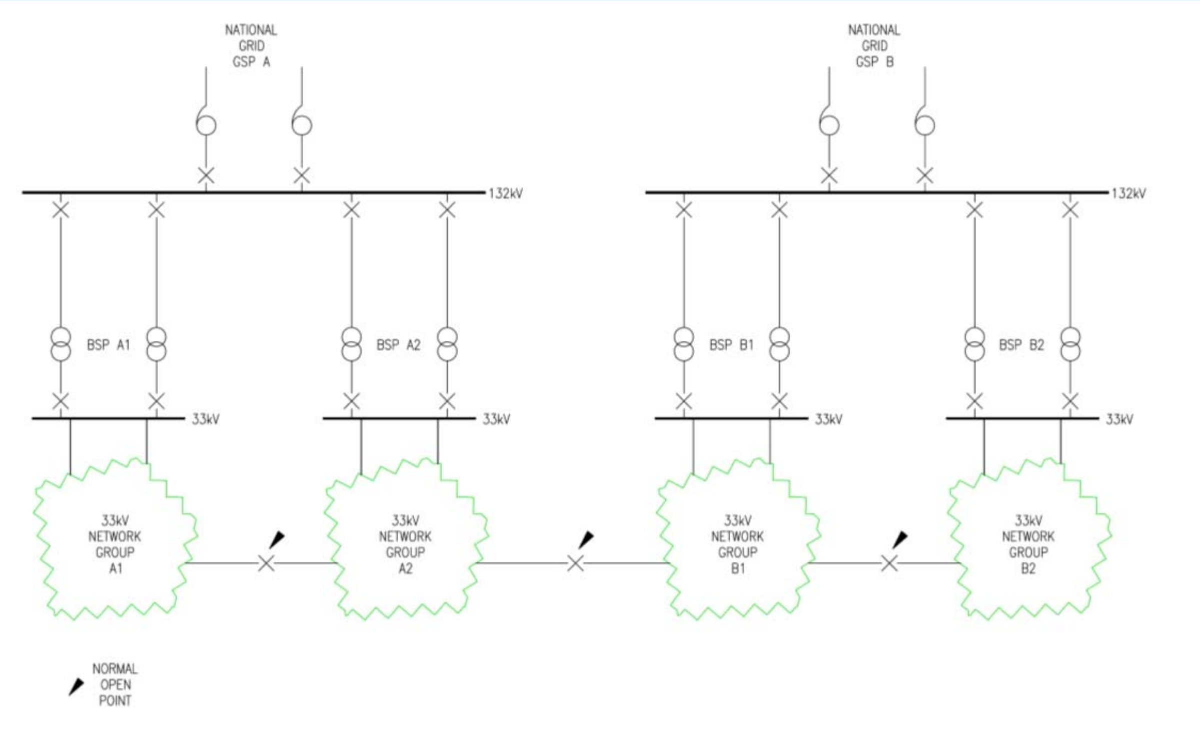

Figure 1-3: Typical Arrangement of a DNO Network

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 Demonstration of Methods

2.1 Enhanced Voltage Assessment

The EVA Method to demonstrate the benefits of widening the existing voltage limits was explored in SDRC-4, documenting the initial results of preliminary studies to increase the availability of the existing 11kV and 33kV infrastructure to accept additional generation on to the network.

As part of the SVO work a plugin was developed to enable the desktop analysis of the benefits and operation of the SVO in a power system analysis environment; this plugin was also developed to understand, in detail, the benefits of widening the voltage limits on the network. The results are discussed in detail in Section 3.1.1, where the average generation connection increase on a primary substation and BSP are 4.81MW and 43.0MW, respectively.

The limit increase values determined as part of SDRC-1 were ±8% for primary substations and ±10% for BSPs, increased from the existing statutory limit of ±6%. These have been used throughout the remainder of the project and are recommended for adoption across the electricity industry.

As part of the project closedown we will deliver a post-project plan to engage, through our Policy Engineers, with the Energy Networks Association (ENA) and in association with other DNOs investigate how this recommendation can be taken forward as an industry trial and to assess its wider implementation.

2.2 System Voltage Optimisation

2.2.1 SVO Operation

In order to ensure that the learning obtained from the trials of the technology are maximised, the trial data have been extracted on a weekly basis for analysis. This includes among other tasks the production of graphs showing the operation of SVO at each site. Automatic analysis using a python script that we have developed as part of this project is also being run on a weekly basis, providing a summary of the behaviour of the technology during that week.

An example of the graphs produced is shown in Figure 2-1, which shows the operation of SVO at Marsh Green Primary (T1) the week commencing the 12th November. In the graph, the SVO Set Points (brown line) and the voltage (blue line) at the substation are shown while the green and red squares are used to indicate when SVO was enabled / disabled at the site. The yellow line represents the traditional target voltage that would be applied at the site statically if SVO was not implemented.

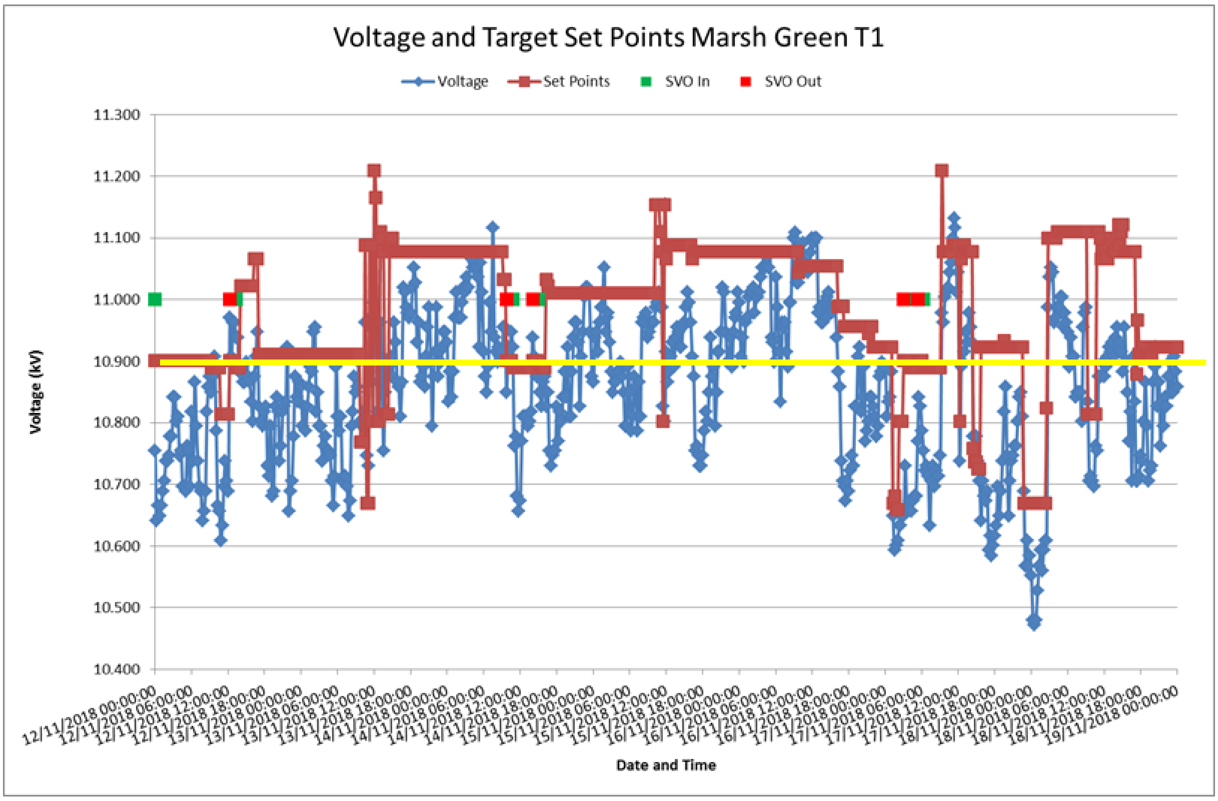

Figure 2-1 SVO Operation Marsh Green Primary T1 - Week commencing 12.11.2018

As can be seen in Figure 2-1, the target voltage that SVO calculates to be the optimal varies significantly with time and in some periods it is lower than the traditional target voltage of 10.9kV while in some other periods it is higher.

The graphs produced in the weekly analysis enable comparisons to be made quickly between the various sites by visually inspecting the set point variations. For example, the SVO Operation graph at Tiverton Moorhayes Primary (T2) produced in the same period as the Marsh Green example, is shown in Figure 2-2. Interestingly, it can be easily observed that the SVO set points at Tiverton Moorhayes Primary vary significantly less frequently compared to the SVO set point variations at Marsh Green Primary. Additionally, for the majority of the time the SVO set point at Tiverton Moorhayes is lower than the traditional target voltage of 11.1 kV. The number of set point changes at each site is also captured in the automatic data analysis and as it is done on a weekly basis, it provides learning on whether each site has a repetitive typical behaviour. The frequency of changes will also impact the level of tapchanger operation, to effectively regulate the voltage. As discussed in SDRC-5 the impact of this on the tapchanger operation and the requirement to, for the wider application of SVO, to move away from the traditional maintenance methodology of tapchangers driven by time and towards a number of operations system. This will further be explored in the remaining elements of the project and discussed in the close down activities.

