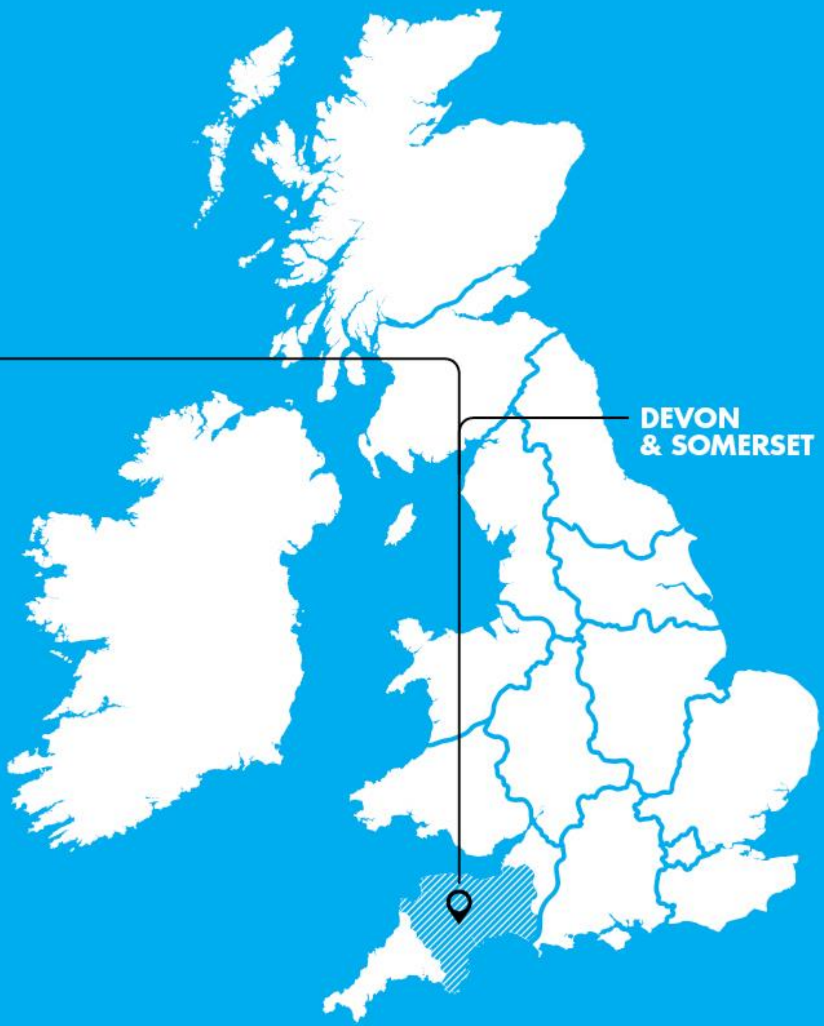
WESTERN POWER DISTRIBUTION

NETWORK EQUILIBRIUM

BALANCING GENERATION AND DEMAND



SDRC-5
Trialling and demonstrating the SVO Method

LCN Fund
Low Carbon Networks

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Contents

Executive Summary

Network Equilibrium is a Tier 2 Low Carbon Networks Fund (LCNF) project which aims to demonstrate how novel voltage and power flow management can release network capacity. This release in capacity shall allow the connection of new customers including embedded generation and Low Carbon Technologies (LCTs), to the distribution network during both normal and abnormal conditions.

The System Voltage Optimisation (SVO) technology of Network Equilibrium is an innovative, centralised voltage control system that aims to release network capacity by adjusting the network voltages in real-time. It has been implemented on eight Bulk Supply Points (BSPs) and eight Primary substations

This report forms one of the eight deliverables as part of Network Equilibrium. SDRC-5 entitled, “Trialling and Demonstrating the SVO Method”, providing a detailed description of how the SVO method has been implemented on the project’s trial area and demonstrates its performance during the trials and the capacity released.

The report provides an overview of SVO, demonstrating its centralised architecture and the interaction with WPD’s Network Management System (NMS) to receive network information and send back optimised target voltage settings for the SVO sites. The detailed implementation of the system using Siemens’ Spectrum Power 5 (SP5) technology and the site work required at each SVO substation are also presented. As part of this, the various design decisions and learning points gained in the process are discussed, showing the knowledge the technology has offered so far.

Significant learning has been gained from the running of the technology trials up to this point, on various areas. The successful integration of SVO with the NMS, for example, offered valuable experience and skills in connecting two control systems over an ICCP link. Additionally, it was shown that it is possible to run the network at lower voltages than how it is run traditionally, with the optimal voltage varying based on the real time operating conditions. All learning points are presented in this document.

Analysis performed using power system analysis tools, developed as part of the project, has enabled the quantification of the expected benefits of the technology. This analysis has indicated that SVO could release at least 160 MW across eight BSPs and at least 48 MW across the eight Primaries.

The performance of the system and the capacity released will continue to be analysed during the remaining of the trials and will be reported in SDRC-7, Trialling and demonstrating the integration of the Enhanced Voltage Assessment (EVA), SVO and Flexible Power Link (FPL) Methods.

1 System Voltage Optimisation

1.1 Overview

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 is explored in greater detail in Section 2 of this document, but in general consists of two 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 1-1.

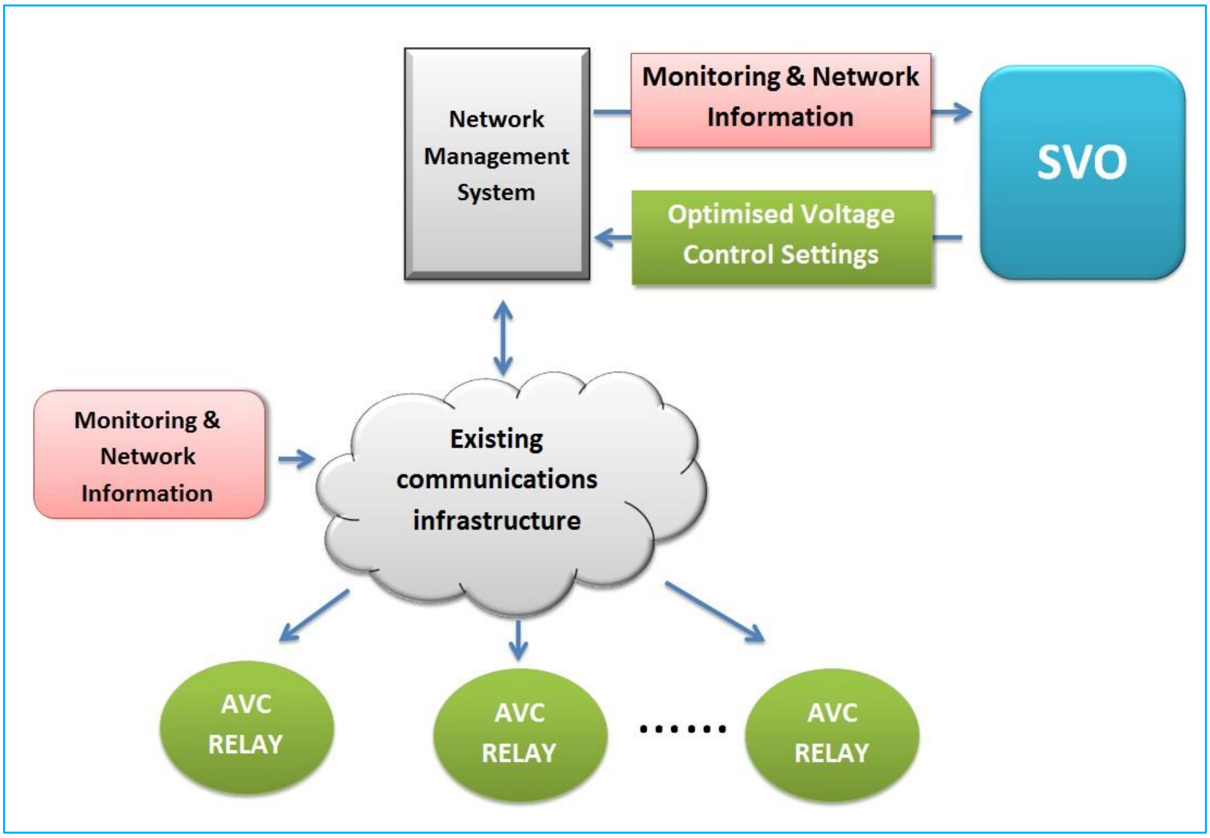


Figure 1-1: SVO Block Diagram

2 Implementation of the SVO Solution

2.1 Voltage Control System Implementation

2.1.1 Overall System Operation

Siemens' SP5 is the tool used to implement the centralised voltage control system of SVO. SP5 is a software based control system that is used to control and optimise electricity distribution networks. In SVO, SP5 is optimising the voltages in the network in real time with the aim to release network capacity. Firstly, it communicates with WPD's NMS to receive network operation and utilisation data which is used to estimate the state of the network in real time. It then runs its optimisation algorithms to calculate the optimised target voltage set points which are sent to the NMS and then to the AVC relays in the network.

Spectrum Power 5 consists of four main software modules:

1. **Information Model Management (IMM):** This includes the network model of each SVO network. These models represent all electrical information required in order to run power flow analysis in those networks, like the lengths and impedances of the lines and electrical parameters of the transformers and their tap changers.
2. **Inter-Control Centre Communications Protocol (ICCP):** Enables the real-time communication with the NMS to receive the network measurement data (active and reactive power flows, currents and voltages) and send back the calculated target voltage controls. Any alarms that are raised in SP5 are also forwarded to the NMS via ICCP and indicate the status of the entire system and the status of the optimisation of each SVO site.
3. **Distribution System State Estimator (DSSE):** Uses the network monitoring information received over ICCP from the NMS and the network models in the IMM to estimate the state of the network. This involves a number of power flow calculations and provides estimates of the voltages and power flows at the points where no monitoring information is available.
4. **Volt-Var Control (VVC):** After the state of the network is estimated by DSSE, the VVC module calculates the optimal target voltage set points for each SVO substation by running a series of optimisation calculations.

Once VVC calculates the target voltage set points, these are sent over ICCP to the NMS which forwards them to the AVC relays in the network.

The function of each SP5 module and how they contribute to the overall system operation is demonstrated in Figure 2-1.

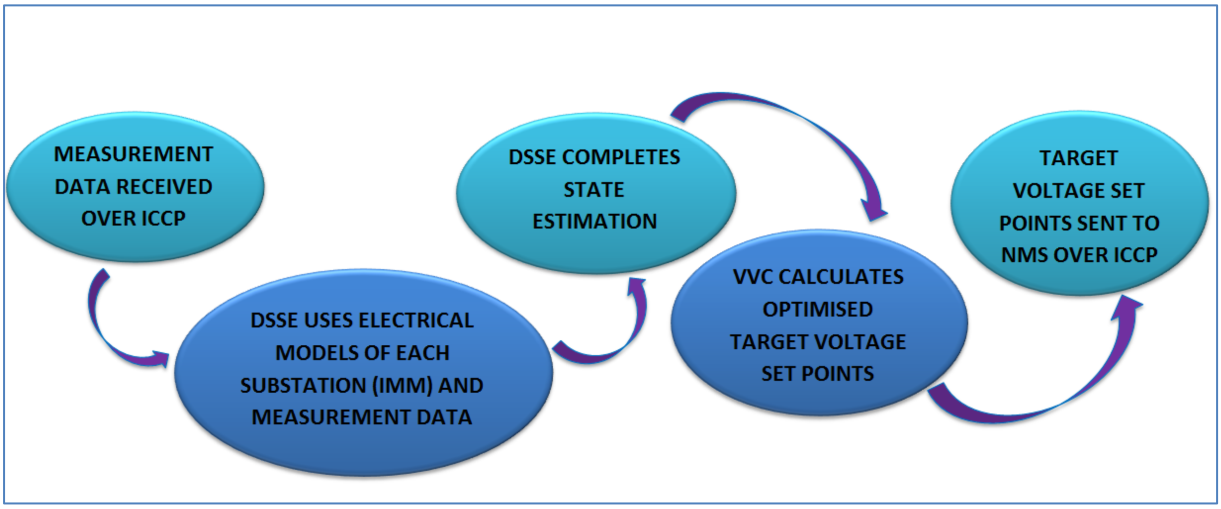


Figure 2-1 SP5 operation

2.1.2 IT Architecture

The IT implementation of SP5 is based on a virtualised architecture which provides the flexibility of using different pieces of hardware and overcomes the restrictions of a traditional hardware based server architecture.

The virtualised architecture means that instead of using one physical server for each part of the system, different applications can share the same hardware. This significantly reduces the amount of physical servers required, increases the efficiency in the usage of the hardware and reduces the cost of the entire architecture. In SVO, the virtualisation of the different applications allowed them to share the same physical resource, reducing the number of servers required and implementation costs. The software modules of SP5 are therefore run on its various virtualised servers.

The Power System Observer Server (PSOS) contains the IMM module described in 2.1.1 and the Historical Information System (HIS) which holds all the captured data (received measurement data, calculated set points, etc.).

The module that supports ICCP, the DSSE and VVC functionalities is located on the Real-Time Server (RTS). For redundancy, there are two RT servers in the SVO system with the second server being in hot standby mode, available to take over if the main RTS stops working successfully. Additionally, the users can access the system through the 15 virtual User Interfaces.

The overall IT Architecture is shown in Figure 2-2, demonstrating logical connectivity of the PSOS, RTS servers and the 15 UIs but also the hardware that is hosting the virtualised system.

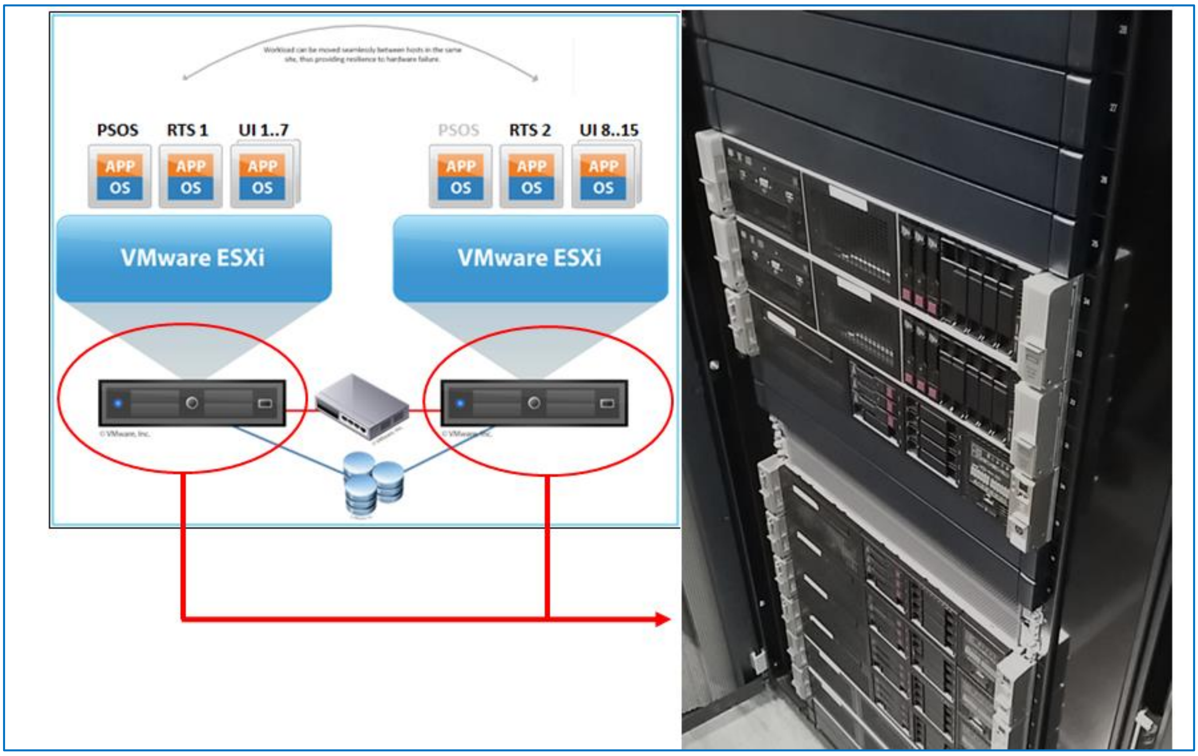


Figure 2-2 Overall IT Architecture and hardware photo

2.1.3 User Interface

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

Figure 2-3, demonstrates the main SP5 User Interface which provides access to the different modules of the system.

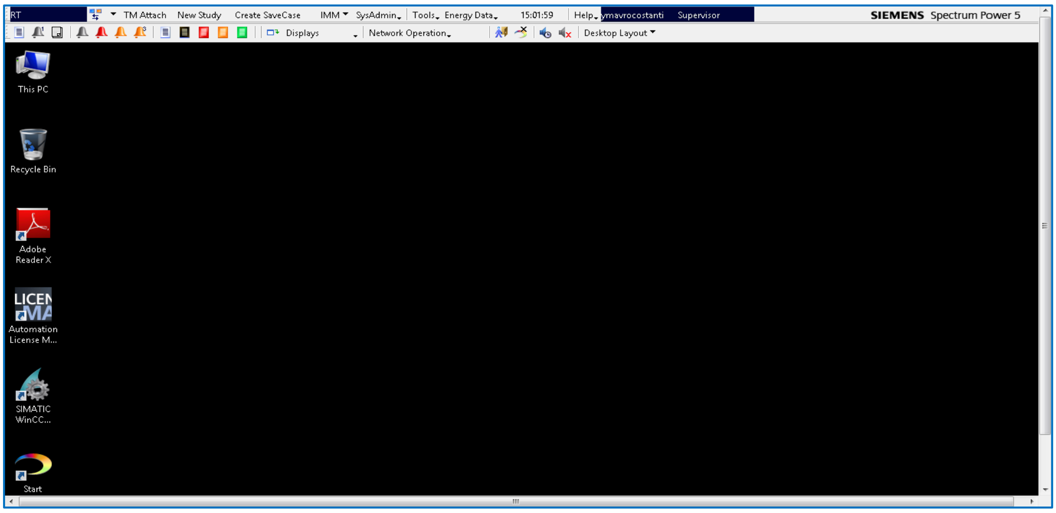


Figure 2-3 SP5 User Interface

The Displays menu shown in Figure 2-3 allows the user to see the SVO network model displays which provide a simplified, schematic representation of each network. An example of the network model is demonstrated in Figure 2-4, where the SP5 model of one of the SVO controlled primary substations is shown.

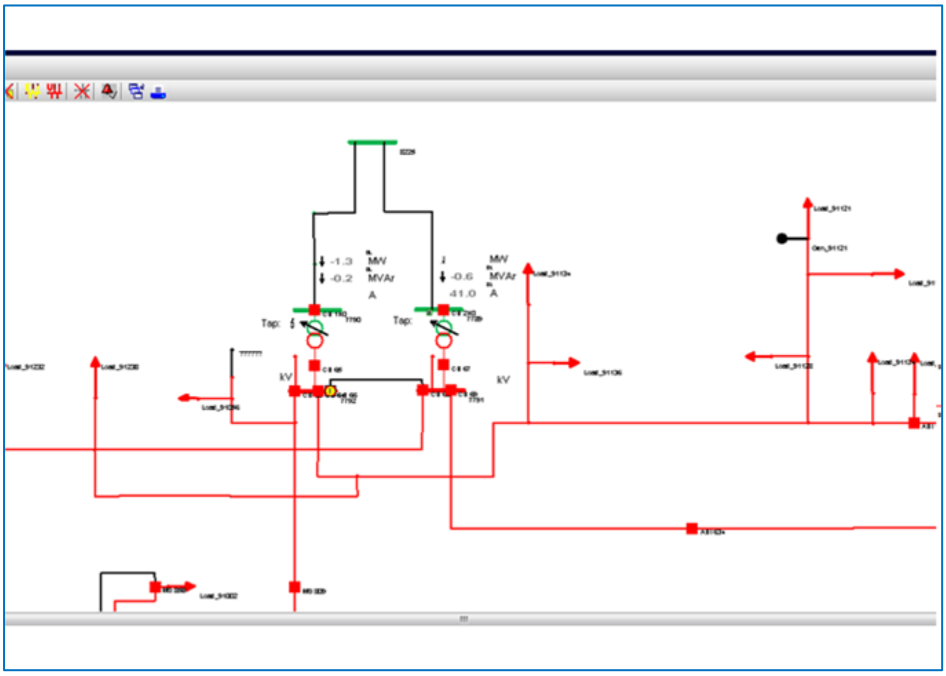


Figure 2-4 Network Display Example SP5

The IMM is also accessible through the main toolbar and provides all the electrical information representing each network model including among others transformer parameters, tap changer information and line impedances. The IMM structure is shown in Figure 2-5, demonstrating the IMM representation of the Marsh Green Primary model.

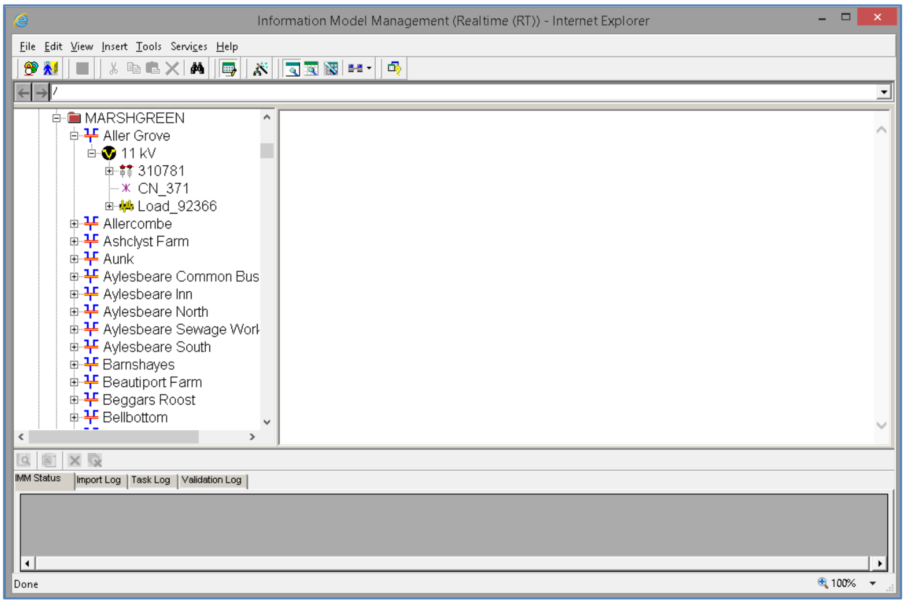


Figure 2-5 IMM Structure in SP5

Figure 2-6 and Figure 2-7 show examples of DSSE and VVC results that can be accessed from the SP5 User Interface.

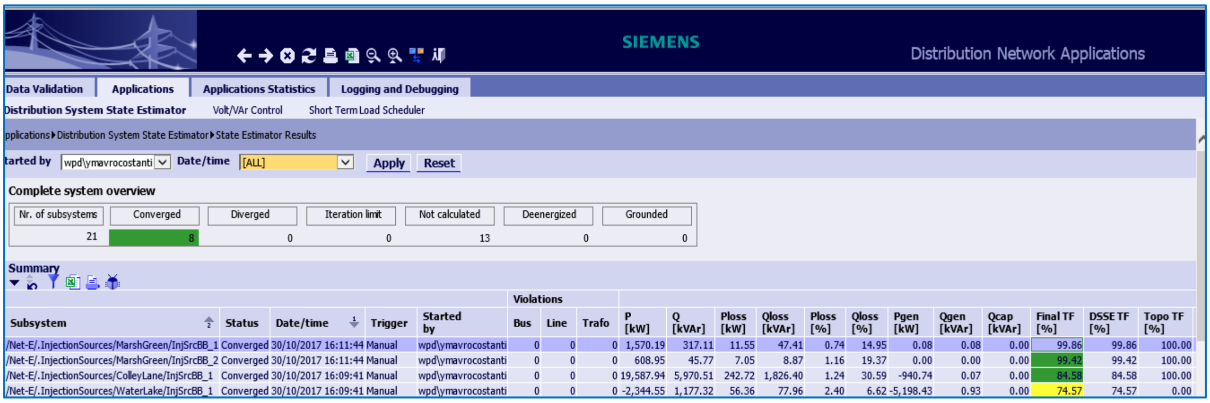


Figure 2-6 Example DSSE Results

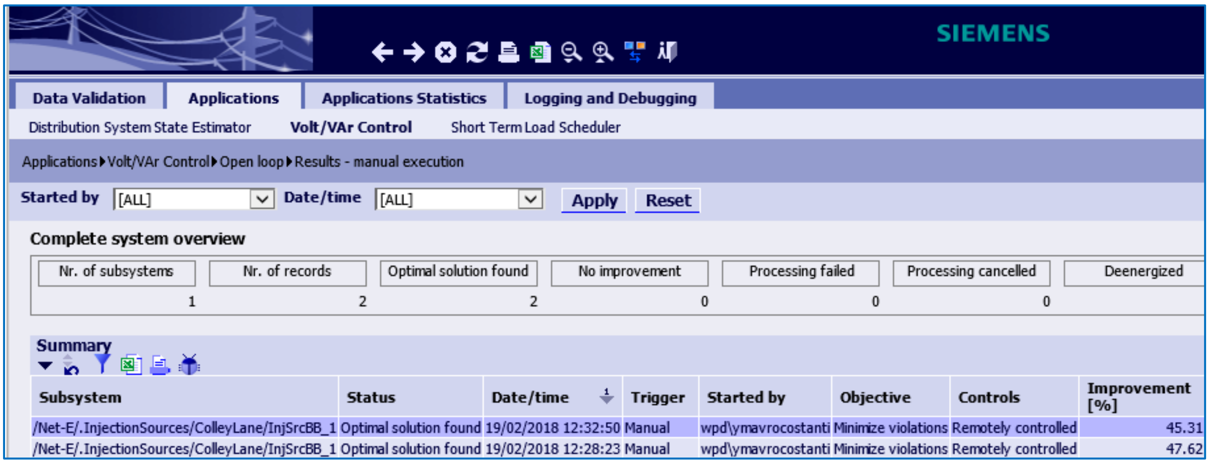


Figure 2-7 Example VVC Results

The access the user has available to the different parts of the system depends on their user type. The following user types have been configured in SP5:

- **Updater:** Allows full access to all IMM functions for the maintenance of the network models and view only access to the remaining parts of the system.
- **Viewer:** Has view only access to all parts of the system. This means that they cannot make any modifications to any settings, network models or controls but can only see the operation of the system.
- **Administrator:** Has full access to all system management tasks like adding new users or configuring the operation of the different software modules.
- **Control Engineer:** Has additional privileges as it allows access to controls while no other user has any control rights.

