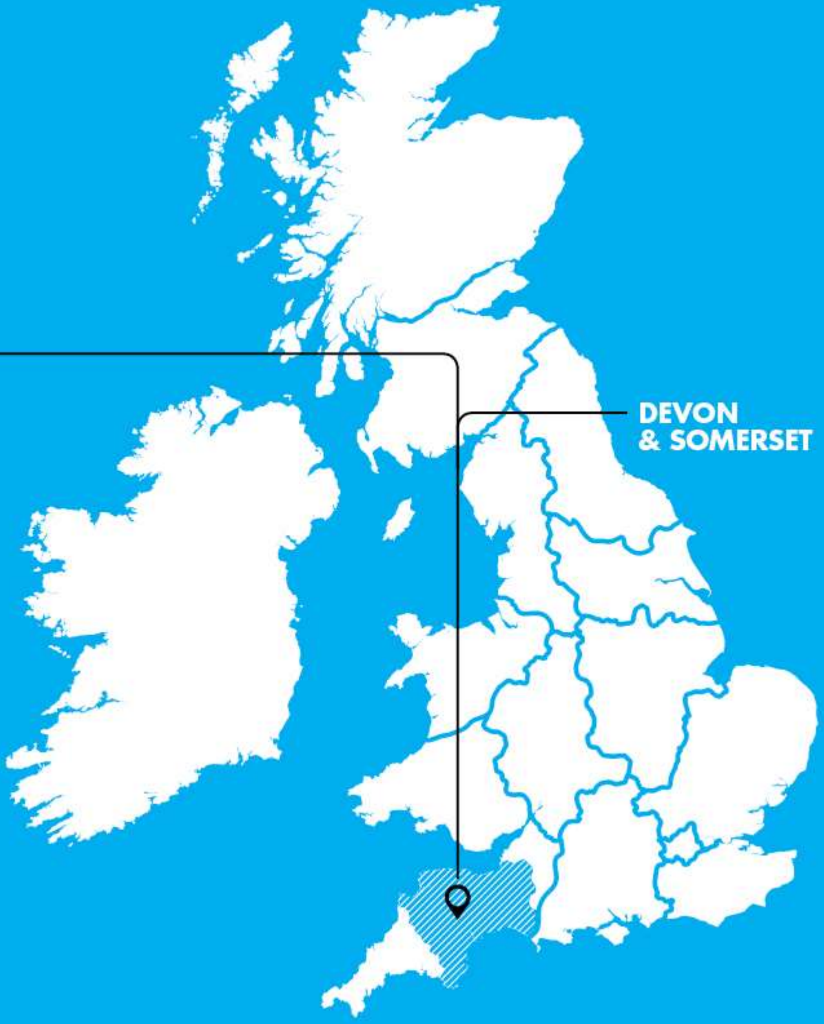
WESTERN POWER DISTRIBUTION

NETWORK EQUILIBRIUM

BALANCING GENERATION AND DEMAND



SDRC-2
Detailed Design of the SVO Method

LCN Fund
Low Carbon Networks

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Prepared by:	Yiango Mavrocostanti	25.01.2016
Reviewed by:	Mark Dale	09.02.2016
Approved (WPD):	Roger Hey	19.02.2006

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Contents

Glossary

Term	Definition
AVC	Automatic Voltage Control
BSP	Bulk Supply Point
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
HIS	Historic Information System
HV	High Voltage
ICCP	Inter-Control Centre Communications Protocol
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
PSS/E	Power System Simulator for Engineering
SCADA	Supervisory Control And Data Acquisition
SDRC	Successful Delivery Reward Criteria
SVO	System Voltage Optimisation
TAPP	Transformer Automatic Paralleling Package
VT	Voltage Transformer
WPD	Western Power Distribution

1 Introduction

1.1 Network Equilibrium

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 trial location for Network Equilibrium encompasses the 33kV and 11kV distribution networks in Western Power Distribution's (WPDs) South West area across the counties of Somerset and Devon.

1.2 Methods

Network Equilibrium will use the latest advances in power, communication and computing systems to release network capacity. The project has been split into three technical methods as follows:

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

This report focuses on the SVO method and will form the Ofgem Deliverable for Successful Delivery Reward Criteria (SDRC) 2: "Detailed Design of the SVO Method".

1.3 SVO Method

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 a particular target value. This target voltage is set to ensure that the network voltage is kept within the statutory limits as stated in the Electricity, Safety, Quality and Continuity Regulations (ESQCRs). Traditional network design was determined using the assumption that power would flow from transmission level down through the various voltage levels to consumers. In this scenario, the worst case operating condition for maintaining voltage would be under maximum demand as this would result in the largest voltage drop due to network impedance. The target voltages at each substation were therefore set to ensure that the voltage across the network was maintained within the limits defined in the ESQCRs during maximum demand.

Power flow in the distribution network has changed significantly over recent years with the introduction of embedded generation and LCTs. The target voltages previously defined on the assumption of maximum demand occurring on the network may no longer be suitable. For instance, during periods of low demand the network voltage may be set artificially high due to the fixed target value. This could prevent the connection of additional generation due to the lack of voltage headroom. Conversely, the fixed voltage target could limit the amount of voltage footroom available during times of maximum demand. An active method of controlling the target voltage has the potential to create more voltage headroom and footroom by adjusting according to actual voltage measurements on the network. The SVO method aims to explore how novel algorithms and control systems can be used to optimise the voltage on the distribution network in real-time. Utilising the latest AVC relay technologies, installing voltage monitoring equipment and implementing a smart control system will enable the SVO method to have the potential to expose voltage headroom and footroom in the existing network.