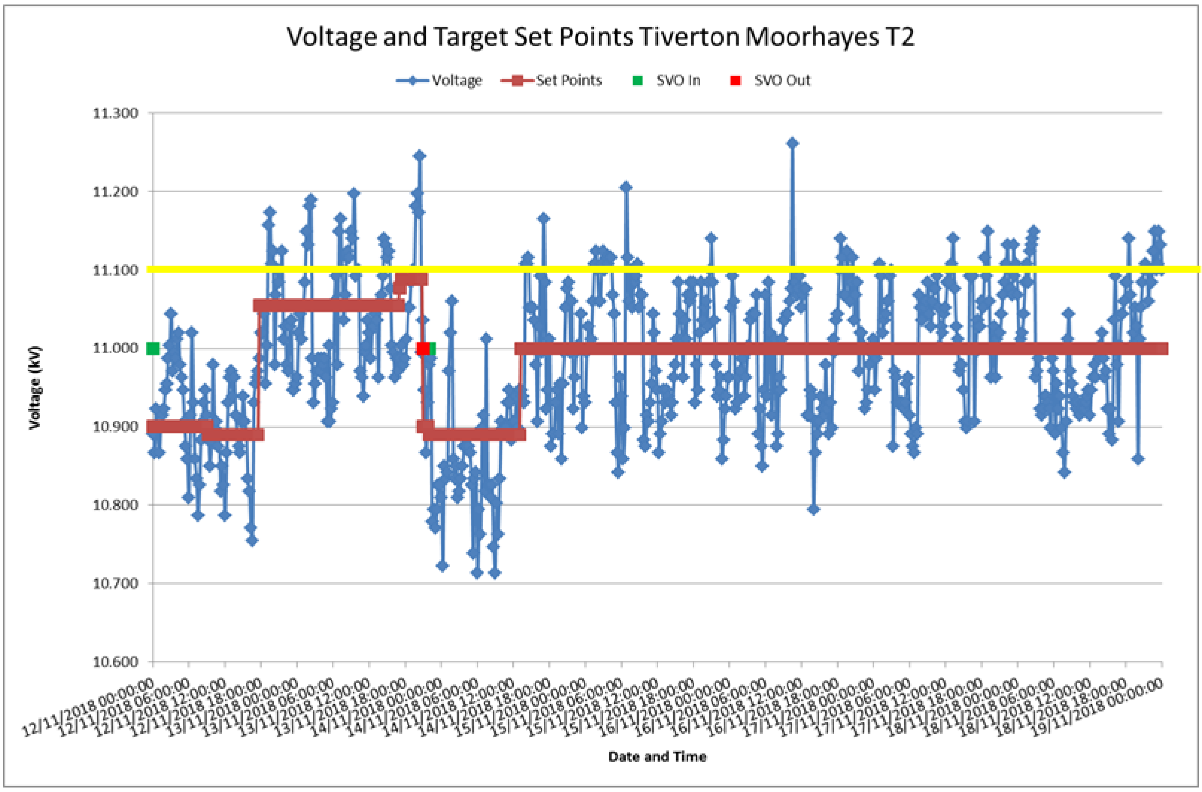

Figure 2-2 SVO Operation Tiverton Moorhayes Primary (T2) - Week commencing 12.11.2018

Additionally, another type of the weekly graphs produced is shown in Figure 2-3. This figure demonstrates the percentage difference between the voltage on site and the SVO set point at Nether Stowey Primary (T1) the week commencing the 12th November 2018. As can be seen, the percentage difference between the set point and voltage varies between 0 and 1.5 % for most of the time which agrees with the bandwidth set at the relay and confirms the successful application of the SVO set points.

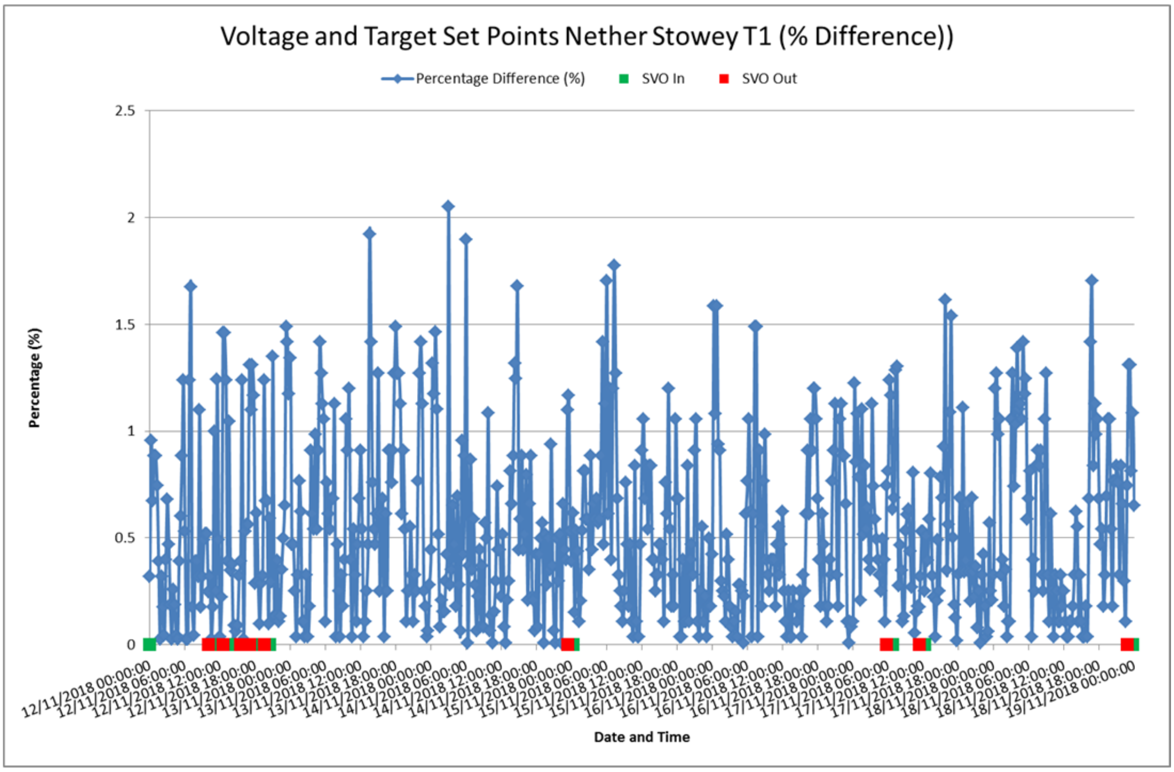

Figure 2-3 Nether Stowey Primary (T1) voltage and set points % difference

The analysis that was developed as part of this project enables conclusions to be made quickly on the operation of SVO at the various sites. It does that by analysing the large volumes of trial data automatically and removing the need to compare a large number of graphs manually. For example, Table 2-1 is an extract of the analysis performed on all sites that had SVO enabled the week commencing the 12th November.

Table 2-1 Extract of Automatic Analysis - Week commencing the 12th of November

SVO Site	Set point changes	Max % Diff. Voltage and Set point
Colley Lane T1 T3	27	2.68
Nether Stowey T1	12	2.05
Marsh Green T1	66	3.36
Tiverton Moorhayes T1 T2	6	2.27
Bowhays Cross GT1 GT2	66	2.80
Tiverton GT1 GT2	162	1.75
Paignton GT1 GT2	9	1.62
Waterlake T1	1	4.03
Waterlake T2	23	4.93

From Table 2-1 it can be seen that the number of set point changes at each SVO site is different, with one site having more than 150 set point changes in that week, two sites having more than 50 changes while some sites having less than 10 changes. This shows that the amount of optimisation required on the various sites is different with some sites showing similar characteristics. Additionally, the percentage difference between the voltage at site and the set points demonstrates the successful application of the set point at site. As can be seen, in that week the highest difference between set point and voltage was at Waterlake Primary which is a site that accepts group settings and not analogue set points. There are four settings groups programmed at the AVC relays at Waterlake, so every time an analogue set point is sent by SVO the setting that is actually applied on site is the setting group that is closest to the set point and not the exact set point. Therefore a higher inaccuracy is expected at Waterlake Primary compared to the other sites that can apply the analogue set point they receive.

The capture and analysis of the trial data will continue until the end of the project to enable further conclusions to be made on the characterisation of the various sites and what type of sites would benefit the most from an SVO implementation.

2.2.2 Learning Points from SVO Implementation

Alarm exchanges between SVO and NMS

Through the trials, valuable learning and confidence in the system has been gained which enabled the simplification of the alarm exchanges between SVO and the NMS and significantly reduced the time that had to be spent by Control Engineers to react to alarms.

The SVO system, SP5, has been designed to send alarms to the NMS that indicate the status of the optimisation at each site but also the status of the system. The alarms were grouped following a traffic light system, where the status of the optimisation of each site could be red, amber or green depending on the highest priority alarm raised for that site. Similarly, the status of the system could be red, amber or green, reflecting the highest priority system alarm raised by SP5. Each category of alarms required a different action, with red site alarms for example, requiring the site to be disabled automatically and the Distribution System Operator (DSO) Technology team (the system owner) to be notified of the alarm by the Control team, amber alarms also required notification while green alarms required no action. This ensured that Control Engineers could easily understand the operational status of SVO without the need of having to interpret a large list of technical alarms and that the action that had to be taken was clear. Additionally, it reduced the traffic between the NMS and SP5, ensuring that the visibility of existing network alarms is not affected by the new SVO alarms. An example of the Green System Status is shown in Figure 2-4 and an example of the Green Site Status is shown in Figure 2-5.

Figure 2-4: System Status Example

Figure 2-5: Site Status Example

The trials have shown that the alarms were successfully exchanged between SP5 and the NMS and as they progressed increased our confidence in the system operation. Through the running of the technology in the first few months, it was proved that the optimisation at each site is correctly reported and that the correct action is taken by the system when required (for example automatic disabling when red alarm is raised). Therefore, we updated our operational procedures to remove the requirement for the Control Engineers to be reporting any optimisation alarms to the DSO technology team. Additionally, the criticality of the majority of the amber optimisation alarms was reduced and those alarms were given green (lowest) priority since the trials have shown that they don't require attention.

Automatic Restoration

With the stable operation of the system being proven in the trials, certain operational procedures have been automated, making the day-to-day operation of the technology more efficient and independent of manual intervention from Control Engineers.