2.1.4 Network Models

Spectrum Power 5 requires 16 network models, one for each of the 16 SVO controlled substations. As demonstrated in 2.1.1, these electrical network models are necessary for the state estimation that will be performed in order to estimate the power flows and voltages at the points in the network where there are no real-time measurements.

The network model creation process involved using WPD's Geographical Information System (GIS) to obtain information about the electrical connectivity of each network (feeder impedances, demand and generation connection points) and then using a conversion tool, which was developed as part of the previous FlexDGrid project, to build a network model in Power System Simulator for Engineering (PSS/E)[1]. Since SP5 supports the import of IPSA[2] models, the PSS/E models were first converted in that format. All switching components (circuit breakers and isolators) were manually added to the converted IPSA models and the schematic representation of the models was arranged to match the representation of the models in the NMS. The NMS and IPSA model representation is shown in Figure 2-8.

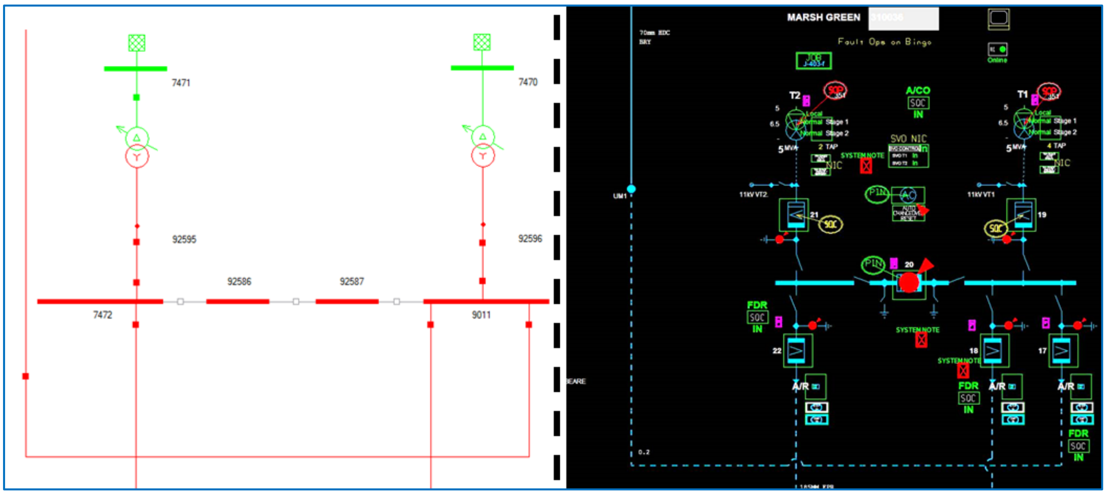


Figure 2-8 IPSA model (left) and NMS (right) representation

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

The entire model creation process is summarised in Figure 2-9.

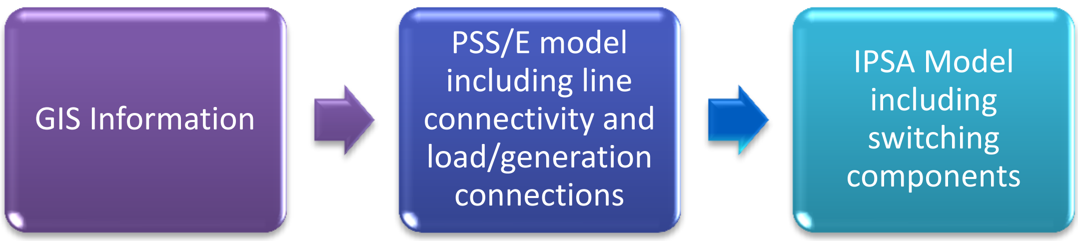


Figure 2-9 Network Model Creation Process

[1] PSS/E is a power system analysis tool which provides the capability of performing power flow calculations on electrical network models.
[2] IPSA is a power system analysis tool which provides the capability of performing power flow calculations on electrical network models.

After completing the validation process shown below, all models were successfully integrated in to SP5:

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

2.1.5 Integration with NMS

SP5 communicates with the WPD NMS[3] over an ICCP link in order to receive network measurement data and exchange controls.

To ensure the successful integration of SP5 with the NMS, the configuration of the ICCP link was agreed from both sides (NMS and SP5) at the initial design stages. This involved agreeing the points that would be exchanged over ICCP and defining the meaning of the values exchanged. The list of points that would be sent over ICCP between the two systems is called the ICCP Bilateral Table and it forms the most important component in the operation of the ICCP link, with each side having its own table.

The creation of the ICCP Bilateral Table was closely linked with the creation of the network models, as it was important to ensure that the measurements received over ICCP by SP5 are linked to the correct component in the network model. This is demonstrated in Figure 2-10.

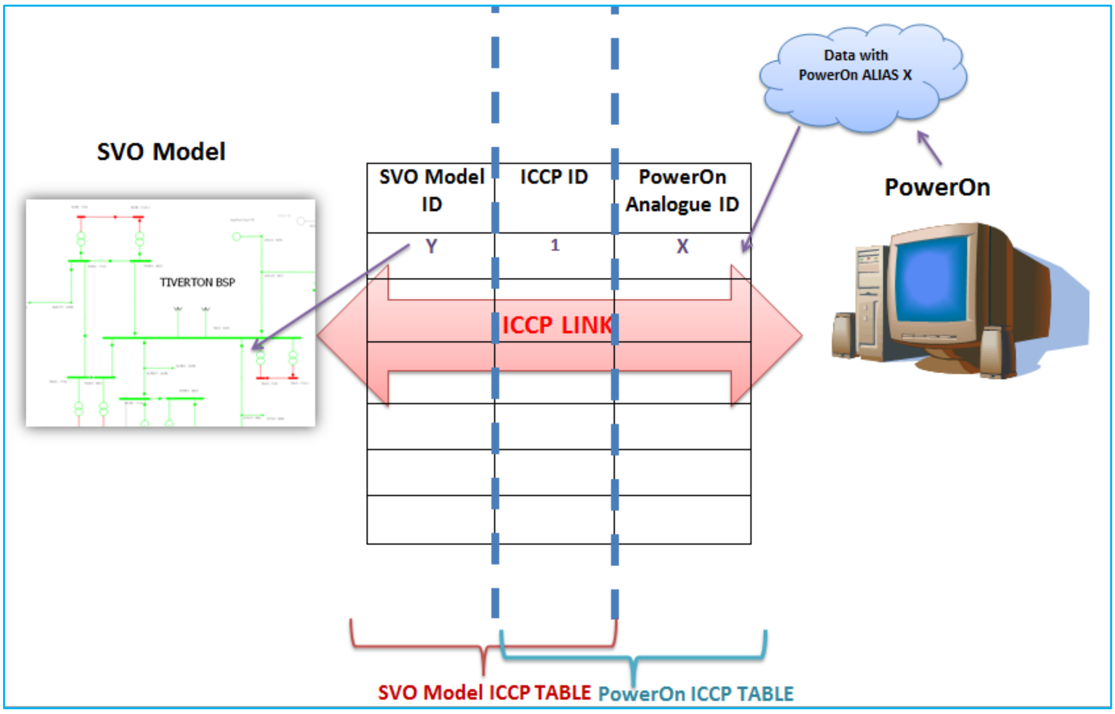


Figure 2-10 ICCP Bilateral Table and Linking of points to the network models.

[3] The current NMS is GE's PowerOn system.

Additionally, the SVO system was designed such that the Control Engineers would be able to control the system through the NMS, removing the need to access Spectrum Power 5. This has the benefits of retaining one central control system, making it easier and more efficient to operate the network. For this reason, a number of controls were created in the NMS that allowed Control Engineers to perform the functionalities required, including enabling/disabling SVO. These controls are sent from NMS to SP5 over the ICCP link. The NMS display of the controls is shown in Figure 2-11.

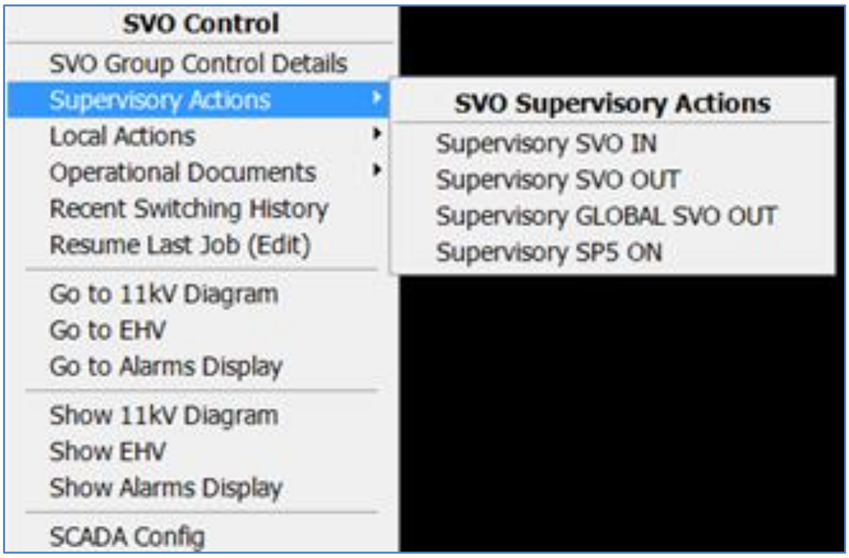


Figure 2-11 NMS SVO Controls

2.1.6 Technology Build

Once the design of the SVO technology was finalised and the various specifications were produced, the building of the system took place. This involved configuring SP5 with all the required functionalities on Siemens' reference system in Germany.

2.1.7 Factory Acceptance Testing

The Factory Acceptance Testing (FAT) involved the testing of SP5, with the aim to prove the correct functionality of the different software modules. It took place at Siemens' offices in Nuremberg, Germany.

The testing setup involved Siemens creating an SP5 system which was a replication of the proposed SVO SP5 system, connected to a simulation tool representing the NMS side and the ICCP link.

In order to ensure that the testing would be done under realistic conditions, it was planned for all of the tests to be performed using real SCADA data. Therefore, as part of the preparations for the FAT, an extract of 2-hours instantaneous SCADA data was captured and exported from the NMS for the two SVO sites that were tested. During the testing, this data was fed into the simulation tool which was sending the data to SP5 over ICCP. The FAT test setup is shown in Figure 2-12.

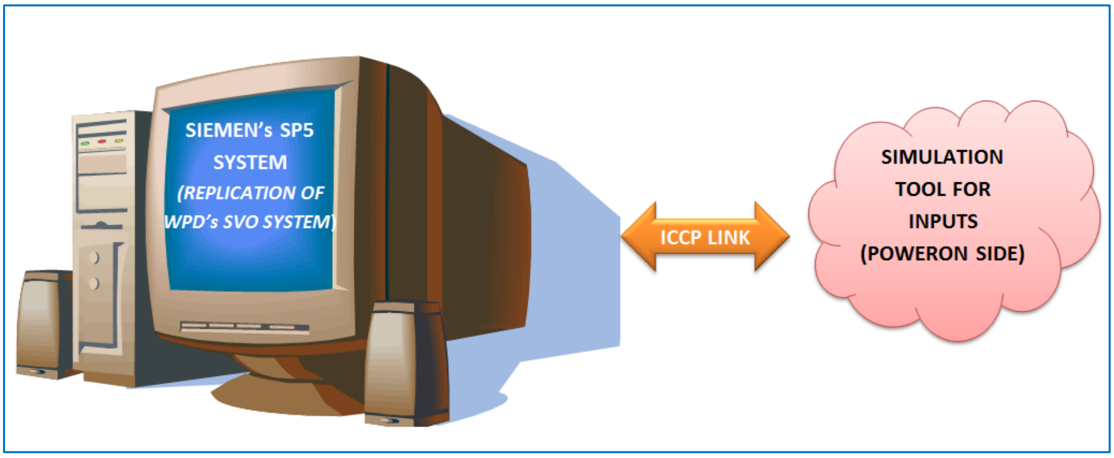


Figure 2-12 FAT Test Setup

The tests included among others, verifying the configuration of the network models, confirming the correct operation of the state estimator, checking the set points calculated by VVC and demonstrating the actions taken by SP5 in certain operating scenarios. In order to test specific operating conditions, the data in the simulation tool was manually changed at different points during the testing to reflect the scenario that had to be tested.

While the majority of the tests were successful, one of the DSSE tests was marked as a showstopper which meant that without its resolution we could not proceed to the next stages of the project. The specific test showed that SP5 could not take into account the voltage measurements when running a state estimation. The project team managed to successfully resolve this issue before the System Integration Testing (SIT).

The testing process enabled the project team to gain an appreciation on what aspects of such a technology need to be tested. Testing the operation of the system in various operating scenarios, for example, proved to be incredibly important as it allowed us to prove that the system responds successfully in challenging situations and that the various software models link correctly. Additionally, being able to modify the input SCADA data is essential in order to be able to test different network conditions. Having a continuous set of simulated data is necessary to test how the different software modules would react in "real-time" conditions and it needs to be tested since the operation might be successful for a specific moment in time but not the next.

The FAT offered a significant amount of learning and enabled improvements to be made to the system. For example, when testing the operation of SP5 when one of the SVO networks was running in an abnormal configuration, it was confirmed that it was responding correctly by pausing the optimisation until the network went back to normal configuration. As part of these tests, it was decided that the system should also send the default target voltage settings to the SVO site when pausing the optimisation to account for the possibility of the network running abnormally for a long duration of time. This modification ensures that the voltages in the network are set to the traditional static value when SVO is unable to optimise due to abnormal running, increasing the reliability of the system. Additionally, the testing showed in more detail how DSSE works and how the state estimation results are affected by the number of available network measurements and their quality. For example, having a higher number of measurements does not always improve the DSSE results. Whether the state estimation improves with more available measurements depends on the type and location of these measurements. Further work will be done during the SVO trials to understand better the relationship between the performance of the state estimation and the available network measurements.

2.1.8 System Integration Testing

The System Integration Testing (SIT) aimed to test the integration of SP5 with the NMS, the ICCP communications, the correct operation of each part of the SVO system and the functionality of SP5 when interacting with the NMS.

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

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

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

The ICCP link between the NMS and SP5 was successfully established before the commencement of the SIT. An extract from SP5 demonstrating the data exchange over ICCP is shown in Figure 2-13.

ICCP Name	ICCP Type	ICCP Value	ICCP Quality	ICCP Timestamp (UTC)	Value	Local Timestamp
A10264	Analog Quality Timestamp	84	Valid | Telem | Norm	27/10/2017 15:05:07	84	27/10/2017 16:05:07 - 0...
A10265	Analog Quality Timestamp	11.32871	Valid | Telem | Norm	27/10/2017 12:42:11	11.32871	27/10/2017 13:42:11 - 0...
A10267	Analog Quality Timestamp	106	Valid | Telem | Norm	26/10/2017 13:08:13	106	26/10/2017 14:08:13 - 0...
A10268	Analog Quality Timestamp	11.32871	Valid | Telem | Norm	27/10/2017 12:43:56	11.32871	27/10/2017 13:43:56 - 0...
A10278	Analog Quality Timestamp	31.64239	Valid | Telem | Norm	27/10/2017 15:13:46	31.64239	27/10/2017 16:13:46 - 0...
A10279	Analog Quality Timestamp	33.04863	Valid | Telem | Norm	27/10/2017 12:50:42	33.04863	27/10/2017 13:50:42 - 0...
A11464	Analog Quality Timestamp	10.09824	Valid | Telem | Norm	27/10/2017 15:13:30	10.09824	27/10/2017 16:13:30 - 0...
A11467	Analog Quality Timestamp	3.353984	Valid | Telem | Norm	27/10/2017 15:14:15	3.353984	27/10/2017 16:14:15 - 0...
A11468	Analog Quality Timestamp	-0.5398911	Valid | Telem | Norm	27/10/2017 15:14:15	-0.5398911	27/10/2017 16:14:15 - 0...
A11469	Analog Quality Timestamp	197	Valid | Telem | Norm	27/10/2017 15:13:38	197	27/10/2017 16:13:38 - 0...
A11833	Analog Quality Timestamp	158	Valid | Telem | Norm	27/10/2017 15:14:13	158	27/10/2017 16:14:13 - 0...
A11834	Analog Quality Timestamp	11.23105	Valid | Telem | Norm	27/10/2017 15:04:10	11.23105	27/10/2017 16:04:10 - 0...
A11837	Analog Quality Timestamp	3.018633	Valid | Telem | Norm	27/10/2017 15:14:29	3.018633	27/10/2017 16:14:29 - 0...
A11838	Analog Quality Timestamp	-0.6003018	Valid | Telem | Norm	27/10/2017 15:14:29	-0.6003018	27/10/2017 16:14:29 - 0...
A12228	Analog Quality Timestamp	0	Valid | Telem | Norm	26/10/2017 07:19:33	0	26/10/2017 08:19:33 - 0...
A12243	Analog Quality Timestamp	127	Valid | Telem | Norm	27/10/2017 14:59:42	127	27/10/2017 15:59:42 - 0...
A12244	Analog Quality Timestamp	10.95762	Valid | Telem | Norm	27/10/2017 13:04:45	10.95762	27/10/2017 14:04:45 - 0...
A12247	Analog Quality Timestamp	2.463045	Valid | Telem | Norm	27/10/2017 15:12:40	2.463045	27/10/2017 16:12:40 - 0...
A12248	Analog Quality Timestamp	-0.9356526	Valid | Telem | Norm	27/10/2017 15:00:33	-0.9356526	27/10/2017 16:00:33 - 0...
A14282	Analog Quality Timestamp	0	Valid | Telem | Norm	26/10/2017 07:19:24	0	26/10/2017 08:19:24 - 0...
A14283	Analog Quality Timestamp	11.09434	Valid | Telem | Norm	27/10/2017 12:32:54	11.09434	27/10/2017 13:32:54 - 0...

Figure 2-13 Data Exchange Over ICCP

In SIT, detailed tests were carried out to assess the performance of the ICCP communications. One of the main learning points gained, is that it is important to ensure not only that the ICCP Bilateral tables agree but also that both sides interpret the ICCP values in the same way. For example, a value of “Closed” for the “SVO IN” indication could be interpreted as the indication being on but it could also be interpreted as the indication being off depending on the point of view of each person. To ensure that both parties communicating over ICCP have the same interpretation, the meaning of each value of each point should be documented and mutually agreed. This was identified as part of the SIT tests, where in certain occasions the correct value was sent from NMS to SP5, but SP5 was interpreting it the opposite way.

The SIT was done with the SP5 system connected to the offline NMS over ICCP as shown in Figure 2-14. The offline NMS is an exact copy of the live NMS and is used for testing purposes as it receives all live network data but has no operational network control. The offline NMS was then connected to two test set-ups consisting of a Remote Terminal Unit (RTU) and a relay, each representing two different SVO sites.

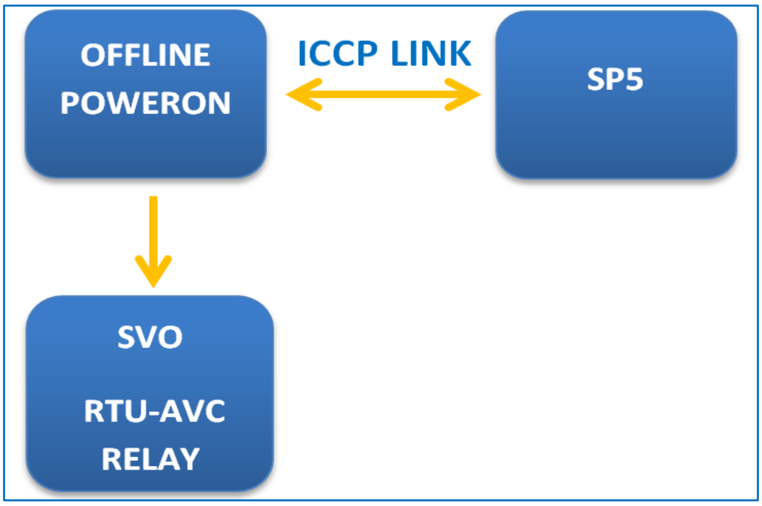


Figure 2-14 SIT Test Setup

The testing demonstrated among others the successful operation of:

- The ICCP link;
- Both systems (SP5 and NMS) under all operating scenarios;
- The SP5 alarms;
- NMS when handling SP5 alarms;
- SP5 when performing a state estimation on an SVO Primary substation network using the SCADA data received over ICCP. An example of the state estimation results is shown in Figure 2-6; and
- SP5 when performing the voltage optimisation on an SVO Primary substation network.

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

2.2 Installation of SVO equipment at BSPs and Primary substations

2.2.1 Relay Selection

Analysis carried out within SDRC-2 provided a list of available relays suitable for dynamic set point control function for SVO. This function enables the temporary alteration of the pre-programmed target voltage to one determined by SP5. Before commencing with design activities our policy engineers were engaged with the aim of getting one or more of the selected relays added to the approved relay list. Following the policy approval process, the Fundamentals SuperTAPP SG relay was selected for use on the project.

Findings in SDRC-2 also showed that the MicroTAPP relay, currently in use on the network, had a total of eight group settings available with only two in use. Therefore it was decided that existing sites with the relay would be modified to enable the selection of voltage settings groups.

2.2.2 Common Design Decisions

All additional control requirements, above what's standard on AVC relays, due to SVO were designed where possible to be separate from the standard control logic. This demarcation within the logic and wiring would enable easy isolation of SVO controls if issues arose.

Each SVO substation contains multiple transformers, each with their own AVC relay. To simplify operation and to ensure that a situation did not arise where with SVO enabled on some but not all transformers at a substation, a single set of SVO controls would enable or disable SVO site wide. This was achieved by placing a single set of local controls on the T1 panel which would operate SVO Control relays for every transformer.

The operation of SVO is dependent on communications links being available at all times while the system is operational. If communications are lost, there is a risk that over time the applied setting will no longer be valid and voltages may move outside of statutory limits. A communications lost signal had previously been developed in the Lincolnshire Low Carbon Hub project, that is controlled by the Remote Terminal Unit (RTU), such that if the RTU does not receive a signal from the control system for four minutes a control can be issued within the substation. For SVO, the control signal was used to temporarily return all relays to their default settings until automatically re-enabling SVO once communications was restored.

2.2.3 SuperTAPP SG Design

As the SuperTAPP SG relay had not been utilised on the WPD network previously it was determined that a standardised AVC panel should be developed, utilising existing AVC standards where possible. This simplification in design reduced the amount of wiring required for on-site user inputs and removed the need for external control logic compared to previous relays. Only changing the AVC relay and interface wiring, keeping all other equipment as per the previous design significantly de-risked the design and minimised the operational differences once installed. The relay schematic is shown in Figure 2-15.