1.4 Summary

This report forms one of the eight deliverables as part of Network Equilibrium. SDRC-2 entitled, “Detailed Design of the System Voltage Optimisation (SVO) Method”, provides a detailed description of the SVO method and how this will be implemented on the project’s trial area.

As part of SDRC-2 a workshop was held with other UK DNOs to share further details of the technical specification of the SVO method and present the proposed design approach. The results of the workshop can be found in Appendix H.

2 Network Voltage Control

2.1 Overview

The voltage on the UK Distribution System is governed by the ESQCRs[1] which state the permissible voltage range. Clause 27 (3) states the following:

> *(b) in the case of a low voltage supply, a variation not exceeding 10 per cent above or 6 per cent below the declared voltage at the declared frequency;*
> *(c) in the case of a high voltage supply operating at a voltage below 132,000 volts, a variation not exceeding 6 per cent above or below the declared voltage at the declared frequency; and*
> *(d) in the case of a high voltage supply operating at a voltage of 132,000 volts or above, a variation not exceeding 10 per cent above or below the declared voltage at the declared frequency.*

Hence, for the 33kV and 11kV networks the permissible voltage variation is ±6% of the declared voltage.

2.2 Controlling Network Voltage

2.2.1 Low Voltage Networks

The Low Voltage (LV) network does not have an “active” form of voltage control. The network is planned and designed for the worst case operating voltage on 11kV terminals of the 11/0.433kV transformer.
However, due to inherent voltage drop that appears along an 11kV feeder, there can be major differences in the voltage seen at substations that are close to the primary substation and those which are at the end of long 11kV radial circuits.

Off-circuit tap changers positioned on the 11kV side of the majority of distribution transformers can be set at one of the following positions: -5%, -2.5%, 0%, +2.5% and +5%. By altering the turns ratio on the primary side of the transformer the voltage on the LV side of the transformer can be set to compensate for the amount of voltage drop in the 11kV feeder it is supplied from. As can be derived from the name, off-circuit tap changers can only be adjusted when isolated from the HV and LV network, meaning that regular adjustment is not possible.

2.2.2 High Voltage Networks

As the load and voltage on the High Voltage (HV) network can vary substantially over a period of hours, a more sophisticated method of controlling voltage is required. OLTCs are able to be adjusted during normal network operation without interruption to customers.
Using inputs from Voltage Transformers (VTs) and Current Transformers (CTs), AVC relays determine if the tap changer needs to be adjusted to ensure that the pre-determined

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[1] Electricity, Safety, Quality and Continuity Regulations. London : UK Legislation, 2002.

voltage set-points are met. Details of the different types of AVC relays and those being considered for the SVO method can be found in Appendix C.

2.2.3 Set Points

As described above, high voltage networks controlled by OLTCs use target values or “set points” to maintain the voltage within limits. The set points are fixed within the AVC relays which instruct the OLTCs to operate to maintain the set point voltage. The particular value for the set point is based on the worst system operating conditions to ensure remote parts of the network are maintained within limits. Typically the worst system operating condition is when the system is at full load and therefore experiencing the most amount of voltage drop. Figure 2-1 below shows the typical constraints a traditional network is subjected to due to voltage.