Originally, the system had been designed such that when a red optimisation alarm (highest priority) was sent from SP5 to the NMS, SVO would be automatically disabled on that site. This was done through a logic that was implemented in the NMS which would send a control to the SVO system to disable SVO on that site once that site's optimisation status turned red. After investigating the issue that caused the red alarm, the Control team had to be contacted over the phone in order to request the re-enabling of SVO on that site.

The numerous investigations that were done following this procedure have shown that in most cases the reason the site's status turned red was transient due to issues with communications. In all the occasions, the site could be safely re-enabled straight after the event with no operational implications as the various safety checks that were added to SP5 ensure that no action is taken that could compromise the network. It was determined that automated re-enabling would be carried out after an hour; this was determined in collaboration with control engineers to ensure that a number of multiple transient issues would not cause a constant on-off situation and it was felt an hour was sufficient time to enable a communications loss event, often driven by weather conditions to pass.

Therefore, additional logic was then added in the NMS in order to re-enable the site automatically an hour after it was disabled due to a red optimisation alarm. This increased the on-time of the technology, reduced the amount of time spent by Control Engineers to manually re-enable sites and also provided additional learning by making it easier to see how long each site would maintain green optimisation status. Figure 2-6, shows the automatic enabling / disabling behaviour at Tiverton Moorhayes Primary with 2.0 indicating that the site is enabled and 1.0 that the site is disabled. As can be seen in the figure, SVO was automatically disabled on the 13th November for one hour, then it was re-enabled automatically again with no further switching taking place after that. It can also be observed that while the site was being re-enabled, its status dropped to zero for a few seconds. This is because of the state changing, with the zero showing the transition.

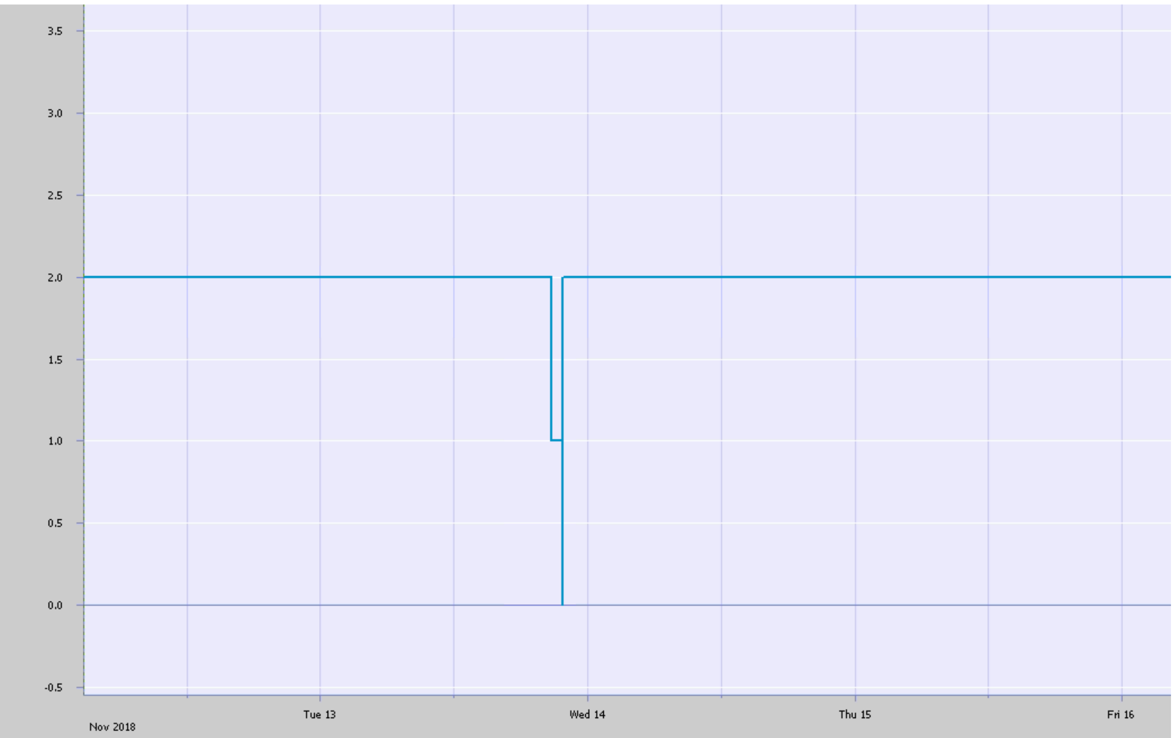

Figure 2-6: Automatic enabling-disabling at Tiverton Moorhayes Primary

The indication that was added to the NMS to show whether automatic restoration was active at each site is shown in Figure 2-7.

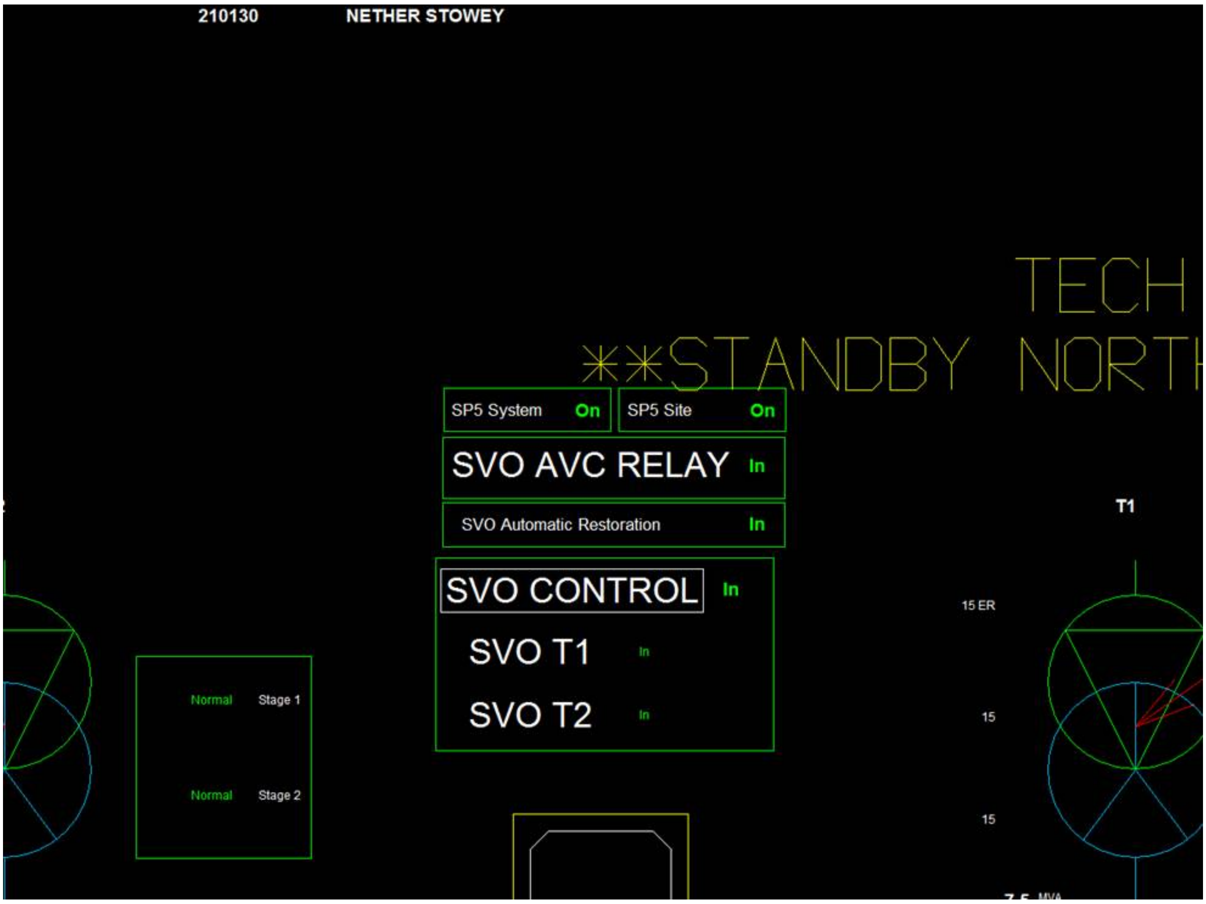

Figure 2-7 Automatic Restoration Indication in the NMS for Nether Stowey Primary

Set Point Resolution

Transmitting analogue set points through the existing Supervisory Control And Data Acquisition (SCADA) infrastructure is one of the main functionalities of the SVO system but something that was not done previously as part of the Business As Usual (BAU) operation of the network. Therefore, through the implementation and trial of SVO, significant learning was gained on the main challenges that need to be overcome when sending analogue settings to equipment on the network and how that can be done.

The biggest challenge is that resolution is lost while the analogue set point is travelling from the SVO system to site, which means that the target voltage set point that reaches the AVC relay on site differs slightly to the set point that was sent by the SVO system. This is because of the conversions that are taking place along the way as the set point is travelling through the SCADA system. To demonstrate this, let’s consider the example where the SVO system is sending the target voltage setting of 33.45kV to Bowhays Cross BSP. After SVO calculates the set point, it sends the value of 33.45kV to the NMS which performs the following translation before sending the value to the Remote Terminal Unit (RTU) on site:

$$SetPoint = \frac{SVOsetpoint \times 1000}{33} = 1013.63 = 1013$$

As can be seen from the above equation, all decimal places are dropped in order to send the value to the RTU. This is because only 16-bit integers are sent from the NMS to the RTU in the implementation of the IEC60870-5-101[1] that is used in the NMS-RTU communications. Therefore, the NMS then sends the value of 1013 to the RTU on site which in turn sends the value to the relay. The relay then applies the value which can be translated into a kV voltage using the equation below:

$$AppliedSetPoint = \frac{SetPoint \times 33}{1000} = 33.429kV = 33.43kV$$

This demonstrates that the initial set point of 33.45kV sent by SP5 is applied as 33.43kV by the relay and even though this difference is small, it had an impact on the way the optimisation system worked. In some cases it was observed that SP5 was sending the same set point sequentially a number of times and that was because it continued trying to achieve the mathematical optimal solution which differed slightly to what was applied on site. This is very valuable learning as it shows the requirement of adjusting mathematically derived optimisation tools to take into account actual operational constraints when finding the “best” solution to ensure that they’re fit for purpose for real network operation.