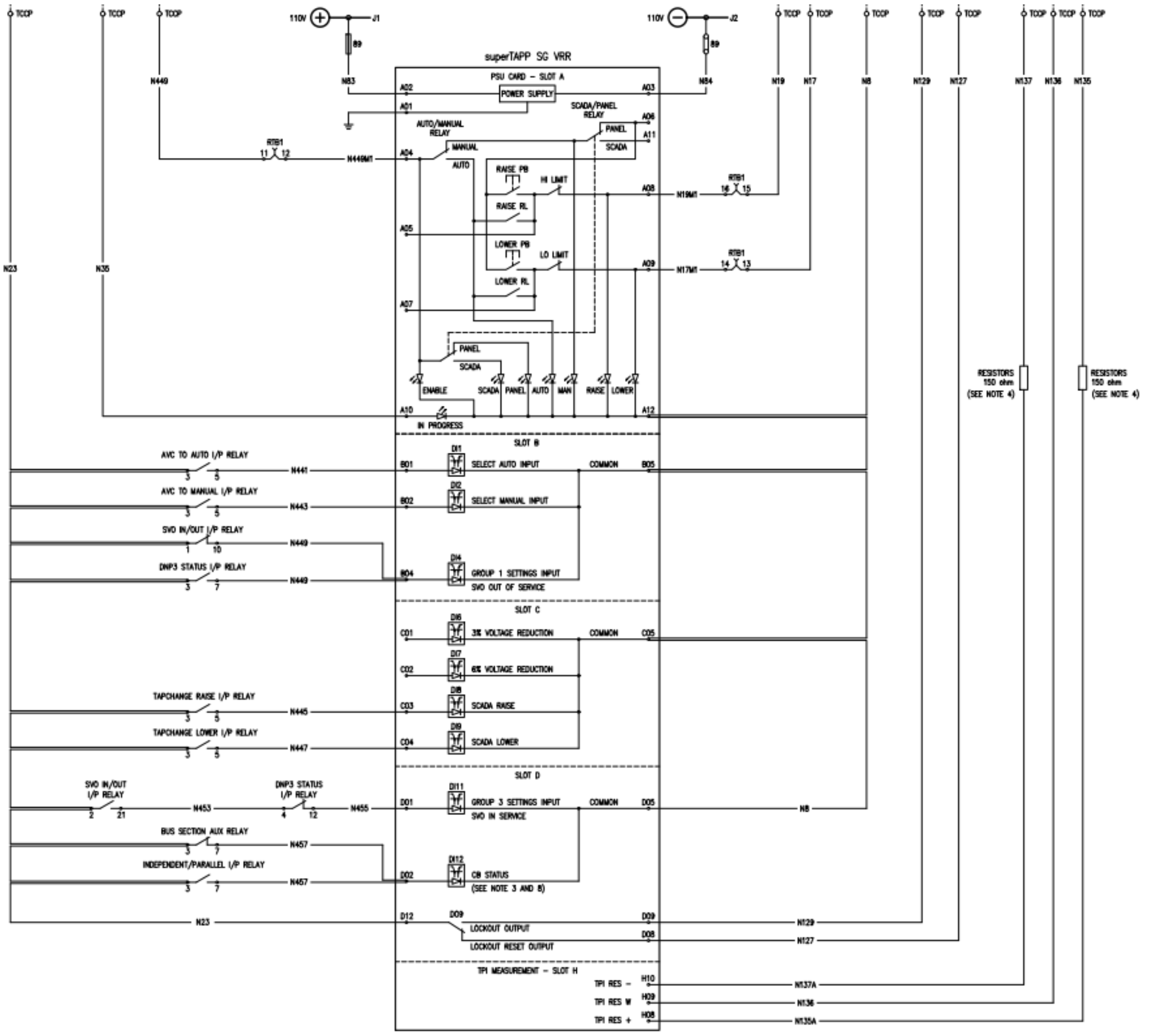


Figure 2-15: SuperTAPP SG Wiring Schematic

2.2.4 MicroTAPP SVO Modifications

The SVO control logic for the MicroTAPP relay was inherently more complex due to the requirement for a hardwire control scheme to control settings groups. Each setting group is selected via a control signal from the substation RTU operating an auxiliary control relay. Due to the limitation of the SCADA system only being able to issue a single control at a time, a logic scheme was developed so that selecting one setting group would automatically deselect all other groups. The control selection schematic is shown in Figure 2-16.

At the interface point with the relay, an auxiliary relay was inserted into the existing control wiring to provide a repeat of the independent operation signal. This would then select the appropriate group of settings to ensure the relay remains in the correct operation mode while switching between settings. The schematic diagram of the SVO control logic for the relay is shown in Figure 2-17.

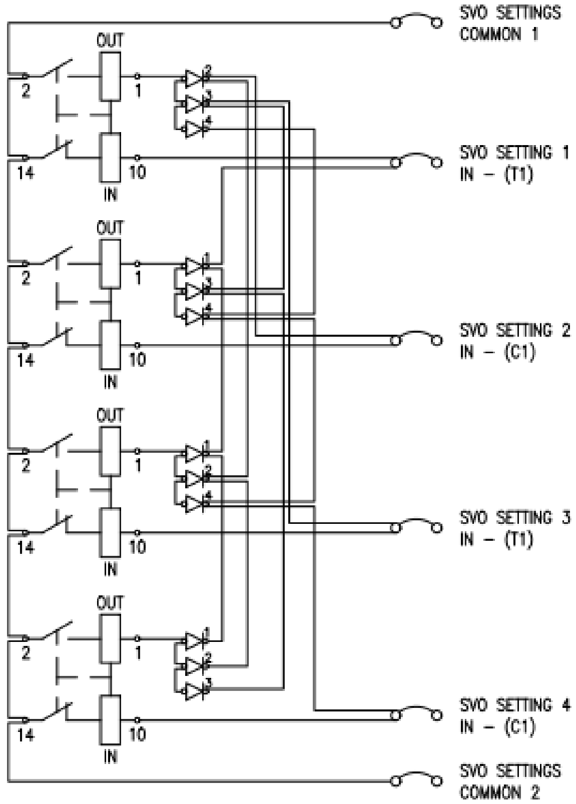


Figure 2-16: MicroTAPP SCADA Control Interface

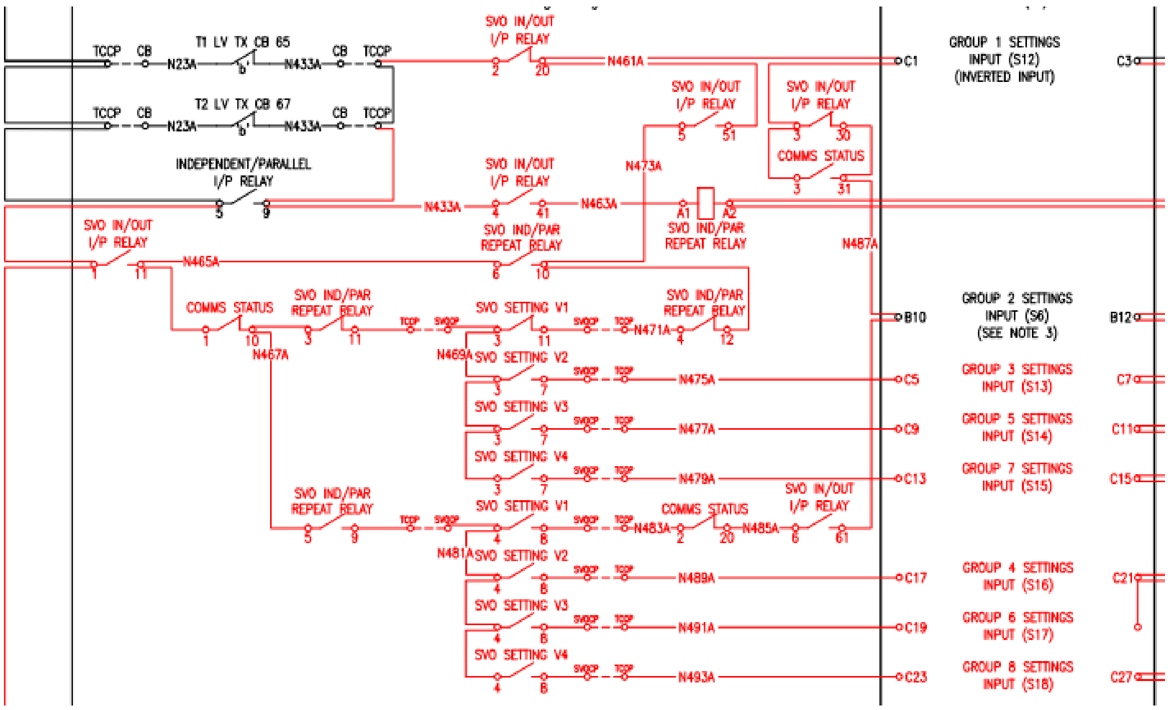


Figure 2-17: MircoTAPP Relay Interface Logic

2.2.5 Selected Substations

Following on from the findings in SDRC2 it was determined that three substations utilising the MicroTAPP relay would be modified to enable SVO via group setting changes and the remaining 13 substations would change the existing AVC relays to the SuperTAPP SG for set point control. A List of substations selected is shown in Table 2-1 below.

Table 2-1: List of Selected BSP's and Primary Substations

Bulk Supply Point	Primary Substation
Bowhays Cross	Colley Lane (MicroTAPP)
Bridgwater	Dunkeswell
Exeter City	Lydeard St Lawrence (MicroTAPP)
Exeter Main	Marsh Green
Paignton	Millfield
Radstock	Nether Stowey
Taunton	Tiverton Moorhayes
Tiverton	Waterlake (MicroTAPP)

During the design stage, an operational issue occurred at Colley Lane substation, unrelated to project activities, meaning it was no longer viable to utilise the MicroTAPP relays. Therefore, the decision was made with WPD Engineering Design to install the SuperTAPP SG instead leaving only two MicroTAPP sites and 14 SuperTAPP SG sites.

2.2.6 Substation Design

Detailed design and installation reports for each substation are provided in Appendix A – Installation Reports. Detailed design work for each substation was undertaken from September 2016 through to January 2017. At the majority of the sites, due to the scale of upgrade, the number of connections and signals to the transformer and RTU increased significantly. The main design issues were the provision of a tap change in progress signal which required wiring modifications to the tap changer and the retrofit connection of tap changer lock out relays.

All substations currently have a GE D20 RTU installed and the connection of the SuperTAPP SG relay was the first device at these substations to utilise the DNP3 communications protocol. Programming work was required for the RTU to enable the pass through of controls from the SCADA system to the relays. The relay communication interface is RS485 which is not compatible with the RTU which uses RS232 connections for peripheral equipment. Therefore an approved convertor was used to interface the two systems..

2.2.7 Site Installation

Site installation works began in February 2017 and were completed in February 2018. A list of the substations and the energisation dates are shown in Table 2-2 below.

Table 2-2: SVO Substation Energisation Dates

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

All substation electrical installation and commissioning works were carried out by the internal Projects team. The selected substations are split between two internal operational areas with nine installations carried out by teams based on Taunton and seven by the team based in Exeter. The split meant that work could be undertaken at multiple substations at the same time reducing the impact on a single team. In each area, a project engineer was assigned to the project ensuring learning was easily shared and experience was not lost between installations.

Where possible all works associated with SVO were programmed to coincide with planned transformer outages for routine maintenance activities. This reduced required outage periods, minimising the amount of time with customers at risk due to the system operating abnormally.

2.2.8 Photographs of SVO hardware at BSPs and Primary substation

A selection of photographs of SVO hardware at a selection of BSP and Primary substations are shown in Figure 2-18 to Figure 2-22 below. Photographs of SVO hardware at each individual substation are provided in the Substation Installation Reports in Appendix A.

Figure 2-18: SuperTAPP SG Relay Install at Colley Lane Primary Substation


Figure 2-19: MicroTAPP SVO Control Panel Wiring at Waterlake Primary Substation

Figure 2-20: SuperTAPP SG Relay Install at Bridgwater BSP

Figure 2-21: SuperTAPP SG Relay Install at Bowhays Cross BSP

Figure 2-22: Rear of GT1 Panel Door at Bowhays Cross BSP

2.2.9 SuperTAPP SG Settings

To ensure that any changes made by SVO do not affect the default settings, an additional settings group was created on the SuperTAPP SG relay. This group is selected once SVO is enabled and initially has the same settings as the default. However with SVO enabled the target setting can be adjusted remotely with the relay returning to default once SVO is disabled.

Historically, AVC relays on the network are set up with two settings groups, one for parallel transformer operation and one for independent operation. To do this push buttons or SCADA controls are used to force relays into the different operating modes. The SuperTAPP SG relay is able to receive circuit breaker status information from the substation and working with other SG relays map out the substation topology using its internal logic. Due to this “smart” functionality of the SG, separate user defined settings groups are not required as per previous relays.

In order to maintain the current operation requirements in line with all other AVC relays a virtual busbar concept was developed. In practice the concept was a manipulation of the relay settings to create a common busbar that the relays connect to when operating in parallel mode as shown in Figure 2-23 below.

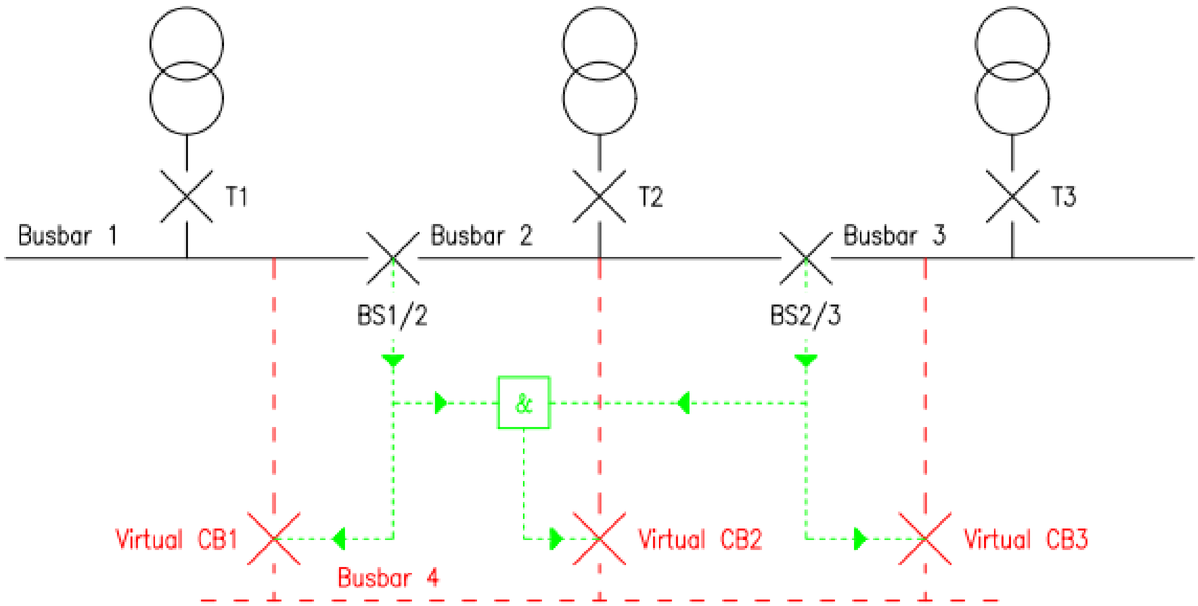


Figure 2-23: SuperTAPP SG Virtual Busbar Concept

2.2.10 MicroTAPP Settings

The MicroTAPP relay is able to have eight individual setting groups pre programmed for selection by the user via SCADA control. The relay requires separate settings groups for parallel and independent transformer operation; therefore only four setting options are available. Each target voltage is also given an allowable voltage bandwidth value that once the voltage tracks outside this value a tap change raise or lower command is given. This bandwidth is set at such a value that the voltage will be maintained within allowable limits while minimising the number of tap operations. The bandwidth must also be set to be greater than half the tap step percentage (typically 1.25% per tap) to prevent "hunting". This is where a tap operation changes the voltage from being outside the bandwidth limit in one direction to then being outside the limit in the other direction. This will cause successive taps in either direction until the voltage gets to such a value that following a tap the voltage falls within the allowable bandwidth. A standard setting for all AVC relays is ±1.5%.

Following an optioneering exercise it was determined to create settings 1.5% apart so that the lower and upper bandwidths for consecutive settings overlap as shown in Figure 2-24.

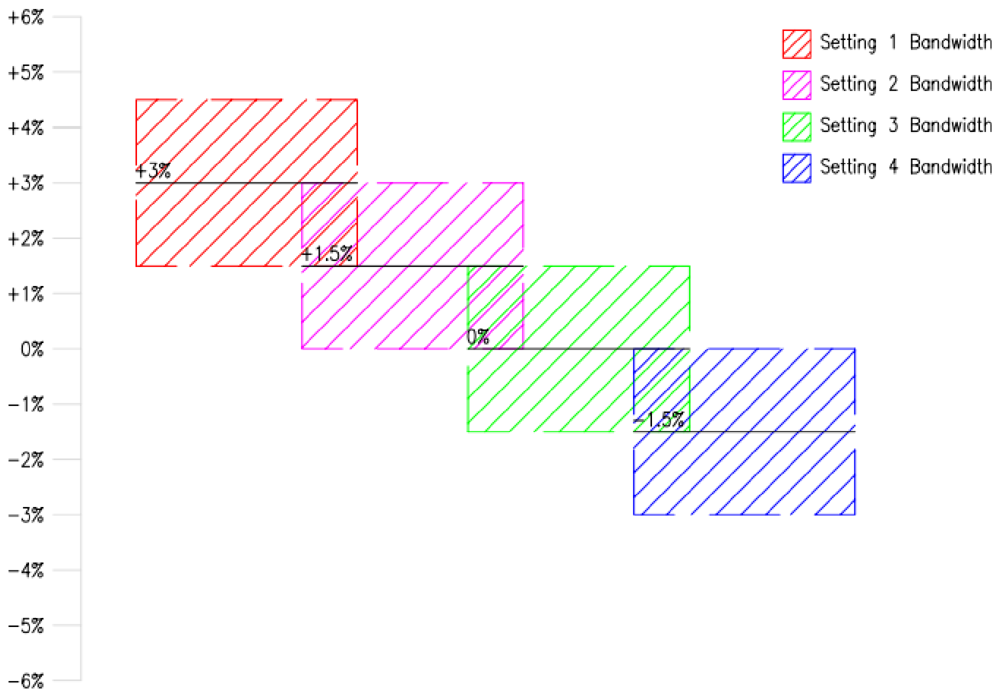


Figure 2-24: MicroTAPP Group Settings Overview

Although not site specific, the same setting methodology can be applied across all sites and fit around the existing relay settings. The settings provide a voltage range of +7.5% and in theory provide greater potential for all settings groups to be used. The two substations with the MicroTAPP relay installed both have the same existing settings therefore the settings in Table 2-3 were applied at both with the settings expressed as a percentage of nominal voltage.

Table 2-3: Proposed % Voltage Set points for SVO

	Setting 1 (Existing)	Setting 2	Setting 3	Setting 4
+1.50%	103.30%	104.80%	101.80%	101.30%
Proposed setting	101.80%	103.30%	100.30%	98.80%
-1.50%	100.30%	101.80%	98.80%	97.30%

2.2.11 Installation Lessons Learnt

During installation and subsequent operation of the relays several lessons were learnt and modifications required.

Tapchanger Lockout

The implementation of the tap change lockout control using digital outputs proved reliable through many installations. On specific defined errors the relay would issue a lockout and then reset by clearing the error. The built in lockout function was not preferred during design as the reset control was separate and not directly linked to the set.

However, one of the substations contains tap changers with separate control and operation circuits that run at different voltages. Other tap changers are wired in such a way that when a raise or lower operation is in progress the relay can sense the operation due to a high voltage being present on the appropriate terminal. In this case this was not possible due to the different interface wiring. Without this the relay was detecting an error in the tap change operation and was locking out.

In order to correct this, a wiring change was made to the relay to utilise the dedicated lockout function. This function runs with an alternative algorithm that is able to cope with not receiving the raise/lower sense and take more factors into consideration before issuing a lockout.

Relay software

To aid relay commissioning computer software was provide to interact with the relay and to allow the upload of settings files. During commissioning at one site, as the upload was taking place, the relay entered into a failure state and would not restart. The engineer was able to boot the relay into a safe mode but was unable get the relay working correctly. Following investigations it was discovered that the computer software version was not compatible with the relay operating software and in this instance had caused a corruption of relay. The latest software was installed on all laptops and relay and software versions locked to ensure compatibility.

Relay Auto Switching Safety Feature

A few weeks after installation, the relays at Colley Lane had unexpectedly changed their operating mode to This Panel/Manual and therefore were unable to be controlled remotely. Tests on site showed that this occurred when the AC control supplies were disrupted from the tapchanger. In discussion with Fundamentals they confirmed that this was planned behaviour due to safety concerns. A loss of control supplies to the relay is a cause of the tapchanger being manually switched into local mode. The relay was therefore programmed to believe that someone was at the tap changer and therefore changed to a safe mode.

However the same effect is caused by a temporary loss of power in the HV network. Previous relays have never had this behaviour and therefore rigorous and well understood procedures are in place for local switching. Working with Fundamentals, a firmware change was applied to the relays to disable this behaviour. Alongside this change further firmware changes were applied to improve the overall reliability of the relay, especially with the communications interface.

RTU Communications Fail

A couple of months after installation it was discovered by WPD Telecoms colleagues telecoms that roughly every 48 days a communications fail signal was being generated by the RTU, taking itself offline even if everything was healthy. Investigations concluded that a timing bug was present in the core RTU software requiring an update from the manufacturer. Due to the critical nature of the substations, the feature was disabled for operational safety at all SVO substations. A suitable fix has not been resolved at the time of writing this report, therefore procedures have been put in place to ensure that in a communications lost scenario the SVO system is manually disabled on site. Once communications have stabilised the system will then be switched on remotely.

Colley Lane Relay Failure

On the 1st March 2018, one of the SuperTAPP SG relays failed entering into an infinite loop attempting to reboot. The transformer remained operational throughout the failure but was placed onto a fixed tap. The relay was replaced with an available spare and the transformer returned to automatic control.

Investigations by Fundamentals discovered that the issue was caused by a memory overload of the built in storage. On reboot of the relay the memory would fail to respond causing the sequence of constant reboots. This bug was previously identified and corrected via firmware update that was yet to be applied at the site. All relays were updated on site with the latest firmware to prevent this issue arising again.

2.3 11kV Voltage Monitoring

To provide suitable feedback to the SVO system and to confirm accuracy of state estimated values measurement of voltages within the network was required. The 33kV network by its design contains measurement points at many points due to the prevalence of historic metering facilities at primary substations or through protection requirements. The 11kV in contrast only has voltage measurement capabilities at the primary substation with no measurements being made at distribution substations.

2.3.1 Monitor Design

Previous monitoring solutions developed, that are suitable for this application, were complete distribution RTU solutions with a capability far in excess of the project requirements. Working with Telecoms and the panel manufacturer, the existing design was modified to reduce capability to the level required. This reduced the unit cost to a suitable level while also ensuring that approved equipment was used minimising time required in the testing and approval process.

Two design options were developed depending on the connection type. For connection to the overhead network, a pole mounted voltage transformer was utilised to step the voltage down to 110V which was then connected directly to the monitoring equipment. For cable connected ground mount substations, connection to the 11kV network would not be possible without intrusive works. Therefore the monitor connected to the LV system at 240V. The HV voltage was then back calculated using the fixed winding ratio along with the live current measurement and transformer impedance to account for losses. For simplicity, this calculation was carried out within the NMS as data is received.

A new data symbol was developed in the NMS to show the connection of monitoring equipment and also display measurement data. This is shown in Figure 2-25 below.

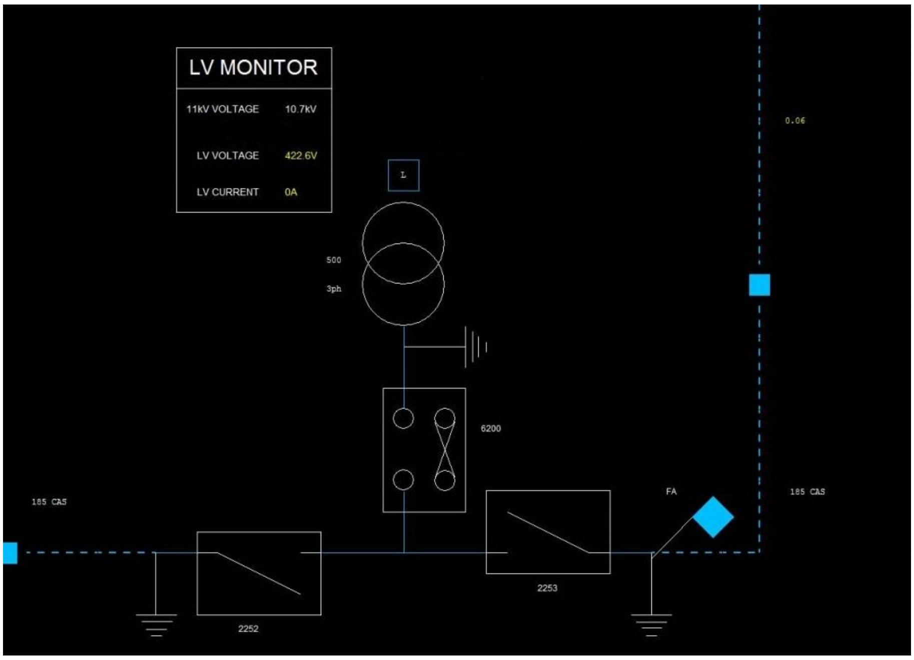


Figure 2-25: LV Monitor Symbol in NMS

Bench testing was carried out on the panel to confirm correct operation and to ensure the chosen radio communicated with the RTU. Testing was also carried out with the RTU to determine suitable analogue bandwidth settings to balance clarity of measurement with the capacity of the communications network to ensure stability and reliability.

2.3.2 Location Selection

The most critical voltages to monitor are at the remote ends of the 11kV network where voltages will be at their lowest. For all eight primary substations, network traces were carried out to identify the last distribution substation, either ground or pole mounted, on each feeder. In some cases where a feeder splits more than one remote end was found on a single feeder. For connections to the overhead network, further checks using GIS were carried out to identify suitable poles with no other equipment attached near the proposed location. A total of 35 monitoring points across all eight substations were identified.

2.3.3 Communications Network

At this current moment in time in the project area there is minimal communications infrastructure associated with SCADA functions for the 11kV network. In order to get any measurements back to the NMS and SP5 a new radio network was required. It was decided to utilise un-licenced radio frequencies as the data being transmitted was not critical for operational purposes and there is currently a shortage of licensed spectrum allocated to DNOs by OFCOM.