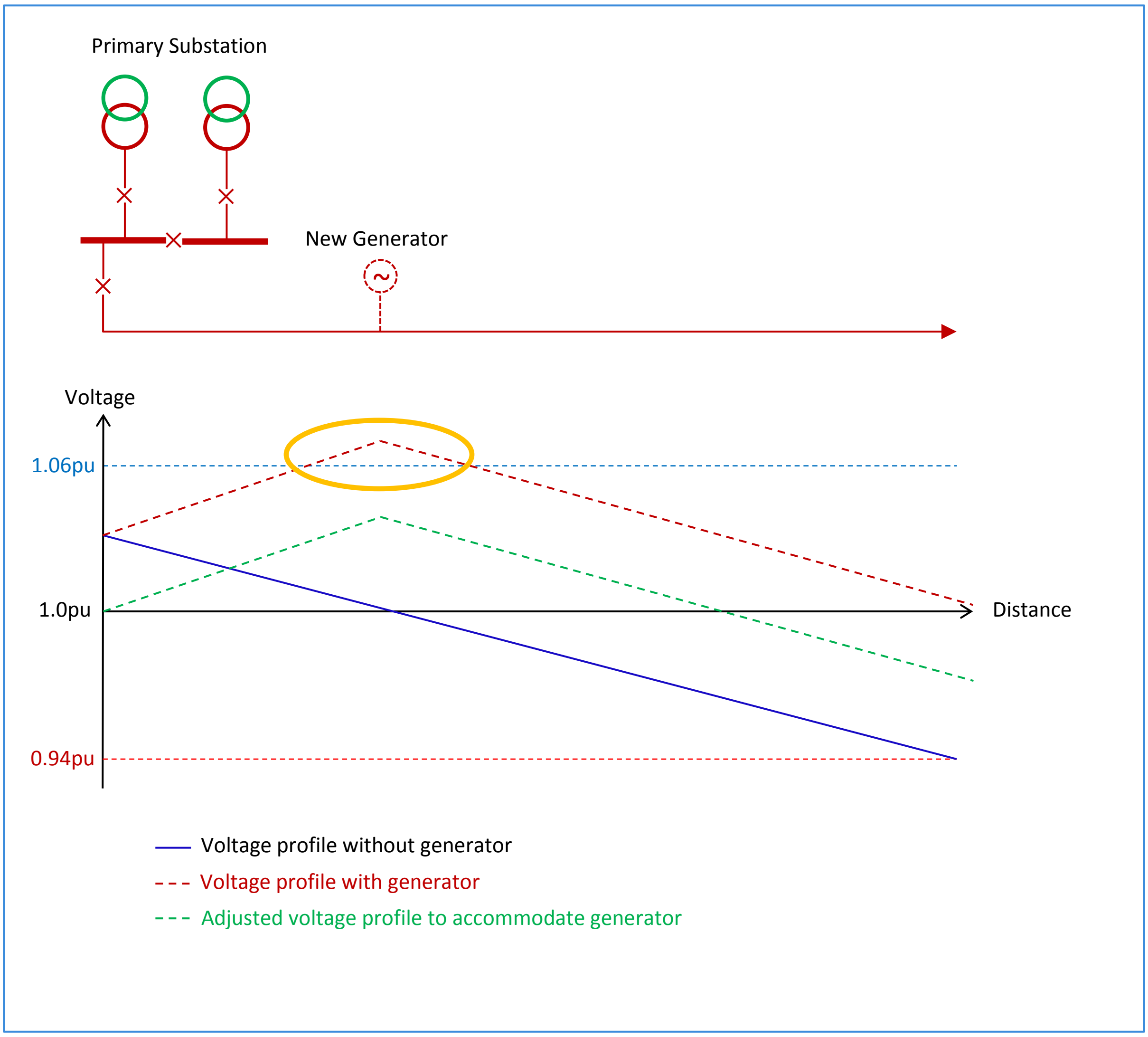

Figure 2-1: Example of simplified voltage profiles on distribution network

3 System Voltage Optimisation

3.1 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.

The static AVC set points currently used are best suited for demand dominated networks. However, 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.

SVO will continuously assess the state of the network in real time and detect these changes. It will respond to them by calculating and sending optimised AVC settings to the voltage control relays.

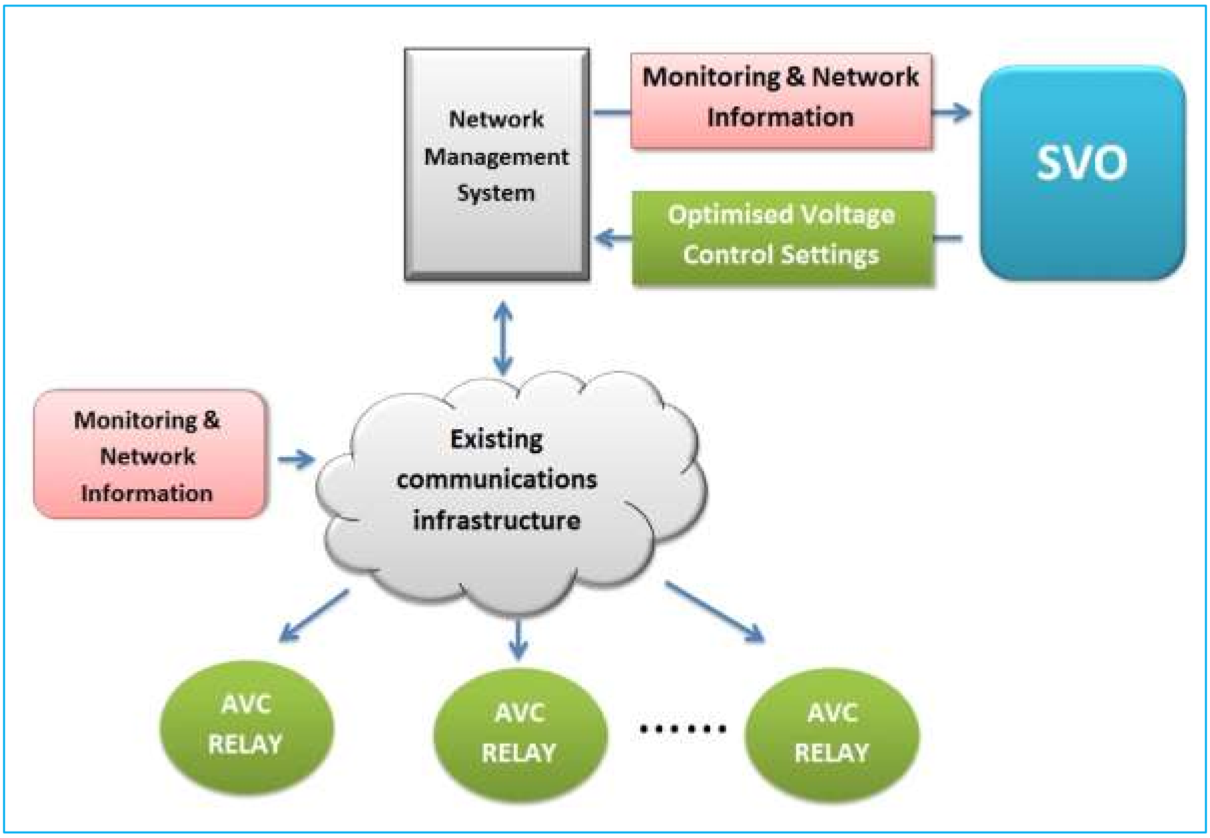

Figure 3-1: SVO Block Diagram

As shown in Figure 3-1, SVO communicates with WPD's Network Management System (NMS) to receive information about the real-time operation of the network. The algorithms within SVO perform all the relevant calculations and the system then outputs the revised voltage control settings, which are sent to the AVC relays through the existing communications architecture.