Correlation Analysis

Significant learning was also gained from the detailed analysis of the trial results that was performed so far. In this analysis, the aim was to see whether the SVO system was dropping the network voltages as expected and if it was possible to identify any trends in the target voltage set points that were sent to the SVO sites.

As part of this work, it was of interest to see if there is any relationship between the SVO target voltage set points, the voltage on site and the total power flow at that site. This was explored initially by investigating the produced weekly graphs. An example is shown in Figure 2-8, where the voltage, set points and total MW for GT1 at Tiverton BSP is shown. The green and red squares indicate when SVO was enabled / disabled in that period.

[1] Transmission Protocols – companion standards especially for basic telecontrol tasks

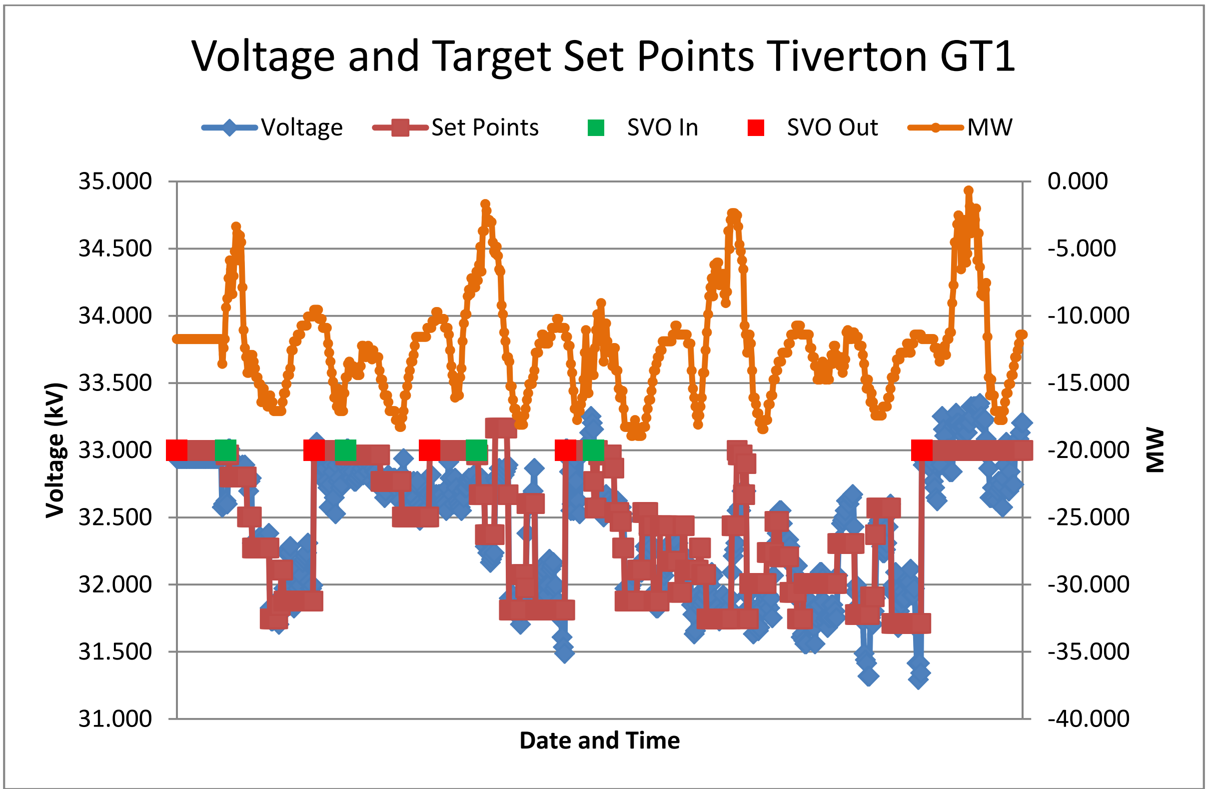

Figure 2-8: Tiverton BSP GT1 Weekly Graph for 03.09.2018-09.09.2018

In order to understand better if the SVO set points are affected by the total substation flow or if there are any other trends that cannot be easily identified from the graph, we performed some statistical analysis on the trial data. This analysis was done automatically using a Python script, making it easy to apply this analysis on the additional data that are extracted every week. As part of this analysis, the voltages, set points, MW and the way all these parameters change were processed outputting a measure of the relationship between the parameters. This is called a correlation coefficient and is a number between -1 and 1, showing how strong the relationship between two parameters is. Zero indicates no relationship, while 1 shows a strong relationship where if one parameter increases the second will increase too and if it decreases the second will decrease too. -1 shows a strong relationship where if one parameter increases the other will decrease. The results for Tiverton BSP, for the period from the 12th November until the 18th November are shown in the table below:

Table 2-2: Correlation Analysis Results for Tiverton BSP for week commencing 12th November 2018

SVO Site	Correlation Set point-MW	Correlation Set point-MW Change	Correlation Set point change-MW	Correlation Set point change-MW change	Correlation Set point-Max V
Tiverton GT1 GT2	0.29	0.01	-0.06	0	0.97

The table shows that there is little relationship between Set Point and MW and no relationship between Set Point and MW change, Set Point Change and MW and Set Point change and MW change. However, as expected, there is strong relationship between the set point and the maximum voltage in the network showing that as the voltage set point at the BSP decreases for example the maximum voltage in the network will also decrease and therefore remove the constraint. In the remainder of the trials, this analysis will be further developed to investigate whether there is a clear link between the set points calculated by SVO and other measurements in the network like power flows at specific substations or voltages at specific sites. As part of that, the calculated optimised set point will be compared with the values of the various network measurements before it changed to see what has the biggest influence in the set point change decision and therefore what determines the optimal target voltage set point.

Up to this point, the analysis has shown that it is currently not possible to provide generalised rules on what the best target voltage in the network is, since it does not get affected by the total substation flow or follow a specific trend. In fact, the distribution of the loads and generation in the network mean that the operation of the network is complex and requires a control system that is able to perform power flow analysis, in order to understand how the constraints change in real time and therefore how voltage control should adapt accordingly. It reinforces the case for the need to have a control system that can understand the complex network we now have and then perform control actions or even optimise it accordingly, where early solutions considering a specific generator had been suitable due to their intermittency and densitiy of connection these solutions are, largely, no longer suitable.

This analysis is ongoing on a weekly basis and the next steps will be to determine whether there are any similarities in the behaviour of the various SVO sites that could group them into categories to benefit future implementations.

2.3 Flexible Power Link

2.3.1 Operation

Following the start of the closed-loop operation of the FPL the device has been operated in a number of different modes to demonstrate the benefits of the FPL on the system. The two key modes that have been tested are the operation of the device in active power (P) mode and with P and reactive power (Q) enabled.

In order to fully test the operation of the FPL the system violation limits of the network assets were reduced compared to what they would be on a BAU implementation; this allowed the FPL to be driven in to operation and present the following information.

The operation of the FPL with respect to its primary solution mechanism being the infeed or absorption of P was demonstrated with reduced load firm capacity to drive the FPL in to operation. Figure 2-9 shows the performance of the FPL. It can be seen that the utilisation of the FPL centres on morning and evening peak demands when considering the loads at both Barnstaple and Taunton BSP as indicated in Figure 2-10 and Figure 2-11.

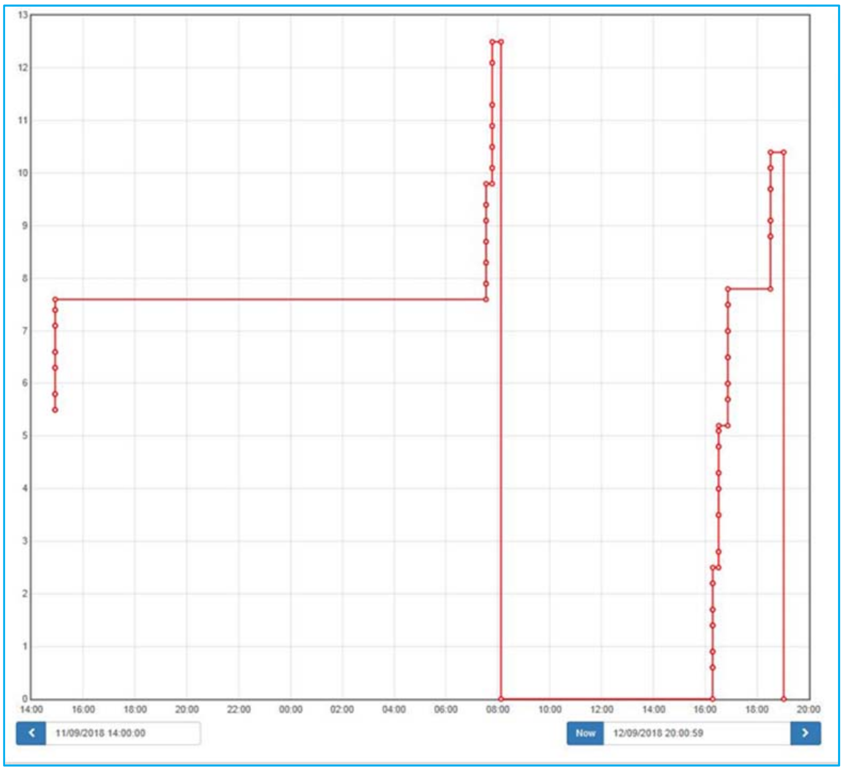

Figure 2-9: Real Transfer Performance of FPL (MW)