The network would work by installing a central receiver at an existing substation containing a station RTU. This would act as a centre point with the network radiating out to each monitoring point. If a connection could not be made directly due to distance or the landscape, additional repeater stations were installed to increase the networks range. The design of the system meant the connection was not necessarily to the same substation as the electrical connection.

Desktop and site surveys were carried out by SURF telecoms to determine how each location would be connected to the communication network and how many and where repeater stations would be installed. Two of the selected locations were unable to get a connection without multiple repeater stations due to being located in the bottom of a natural bowl in the landscape.

2.3.4 Installation

The first installation of the prototype panel was carried out at Lilac Road Distribution Substation on 12th December 2017. Further installations have been carried out following successful operation of the prototype device at the remaining ground mount distribution substations, with installation at all other locations currently in progress at the time of writing this report.

2.4 System Acceptance Testing

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

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

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

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

After the initial tests verified the successful interaction between NMS and SP5 and the correct operation of the various SP5 modules, the end-to-end tests followed. During the end-to-end tests, manually entered set points were first sent from SP5 to each of the two sites that were tested. Figure 2-26 shows the SP5 window that was used to manually send set points to Waterlake Primary. In order to ensure that the tests had no operational impact on the network, the relays at each site were switched to Manual mode which prevented them from issuing any controls to the OLTCs on site. The successful application of analogue set points and group settings was proved in these first tests.

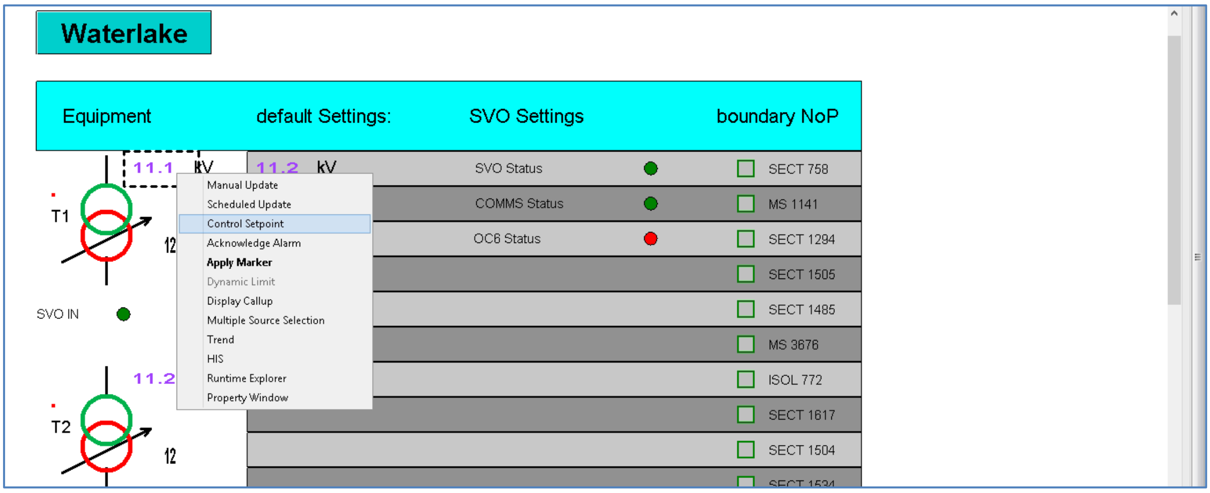


Figure 2-26 Manual Sending of Set Points through SP5

The final tests involved SVO being enabled at the two sites, performing a state estimation and sending target voltage set points. Figure 2-27 shows a screenshot from the NMS when SVO was enabled at Paignton BSP as part of the SAT, with all SVO indications shown as “IN”.

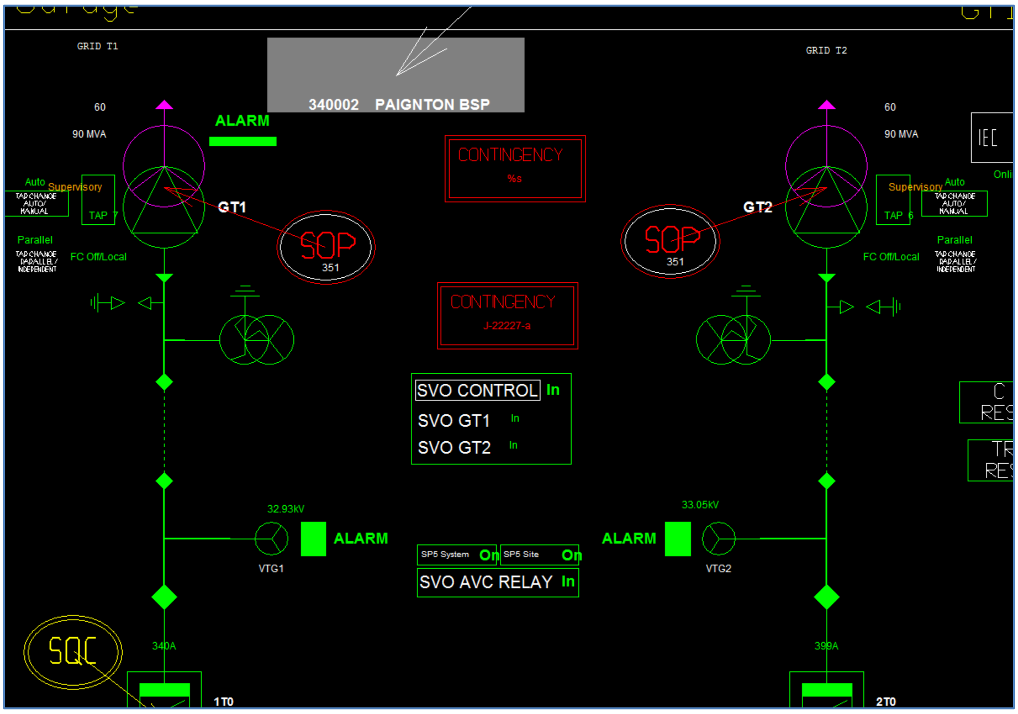


Figure 2-27 SVO Enabled at Paignton BSP in SAT

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

2.5 SVO Live Operation

The commissioning of all 14 remaining SVO substations followed after the completion of the SAT.

Incorporating the learning obtained from the SAT, the commissioning procedures followed included the following tests:

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

With the completion of the commissioning, SVO was enabled at all sites.

The operation of the system is being closely monitored and procedures have been put in place to analyse its performance.

One of the most valuable learning points from the trials so far is that it is possible to adjust the target voltage at BSPs and Primaries in real-time. This was proved from the operation of SVO which was frequently changing the target voltages both at BSPs and Primaries, often making significant changes in the value of the target voltage setting. In fact, the optimal target voltage setting varied and depended on the real-time operating conditions. Detailed results are provided in Section 5.

3 SVO Policies

3.1 Overview

Developing new procedures and specifications is a critical part of connecting new technologies to the distribution network. WPD have two types of document for each of the main components installed on the network:

- Engineering Equipment Specification (EE Specification) – This type of document details the information that would be sent to potential suppliers of equipment. The document includes information on the functional, design, construction and testing requirements of equipment.
- Standard Technique (ST) – This type of document details the procedures associated with equipment. The documents generally cover aspects including the integration of equipment into the network and how to safely operate, control, inspect and maintain equipment.

For Network Equilibrium a suite of new policies were developed to assist engineers with the connection and on-going operation of SVO. The following section provides an overview of each of the policies developed.

3.2 Operation and Control of System Voltage Optimisation – Standard Technique ST:OC1AB

The SVO Operation and Control Policy was created with close cooperation with WPD Control Engineers and includes all information required to operate SVO from the NMS. Among others, it explains the basic operation of the system, how to enable and disable SVO at each site and what actions need to be taken for each SP5 alarm that is received in the NMS. The policy was issued and all Control staff had been trained on the procedures before the first SVO sites were commissioned, ensuring that all operators are able to safely operate the technology prior to enabling the system. This policy document is available for other DNOs upon request.

3.3 System Voltage Optimisation Technology for use on the 33kV and 11kV Network – Engineering Equipment Specification

As part of the project, significant knowledge has been gained on the various elements of the SVO technology and their required performance. This knowledge has been captured in the Policy Document "System Voltage Optimisation Technology for use on the 33kV and 11kV Network – Engineering Equipment Specification" which provides the detailed specification of the SVO technology. This policy document is available for other DNOs upon request.

3.4 Application and Connection of the System Voltage Optimisation technology for the Network Equilibrium project

The SVO Applications and Connections Policy includes the requirements for the application and connection of SVO in 33kV and 11kV networks. It demonstrates all considerations that need to be taken into account when implementing SVO and the required works that need to be completed. This document is available for other DNOs upon request.

4 Key Learning

The SVO trials have provided valuable learning in the operation of the technology.

For example, during the trials, the dependency of the technology on the configuration of the existing network equipment was appreciated. More specifically, it was observed that one of the Primaries fed by Paignton BSP was not tapping as regularly as the other Primaries due to its settings, which meant that it could not respond to all changes in the 33kV voltage that was being adjusted by SVO. It was therefore limiting the impact SVO could have in the Paignton network. From this, it was learned that it is important to check the AVC relay settings and more specifically the bandwidths of all Primaries in an SVO controlled 33kV network, to ensure they can respond to 33kV voltage changes as required.

Additionally, knowledge has been gained on the way the state of the network circuit breakers is communicated to the NMS and how it changes values in different operating conditions. It was expected that circuit breakers would have a “Closed” state when they are closed and fully connected to the network, an “Open” state when the contact of the circuit breaker is open and a Don’t Believe It (DBI) state when the contacts of the circuit breaker are neither in the fully open or fully closed position. The DBI state usually happens during unsuccessful switching operations. However, while SVO was running at Waterlake Primary, the circuit breaker of the second 33/11kV transformer (T2) at Waterlake went into a DBI state as shown by the question mark on its symbol in Figure 4-1. This automatically disabled SVO and after investigation it was found that the circuit breaker was isolated on site. Therefore, it was learned that when circuit breakers are isolated, they could be reporting DBI states back to the NMS, interrupting the SVO operation. The project team is working on resolving this issue at the time of writing this report, by trying to find ways of changing the reporting of switches that are isolated.

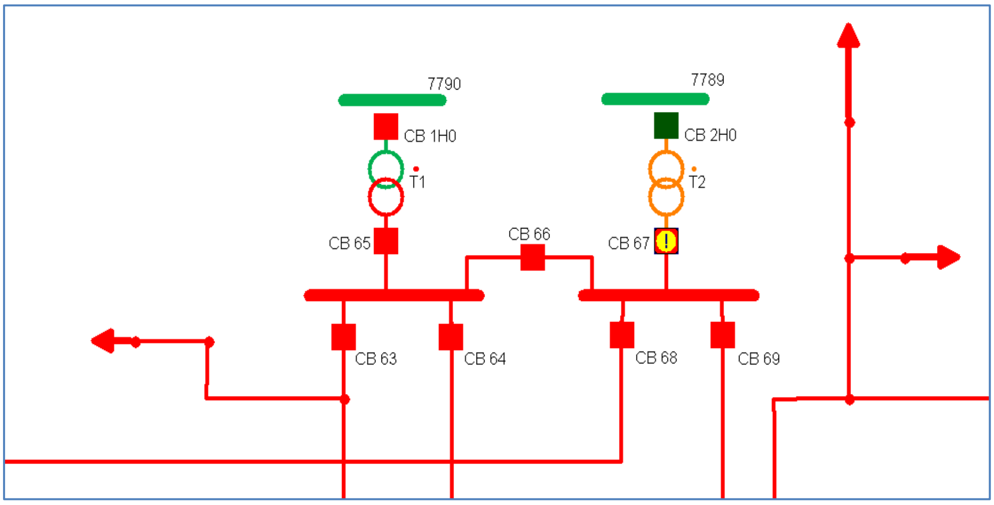


Figure 4-1 Waterlake CB 67 in DBI state

One of the most valuable learning points from the trials so far is that it is possible to adjust the target voltage at BSPs and Primaries in real-time. This was proved from the operation of SVO which was frequently changing the target voltages both at BSPs and Primaries, often making significant changes in the value of the target voltage setting. Additionally, it was shown that the optimal target voltage setting varies and depends on the real-time operating conditions. Detailed results are provided in Section 5.

5 Performance and capacity released by the SVO method

5.1 Performance of the SVO method

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

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

For example, the target voltage set points at Paignton BSP between 03/04/2018 and 06/04/2018 are demonstrated in Figure 5-1. Paignton BSP has two 132/33kV Grid Transformers and SVO has been sending optimised target voltage set points to the AVC relays controlling the voltage at each of these two transformers. SVO has been enabled only during the daytime during the period shown.

Traditionally, the target voltage at both AVC relays at Paignton BSP was statically set to 1 per unit (or 33 kV), which means that the AVC relays were regulating the voltage to keep it as close as possible to 33kV at all times. For reference and comparison, this is shown with the black line.

During the period shown in the figure, SVO has been amending this target voltage and the set points applied are shown with the blue (Grid Transformer 1) and orange (Grid Transformer 2) lines. The figure shows that for the majority of the time the target voltage was different to the traditional static target value of 1 per unit, verifying the capability of amending the previously static target voltage dynamically, based on the network operating conditions.

Additionally, for the majority of the time that SVO was enabled it can be seen that the target voltage was set to values lower than the traditional setting of 1 per unit which verifies that optimally, the target voltage should be set lower than what it has been set in Business As Usual operation. Enabling the reduction of the voltages in the network could allow generation, that would otherwise be constrained by high network voltages, to connect to the network.

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

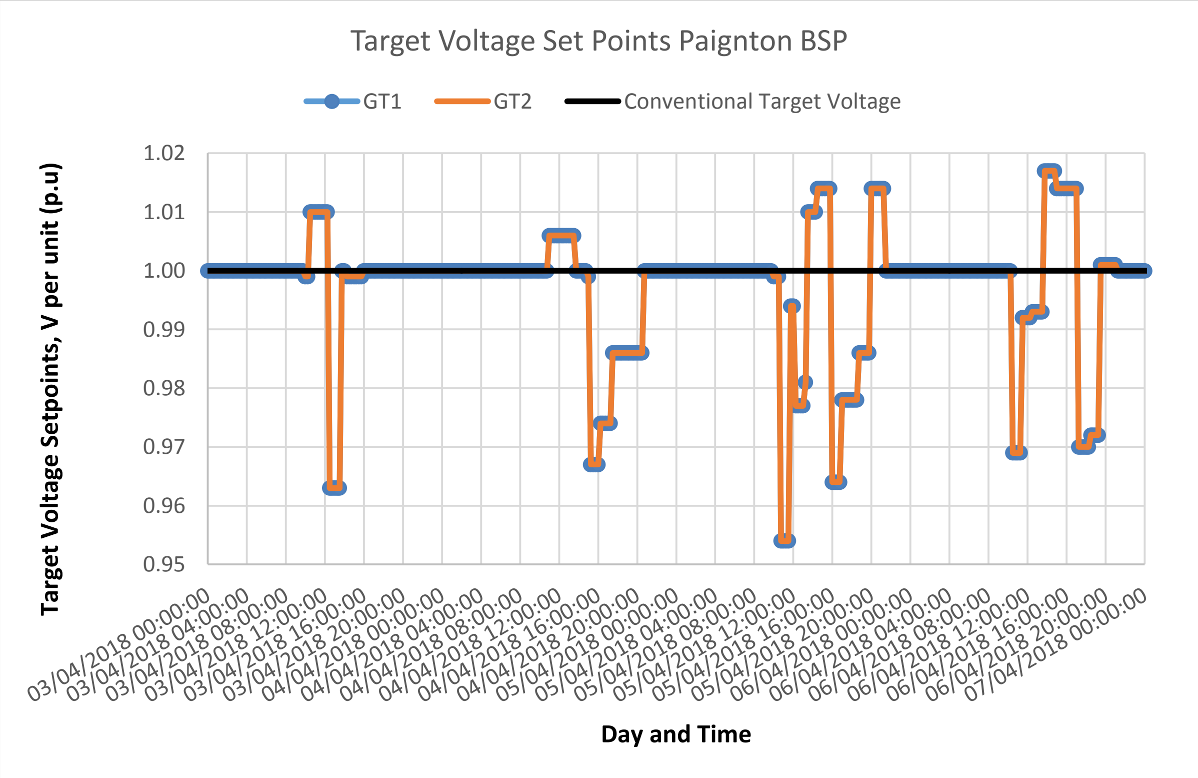


Figure 5-1 Paignton SVO set points

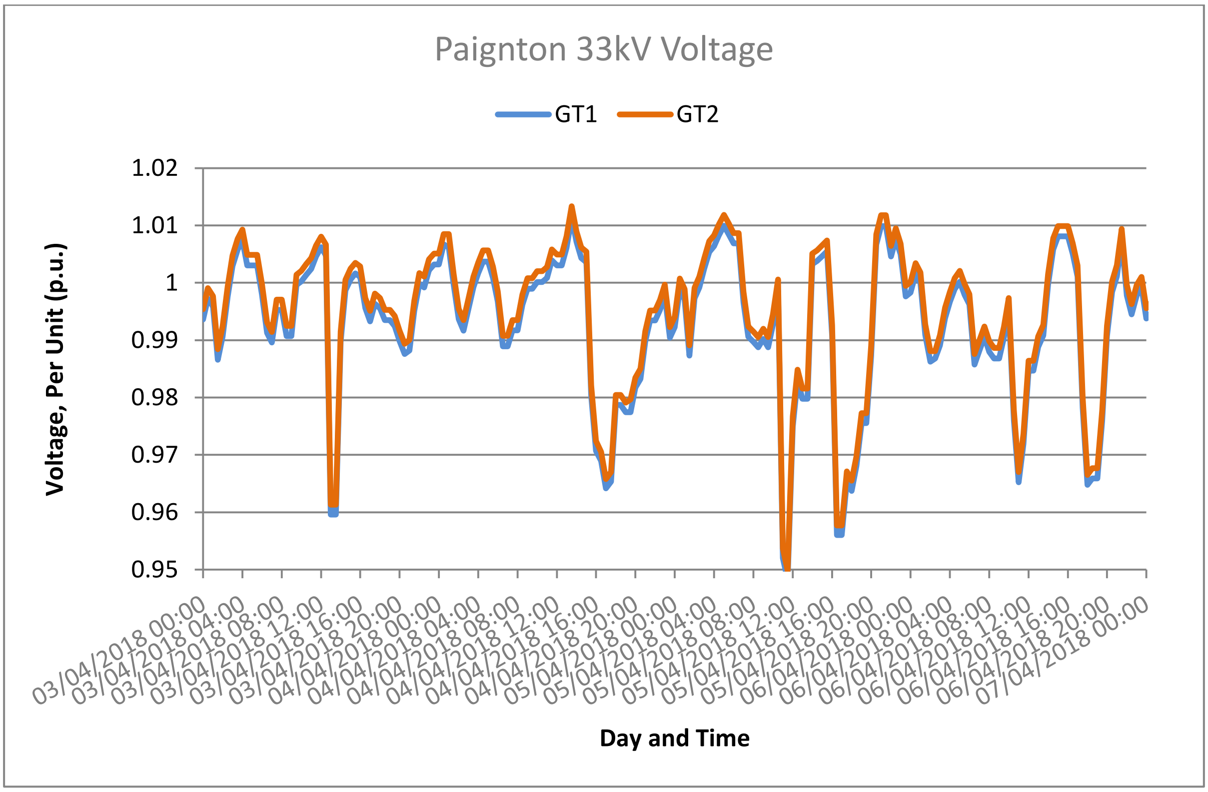


Figure 5-2 Paignton 33kV Voltage

The example of the operation of SVO at a different substation is shown in Figure 5-3. This figure demonstrates how the target voltage at Waterlake Primary substation varied between 03/04/2018 and 06/04/2018 when SVO was enabled during the daytime.

Waterlake Primary has two 33/11kV transformers and traditionally, the target voltage at both AVC relays at this substation was statically set to 1.018 per unit (or 11.2 kV), which means that the AVC relays were regulating the voltage to keep it as close as possible to 11.2 kV at all times. For reference and comparison, this is shown with the black line.

During the period shown in the figure, SVO has been amending this target voltage and the set points applied are shown with the blue (Transformer 1) and orange (Transformer 2) lines. The figure shows that at certain times SVO has amended the target voltage to values different than the static setting of 1.018 per unit and all amendments made were to reduce the target voltage.

Additionally, it can be seen that different set points were applied at each of the two Transformers at certain occasions. This is because the transformers at Waterlake Primary are not electrically connected together as the bus section switch is open and they feed different network feeders. Therefore, the optimised target voltage at each transformer can be different as they feed different networks. The transformers at Paignton BSP, however, are electrically connected together (bus section switch is closed) and they need to have the same target voltage to avoid circulating current issues.

Looking at how the voltage varies at each of the two Waterlake transformers in Figure 5-4, a different behaviour is observed compared to the variation of voltage at Paignton BSP. Even though in the example of Paignton BSP, the voltage at each transformer matched the optimised target voltages, this was not the case at Waterlake Primary. This is because Waterlake Primary operates with settings group control (MicroTAPP relays) while Paignton BSP can receive analogue set points (SuperTAPP SG relays). Since Paignton BSP can receive and apply any value of target voltage set point, the voltage at the substation is very close to the optimised target voltage it received from SVO. However, due to the operation of the settings group control, inaccuracies are introduced which cause variations between optimised target voltage sent by SVO and voltage at site. Additionally, in Figure 5-4 it can be seen that there is no measurements for the voltage at T2 after the morning if the 5th of April 2018. This is because the local team were performing work at that part of the substation that day, which interrupted the transmission of the voltage measurements. During the time that the work was undertaken, the SVO operation was paused as explained in Section 4 and demonstrated in Figure 4-1. This is also verified by Figure 5-3, as it is shown that the target voltage set points at Waterlake Primary were set to the traditional static valued after the morning of 05.04.2018 until the afternoon of 06.04.2018 when the network was reverted back to normal operation and SVO started optimising again.

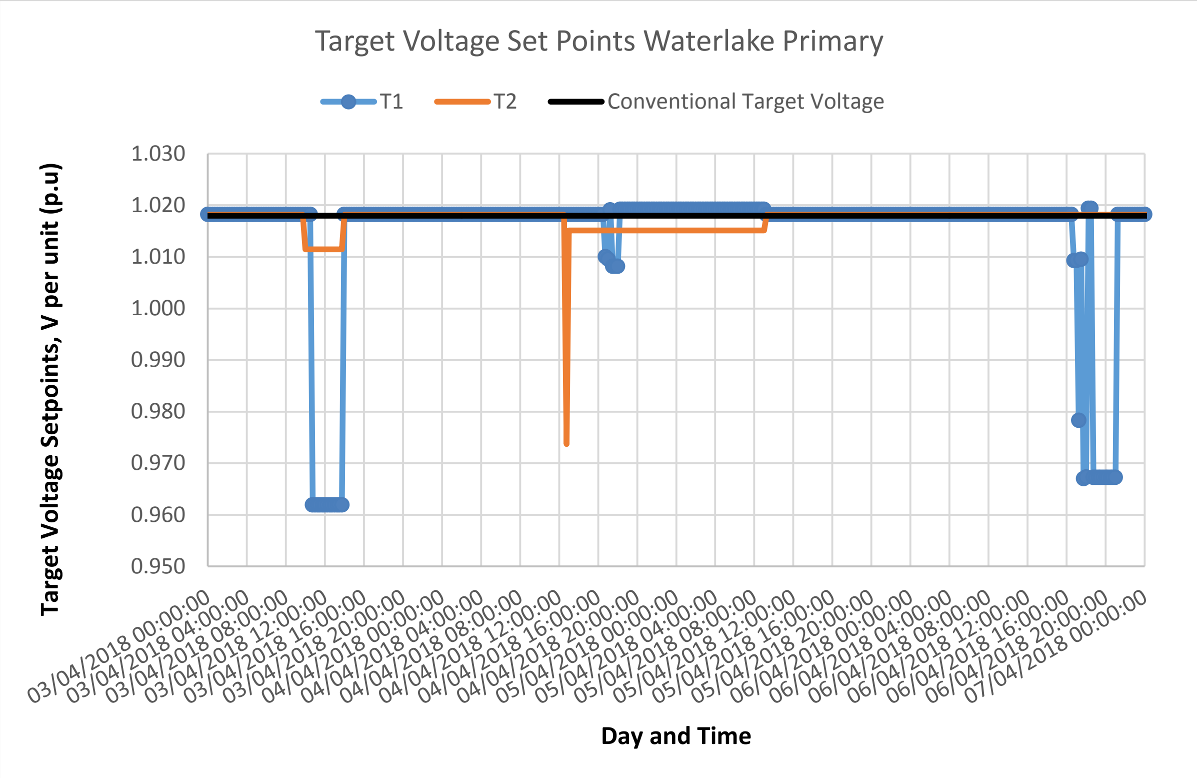


Figure 5-3 Waterlake SVO Set Points

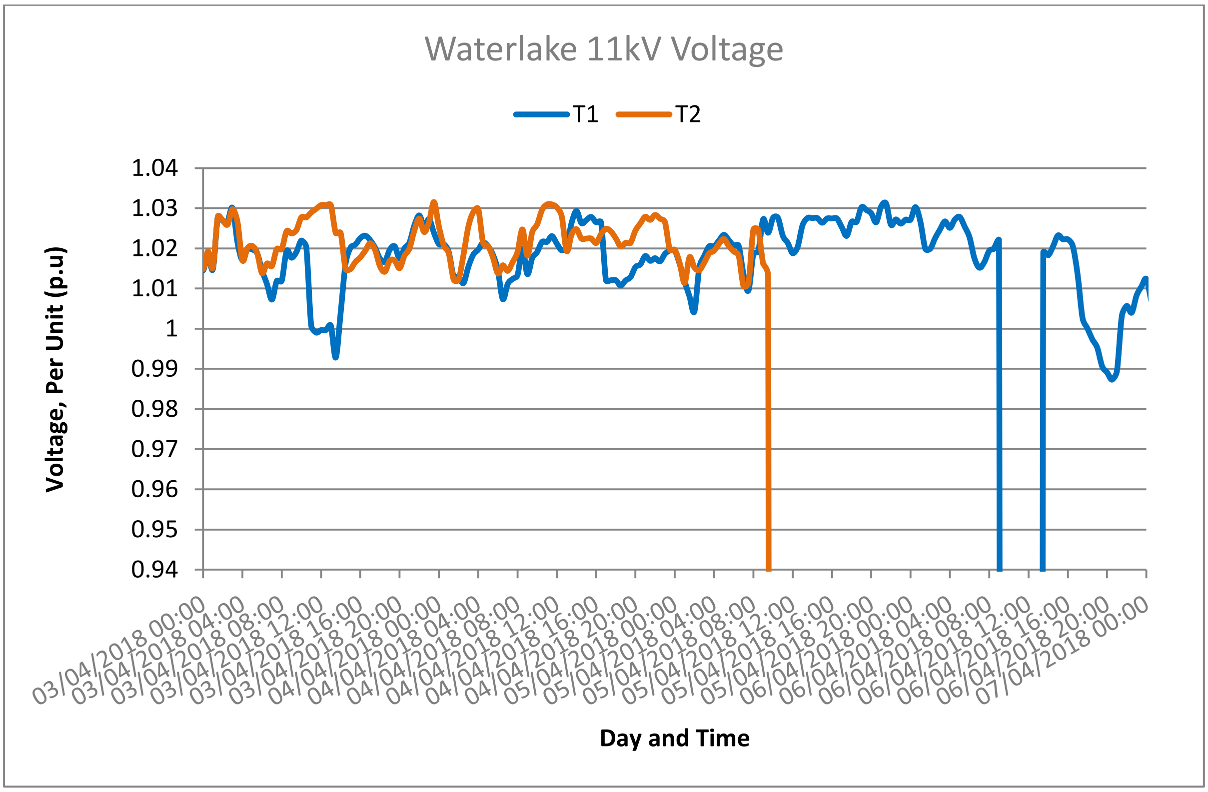


Figure 5-4 Waterlake 11kV Voltage

5.2 Capacity released by the SVO method

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

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

For example, the available network capacity in Exeter City BSP with SVO enabled (blue line) and without SVO (brown line) during a winter day is shown in Figure 5-5. The average capacity of the network without SVO enabled for the 24hr period is 224 MW of generation. With SVO enabled this average increases to 236 MW unlocking an additional 12 MW of generation capacity at this BSP.