With the use of SVO voltage control becomes dynamic, responding to the new, challenging nature of electricity distribution networks.

3.2 SVO Algorithm Design and Considerations

3.2.1 Settings Control

The optimised calculated settings derived from SVO can be applied to the AVC relays by using their “Alternative Settings Group” functionality. Each setting group will represent a pre-defined target voltage adjustment and SVO will choose the group that will bring the target voltage closest to the calculated optimised value.

Settings control can be used at sites with older AVC relays which do not support fine control, enabling us to make the most of our existing equipment.

It will require programming the set of target voltage adjustments to the relays. SVO will be able to choose the most appropriate value within the pre-programmed set and as those values will be fixed, SVO will not have the capability of modifying them.

To ensure that SVO will have a number of realistic values to choose from, it is necessary to be able to determine this set of target voltage adjustments with confidence. Using the existing planning tools and following the traditional planning procedures that involve considering the worst case scenarios, a conservative value for the target voltage modification at each site can be determined. This conservative value and a range of smaller values can then be used to define suitable settings groups. If for example, the analysis shows that the target voltage at Substation A can be reduced by 1.6V in the worst case scenario, then 0.8V, 1.0V and 1.6V target voltage reduction are all setting groups that can be pre-programmed to the AVC relay with confidence in their suitability. Clearly, at sites where the calculated worst case value is very little or zero, it is challenging to determine a set of values with certainty, making settings control the less preferred option.

3.2.2 Fine Control

Application of the optimised target voltage settings can also be performed by sending the exact analogue value to the AVC relay. This is called fine control and allows for more precise voltage management.

Contrary to Settings Control, there is no requirement for a pre-defined set of target voltage adjustments as SVO calculates the most optimal target voltage setting and directly applies it to the relay.

Fine control can only be used at sites where the AVC relays installed have the functionality of receiving any target voltage set point (older relay models do not support this).

Although it requires modern relays to be installed on site, fine control offers some important advantages compared to settings control. The fact that fine control is a completely independent form of voltage control, not restricted to choosing set points within a pre-defined set, makes it an attractive implementation for a number of reasons. Most importantly, it removes any constraints imposed by the conservative procedure followed when determining the pre-defined set points making the voltage control more flexible and accurate, releasing the maximum amount of network capacity possible. Furthermore, contrary to settings control, fine control can be applied at sites of very little conservative target voltage modification, enabling the optimisation of heavily constrained networks.

3.2.3 Spectrum Power 5

Spectrum Power 5 is the tool on which SVO is based. It has three main functionalities:

1. **Input data and validation:** Communication with WPD's existing NMS to receive network information.
2. **System Optimisation:** Evaluation of the network's state using the information received from the NMS and calculation of the optimised target voltage settings.
3. **Output data:** Communication with WPD's existing NMS to output the calculated settings.

It comprises a number of interlinked subsystems each performing a different task.

Firstly, the available measurements are received through the communications link connecting Spectrum Power 5 with WPD's NMS. There are in fact, 2 communication links, also called Inter-Control Centre Communications Protocol (ICCP) links, between the two systems with one acting as a back-up, increasing the redundancy of the solution.

Then, the information received is processed by the Distribution System State Estimator (DSSE) module of Spectrum Power 5 that provides an estimation of the current state of the network. It checks the measured values (current, voltage etc.), corrects any errors and performs power flow calculations to determine the branch flows and voltages at every node that is not monitored.

After the state of the network is evaluated by the DSSE, the information is passed to the Volt/VAr module of Spectrum Power 5 that is responsible for the system optimisation. More specifically, it uses the information received from DSSE to run the optimisation algorithms which produce the optimised AVC settings. These are then sent to the NMS through the ICCP link to be forwarded to the AVC relays using the existing communications infrastructure.

This procedure is demonstrated in the High Level Logic Diagram shown in Figure 3-2.