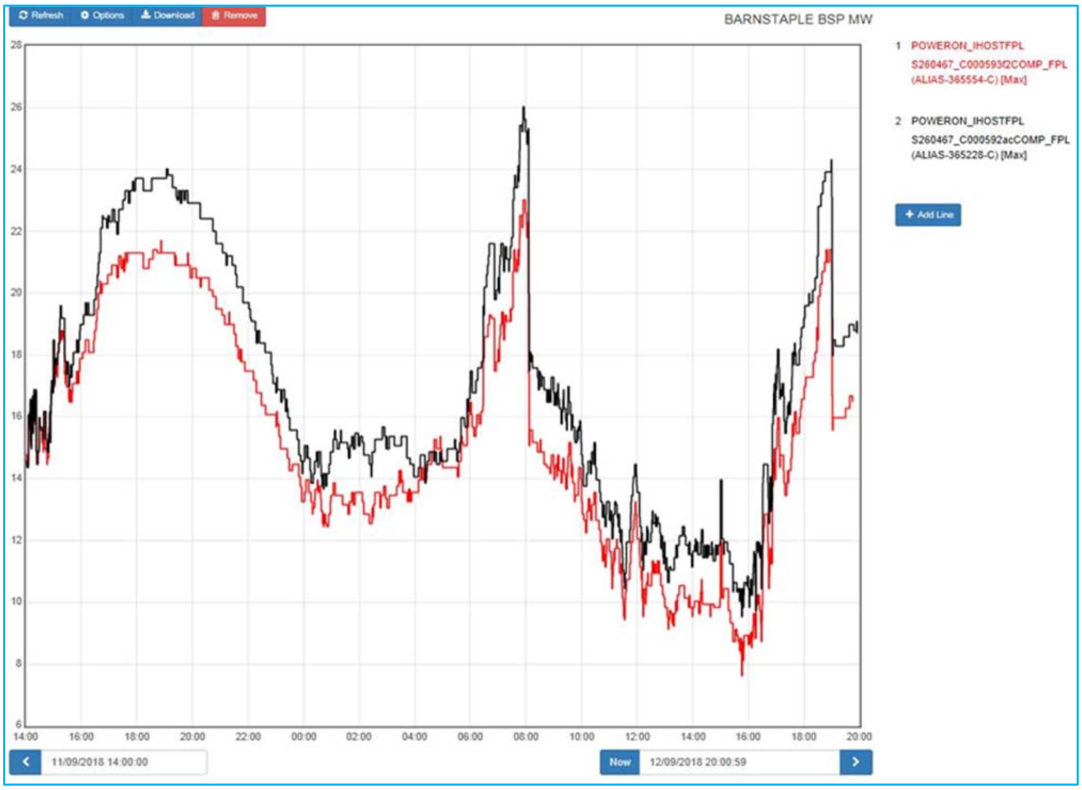

Figure 2-10: Barnstaple BSP Power (MW)

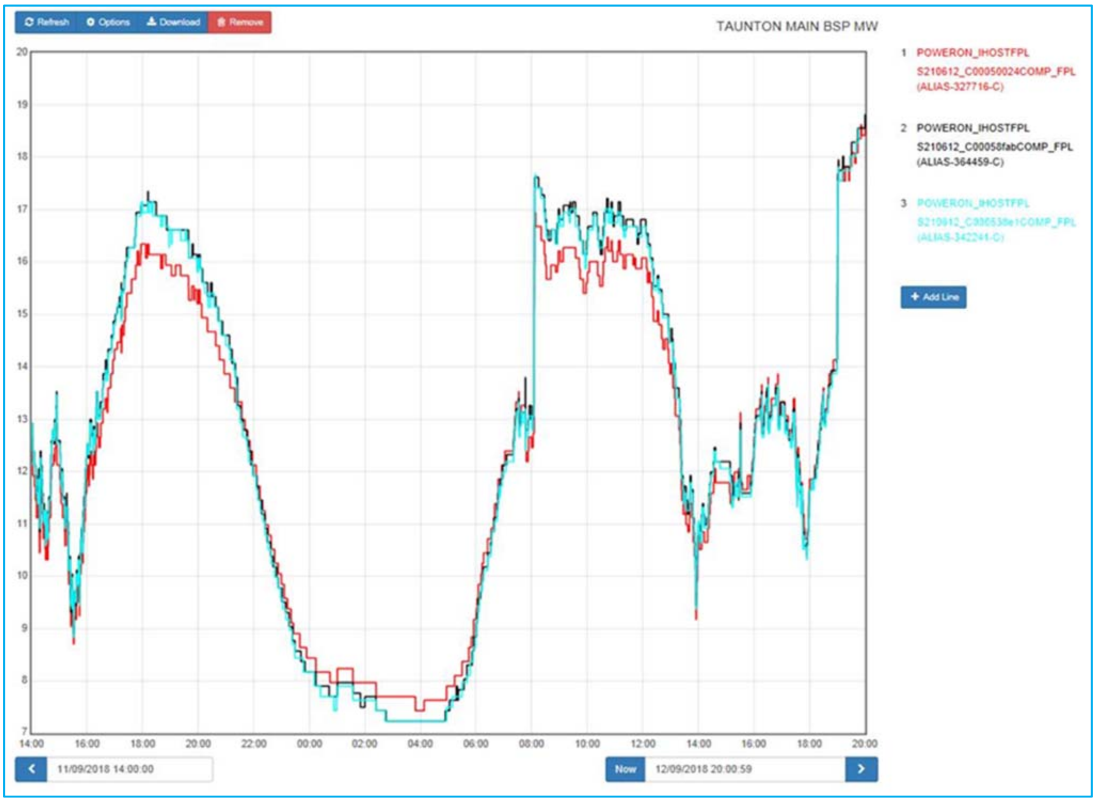

Figure 2-11: Taunton BSP Power (MW)

The graphs show that at times of high load on Taunton BSP, the FPL transfers between 10.5MW and 12.5MW from Barnstaple BSP. This is due to the higher capacity availability at Barnstaple.

In demonstrating the performance of the FPL in P and Q mode, but with the emphasis on Q, the voltage limits for the FPL to regulate were set at ±4% (opposed to the statutory limits of ±6%) to enable the demonstration of the FPL's operation. There is a significant amount of generation connected on the feeder between Barnstaple BSP and the FPL at Exebridge; this generation was previously connected in to the Taunton BSP network and the voltage rise mitigated by the load connected to the same system. It can be seen in Figure 2-12, which demonstrates the reactive power on the Barnstaple side of the FPL (Q1) operating between 0MVAR and -5MVAR, indicating that the FPL is absorbing reactive power to ensure that that voltage remains within limits to support the connected generators' operation. The graph demonstrates a week's operation of the FPL and it can be seen that for the majority of the week the level of reactive power being absorbed is just over -1MVAR, however, towards the end of that week the value rises to -5MVAR; this aligns with a sunny and windy weather condition meaning that the level of generation output connected on the system at that point was towards its maximum. This provided a robust test case for the operation of the FPL as the wider system voltage was kept within limits at all times.

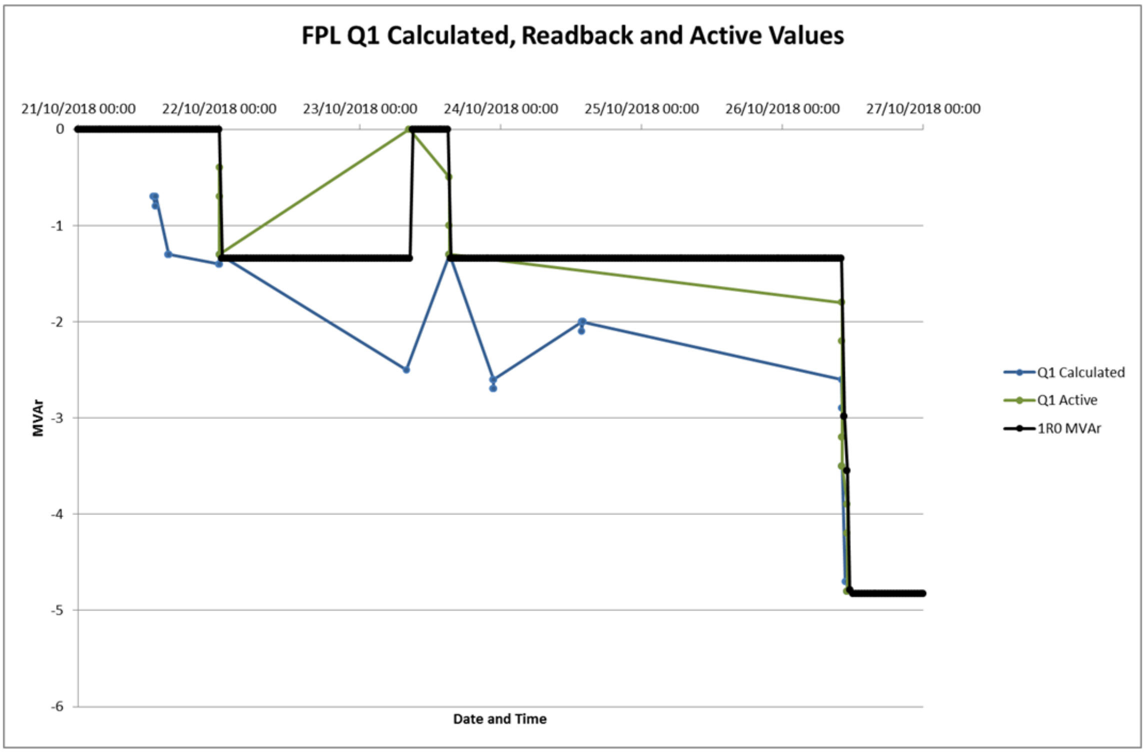

Figure 2-12: FPL operation to limit voltage rise (Q1)

Further operation of the FPL until the closedown of the project, June 2019, will provide additional learning of the operation of the FPL for different scenarios as it operates through different seasons affecting both the load and generation output on the connected system.