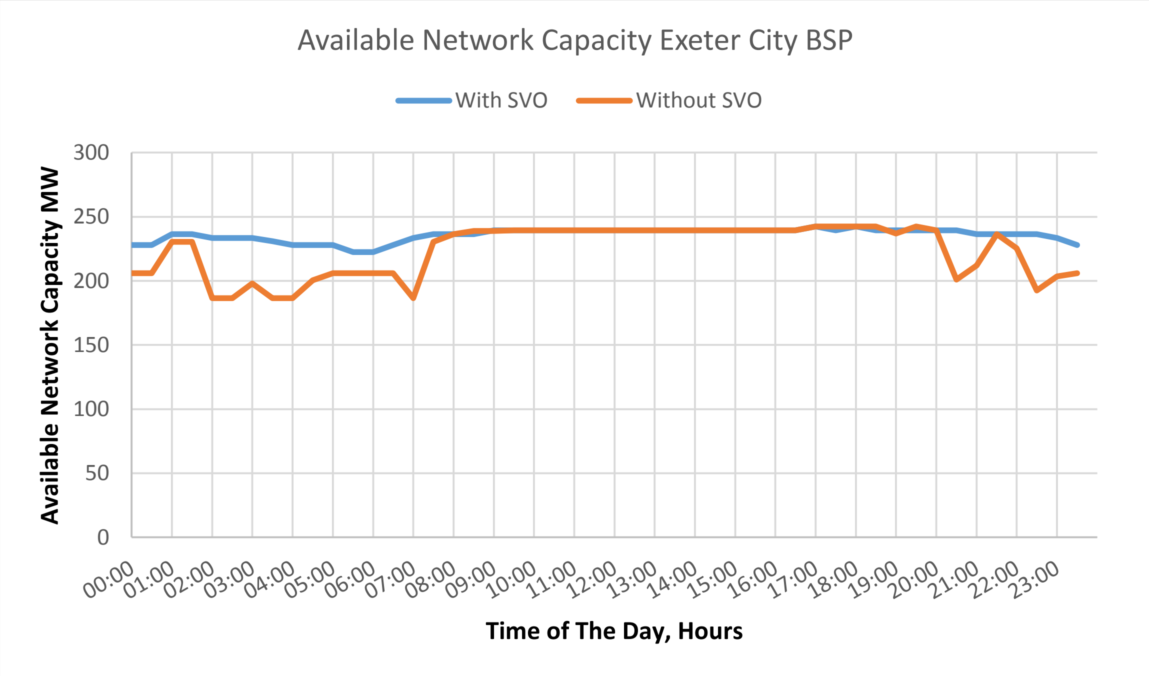


Figure 5-5 Available Network Capacity Exeter City BSP Winter Day

Figure 5-6 demonstrates the available network capacity in Nether Stowey Primary with and without SVO. The average capacity of the network without SVO enabled for the 24hr period is 10.1 MW of generation. With SVO enabled this average increases to 13.6 MW unlocking an additional 3.5 MW of generation capacity.

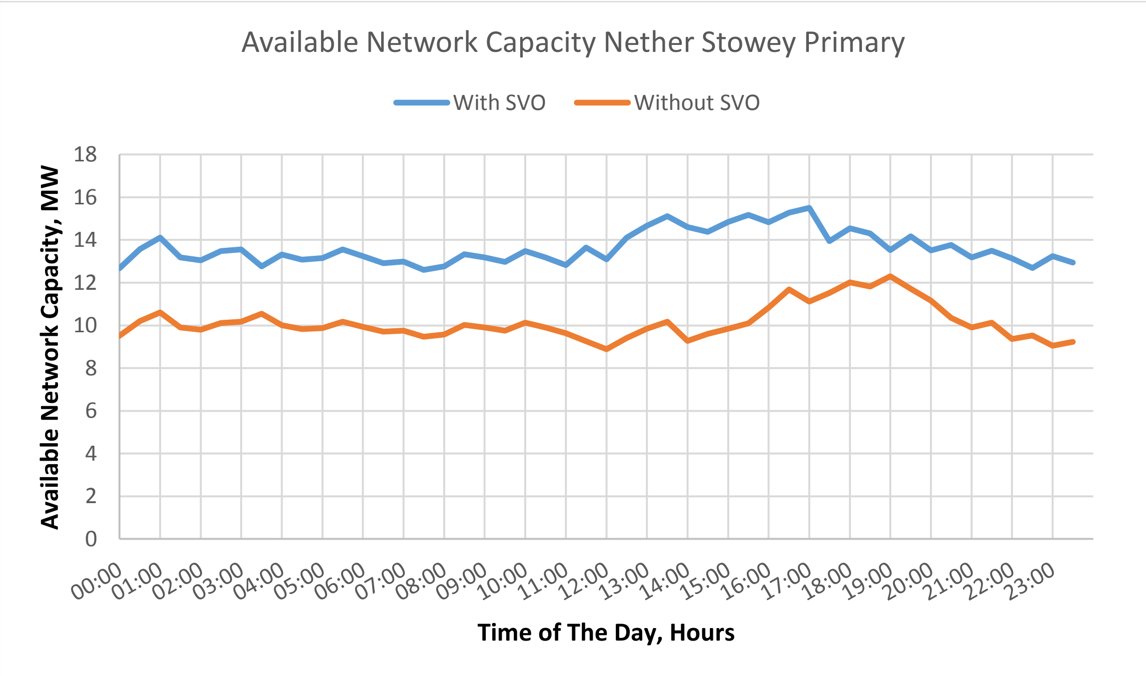


Figure 5-6 Available Network Capacity Nether Stowey Primary Winter Day

To gain an appreciation of the capacity benefits SVO can introduce over all eight BSPs, Figure 5-7 shows how the average network capacity over the 8 SVO BSPs varies in a winter day when SVO is enabled (blue line). As can be seen in the figure, the average existing network capacity (brown line) is lower than the capacity when SVO is enabled, showing that SVO overall provides additional network capacity at all times. By calculating the difference of the two capacities (with and without SVO), it is found that at least 20 MW of average capacity at each of the eight BSPs is released using SVO in winter, giving a total capacity release of 160 MW. This provides a capacity increase of 15%.

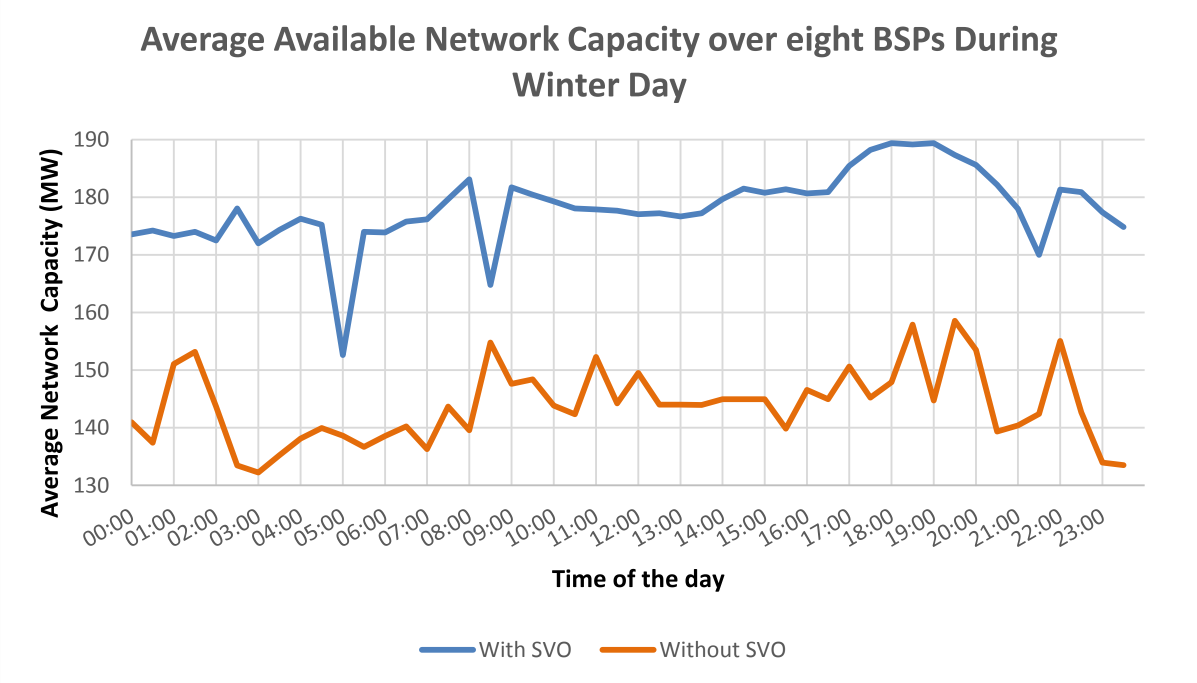


Figure 5-7 Winter Day Average Available Network Capacity over eight SVO BSPs – With and without SVO

Similarly, Figure 5-8 shows the average network capacity over the eight BSPs in a summer day, with and without SVO enabled. Again, SVO is shown to provide additional network capacity at all times. The minimum capacity release by SVO in summer is found to be 20 MW average at each BSP, releasing 160 MW in total and providing 15% increase in capacity.

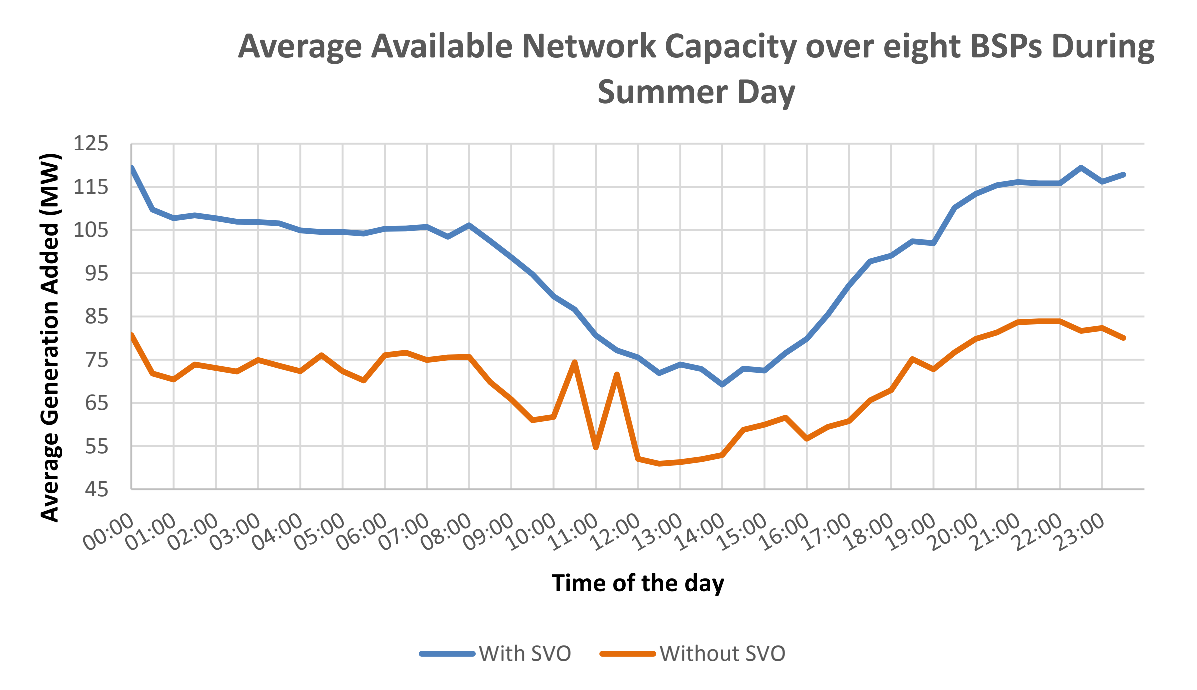


Figure 5-8 Summer Day Average Available Network Capacity over eight SVO BSPs – With and Without SVO

Figure 5-9 and Figure 5-10 demonstrate how the average network capacity over the eight SVO Primaries varies in a Winter Day and a Summer Day with and without SVO. By considering the difference between the two lines, it is calculated that with SVO enabled the average capacity over the eight Primaries increases by at least 9 MW in winter and 6 MW in summer. This provides a total capacity release of 72 MW (75% increase) in winter and 48 (60% increase) MW in the summer across the eight Primaries.

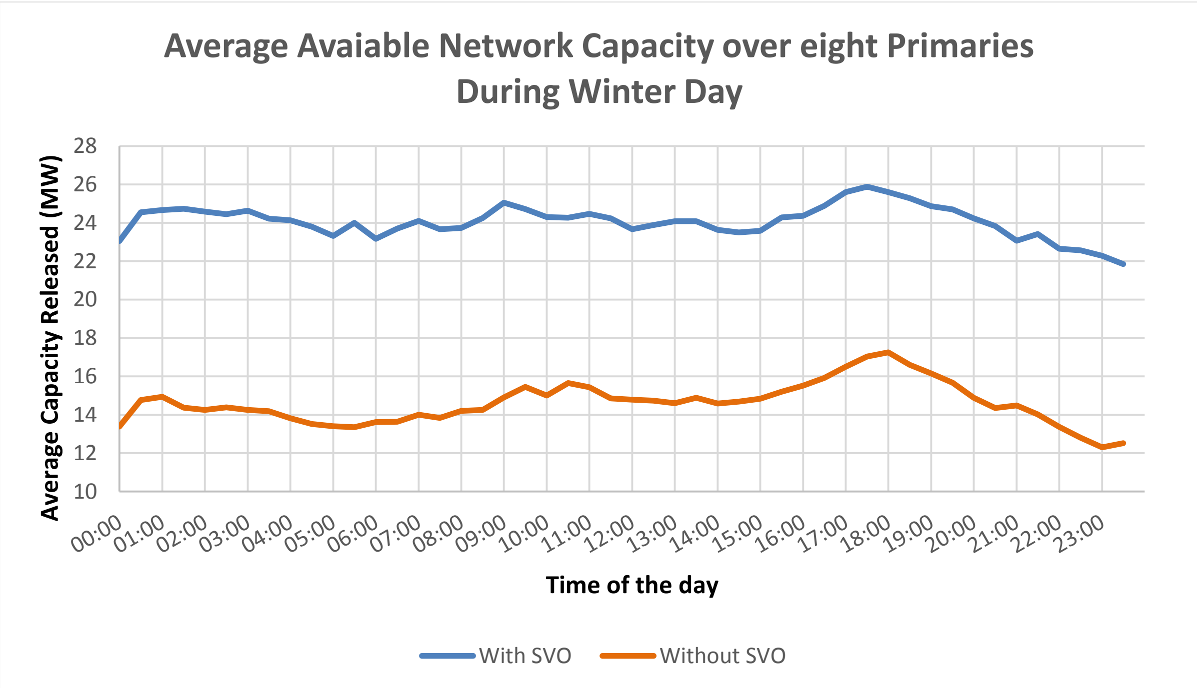


Figure 5-9 Winter Day Average Available Network Capacity over eight SVO Primaries – With and Without SVO

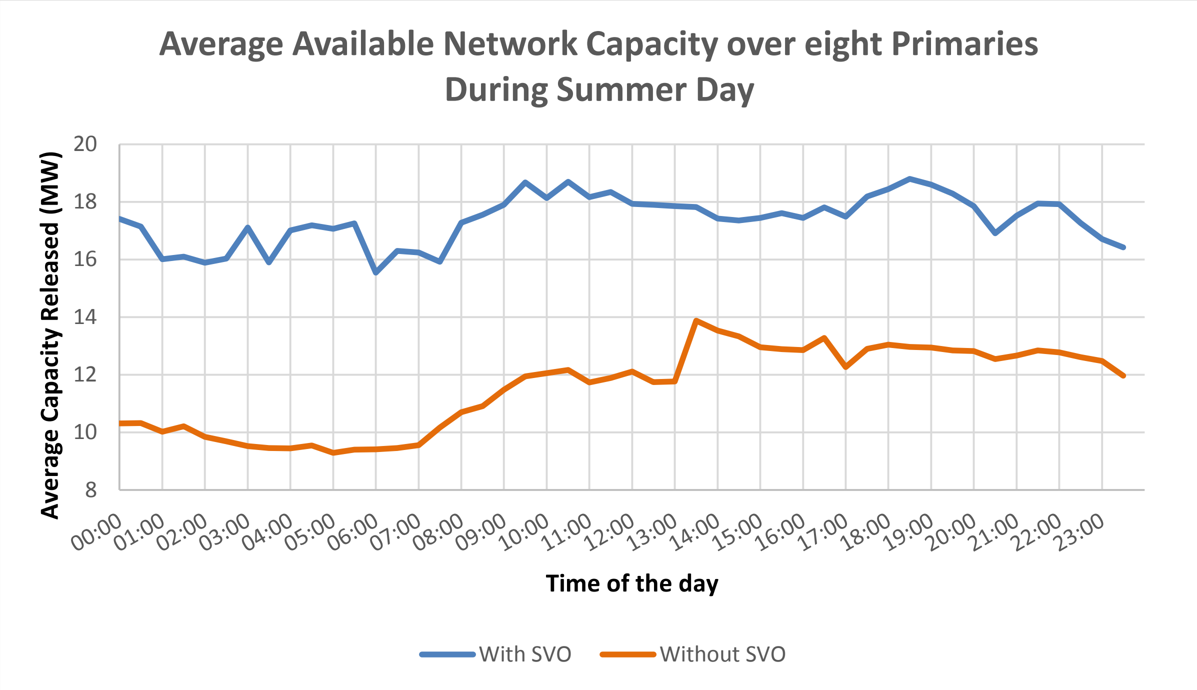


Figure 5-10 Summer Day Average Available Network Capacity over eight SVO Primaries – With and Without SVO

6 Next Steps

The performance of SVO will be closely monitored during the remaining period of the trials (until June 2019) and will be analysed in further detail. The outputs will be published in SDRC-7, Trialling and demonstrating the integration of the EVA, SVO and FPL Methods, and SDRC-8, Knowledge capture and dissemination, of Network Equilibrium.

The calculated set points at the different SVO sites will be investigated to identify any patterns in the set point value, time of day, season and type of substation. This will also be compared to the analysis performed in SDRC-2, to conclude whether the actual target voltage amendment agrees with the expected performance.

Additionally, the SVO set points that are calculated by the PSS/E plugins will be continuously compared to the actual set points applied by SP5 in order to refine the plugin operation and ensure it matches the real operation as much as possible.

The information collected from the remaining of the trials, will form the basis of the Cost Benefit Analysis (CBA) that will be presented in SDRC-7, Trialling and demonstrating the integration of the EVA, SVO and FPL Methods.

Glossary

Term	Definition
AVC	Automatic Voltage Control
BSP	Bulk Supply Point
CBA	Cost Benefit Analysis
CT	Current Transformer
DNO	Distribution Network Operator
DSSE	Distribution System State Estimator
ESQCRs	Electricity, Safety, Quality and Continuity Regulations
EVA	Enhanced Voltage Assessment
FPL	Flexible Power Link
GIS	Geographical Information System
HIS	Historic Information System
HV	High Voltage
ICCP	Inter-Control Centre Communications Protocol
IMM	Information Model Management
IP	Ingress Protection
kV	Kilo Volt
LCNF	Low Carbon Networks Fund
LCT	Low Carbon Technology
LV	Low Voltage
NMS	Network Management System
OLTC	On-Load Tap Changer
PSOS	Power System Observer Server
PSS/E	Power System Simulator for Engineering
RTS	Real-Time Server
RTU	Remote Terminal Unit
SCADA	Supervisory Control And Data Acquisition
SDRC	Successful Delivery Reward Criteria
SP5	Spectrum Power 5
SVO	System Voltage Optimisation
TCCP	Tap Change Control Panel

VT	Voltage Transformer
VVC	Volt-Var Control
WPD	Western Power Distribution

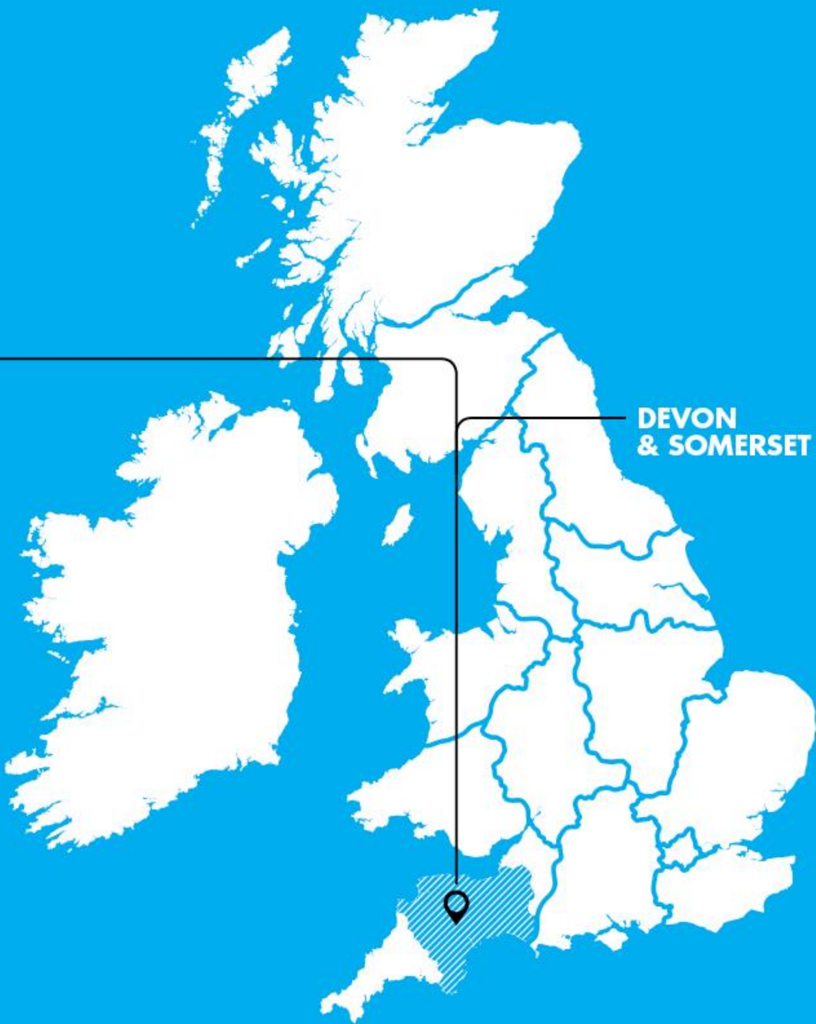
Appendices

Appendix A – Installation Reports

WESTERN POWER DISTRIBUTION

NETWORK EQUILIBRIUM

BALANCING GENERATION AND DEMAND



SVO Installation Report

Bowhays Cross BSP

LCN Fund
Low Carbon Networks

7 Site Overview

Bowhays Cross 132/33kV substation consists of two 40/60 MVA transformers and is normally fed via two 132kV circuits from Taunton GSP. The substation was originally constructed in the mid 1970's with both transformers and associated relays replaced in 2006. Bowhays Cross BSP supplies five primary substations with around 48,000 customers and currently has a single 6 MW solar PV generator connected.