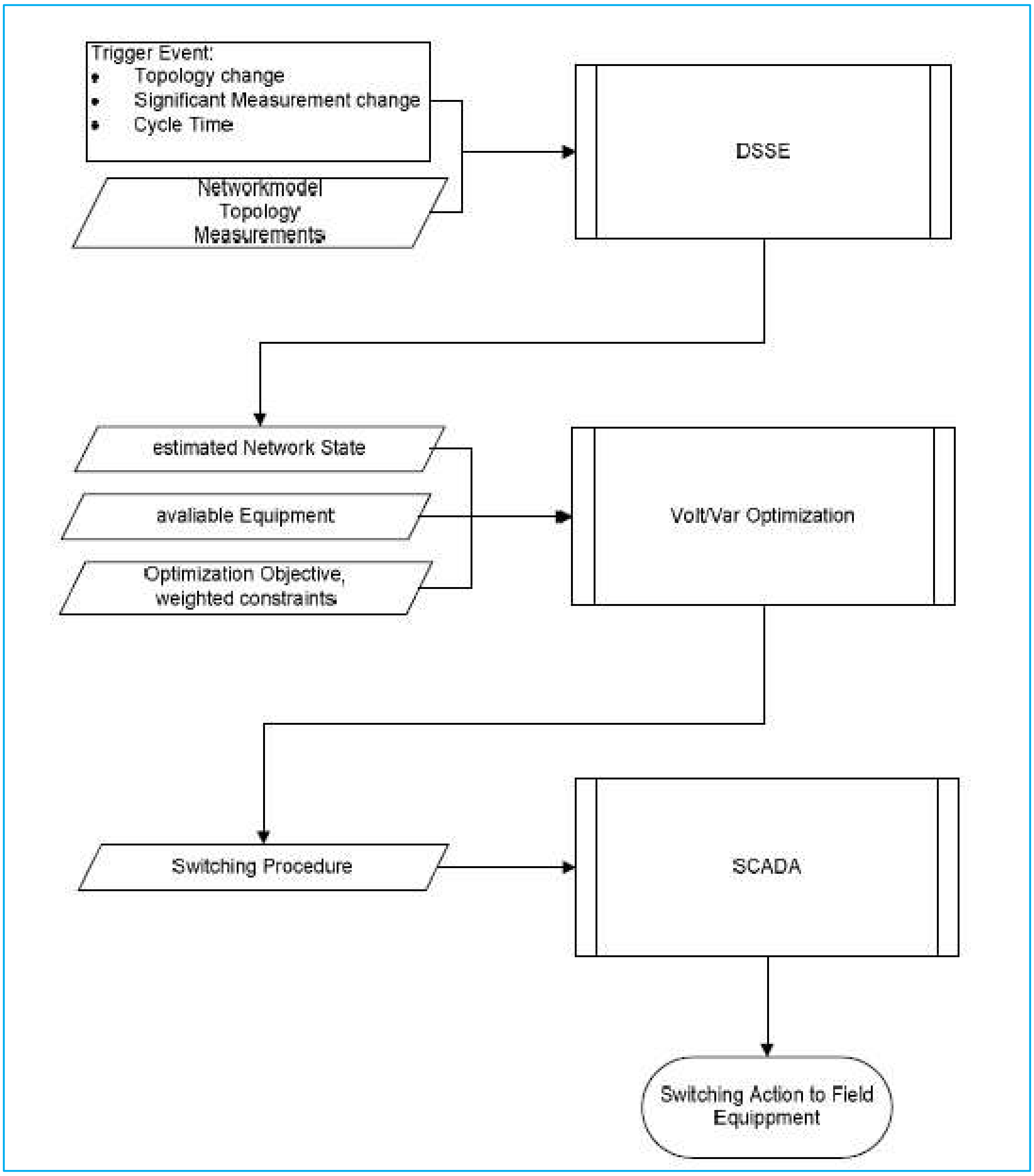

Figure 3-2: High Level Logic Diagram

The User Interface of Spectrum Power 5 will enable control engineers to get a real-time view of the network including the network connectivity, power flows, voltages, equipment statuses and alarms. In addition, through the User Interface, the control engineers will be able to perform functions to control the network and authorise actions proposed by Spectrum Power 5.

Important real-time information will be stored in a database using the Historical Information System (HIS). This will enable valuable analysis to be performed on the data collected to understand how the network behaves over time, compare real operation with the existing planning assumptions and evaluate the benefit offered by such a dynamic voltage optimisation system. HIS will collect and store analogue values (voltage and current measurements), digital values (status information and alarms), transformer tap positions and data related to the operation of SVO (for example DSSE historical results). The data collected and stored by HIS will then be exported in report or Microsoft Excel format for analysis.

3.2.4 Voltage Optimisation

The algorithms within Spectrum Power 5 are located within the Volt/VAr module, designed to efficiently calculate the optimal network solution. They perform all the necessary calculations in order to find the target voltage settings that would maximise network capacity while ensuring that all network constraints are satisfied. Calculating these optimal target voltages is a complex optimisation problem as it consists of a number of variables, an objective function to maximise and a set of constraints to satisfy.

Finding a solution to such a multi-objective optimisation problem is not straight forward due to the number of variables that need to be taken into account and for this reason, sophisticated algorithms are used.

In the design of these algorithms a systematic approach was followed which aimed to specify the decision process and the considerations that need to be made to produce the best solution. The aim was to ensure that the optimisation procedure would take into account important network variables, consider the operation of the network or equipment not taking part in SVO and be able to make the decisions in an efficient manner. These key considerations can therefore be separated in two categories, network and software specific.

Satisfying voltage and thermal constraints and ensuring that the voltage change is within specified limits are examples of the network specific considerations to be made by SVO. In addition, the optimisation procedure needs to ensure that the voltage control of traditionally controlled transformers in the network will not be limited (by keeping HV voltages within HV tap range limit) and that SVO controlled transformers will not impose restrictions in the voltage control of each other.