2.3.2 System Performance

Critical to the learning of the operation of the FPL is the relationship between the online calculation methodology for its required operation, driven by the FPL Control Module, and the device's capability to respond as required to the Control Module's signals. Using the Q operating example in Figure 2-12 shows the calculated value from the Control Module (in blue), the active output of the FPL from the Control Module read back (in red) and the output as captured in our NMS. It can be seen that whilst the trend of the actual output is aligned with the calculated values there is, in some instances, an off-set between these two values. This off-set is driven by the internal algorithm of the FPL, which translates the signal from the Control Module to the operation of the device as well as the accuracy of the measurement devices on site. As part of the Control Module development a relatively small difference in these values was allowed for and the operation of the FPL, to date, has been within these limits. As seen in the graph once the FPL operates at a greater reactive power value the data points are much closer aligned, which is driven by reduced impact of the power measuring devices (current transformers) inaccuracies. This has also been demonstrated operating the FPL in P mode.

2.3.3 Learning Points from FPL Implementation

Through the open and closed loop testing of the FPL on the network, where the device operated without issue, the system was shown to be reliable and stable. Through the closed loop operation the FPL has been exposed to a number of external events that have caused its disconnection from the network.

On several occasions the device automatically shut down for a short period of time. Following analysis of the FPL, FPL CM and other network data the issue was identified as being caused by the trip operation and auto reclose of the 11kV switchgear at the FPL substation, Exebridge, during adverse weather conditions. This caused a short-term loss of the LV supply that supplies the FPL's auxiliary systems including the cooling system. This demonstrated the requirement for future FPL implementations to have a specific dual-redudant LV supply to avoid this issue.Modifications were made to the LVAC connections to ensure that the FPL wasn't succesptable to short-term LV disconnections. Since the change there has been no further period of unavailability of the FPL device.

The FPL has also demonstrated its protection performance for external faults on the remote system of which it connects. Looking at a specific example where there was a single-phase to earth fault on the network on two separate occasions; in both these instances the FPL identified the fault and disconnected from the system within 600 milliseconds. This can be seen in the events log for one of these events in Figure 2-13.

2018-10-28 13:57:58.301,1X1_ARU_SWG,612,E6312_E,FPL1 CB is open,Opened
2018-10-28 13:57:58.301,1X2_INU_SWG,612,E1312_E,FPL2 CB is open,Opened
2018-10-28 13:57:58.273,1X2_GEN,623,E0123_E,Ctrl. 800PEC transient recorder B recording,Active
2018-10-28 13:57:58.273,1X2_GEN,621,E0121_E,Ctrl. 800PEC transient recorder A recording,Active
2018-10-28 13:57:58.273,1X2_GEN,611,E0111_E,Group warning control,Active
2018-10-28 13:57:58.251,1X2_INU,602,E1102_E,Converter FPL2 pulses are blocked,On
2018-10-28 13:57:58.230,1X2_GEN,26,G0123_CH16_W,Protection-PEC has set TRIP MATRIX channel(s),Warning reset
2018-10-28 13:57:58.218,1R2_GEN,15,G0124_CH05_W,Control-PEC has set TRIP MATRIX channel(s),Warning reset
2018-10-28 13:57:58.217,1R2_GEN,625,E8125_E,Prot. 800PEC transient recorder C recording,Active
2018-10-28 13:57:58.217,1R2_GEN,623,E8123_E,Prot. 800PEC transient recorder B recording,Active
2018-10-28 13:57:58.217,1X1_ARU,1,A0026_W,FPL1 grid fault causes pulse blocking,Warning reset
2018-10-28 13:57:58.215,1X2_GEN,16,G0123_CH06_W,Protection-PEC has set TRIP MATRIX channel(s),Warning
2018-10-28 13:57:58.215,1X2_GEN,15,G0123_CH05_W,Protection-PEC has set TRIP MATRIX channel(s),Warning
2018-10-28 13:57:58.215,1X2_GEN,12,G0123_CH02_W,Protection-PEC has set TRIP MATRIX channel(s),Warning
2018-10-28 13:57:58.215,1X2_GEN,26,G0123_CH16_W,Protection-PEC has set TRIP MATRIX channel(s),Warning
2018-10-28 13:57:58.215,1X2_GEN,25,G0123_CH15_W,Protection-PEC has set TRIP MATRIX channel(s),Warning
2018-10-28 13:57:58.215,1X2_GEN,24,G0123_CH14_W,Protection-PEC has set TRIP MATRIX channel(s),Warning
2018-10-28 13:57:58.215,1X2_GEN,11,G0123_CH01_W,Protection-PEC has set TRIP MATRIX channel(s),Warning
2018-10-28 13:57:58.214,1R2_GEN,621,E8121_E,Prot. 800PEC transient recorder A recording,Active
2018-10-28 13:57:58.213,1R1_ARU_PRIM,430,A0006_T,FPL1 XFMR primary side earth fault,Trip
2018-10-28 13:57:57.752,1X1_ARU,602,E6102_E,Converter FPL1 pulses are blocked,On
2018-10-28 13:57:57.704,1R2_GEN,15,G0124_CH05_W,Control-PEC has set TRIP MATRIX channel(s),Warning
2018-10-28 13:57:57.703,1X1_ARU,1,A0026_W,FPL1 grid fault causes pulse blocking,Warning

Figure 2-13: FPL Event Log for External Trip

The fast acting operation of the FPL's protection functions, which initially needed to be understood in terms of its relationship to existing, slower, protection on the wider system, demonstrated significant benefit to the protection requirements. This will be increasingly important on more complex networks, where the type of fault can be detected as well as the device being isolated from the system almost instantaneously.

For the first time as part of a new technology installation we developed a separate information interface system, above that included in the FPL. Figure 2-14 provides a snapshot of the FPL CM interface. The availability for the project team and wider support staff to visualise the status and operational performance has been particularly useful, especially the capturing of data at 10 second internals for the purpose of detailed analysis.

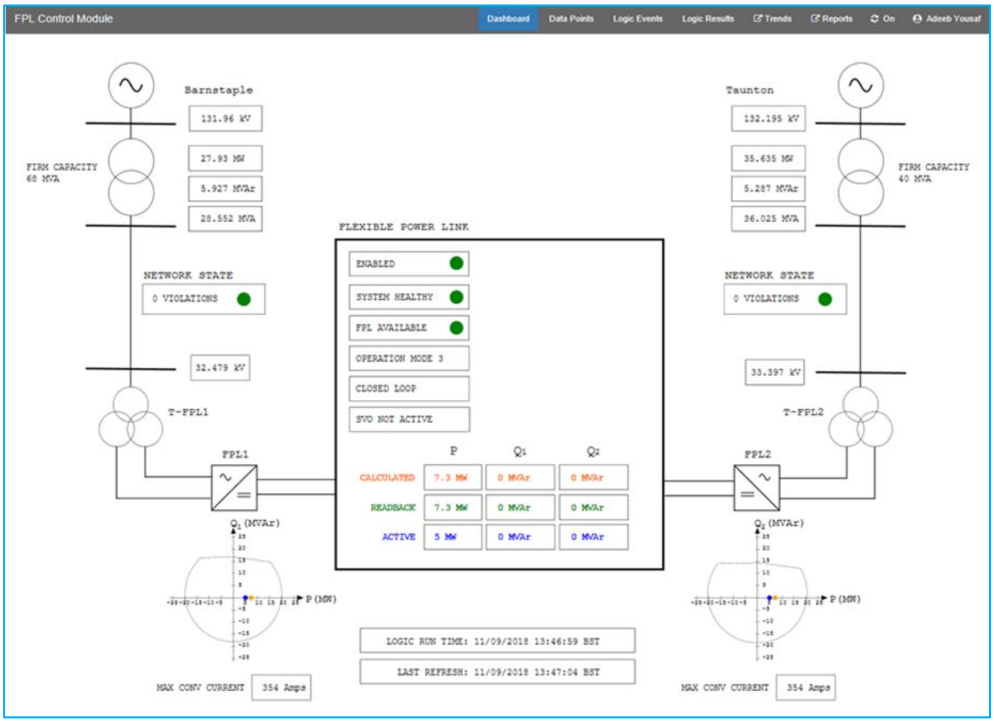

Figure 2-14: FPL CM Screenshot

The benefit of such an interface has been paramount to the successful operation of the FPL and would be considered for further technology installations moving forwards.

3.0 Incorporation and Impacts of all Three Techniques

3.1 Capacity Released

Power system studies have been performed using the Power System Simulator for Engineers (PSS/E) plugins that have been developed in this project to quantify the capacity release for each of the methods individually and combined. These studies were run for the period from the 20th October 2018 until the 27th October 2018, using actual network data.

3.1.1 EVA

As part of the studies performed to evaluate the capacity released using EVA, the voltage limits were extended to ± 10% for the BSPs and ± 8% for the Primaries as recommended in SDRC-1. This was then compared to the capacity the network has with the current statutory voltage limits of ± 6% for both BSPs and Primaries in order to calculate the additional capacity released using the EVA technique. The results are shown in Table 3-1 and Table 3-2 and include the maximum and average capacity released in that week for each substation.