8 Design

Each transformer has a dedicated Tap Change Control Panels (TCCP) at Bowhays Cross BSP with both situated next to the transformer protection panels. The panels themselves are front entry with a solid plate door. It would have been possible to install a new panel at the substation; however the decision was made to replace both panel doors as they were large enough to accommodate all the required relays, effectively being a brand new panel.

9 Installation and Commissioning

Installation of the SVO scheme began on the 9th October 2017 and finished on the 20th October 2017 with each transformer out of service for one week. The tap changer at Bowhays Cross was unique among all other SVO substations in that the tap change control and drive systems operated at different voltages. The tap raise and lower connections to the relay are designed such that they sense the operation of the tap changer in a certain direction through receiving a high signal on the respective output terminal. With the separate control system this was not the case. It was discovered that without the tap sense, a lockout would be triggered for tap run away as the relay would see the tap changer operating but not know the direction of travel.

The relay has a built in tap change lockout function using a dedicated contact. During discussions with WPD policy, it was determined that without a dedicated lockout reset electrically connected to the set contact, this function would not be used. Therefore the decision was made to use a programmable binary output to provide the lockout functionality. The control algorithms for the dedicated lockout are more advanced in that they look at more inputs and feedback to the relay before issuing a lockout. The binary output was driven by individual alarms covering separate functions, with a single issue causing a lockout. During commissioning wiring modifications were carried out to use the dedicated lockout function but maintain use of the binary output to reset.

During commissioning, computer software was provided to simplify the management of settings on the relay. The relay firmware and software are under constant development and unfortunately in this case the software being used was not fully compatible with the firmware on the relay. This incompatibility caused a memory issue within the relay leading to corruption of the device. In order to correct this, the relay was swapped on site for another and sent back to the manufacturer for refurbishment. Checks were also put in place to ensure that relay firmware and laptop software are properly maintained to ensure compatibility.

10 Photos

Figure 10-1: GT1 and GT2 SuperTAPP SG Installation

Figure 10-2: Rear of TCCP Door

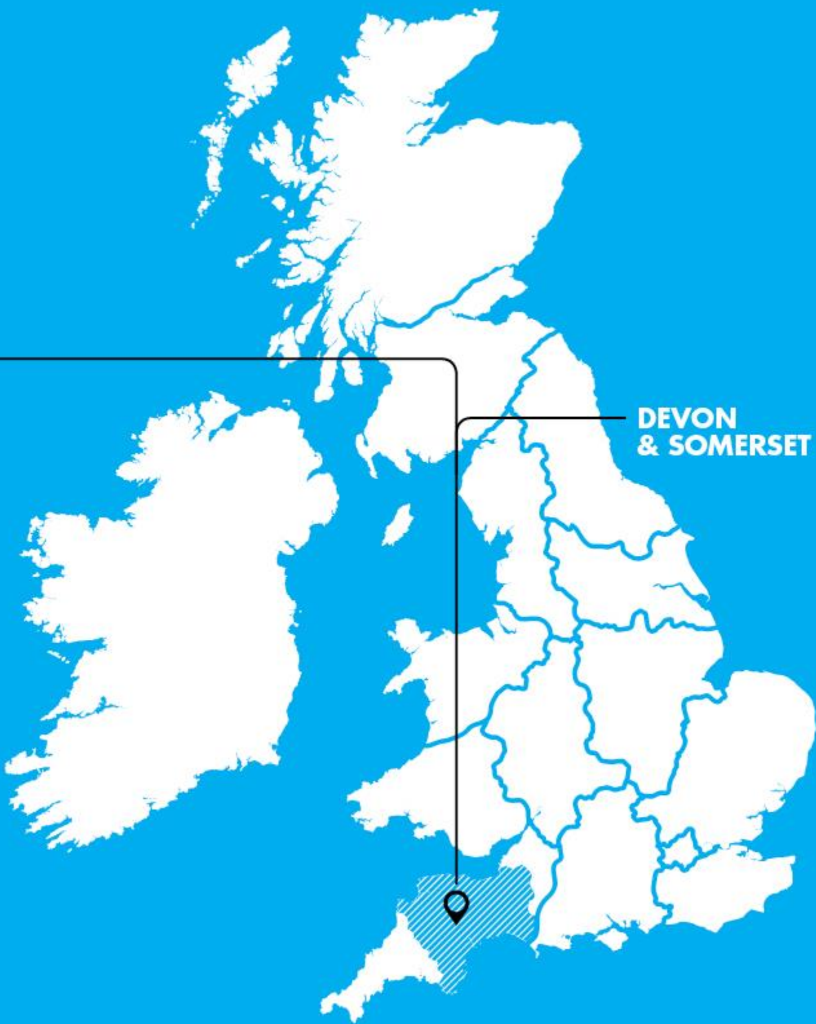
Figure 10-3: Detail of GT1 SuperTAPP SG Installation

Figure 10-4: Detail of GT2 SuperTAPP SG Installation

WESTERN POWER DISTRIBUTION

NETWORK EQUILIBRIUM

BALANCING GENERATION AND DEMAND



SVO Installation Report

Bridgwater BSP

LCN Fund
Low Carbon Networks

11 Site Overview

Bridgwater 132/33kV substation consists of one 40/60 MVA transformer and two 30/60 MVA transformers. The substation is normally fed via three 132kV circuits from Bridgwater Main GSP. The substation operates in parallel with the single transformer fed Street BSP.
The substation was originally constructed in the mid 1970's with two transformers and the 33kV switchboard upgraded in 2013. The AVC schemes for all three transformers were replaced as part of the capital works.

The Bridgwater and Street BSP group supplies 16 primary substations with around 47,000 customers. There is currently 81 MW of generation connected to the 33kV network consisting of 10 solar PV sites and two gas generators.

12 Design

The existing AVC schemes at Bridgwater BSP are split across two panels, with GT1 and GT2 in one and GT3 in the other. These are installed in the middle of a suit of transformer protection making a whole panel replacement unfeasible. The existing panels are rear entry with a 19 inch rack mountable front. The decision was therefore mode to construct new front sheets for the panel. All equipment was designed to be mounted on each front sheet removing the need for additional wiring or relays to be installed within the panel.

13 Installation and Commissioning

Installation of the SVO scheme began on the 1st May 2017 and finished on the 26th May 2017 with each transformer out of service for one week. Bridgwater was the second BSP to have SVO enabled relays installed and commissioned.

The existing transformers did not contain tap change lockout relays with these installed as part of the change of AVC relays. Following installation an issue was discovered where by when a lockout was triggered by the AVC relay it could then not be reset. On investigation it was discovered that the lockout relay had been installed on the wrong side of the supply transformer for the AVC scheme. Therefore a tap change lockout would cut supplies to the relay control interface.

14 Photos

Figure 14-1: GT1, GT2 and GT3 SuperTAPP SG Installation

Figure 14-2: GT1 Front Panel Rear

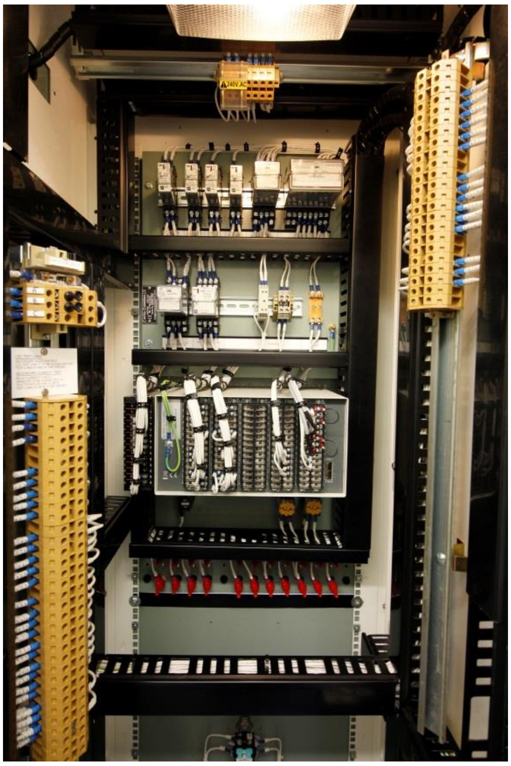
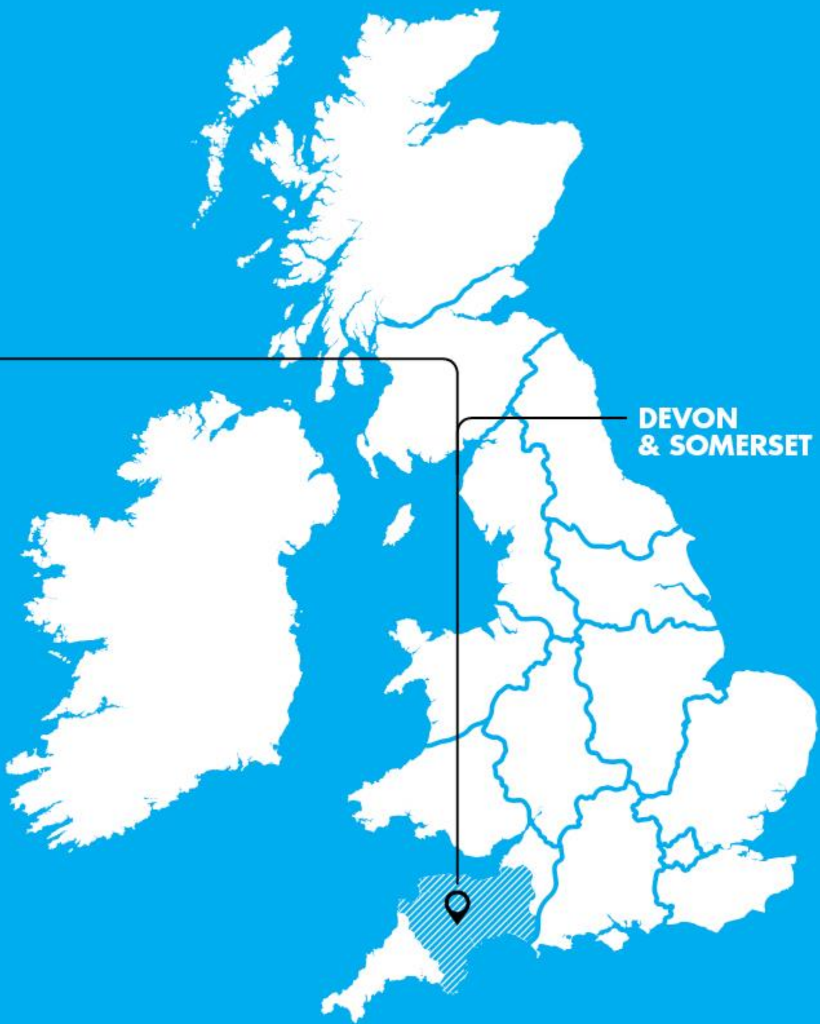


Figure 14-3: GT3 Front Panel Rear

WESTERN POWER DISTRIBUTION

NETWORK EQUILIBRIUM

BALANCING GENERATION AND DEMAND



SVO Installation Report

Colley Lane Primary

LCN Fund
Low Carbon Networks

15 Site Overview

Colley Lane 33/11kV substation contains three 12/24MVA transformers and is normally fed via two 33kV circuits from Bridgwater BSP. Two transformers were installed in 2008 with the third installed in 1989. The existing MicroTAPP AVC relays were installed in 2016 as part of capital replacement works of the 11V switchboard.

16 Design

It was originally planned that SVO would be enabled at the substation through the use of group settings with the existing MicroTAPP relay. The additional SVO control equipment was to be installed in a spare cubicle in the T3 tap change control panel. However, in December 2016 one of the MicroTAPP relays failed and the replacement was required. Following discussions with WPD Engineering Design it was decided to change the relays to the SuperTAPP SG and enable fine point setting control instead.

The SuperTAPP SG relay has the same footprint as the MicroTAPP relay meaning that the panel front did not require modification to fit the new relay. Two additional Pushbuttons and an Indication lamp were required on the T1 panel for SVO control and communications fail respectively. No modifications to the front panels were required for T2 and T3. Due to a similar interface between the two relay types, all other auxiliary control wiring could remain largely the same with only minor rewiring required to add SVO fail safes.

17 Installation and Commissioning

Installation of the SVO scheme began on the 6th February 2017 and finished on the 24th February 2017 with each transformer out of service for one week. Colley Lane was the first site to have SVO enabled relays installed and commissioned. As such several issues were identified during and after the commissioning of the SVO scheme.

During the installation it was noted by the installation team that the relay case was slightly bigger than the existing relay even though manufacturer measurements indicated that it would fit within the existing aperture. This was also noted by the third party panel manufacturer who was used for the offline build of panels for other sites as an issue. This meant that a very thin sliver had to be shaved off the panel reducing the gap between the opening and mounting screws to a minimum.

The design of the existing Independent and parallel selector relay is for it to latch on the current operating state. However, the SG relay is able to determine this based on breaker status and will auto switch without this input. If this happens, WPD Control is unable to change operating mode as the interposing relay is latched in the wrong position compared to the indication in the NMS. The solution was to change the designation of the control within the NMS and to change the interposing relay from a latching type to a self reset type.

Post commissioning of the site, it was noted by site engineers that the relay was randomly switching to manual mode with no control action being taken. Discussions with the manufacturer identified that a “safety” feature had been added to the relay software, such that on loss of power from the tap changer, the relay would switch operating mode on the assumption that someone was manually operating the tap changer. However, for any momentary loss of power from switching or a fault would cause the relay to change mode and require personnel to visit site to return it to the previous state.

No other tap change relay installed on the WPD has this behaviour and systems of work are in place such that this scenario would not occur. The relay manufacturer carried out a modification to the firmware to adjust this feature so that momentary power outages did not result in the relay changing operation mode.

18 Photos

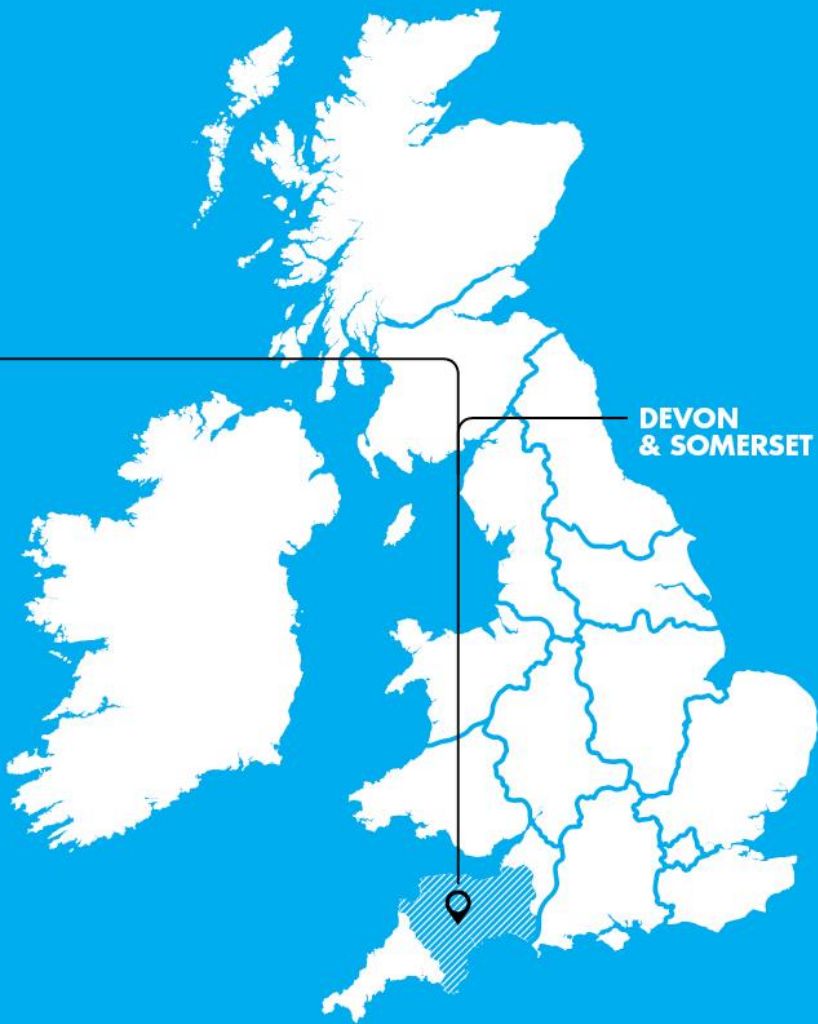
Figure 18-1: T1 and T2 SuperTAPP SG Installation

Figure 18-2: T3 SuperTAPP SG Installation

WESTERN POWER DISTRIBUTION

NETWORK EQUILIBRIUM

BALANCING GENERATION AND DEMAND



SVO Installation Report

Dunkeswell Primary

LCN Fund
Low Carbon Networks

19 Site Overview

Dunkeswell 33/11kV substation consists of two 5/6.25 MVA transformers; however the substation is supported by only a single transformer supplied from Tiverton BSP. The other transformer is supplied from Exeter Main BSP and is run normally open. The transformers and associated AVC relays were installed in 1997.

20 Design

The existing panels were front entry with each transformer having a dedicated Tap Change Control Panel (TCCP). The panels are located at the end of a line of panels and due to each transformer being separated meant that a new panel could be installed. An alternative would be to carryout a relay replacement and panel modification on site. Programming works across all primaries the decision was made to install a new panel at Dunkeswell, removing both existing panels.

21 Installation and Commissioning

Installation of the SVO scheme began on 4th December 2017 and was completed on 8th December 2017. The T1 TCCP was first to be decommissioned as the transformer is normally open with the replacement panel then installed in its place.

Following commissioning of the substation the T1 relay was locking out regularly requiring a manual onsite reset. Investigations found that the relay was losing confidence in the tap change position while the transformer was tapping due to variations in the 33kV voltage level. The transformer is rarely operated on load with tap changer operations occurring infrequently. Because of this the tap changer indication contacts are not well used and therefore slightly “dirty”.

The previous tap position indication (TPI) unit utilised a 50V supply through the tap changer, however the SuperTAPP SG’s built in TPI unit uses a 12V supply. This lower supply voltage was unable to provide enough power to overcome the additional resistance causing errors. Additional maintenance was carried out on the tap changer to clean the contacts, clearing the error.

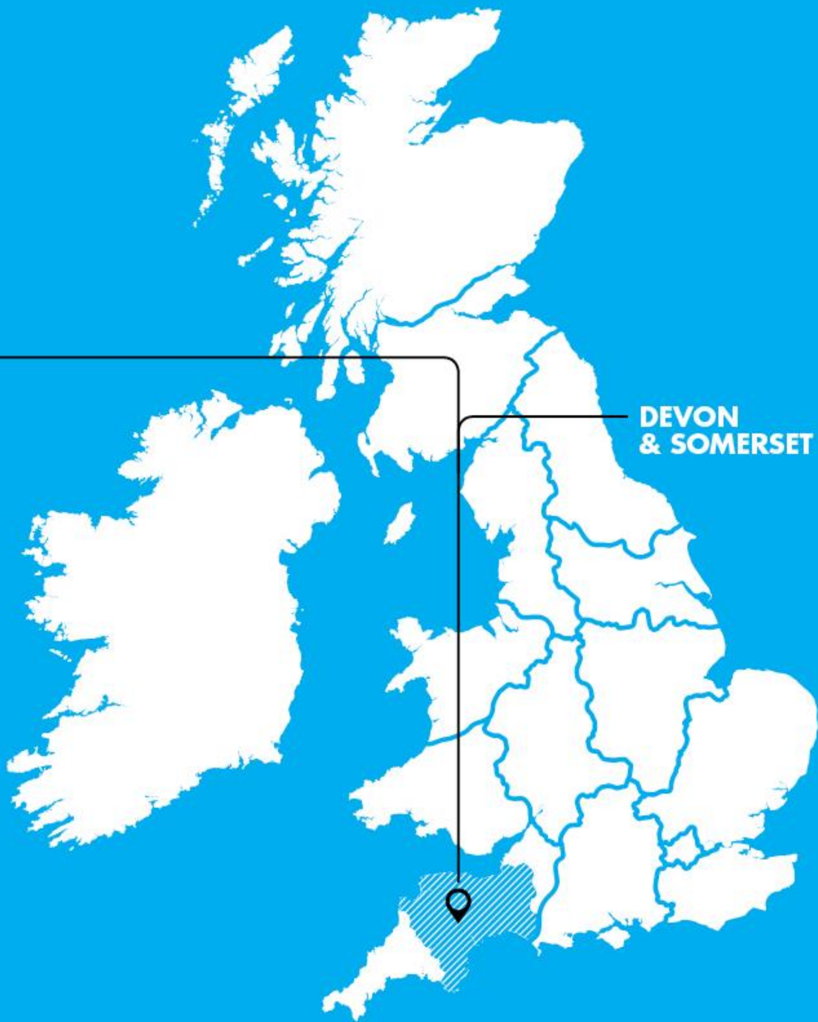
22 Photos

Figure 22-1: New Panel Installation

WESTERN POWER DISTRIBUTION

NETWORK EQUILIBRIUM

BALANCING GENERATION AND DEMAND



SVO Installation Report

Exeter City BSP

LCN Fund
Low Carbon Networks

23 Site Overview

Exeter City 132/33kV substation consists of two 45/90MVA transformers and is normally fed via two 132kV circuits from Exeter Main GSP. The substation was originally constructed in the mid 1970's with both transformers and associated relays replaced in 2008. Exeter City BSP supplies eleven primary substations with around 58,000 customers. The substation also has three solar PV sites totalling 15.75MW and two STOR sites totalling 40.88MW committed for connection.

24 Design

The Tap Change Control Panel at Exeter City BSP is a front entry swing door panel that is standalone from all other equipment. Unlike other panels, this one consisted of a single door containing all relays rather than split doors for each one. Due to the fact the panel was standalone with space either side the decision was made to replace the whole panel.

The substation has been designed to enable the installation of a third transformer with plans to add this in the near future. As part of Equilibrium, the design ensured that the future transformer was accounted for so that intrusive re-wiring and commissioning of the whole system would not be required at a later date. The increased size of the panel due to having three transformers installed meant that for accessibility, the SVO controls were positioned in the GT2 section.

25 Installation and Commissioning

The new panel installation began on the 9th October 2017 with both transformers commissioned by the 13th October 2017. With the only interface being to external equipment, installation time was reduced as all existing wiring was reconnected from the old panel. The only new interface was with the two bus section circuit breakers to provide status inputs for the logic scheme.

26 Photos

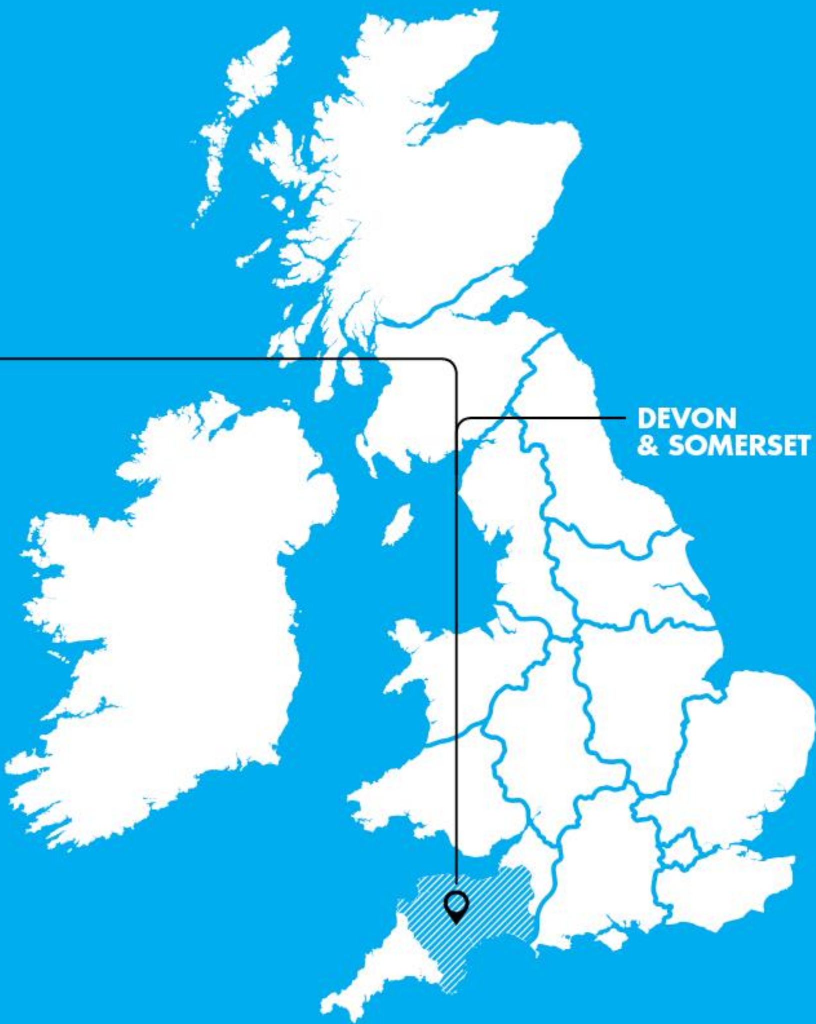
Figure 26-1: New Panel Installation

Figure 26-2: Internal Panel Layout

WESTERN POWER DISTRIBUTION

NETWORK EQUILIBRIUM

BALANCING GENERATION AND DEMAND



SVO Installation Report

Exeter Main

LCN Fund
Low Carbon Networks

27 Site Overview

Exeter Main 132/33kV substation consists of two 40/60MVA transformers and is normally fed via two 132kV circuits from Exeter Main GSP. Both transformers were installed in 2010 along with upgraded protection and AVC relays. Exeter Main BSP supplies six primary substations with around 22,800 customers and currently has a two solar PV generators connected outputting 20MW on the 33kV network.