Two very important characteristics of the software are efficiency and reliability. The reliability of the produced outputs depends on the accuracy of the network's state estimation which is directly affected by the quality of the input data (current, power flow and voltage measurements). Therefore, the capability of assessing the quality of the input data is a crucial functionality of a reliable real-time network optimisation system like SVO. Furthermore, the centralised implementation of SVO increases the efficiency of the solution as it allows a number of voltage control devices to be controlled at the same time in a coordinated manner.

3.2.5 Voltage Monitoring

In order for the SVO system to be able to accurately determine the state of the network, it needs to receive voltage monitoring information to use as a starting point in the state estimation procedure. Therefore, as part of the design of SVO it was important to identify the amount of monitoring already present in the network, determine whether it is necessary to introduce additional measurement points and where it is best to do so. In this process, the 33kV and 11kV networks were investigated separately.

To be able to provide an accurate estimation of the state of the 33kV networks fed by each BSP, SVO needs to know the actual voltages at a sufficient number of nodes in that network. Currently, voltage is monitored at every Primary substation through voltage transformers which are connected either on the 33kV or 11kV side of the substation's transformers. This means that at every point there is a substation connected to the 33kV network, a voltage measurement is available. When that measurement comes from the 33kV side, no processing is required but if it comes from the 11kV side of the Primary transformer, it needs to be translated to a 33kV voltage using transformer and tap position data. More specifically, the Transformer's HV side voltage can be calculated when knowing the LV side voltage using the following equation:

$$V_{HV} = V_{LV} + IZ_{TX} \qquad (2)$$

Where V_{HV} is the Transformer HV side voltage, $V_{LV}$is the Transformer LV side voltage, I is the current through the transformer and Z_{TX} is the impedance of the transformer as shown in Figure 3-3:

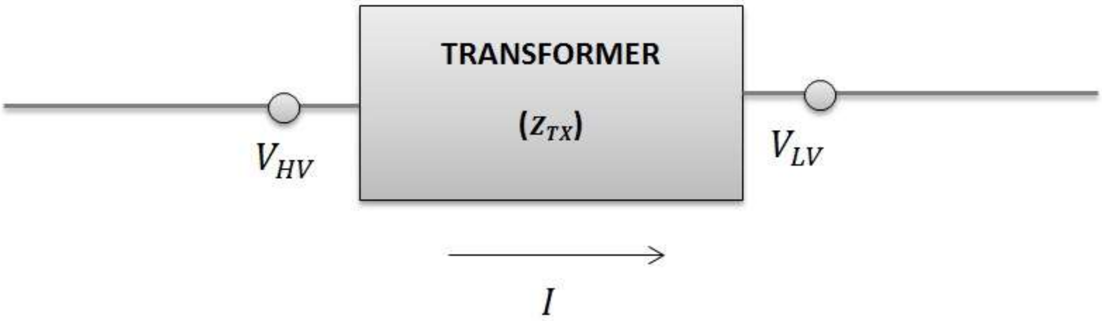

Figure 3-3: Transformer HV and LV voltages

The voltage on the LV side, V_{LV}, and the current through the transformer, I, are both measured. However, the transformer's impedance, Z_{TX}, varies as the tap position of the transformer changes and can be calculated with the following equation:

$$Z_{TX} = (tap_{position} \times tap_{step}) + Z_{TX}min \quad (3)$$

Where $tap\_position$ is the transformer's tap position, tap_{step} is the change in impedance per tap step and $Z_{TX}min$ is the minimum transformer impedance.

All embedded generation connected at 33kV is also monitored and fed into the existing NMS system. Therefore, a good amount of voltage and generation monitoring on the 33kV network already exists.

Similarly, for the state estimation of the 11kV network SVO will need to receive actual voltage measurements from a sufficient number of nodes. However, the distribution substations connected to the 11kV network have no voltage monitoring, which means that there is no measured information available in terms of voltages along 11kV feeders. Furthermore, no 11kV connected generation in the considered project area is currently monitored. Therefore, to ensure that SVO will be able to determine the state of 11kV networks with sufficient accuracy it is necessary to introduce voltage monitoring points at a number of nodes. For each Primary, it was decided to monitor key generation points and also the four points that experience the lowest voltages in the 11kV network fed by the substation. To understand the relationship between the number of monitoring points and the accuracy of the SVO calculations, one Primary substation will be fully monitored.

3.2.6 TAP Position Monitoring

Knowing the tap position of the transformers in the network is essential in order to be able to calculate the voltages at the locations where measurements are not available, as demonstrated in section 3.2.5. Keeping a historical record of these tap positions, could also provide useful information by showing how the tap position of each transformer changes over time and giving a good indication of the voltage variation in the upstream network. A high frequency of tap position changes would mean that the voltage on the high voltage side of the transformer varies significantly over time, having a negative impact on the tap changer’s lifetime. To be able to understand the impact of SVO on the voltage control equipment, the transformer tap positions will be stored in the Historian Information System. As part of the SVO implementation tap position monitoring will be introduced at a number of locations since currently not all of the transformers have their tap position monitored and communicated to the NMS.

4 Substation Selection Process

4.1 Overview

In the Equilibrium trial area there are 28 BSPs and around 200 Primary substations, out of which only eight of each will be selected for the trials of SVO.

As part of the site selection process, a number of network studies were performed to identify the most suitable substations to be used as part of the trials. The main aim was to ensure that through the implementation of SVO at the selected locations, the learning potential would be maximised.