As can be seen, the maximum capacity release varied across the eight BSPs with some sites indicating no capacity release while others having amounts of maximum capacity release ranging from 3MW in Paignton BSP to 172MW in the meshed 33kV network of Bridgwater and Street BSPs. The maximum capacity released for the Primaries ranged between 0MW and 10.86MW. Interestingly, it can be seen that although the maximum capacity release at Paignton BSP is 3MW, the average capacity is zero. This is because widening the voltage limits could reduce the capacity in certain periods in which the studies identify thermal constraints due to the extreme voltages. However, it is clear that overall EVA can have significant capacity benefits.

Table 3-1 Capacity Release form EVA for each BSP

BSPs	Maximum Capacity Release (MW)	Average Capacity Release (MW)
Bowhays Cross	45.75	33.80
Bridgwater	172.25	124.53
Exeter City	0.00	0.00
Exeter Main	35.50	17.51
Paignton	3.00	0
Radstock	0.00	0.00
Taunton	86.00	66.49
Tiverton	0.00	0.00

Table 3-2 Capacity Release from EVA for each Primary

Primaries	Maximum Capacity Release (MW)	Average Capacity Release (MW)
Colley Lane	0.00	0.00
Dunkeswell	2.32	0.34
Lydeard St Lawrence	5.37	0.32
Marsh Green	4.48	2.65
Millfield	10.86	5.57
Nether Stowey	1.86	0.44
Tiverton Moorhayes	8.81	4.06
Waterlake	4.84	2.66

3.1.2 SVO

The studies have shown that the SVO technology can release network capacity at both BSPs and Primaries as shown in Table 3-3 and Table 3-4. The maximum capacity release at the BSPs ranges between 0MW and 62MW and 0MW and 16MW at the Primaries. The negative capacity indicates a reduction in network capacity which is observed in the networks of some BSPs. This is because when SVO drops the voltage in some networks, the loads in the model increase causing thermal constraints and limiting the network capacity. This is a limitation of the power system analysis models used and provides a conservative view of the capacity release.

Table 3-3 Capacity Release from SVO for each BSP

BSPs	Maximum Capacity Release (MW)	Average Capacity Release (MW)
Bowhays Cross	62.00	55.72
Bridgwater	16.00	-1.53
Exeter City	0.00	-0.02
Exeter Main	29.75	15.80
Paignton	3.00	0.00
Radstock	0.00	-0.08
Taunton	31.00	9.05
Tiverton	0.00	-1.90

Table 3-4 Capacity Release from SVO for each Primary

Primaries	Maximum Capacity Release (MW)	Average Capacity Release (MW)
Colley Lane	9.64	4.25
Dunkeswell	2.32	0.35
Lydeard St Lawrence	6.98	0.20
Marsh Green	5.72	2.84
Millfield	11.35	5.62
Nether Stowey	1.67	0.43
Tiverton Moorhayes	15.12	11.11
Waterlake	16.75	15.72

3.1.3 FPL

It was calculated that the FPL could release up to 6.5MW of capacity in the Barnstaple network and 13.5 MW of capacity in the Taunton network while the average capacity release in the Barnstaple 33kV network was 4MW and in the Taunton 33kV network it was 3MW.

Table 3-5 Capacity Release from FPL

Network	Maximum Capacity Release (MW)	Average Capacity Release (MW)
Barnstaple	6.5	4
Taunton	13.5	3

3.1.4 EVA and SVO

Combining EVA and SVO provides additional capacity release that varies between 0MW and 69.5MW for the BSPs and 0MW and 14.3MW for the Primaries compared to the capacity released when implementing only EVA in the week studied. The benefits demonstrate that SVO combined with EVA can optimise the network even further and increase the capacity that could be released. This combined capacity release is also higher than the capacity that could be released by implementing only SVO, showing that widening the voltage limits can enable SVO to optimise the network even more.

Table 3-6 Additional Capacity Release from EVA and SVO for each BSP

BSPs	Maximum Capacity Release (MW)	Average Capacity Release (MW)
Bowhays Cross	2.00	0.08
Bridgwater	21.00	-4.67
Exeter City	4.00	0.00
Exeter Main	0.00	-1.17
Paignton	3.00	0.04
Radstock	0.00	-0.07
Taunton	69.50	14.28
Tiverton	0.00	-1.90

Table 3-7 Additional Capacity Release from EVA and SVO for each Primary

Primaries	Maximum Capacity Release (MW)	Average Capacity Release (MW)
Colley Lane	9.64	4.25
Dunkeswell	0.70	0.01
Lydeard St Lawrence	6.98	0.21
Marsh Green	2.84	0.20
Millfield	1.62	0.02
Nether Stowey	0.00	-0.02
Tiverton Moorhayes	12.36	7.49
Waterlake	14.32	13.18

3.1.5 EVA and FPL

The studies performed to evaluate the capacity that could be released in the week examined by combining both the EVA and FPL have shown that an additional 4MW can be released in the Barnstaple network and 5MW in the Taunton network compared to the capacity that could be released if only EVA was used. The capacity release by combining these two technologies is also higher than the capacity released by using inly the FPL, demonstrating that when FPL is combined with EVA, the capacity benefits increase with EVA allowing the FPL to use its reactive power support capability even more.

Table 3-8 EVA and FPL Additional Capacity Release

Network	EVA limits	Maximum Capacity Release (MW)	Average Capacity Release (MW)
Barnstaple	10%	4	6
Taunton	10%	5	6

3.1.6 SVO and FPL

The power system studies have shown that combining the SVO and FPL technologies provides little to no additional benefits compared to just implementing the FPL. This is because the reactive power support provided by the FPL is sufficient to keep the voltages within limits on that feeder, eliminating the need for a voltage optimisation system. Therefore, in networks where an FPL is installed, the costs associated with also implementing the SVO technology can be avoided as long as the FPL is installed on the feeder that has the constraints limiting the capacity of that network. However, if the capacity of the network is limited due to voltage constraints on more than one feeders, then the SVO technology would be required to remove those constraints and increase network capacity.

3.1.7 EVA, SVO and FPL

The results from our assessment have shown that implementing all three techniques does not introduce additional significant benefits compared to implementing only EVA and FPL or EVA and SVO. This agrees with the conclusions in 3.1.6 that explained how the reactive power support provided by the FPL removes the need for implementing SVO on the particular network, therefore any combination of techniques that includes both SVO and FPL does not provide further capacity release.

3.1.8 Summary

The results of the studies are summarised in Table 3-9, showing the significant capacity benefits that EVA, SVO and FPL can offer individually but also the increase in the capacity that could be created by combining EVA with any of the other two technologies.

Table 3-9 Result Summary

Technology	Average Maximum BSP Capacity Release (MW)	Average Maximum Primary Capacity Release (MW)
EVA	43	4.81
SVO	17.7	8.69
FPL	20	N/A
EVA and FPL	9 (additional to just using EVA)	FPL only applied at BSP level
EVA and SVO	12.43 (additional to using just EVA)	6 (additional to using just EVA)

3.2 Wider System Benefits

Through the integration of these technologies and solutions we have both developed a detailed understanding of the immediate benefits of the three Methods, to more readily make available the connection of DG to the 11kV and 33kV network; however, throughout the trials we have learnt of a number of wider system benefits borne by the trials.

Network flexibility, above that of enabling additional generation to connect has been a prime system benefit. In relation to the SVO, the value of a dynamic and remote system, which when required can change the voltage setting at a substation when a system fault or network reconfiguration occurs can be significant. Previously the voltage setting of a faulted or reconfigured network would remain the same; however, with a dynamically reconfiguring system the voltage can be updated to best suit the current conditions of the network. Through the trials we have seen that this is advantageous, both in terms of ensuring that generation customers remain connected in these situations but that previously unavailable network arrangements, due to voltage imbalance, are now feasible.

The operation of the FPL as part of the project Method has been to demonstrate the use of real and reactive power to enable the connection of additional generation on the system, thereby only using either power to ensure that the network does not operate outside limits for both thermal and voltage capacity and capability. The operation of the FPL has demonstrated that it has the capability to balance the network if required, this would provide an operating regime whereby it could operate to minimise losses on the wider system. Future implementations of an FPL, or similar technology, could be implemented to operate for a loss minimisation target where the losses within the device are sufficiently low to make this practical.

The demonstration of the FPL has also enabled significant learning to be gathered in the role that power electronics on a distribution network can play. The benefits of DC being introduced in to an otherwise AC system are well understood but the power electronic impacts have been demonstrated throughout this project. A key system benefit has been learnt through the FPL's operation under a system fault scenario, where the rapid response of the power electronics' action once a fault has been detected to disconnect is significantly faster than traditional relay and circuit breaker systems. The detection and operation of the power electronics devices to act to block the flow of current in to the faulted system is an order of magnitude faster than that of the traditional solution. As the network evolves and the need for faster operating and increasingly sensitive protection is required, the use and operation of power electronics will be able to play an important role in the complete system.

4.0 Benefit of EVA, SVO and FPL Methods

As part of the bid phase of the project the cost benefit analysis (CBA) and the carbon benefits of implementing the three Methods were developed and are presented below.

Table 4-1: Financial benefits at bid stage

	Method Cost (£M)	Base Case Cost (£M)	2030 (£M)	2050 (£M)
EVA	0.3	10.2	9.9	9.9
SVO	3	28.9	25.9	25.9
FPL	5.6	15	9.4	9.4

The Method costs described in the financial benefits are that of the post project implementation, where the one of a kind costs have been removed. At the bid stage, whilst the carbon benefits increased over time the financial benefits of each solution remained the same. This considers simply the financial benefits to a Distribution Network Operator (DNO) in savings against employing the traditional base case solution to release the required capacity.

Table 4-2: Carbon benefits at bid stage

	2030 (MVA)	2050 (MVA)
EVA	81	97.2
SVO	194.4	252.8
FPL	36.2	36.2

The carbon benefits from the bid, Table 4-2**Error! Reference source not found.**, show that over 300MVA of generation connection capacity was estimated to be made available through the implementation of the three project Methods, where it further increases towards 2050 based on the interaction between the Methods, specifically the capacity release associated with SVO including the benefit of widening the limits as part of EVA.