28 Design

The Tap Change Control Panel (TCCP) at Exeter Main BSP is in the middle of two panels containing protection relays and control systems for each transformer. As such, a direct replacement of the panel was not possible. The panel itself is a rear entry with a rack mounted front, therefore it was decided to construct new front plates for a direct replacement.

The size of the new panel meant that it was possible to mount all equipment, including auxiliary relays, to the front panel. This meant that the installation works would be minimised as everything would be pre-wired and would only require termination into the existing terminals connecting up to the transformer and remote terminal unit.

29 Installation and Commissioning

Due to outage constraints it was not possible to carryout the works for each transformer back to back with GT1 commissioning on 29th September 2017 with GT2 commissioned on the 10th November 2017. During this period the new SuperTAPP relay was placed into Manual mode with the remaining KVGC tapping around it for voltage control with a temporary increase in circulating current.

No issues were experienced during either installation, with careful care taken with the installation and commissioning of the tap change lockout relays as the pre installed relays were the same as Paignton BSP.

30 Photos

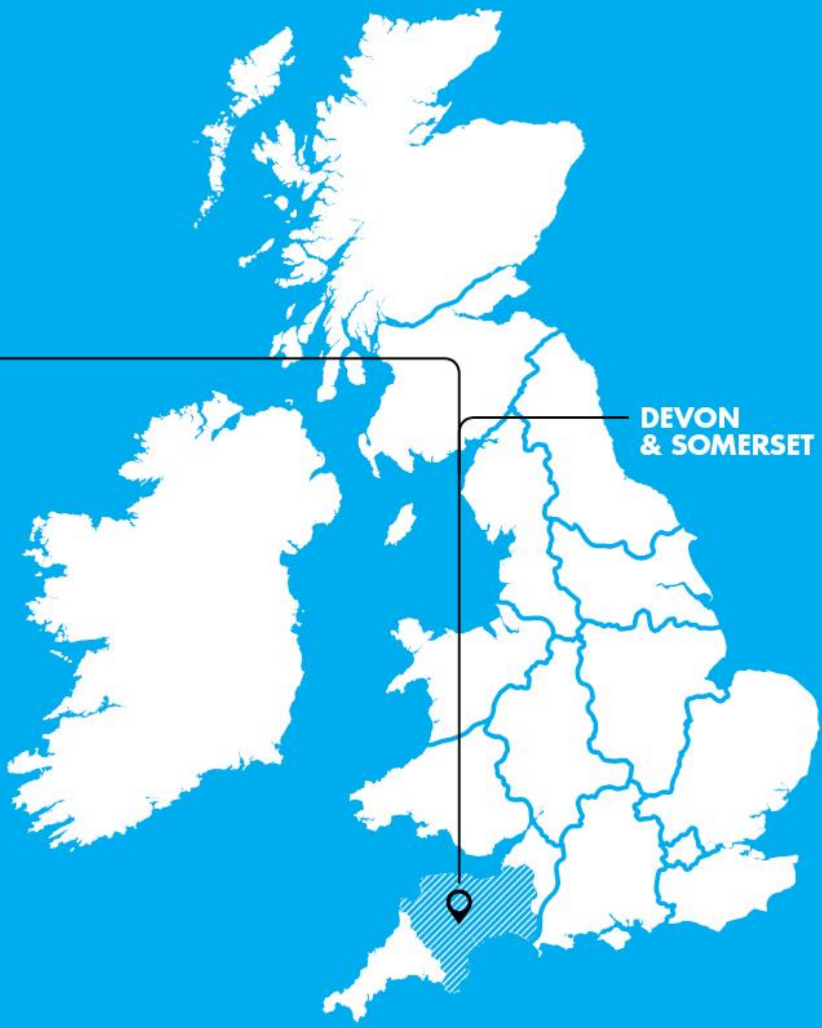
Figure 30-1: GT1 Panel Front

Figure 30-2: GT2 Panel Front

WESTERN POWER DISTRIBUTION

NETWORK EQUILIBRIUM

BALANCING GENERATION AND DEMAND



SVO Installation Report

Lydeard St Lawrence

LCN Fund
Low Carbon Networks

31 Site Overview

Lydeard St Lawrence 33/11kV substation consists of two 5/6.25 MVA transformers, however the substation is supported by only a single transformer supplied from Taunton BSP. The other transformer is supplied from Bowhays Cross BSP and is run normally open. The transformers and associated AVC relays were installed in 2014.

32 Design

The ability of the MicroTAPP relay to accept eight group settings, it was decided to keep the existing relay, adding the required control functionality to enable the extra settings groups. Additional control relays were placed in a separate, wall mounted cabinet to preserve existing space within the Tap Change Control Panel (TCCP). This approach also enabled an offsite build, simplifying the on site wiring and transformer outage time. Construction and wiring out of the SVO Control Cubicle was completed in house by WPD.

33 Installation and Commissioning

Installation of the SVO scheme began 20th February 2017 and was completed on 3rd March 2017. Lydeard St Lawrence was the second and final MicroTAPP SVO scheme commissioned. Following the experience of wiring the first substation, Waterlake, the installation time on site was reduced to under five days per transformer as the same team was utilised. However the lesson from Waterlake remains that a single logic scheme is required going forward and prior knowledge would be beneficial if modifications are required in the future.

34 Photos

Figure 34-1: SVO Modifications to T1 Front Panel

Figure 34-2: SVO Control Cabinet

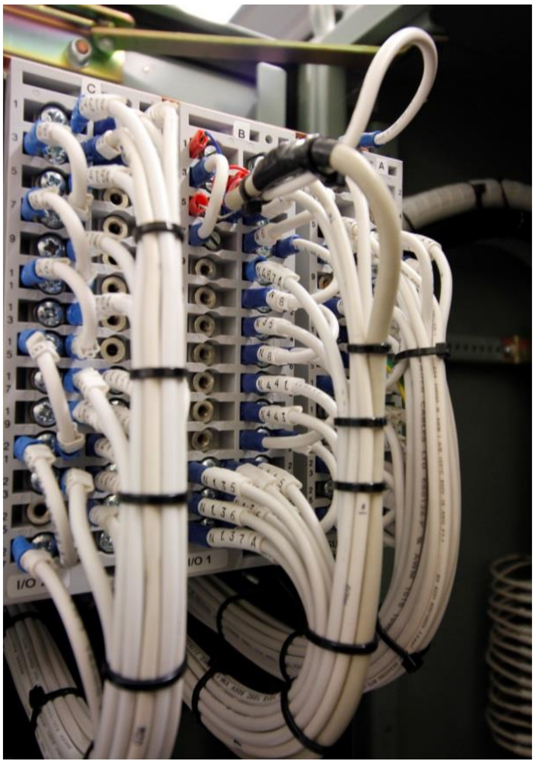


Figure 34-3: Wiring to back of MicroTAPP relay

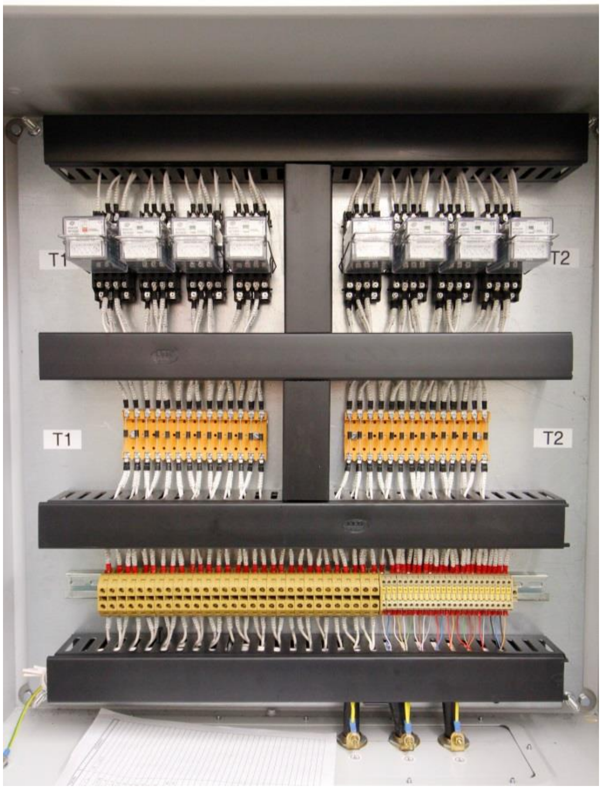


Figure 34-4: SVO Control Cabinet Internal

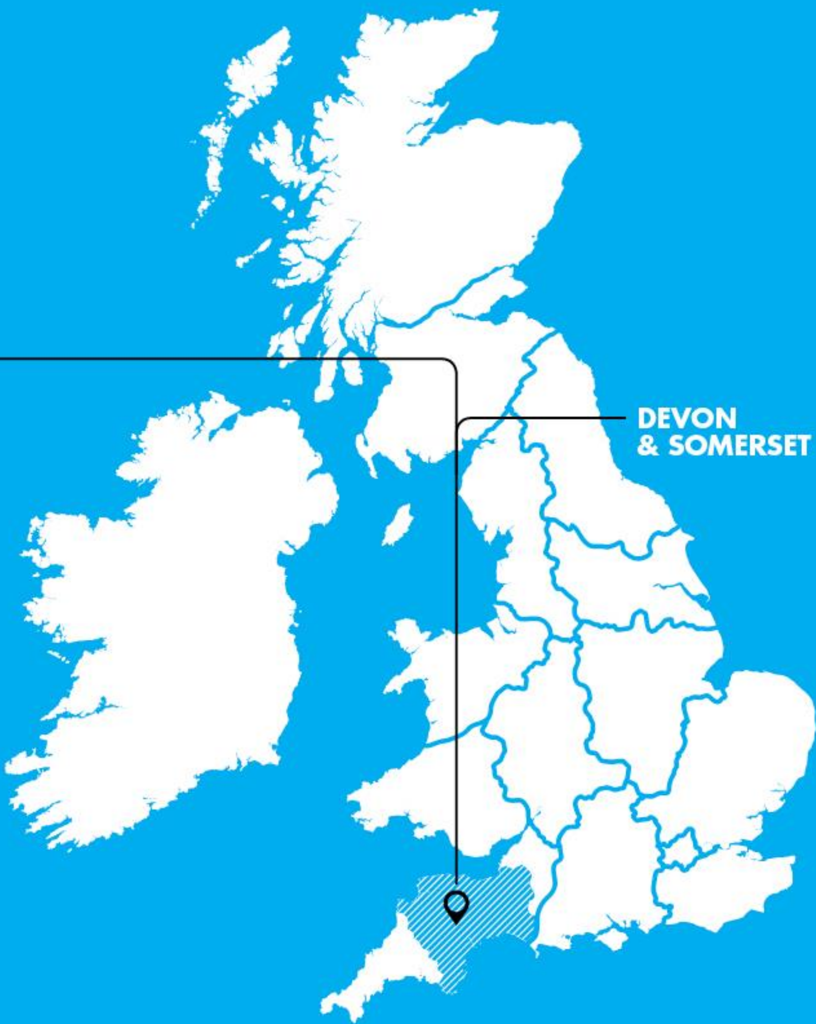
WESTERN POWER DISTRIBUTION

NETWORK EQUILIBRIUM

BALANCING GENERATION AND DEMAND

SVO Installation Report

Marsh Green Primary



LCN Fund
Low Carbon Networks

35 Site Overview

Marsh Green 33/11kV substation consists of two 5/7.7 MVA transformers with one supplied from Exeter Main BSP and the other supplied from Sowton BSP. The substation is normally operated with the 11kV bus section open due to this. The 11kV switchboard and AVC relays were installed in 2008 with one transformer installed in 1960 and the second in 1980.

36 Design

The existing Tap Change Control Panel (TCCP) is a front entry split panel with separate doors for each transformer. Replacement of the panel was not possible due to its location in the middle of a suite of panels. The primary panels are reduced in size compared to BSP panels meaning that on site replacement would be difficult. Therefore the decision was made to procure replacement doors for the panel.

The reduced size meant that only the additional SVO control relays could be installed on the rear of the door, however the existing auxiliary relays would need to be rewired on site for the change in logic. Due to the age of the transformers, larger than normal modifications were required within the tap changer to provide the required control signals and lockout functionality.

37 Installation and Commissioning

Installation of the SVO scheme began on 22nd January 2018 and was completed on 2nd February 2018. The installation took longer than other sites due to the more extensive modifications required to the transformer however the installation and commissioning of went smoothly with no issues discovered.

38 Photos

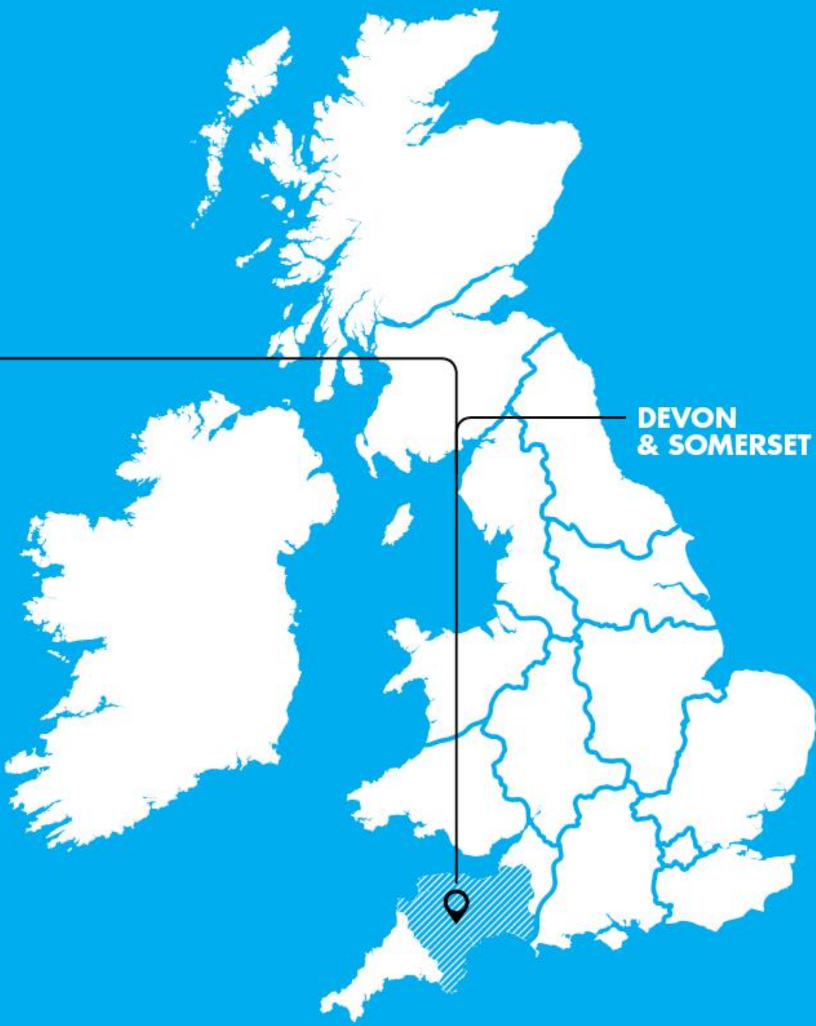
Figure 38-1: Replacement Front Doors containing SuperTAPP SG

Figure 38-2: Rear of Front Door with SVO Controls

WESTERN POWER DISTRIBUTION

NETWORK EQUILIBRIUM

BALANCING GENERATION AND DEMAND



SVO Installation Report

Millfield Primary

LCN Fund
Low Carbon Networks

39 Site Overview

Millfield 33/11kV substation consists of two 12/24 MVA transformers normally fed via two 33kV circuits from Street BSP. Both transformers and their associated AVC relays were installed in 2004.

40 Design

The existing Tap Change Control Panel (TCCP) is a front entry split panel with separate doors for each transformer. Replacement of the panel was not possible due to its location in the middle of a suite of panels. The primary panels are reduced in size compared to BSP panels meaning that on site relay replacement would be difficult. Therefore the decision was made to procure replacement doors for the panel.

The reduced size meant that only the additional SVO control relays could be installed on the rear of the door, however the existing auxiliary relays would need to be rewired on site for the change in logic.

41 Installation and Commissioning

Installation of the SVO scheme began on 15th January 2018 and was completed on 26th January 2018. The installation and commissioning of went smoothly with no issues discovered.

42 Photos

Figure 42-1: Replacement Front Doors Containing SuperTAPP SG Relays

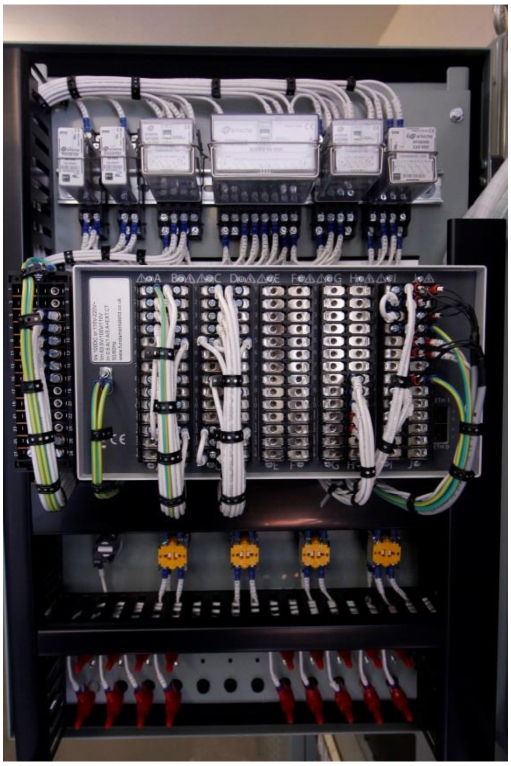


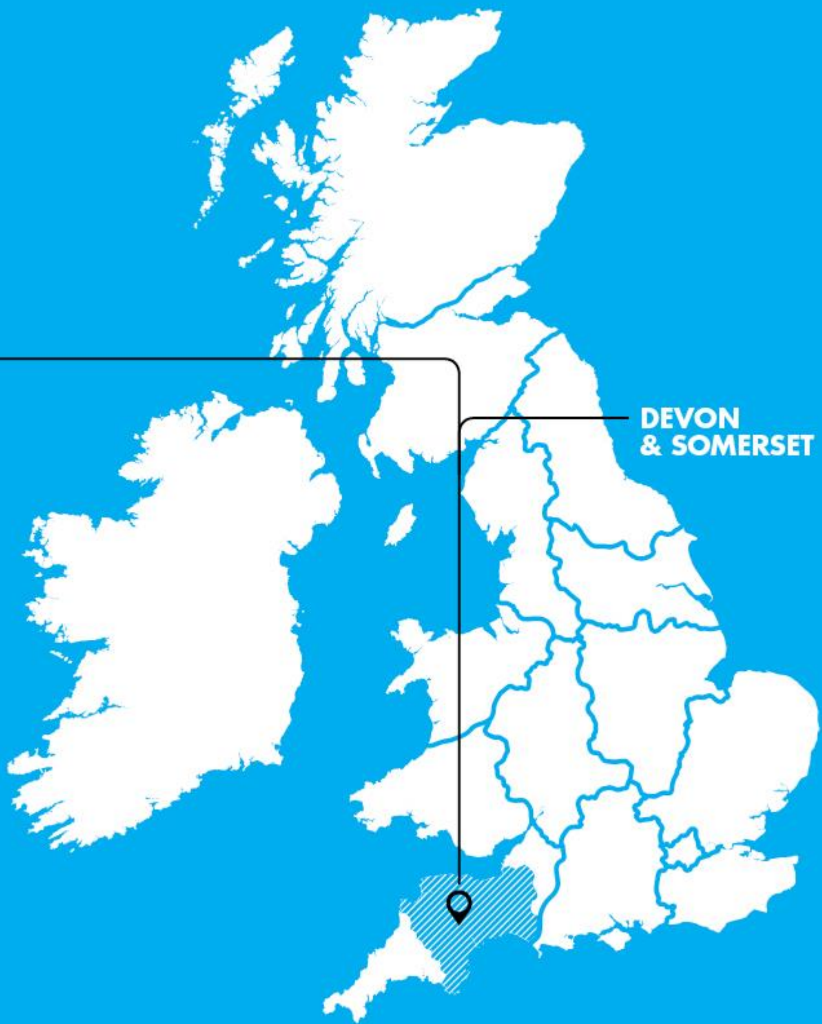
Figure 42-2: Rear of T1 Front Door

Figure 42-3: Internal Auxiliary Relays for T1

WESTERN POWER DISTRIBUTION

NETWORK EQUILIBRIUM

BALANCING GENERATION AND DEMAND



SVO Installation Report

Nether Stowey Primary

LCN Fund
Low Carbon Networks

43 Site Overview

Nether Stowey 33/11kV substation consists of two 7.5/15 MVA transformers; however the substation is supported by only a single transformer supplied from Bridgwater BSP. The other transformer is supplied from Bowhays Cross BSP and is run normally open. The transformers and associated AVC relays were commissioned in 1990.

44 Design

The existing panels were front entry with each transformer having a dedicated tap change control Panel (TCCP). The panels are separated from all other panels within the substation so would have been suitable for replacement by a new panel. However the existing panels contain relays for transformer protection functions, therefore the decision was made to carryout an onsite replacement of the relays and modification of the existing panel.

The SuperTAPP relay was positioned over the voids left by removal of the Tap Position Indicator and Voltage Indication to minimise the amount of panel cutting required. A new DIN rail was mounted within the panel to mount all the additional SVO controls and auxiliary relays to bring the scheme up to current standards.

45 Installation and Commissioning

Installation of the SVO scheme began on 29th January 2018 and was completed on 9th February 2018. The installation and commissioning of the new AVC relays went smoothly with no issues discovered.

46 Photos

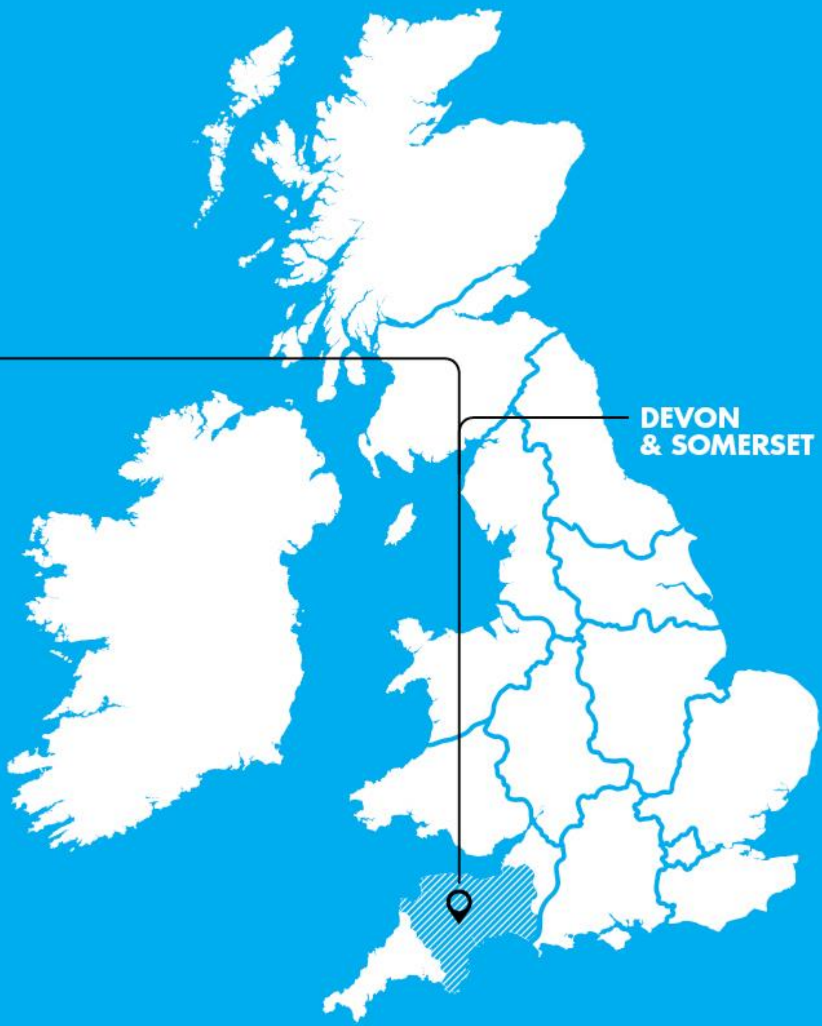

Figure 46-1: T1 and T2 Modified Tap Change Panels


Figure 46-2: Rear of T1 Front Panel

WESTERN POWER DISTRIBUTION

NETWORK EQUILIBRIUM

BALANCING GENERATION AND DEMAND



SVO Installation Report

Paignton BSP

LCN Fund
Low Carbon Networks

47 Site Overview

Paignton 132/33kV substation consists of two 60/90MVA transformers and is normally fed via two 132kV circuits from Abham GSP. The substation was originally constructed in the mid 1970's with both transformers and associated relays replaced in 2008. Paignton BSP supplies eight primary substations with around 47,500 customers and currently has a single 3MW solar PV generator connected.