4.2 Selection Criteria

4.2.1 The bid stage

In the bid stage, 12 BSPs and 10 Primaries were selected out of the 228 sites. This involved performing power system analysis to identify the BSPs that have the highest number of voltage constraints and would therefore benefit the most from SVO. The Primary substations supplied by those 12 BSPs were then investigated to shortlist those with the highest amount of embedded generation connected to their networks, as these would be most likely to have the least headroom for generation and biggest need for optimisation.

Following the bid stage, a number of sophisticated power system studies were carried out to produce the final list of the eight BSPs and eight Primaries to take part in the SVO trials. The criteria taken into account and the procedure followed are described in section 4.2.2 below.

4.2.2 BSP Categories

In the selection of the final eight BSPs, the main aim was to ensure a good representation of the entire network to enable valuable conclusions to be made on the implementation of SVO as business as usual. To achieve this, a combination of substations with different characteristics was required.

For this reason, four categories of substations to be included in the trials were identified each offering different type of learning.

Category A includes the BSPs at which the target voltage can be easily modified even in the worst case operating conditions. The substations which belong to this category will allow the full SVO system to be tested (from receiving the network measurements to applying the optimised settings), with no risk of operational constraints preventing the amendment of the target voltage.

BSPs which can have small changes to the AVC settings in the worst case operating conditions belong to Category B. These substations will provide understanding on the degree of improvement in the target voltage modification capability that can be realistically achieved using a dynamic system compared to the conservative estimated static reductions.

Category C represents the BSPs at which the capability to amend the target voltage is limited and challenging at certain times. Including these substations in the trials will demonstrate how restrictive the existing planning procedures are when analysing constrained sites.

BSPs with very limited to zero target voltage modification capability under worst case operating conditions, belong to Category D. At these sites static changes to the AVC settings are not possible, making SVO the only solution to release network capacity through voltage control. The trials at these sites will provide valuable learning on the benefit that a dynamic voltage control system can have in heavily constrained networks.

The four categories, their description and the learning potential of each are summarised in Table 4-1.

Table 4-1: BSP Categories

Category Name	Description	Static Vs Dynamic Voltage control settings	Learning Potential
Category A	Substations with significant target voltage modification capability. Changing the voltage control settings at these sites is expected to be easily achievable, ensuring the full testing of the SVO solution.	With existing planning tools, static changes to AVC settings are possible.	Demonstration and trial of all SVO system components, from network assessment to target voltage application.
Category B	Substations with good target voltage modification capability. Changing the voltage control settings at these sites is expected to be achievable for the majority of time.	With existing planning tools, small static changes to AVC settings are possible.	Understanding the degree of improvement that can be achieved at sites where static AVC changes are possible compared to dynamic adjustment.
Category C	Substations with limited target voltage modification capability. Changing the voltage control settings at these sites is expected to be achievable but challenging at certain times.	With existing planning tools, static AVC setting changes of very small magnitude are theoretically possible but practically unrealistic.	Understanding how restrictive the existing planning procedures are compared to what can be achieved in real operation at constrained sites.
Category D	Substations with very limited target voltage modification capability. Changing the voltage control settings at these sites is expected to be challenging for the majority of time.	With existing planning tools, static AVC setting changes are not possible making dynamic voltage control through SVO the only solution to release network capacity.	Using SVO to release capacity and improve voltage profiles in heavily constrained networks.

In order to understand in which category each of the 12 BSPs belonged, the networks were analysed using Siemens Power System Simulator for Engineering (PSS/E). This analysis quantified the worst case target voltage reduction that could be applied at each BSP without violating the statutory voltage limits of ±6% and ensuring that no restrictions were imposed on the traditional voltage control of the surrounding transformers.

It involved simulating the network in the most restrictive operational conditions (minimum generation and maximum demand) and calculating the worst case target voltage reduction (*VTreduction*) using:

$$VTreduction = Vmin - 0.94 \quad (1)$$

where *Vmin* is the minimum voltage in the BSP network and 0.94 is the lower statutory voltage limit expressed in the per unit system.

Therefore, *VTreduction* shows by how much the voltage in the 33kV network could be reduced before the voltage at any network node reaches the low statutory limit. The network voltages are reduced by amending the target voltage at the BSP, hence *VTreduction* indicates the reduction in target voltage that can be applied at the BSP while maintaining all network voltages within statutory limits.

To ensure that no restrictions were imposed on the traditional voltage control of the surrounding transformers when the calculated target voltage reduction was applied, the tap positions of all transformers were calculated. A check was then made to confirm that the current tap position was at least three steps away from the top/bottom tap. This confirmed that there was enough room available for the traditional voltage control to be able to regulate the voltage to the target value.

Finally, based on a combination of criteria, two BSPs were chosen from each category, with the third remaining BSP of each group being the backup option.

Table 4-2 below shows the final grouping of BSP categories following application of the method described above.