The sections below will discuss how the estimated benefits at the bid phase have been adjusted based on the learning from delivering the three Methods as part of the project.

4.1 Cost Benefit Analysis of the EVA, SVO and FPL Methods

This section describes the cost benefit analysis (CBA) of each of the three Methods and consideration for the implementation for multiple Methods together on the system. Each Method's cost is reviewed from what was used at the bid stage and updated where appropriate based on project learning for both the capital and ongoing operational costs. The base case costs used in the bid, i.e. the costs of traditional DNO solutions to the same challenges have not been updated as those solutions are still valid and relevant.

4.1.1 EVA

The nature of the EVA is that it is the widening of existing limits on the network, from ±6% to 8% on the 11kV network and 10% on the 33kV network. The rationale for this is documented in SDRC-1. In order to enable this to be carried out in practice there would need to be some updates to the existing relays on site and additional monitoring established on the network; this would be required to facilitate more granular understanding of the voltage conditions throughout the network based on the significant change in limits the system would now be exposed to. This work required is the same as was proposed at the bid stage with a total cost of £300k, with £18.75k being allocated to each site as part of a post-trial project scale replication. Whilst there may be some variation throughout the UK these figures are expected to also be replicable for wider UK implementation. These values are still applicable following the detailed investigation of the application of the EVA Method. There would also be no on-going additional operational costs further impacting on the CBA of the EVA implementation.

4.1.2 SVO

The projected post-trial Method cost of SVO, at the bid stage, was £3.0M. This was based on savings from the project cost budget of SVO, which is £4.09M. The project has delivered the SVO to the original planned budget, however, learning from the delivery of the SVO's central control system and the on-site activities at the 16 sites has enabled a re-baselined estimation of the post-trial Method cost to be £1.718M. This saving of over £1.2M has been calculated on the basis that less additional development would be required for the future implementation, where the system that has been developed as part of the project is suitable for roll-out of a scale the same as the project deployment of 16 sites; this is largely due to additional system developments carried out as part of the project that were originally out of scope. Another significant saving is the level of monitoring required, and therefore the capital and operational costs, on the system to ensure that the voltage stays within limits at all times throughout the entirety of the network. Trialling of the complete SVO system has shown that if the data within the central system is live and accurate then minimal monitoring is required. A slight increase in the post-trial cost has been identified, which is the person days effort to ensure that the central system is live and up to date to ensure that the background model, enabling the real-time voltage calculations, to remain accurate.

4.1.3 FPL

The cost to deliver the FPL in the project budget was £6.95M and the project is on track to deliver against that original budget. The post-trial Method cost, at the bid phase, was projected to be £5.6M, these costs were largely based on the design costs associated with the first of a kind install of an MVDC device on a DNO network. Throughout the delivery of the project elements of the cost have changed, for example the cost of the FPL device was slightly lower than the budgeted cost of £4.55M, however the development of the centralised FPL Control Module was greater than initially envisaged. The site works were as expected and as documented in SDRC-6, the future connection arrangement of an FPL would be the same as delivered as part of the project. The connection arrangement and the fundamental technology remaining the same means that the operational component of the post-trial Method cost would remain the same. It is also estimated, based on the delivery costs and wider project learning that a reduction from the project costs to the post-trial costs of £1.35M is valid and therefore the CBA remains the same for the FPL implementation.

4.1.4 Implementation of Multiple Methods

In relation to the CBA of integrating a number of Methods in a specific area, the base case costs have a significant element of overlap, for example the EVA cost is for greater overhead line networks with additional capacity, where the voltage drop does not have to be considered, and the SVO cost is for the same capacity but implemented through cable installations, which do not have as great a voltage drop, usually, associated with them. This would mean that for the instance where the SVO and EVA are implemented together there would only be the need for the base case cost of SVO. Similarly the FPL base case cost is that of the EVA, across two BSPs, with the addition of transformers as the FPL relates to additional real-power flow capability as well as voltage control. Therefore, in both instances the actual CBA of implementing multiple Methods would appear to be reduced, the following section, which focusses on the carbon benefits, provides the detail of the additional connection benefits and these two elements considered together provide an overview of the wider benefits of employing multiple Methods across a single network area.

4.2 Carbon Benefits of the EVA, SVO and FPL Methods

4.2.1 EVA

At the bid stage the EVA was estimated to make available another ±1% up to 2030 and then a further 1% to ±2% through to 2050, which provided 81MVA and 97.2MVA respectively. However, as described in SDRC-1, it was determined that whilst ±2% was suitable for the 11kV system, an additional ±4% can be utilised on the 33kV system. This change has had a significant benefit on the overall capacity release of the EVA system. Using the average maximum capacity release data from the project, as was the methodology at the bid stage, the new capacity released over eight BSPs and eight primaries is now 382.4MVA.

4.2.2 SVO

The carbon benefits of the SVO as part of the bid were split in to two elements, a roll out by 2030 without the interaction of EVA and to 2050 including EVA. This section will focus on the roll out without the EVA included, which was 194.4MVA. Following learning generated as part of the project and discussed early in this report the average maximum capacity release of a BSP due to the implementation of SVO is 17.7MVA and 8.7MVA at a primary. Therefore, the carbon benefits and capacity release can be calculated to be 211.2MVA, which is an increase of 16.8MVA.

4.2.3 FPL

The benefits of the FPL had been calculated as 36.2MVA at the bid stage. This was calculated through the preliminary modelling work to aim to account for both the benefits brought by real power transfer and reactive power to actively control the system voltage. Through the development of the FPL plugin, discussed in detail in earlier documents, the capacity released at Exebridge, the site of the FPL installation the capacity released is 20MVA. However, implementing the plugin on a wider selection of FPL suitable networks, where BSPs can be implemented, the average capacity release is 12MVA.

4.2.4 EVA and SVO

The 2050 carbon benefits, as per the bid, for the SVO also included the benefits of implementing EVA. The capacity release associated with this was 252.8MVA. From the analysis undertaken throughout the project the additional benefit of implementing EVA on an SVO enabled BSP is 12.4MVA and 6.0MVA on a primary. This means that the total capacity released with the combined Methods across the project area is calculated to be 358.4MVA.

4.2.5 EVA and FPL

The implementation of an FPL and the EVA had not previously been investigated. Applying the widened voltage limits, 10% on the 33kV system, to the FPL plugin has demonstrated an additional 9MVA capacity release. This means that the capacity released through this implementation would be 29MVA at Exebridge and 21MVA on an average FPL installation.

5.0 Conclusion

The design, development and trialling of the three Methods has enabled a significant amount of technical and operational learning for each to be developed, providing the basis for updated benefit analysis calculations to be developed. This analysis has shown that the project Methods, which at the bid phase projected a capacity release of 311.6MVA, could release up to 613.6MVA when they're considered independently, when considered together the capacity release could increase by a further 114.6MVA – *this considers the implementation of the Methods on separate networks rather than overlapped as delivered in this project*. This increase in capacity release is also available with a reduced post-trail cost reduction of 1.72M to 7.18M.

The key learnings from the EVA Method are that the initial, bid phase, proposals to extend the limits up to a maximum of ±2% were conservative. The analysis to date has shown that the limits can be increased by ±2% on the 11kV system; however, on the 33kV an increase of ±4% can be released. This means that the potential capacity realise in the project area has increased from 97.2MVA to 382.4MVA, whilst the implementation costs have remained the same. The work to develop a methodology for the implementation of the EVA Method will be taken forwards by our Policy Engineers in conjunction with other DNOs' Policy Engineers through the ENA to develop an enduring solution for the application, where appropriate.

The trialling of SVO on eight primary substations and eight bulk supply points has demonstrated that the initial calculations of capacity release, 194.4MVA, were largely accurate. This value has increased by 16.8MVA to 211.2MVA through more accurate analysis and experience of the system in operation. However, the replication costs for future deployments of the SVO system have significantly reduced from £3.0M to £1.72M. This reduction has centred on the increased system development undertaken throughout the project and the reduced amount of system monitoring required to ensure that the central SVO has the correct level of detail to accurately calculate optimised voltage settings. It has also been learnt that the process to keep a separate system, connected to the incumbent NMS, up to date is significant and whilst the costs to implement another project scale solution (16 sites) have reducted to £1.72M it is anticipated that a large-scale roll-out, DNO licence area or similar, would require a different end to end solution, either implemented within the existing NMS or an automated data extraction and processing technique for the updating of the system. It has also been learnt that the implementation of the SVO system has tangible capacity release benefits on between a third and a half of sites as part of the project. This learning can be used for any further implementations as to the benefit of applying the system. There are also some sites where there is benefit in applying the Method for some but not all of the time; this will be further developed towards the end of the project to support future implementations at site, where for certain conditions, it is appropriate to switch off the SVO system at some points to best suit the wider network.

Installing and operating the FPL on the 33kV system has shown that the bid phase projection of post-project replication costs were accurate; this was supported by a detailed procurement exercise to understand the FPL as this is the dominating cost. The learning from the implementation and supporting modelling has shown that the projected capacity release of 36MVA was over ambitious and the more realistic value is 20MVA. The implementation of the FPL was complex, specifically the wider network changes required (as discussed in SDRC-6), however the project has enabled the demonstration of power electronics based MVDC technology in to an otherwise AC system. The implementation of an FPL remains a bespoke solution and is envisaged to be utilised in a select number of networks moving forwards.

Finally, the modelling and analysis throughout this project has shown that the benefit of applying multiple Methods in a single network area focusses on the EVA being applied with either the SVO or FPL. For the situation where the EVA and SVO are applied across the project area, a further 147.2MVA of capacity was released – an additional release of over 40%. The application of the FPL and EVA released another 9MVA of load or generation capacity – an additional capacity of over 30%.

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