48 Design

The Tap Change Control Panel (TCCP) at Paignton BSP is in the middle of two panels containing protection relays and control systems for each transformer. As such, a direct replacement of the panel was not possible. The panel itself is a rear entry with a rack mounted front, therefore it was decided to construct new front plates for a direct replacement.

The size of the new panel meant that it was possible to mount all equipment, including auxiliary relays, to the front panel. This meant that the installation works would be minimised as everything would be pre-wired and would only require termination into the existing terminals connecting up to the transformer and remote terminal unit.

49 Installation and Commissioning

Installation of the SVO scheme began on the 15th May 2017 and finished on the 26th May 2017 with each transformer out of service for one week. Paignton was the first BSP to have SVO enabled relays installed and commissioned.

The existing transformer lockout relays were not commissioned at the time of the original installation. With the change of AVC relay it was decided to commissioning the lock out relays to match the existing standards. The type of relay used, as it was part of the transformer, did not have a visible indication of its current position. During commissioning of the first transformer, the tap changer was exhibiting strange behaviour. After a detailed investigation it was eventually determined that set and reset wiring was round the wrong way.

The substation was also unique in that the remote terminal radio unit was in a different building to the TCCP. In order to enable the DNP3 communications, a new cable was required from one building to the other. This required trenches to be dug and delayed completion of the overall scheme for another month.

50 Photos

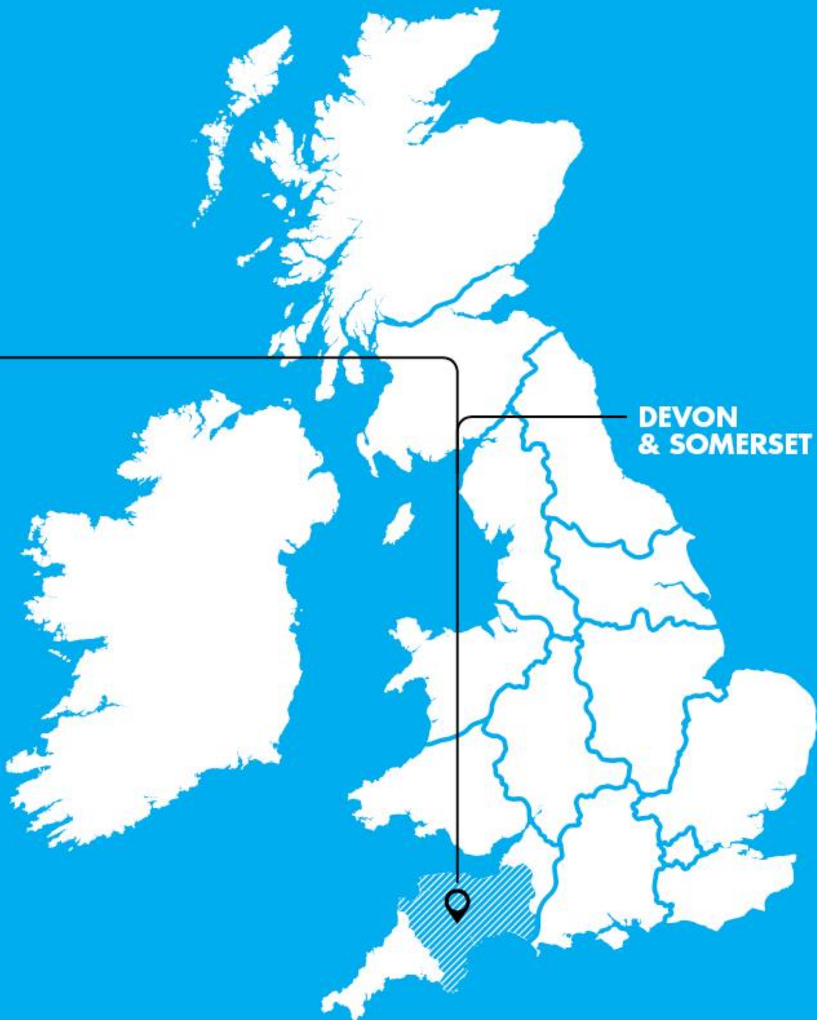
Figure 50-1: GT1 Front Panel

Figure 50-2: GT2 SuperTAPP relay and Controls

WESTERN POWER DISTRIBUTION

NETWORK EQUILIBRIUM

BALANCING GENERATION AND DEMAND



SVO Installation Report

Radstock BSP

LCN Fund
Low Carbon Networks

51 Site Overview

Radstock 132/33kV substation consists of two 60/90 MVA transformers and is normally fed via two 132kV circuits from Seabank GSP. The substation was originally constructed in the early 1960's with both transformers replaced in 2013. Radstock BSP supplies 12 primary substations with around 53,000 customers. There is currently 25.25 MW of generation connected to the 33kV network consisting of six solar PV sites and a single wind farm.

Since early 2017 there has been capital replacement works being undertaken on the 132kV AIS compound. This is scheduled for completion before commissioning o f the SVO system but was delayed and is now scheduled for completion in the summer of 2018.

52 Design

The existing AVC scheme and panels were not fully updated as part of the transformer capital replacement works and are the original panels from the commissioning of the substation. The panels were rear entry with a solid plate front, meaning the only option was installation in the existing panel or a complete new panel. The availability of a spare panel from Exeter Main substation installation meant that the decision was made to install a new panel.

The existing control room contained minimal space for new panels due to a lack of wall space. With the ongoing capital works, half the of 132kV protection panels were decommissioned with the other half still in commission awaiting transfer of the systems. In order to accommodate the new panel the decommissioned panels were cut away from the live panels and removed.

53 Installation and Commissioning

Installation of the SVO scheme began on the 15th May 2017 and finished on the 26th May 2017 with each transformer out of service for one week. Radstock was the final substation to have SVO enabled relays installed and commissioned.

Due to the change on location of the AVC panel the entry and routing of existing multicores within the substation, termination boxes were installed close to the cable entry points. New cables were then run from there to the new panel. Helped to consolidate and reduce the number of cables within the building and provided a greater level of flexibility for the routing.

Following commissioning, one of the relays experienced a data warning similar to the one seen at Colley Lane. Due to a newer firmware this did not cause a mal-operation of the relay and occurred on the relay that was out of service due to the capital works. A new data storage drive was installed in the relay and the data logging interval adjusted to stop a recurrence of the error.

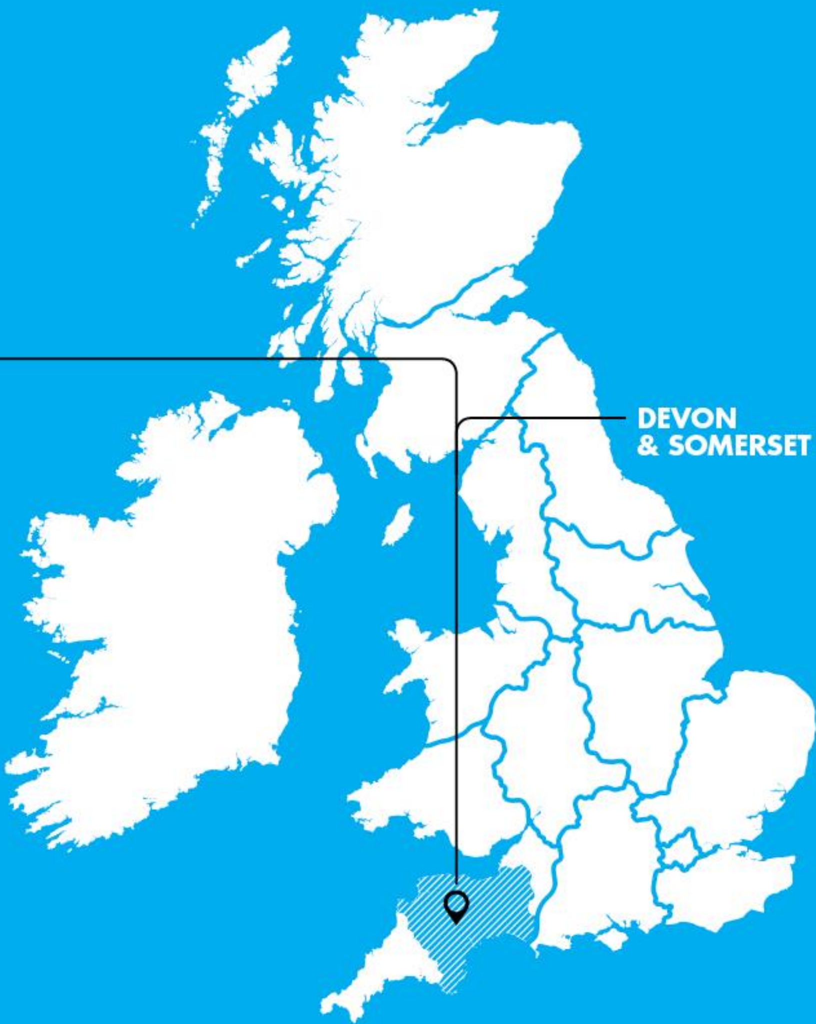
54 Photos

Figure 54-1: New Panel Installation

WESTERN POWER DISTRIBUTION

NETWORK EQUILIBRIUM

BALANCING GENERATION AND DEMAND



SVO Installation Report

Taunton BSP

LCN Fund
Low Carbon Networks

55 Site Overview

Taunton 132/33kV substation consists of three transformers with the following sizes; 45/90 MVA, 60/90 MVA and 22.5/45 MVA. The 33kV substation was constructed in 1998 with the transformers being installed between 2009 and 2011. Taunton supplies 10 primary substations with around 56,000 customers. There are currently six solar PV generator sites connected to the 33kV network generating 30.75MW.

56 Design

Each transformer has a dedicated Tap Change Control Panel (TCCP) that are installed together opposite the 33kV protection panels. The panels are all front entry and reduced in height compared to standard panels due to the restricted space in the switchroom. The panels are situated at the end and therefore could have been removed and replaced. However, this would have to be a direct replacement due to lack of space causing additional difficulties in maintaining operations during installation works. Therefore, the decision was made to replace the front door of each panel.

57 Installation and Commissioning

Installation of the SVO scheme began on the 24th July 2017 and finished on the 18th August 2017 with each transformer out of service for one week. The installation of GT1 and GT2 went smoothly with no issues to report.

During the commissioning of Grid Transformer 3, the tap position indicator within the tap changer failed causing incorrect readings of tap position by the relay. This incorrect reading meant that the relay was locking out during normal operation and the tap position was uncertain. The relay was left in Manual mode with the other two transformers tapping to control overall site voltage. Work to correct the tap change indication is scheduled as part of planned maintenance activities.

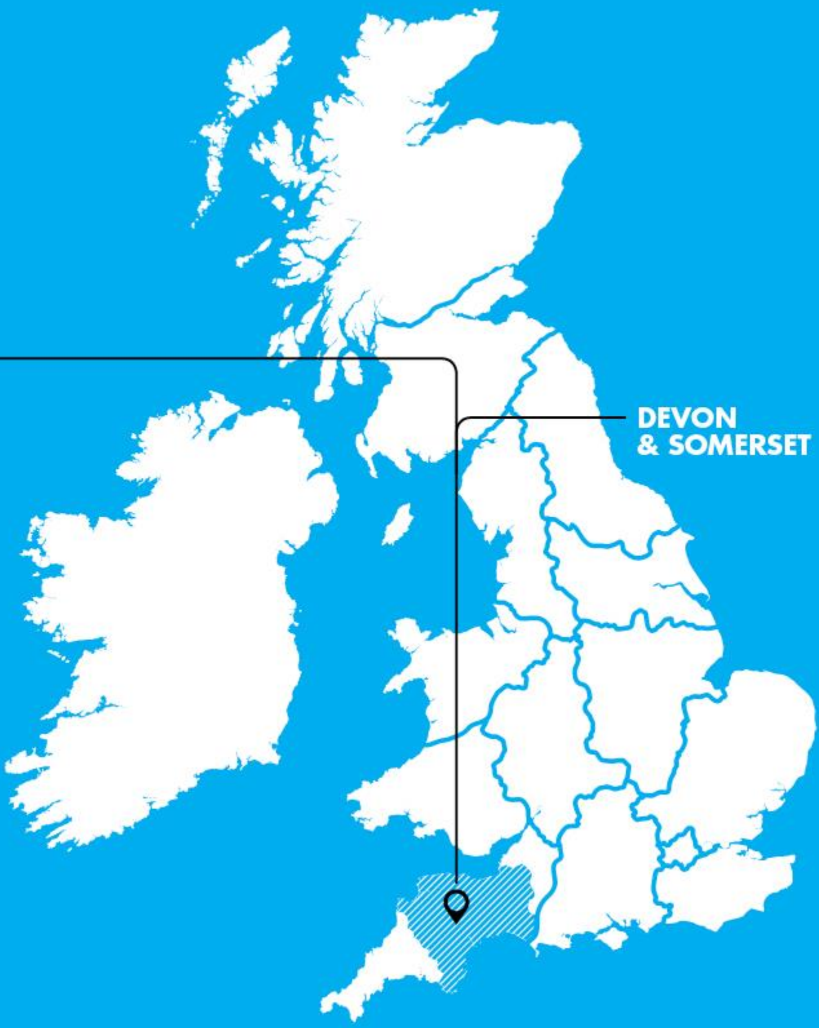
58 Photos

Figure 58-1: GT1, GT2 and GT3 Tap Change Panels with SuperTAPP SG Relays Installed

WESTERN POWER DISTRIBUTION

NETWORK EQUILIBRIUM

BALANCING GENERATION AND DEMAND



SVO Installation Report

Tiverton Moorhayes Primary

LCN Fund
Low Carbon Networks

59 Site Overview

Tiverton Moorhayes 33/11kV substation consists of two 7.5/15 MVA transformers normally fed via two 33kV circuits from Tiverton BSP. Both transformers and their associated AVC relays were installed in 2006.

60 Design

The existing Tap Change Control Panel (TCCP) is a front entry split panel with separate doors for each transformer. The existing panel is separated from all other panels within the substation making it feasible for a replacement panel to be installed. To reduce installation time, the decision was made to install a new panel at Tiverton Moorhayes with the existing panel refurbished off site for installation at another SVO Primary.

61 Installation and Commissioning

Installation of the SVO scheme began on 16th October 2017 and was completed on 27th October 2018. Following the experience gained of replacing doors at other sites, the projects team decided to carryout the door change on the existing panel in situ. The new panel designated for Tiverton Moorhayes was then reassigned to another substation. The installation and commissioning of went smoothly with no issues discovered.

62 Photos

Figure 62-1: New Panel Door for T1

Figure 62-2: New Panel Door for T2

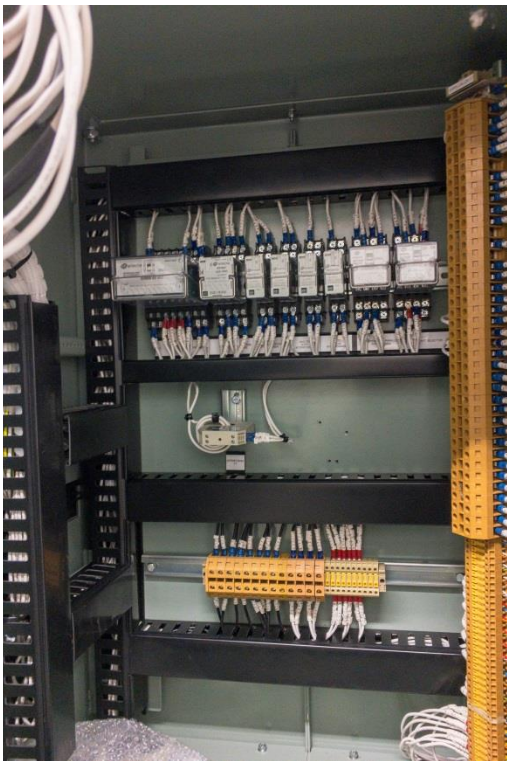
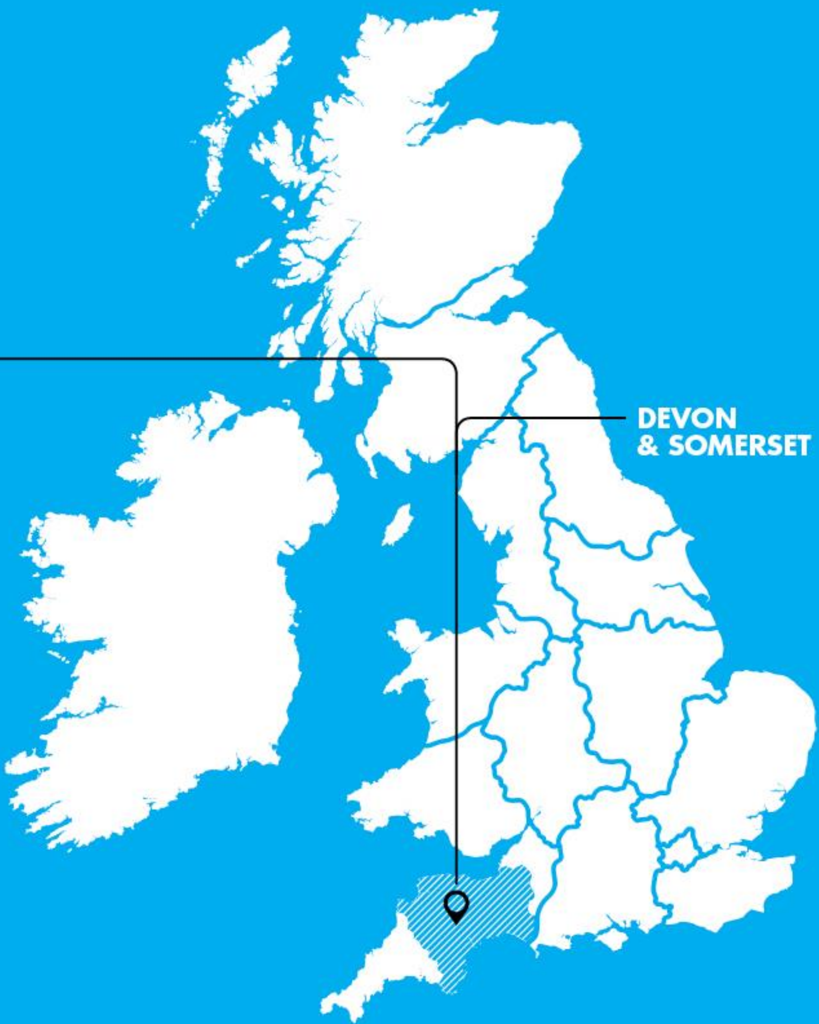


Figure 62-3: T1 Panel Internal Compartment

WESTERN POWER DISTRIBUTION

NETWORK EQUILIBRIUM

BALANCING GENERATION AND DEMAND



SVO Installation Report

Tiverton BSP

LCN Fund
Low Carbon Networks

63 Site Overview

Tiverton 132/33kV substation consists of two 22.5/40 MVA transformers and is normally fed via two 132kV circuits from Exeter Main GSP. The 33kV outdoor switchgear was replaced in 2015 for a new indoor switchboard with new AVC relays installed at the same time. Both transformers were installed in 1964. Tiverton BSP currently supplies ten primary substations with a total of 48,000 customers connected. There is currently only single solar PV site generating 4.55MW connected at 33kV.

64 Design

The Tap Change Control Panel (TCCP) at Tiverton BSP is front entry with separate doors for each transformer. The existing AVC relay was the SuperTAPP N+ which was the previous generation of the SuperTAPP SG. Due to the age of the panel, minimal changes were required to the auxiliary controls to connect to the SG and enable SVO. For this reason the decision was made to carryout a direct replacement of the relay in place.

With the SG incorporating controls within the relay compared to the N+ meant that the interface wiring was simplified due to required external logic to prevent mal-operation now not required. Exiting push buttons were reutilised for the new SVO controls and indications.

65 Installation and Commissioning

Installation of the SVO scheme began on the 4th September 2017 with the second transformer commissioned on the 3rd November 2017 with each transformer out of service for one week. Between the installations for both transformers the SuperTAPP SG relay was kept in Manual with the second relay controlling the substation voltage. The installation and commissioning of the new AVC relays went smoothly with no issues.

66 Photos

Figure 66-1: Panel Front Door for GT1

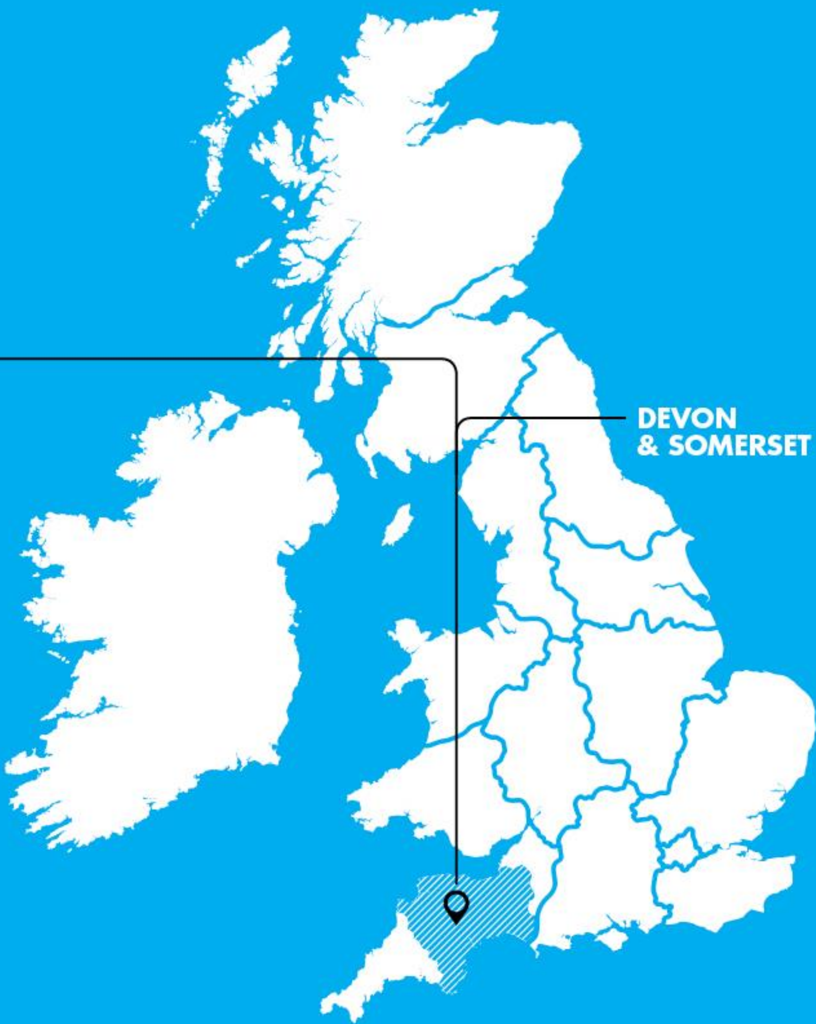
Figure 66-2: Panel Front Door for GT2


Figure 66-3: Rear of GT1 Door

WESTERN POWER DISTRIBUTION

NETWORK EQUILIBRIUM

BALANCING GENERATION AND DEMAND



SVO Installation Report

Waterlake

LCN Fund
Low Carbon Networks

67 Site Overview

Waterlake 33/11kV substation consists of two 7.5/15MVA transformers and is normally fed via two 33kV circuits from Woodcote BSP. Both transformers and associated MicroTAPP AVC relays were replaced in 2013. The site is normally run with the primary transformers split due to the position of the 33kV normally open point.

68 Design

The ability of the MicroTAPP relay to accept eight group settings, it was decided to keep the existing relay, adding the required control functionality to enable the extra settings groups. Additional control relays were placed in a separate, wall mounted cabinet to preserve existing space within the Tap Change Control Panel. This approach also enabled an offsite build, simplifying the on site wiring and transformer outage time. Construction and wiring out of the SVO Control Cubicle was completed in house by WPD.

69 Installation and Commissioning

Installation of the SVO scheme began on 6th February 2017 and was completed on 24th February 2017. Waterlake was the first MicroTAPP SVO scheme commissioned. The complexity of wiring caused by maintaining the existing wiring logic and installing SVO logic separately meant that installation times were longer than planned with the first transformer taking seven days from start to finish. With experience the time taken reduced but a full five day outage was still required for the second transformer.

For future installations optimisation of the logic should take place such that only a single logic scheme is required. At this stage no issues have been experienced during the operation of the SVO scheme. However if issues arise in the future it was noted that if modifications are required to the logic wiring, it will not be the easiest to follow without prior knowledge.

70 Photos

Figure 70-1: SVO Control Modifications to T1 Panel


Figure 70-2: SVO Control Panel Internals

Figure 70-3: SVO Control Panel