Table 4-2: VTreduction BSPs

BSP	TARGET VOLTAGE REDUCTION	SUBSTATION CATEGORY
BRIDGWATER	0	Category D
EXETER CITY	0	Category D
STREET	0	Category D
PAIGNTON	0.005	Category C
EXETER MAIN	0.005	Category C
SOWTON	0.007	Category C
WOODCOTE	0.014	Category B
TAUNTON	0.021	Category B
TIVERTON	0.024	Category B
RADSTOCK	0.024	Category A
TOTNES	0.026	Category A
BOWHAYS CROSS	0.054	Category A

4.2.3 Primary Categories

In the selection of the final 8 Primaries, the substations were separated into categories following a similar procedure as for the BSPs. However, due to the lack of load monitoring data available for the 11kV networks fed by the Primary substations, certain inaccuracies were introduced to the modelling. For this reason, the Primary substations have been split to only two categories.

Category 1 includes the substations at which the target voltage modification capability is good under worst case operating conditions. The substations which belong to this category will allow the full SVO system to be tested (from receiving the network measurements to applying the optimised settings).

The substations at which it is challenging to amend the target voltage belong to Category 2. The trials at these sites will provide valuable learning on the benefit that a dynamic voltage control system can have in heavily constrained networks.

The two categories, their description and the learning potential of each are summarised in Table 4-3.

Table 4-3: Primary Categories

Category Name	Description	Static Vs Dynamic Voltage control settings	Learning Potential
Category 1	Substations with good target voltage modification capability. Changing the voltage control settings at these sites is expected to be achievable, ensuring the full testing of the SVO solution.	With existing planning tools some static changes to AVC settings are possible.	Demonstration and trial of all SVO system components, from network assessment to target voltage application.
Category 2	Substations with challenging target voltage modification.	With existing planning tools, static changes to AVC settings are not possible.	Using SVO to release capacity and improve voltage profiles in heavily constrained networks.

Finally, based on a combination of criteria, four Primaries were chosen from each category, leaving one site as the backup option in each.

Table 4-4 below shows the final grouping of Primary categories following application of the method described above.

Table 4-4: VTreduction Primaries

PRIMARY	TARGET VOLTAGE REDUCTION	SUBSTATION CATEGORY
COLLEY LANE	0	Category 2
MILLFIELD	0	Category 2
TIVERTON JUNCTION	0	Category 2
TIVERTON MOORHAYES	0	Category 2
NETHER STOWEY	0.0126	Category 2
MARSH GREEN	0.014	Category 1
STAPLEGROVE	0.0149	Category 1
LYDEARD ST LAWRENCE	0.015	Category 1
WATERLAKE	0.016	Category 1
DUNKESWELL	0.041	Category 1

4.2.4 Practical Criteria

With the BSPs and Primaries categorised into groups dependent on the voltage reduction that could be achieved, a method was developed to score each substation to determine which should be selected for SVO implementation.

Table 4-5 below shows four areas that each substation was scored against along with the weighting of each area.

Table 4-5: Practical criteria for scoring

Area	Weighting
Existing AVC capability	50%
Site Condition	30%
Connected customer impact	10%
Customer connection activity	10%

Existing AVC capability

The capability of the existing AVC equipment at each substation is a key area in deciding which substation should be chosen for SVO. Substations that have already been equipped with modern AVC relays that can be easily adapted for SVO will be more cost effective and involve less risk compared to sites that require AVC relays to be replaced.

Site condition

The condition of the substation where SVO is to be implemented can have a major impact on the success of the trial. Where a substation has equipment that is in poor condition it may generally require more regular maintenance intervals and experience more frequent electrical and mechanical problems. As such it would not be prudent to implement SVO at sites that are in poor condition, due to the fact they could become unavailable during periods of the trial due to outages required for preventive maintenance and fault repairs.

Customer impact

Implementing SVO is likely to result in voltage profiles varying more than compared with the current static AVC set points. Using WPD's knowledge of the network, customers that could be sensitive to voltage variation will be considered when deciding which sites to select for SVO. However, as the voltage will be maintained within permissible limits there should not be any adverse problems with customers' connections.

Customer connection activity

The aim of implementing SVO is to release additional capacity in the network and allow the connection of more LCTs. By implementing SVO in areas that have high levels of customer connection activity the benefits are more likely to be realised during the project lifetime.

4.3 Substations selected for SVO

Table 4-6 and Table 4-7 below show the substations that have been selected for SVO implementation.

Table 4-6: BSP substations selected for SVO

	Bulk Supply Point
1	Bowhays Cross
2	Radstock Main
3	Tiverton
4	Taunton
5	Paignton
6	Exeter Main
7	Exeter City
8	Bridgwater Water Main

Table 4-7: Primary substations selected for SVO

	Primary Substation
1	Waterlake
2	Lydeard St Lawrence
3	Marsh Green
4	Dunkeswell
5	Colley Lane
6	Tiverton Moorhayes
7	Millfield
8	Nether Stowey

Appendix A and B provide tables showing how these substations were scored and ranked.

5 SVO Installation

5.1 Overview

In order for the SVO method to be implemented at a particular substation, the AVC relay controlling the OLTC must be capable of communicating with WPD's NMS and have the functionality to receive new target voltages.

Design work has been completed for each substation site to establish what modifications would need to be completed in order to implement the SVO method. The following section provides an overview of the relay technology available to provide SVO functionality.

5.2 Relay Technology

The last thirty years have seen significant changes in AVC relay technology. The electro-mechanical AVC relay in various forms has been replaced successively by static, digital and numerical AVC relays, each change bringing improvements in control functionality and implementing new techniques not available with older AVC relay types.

The original type of AVC scheme used with electro-mechanical relays was a simple master-follower arrangement where one AVC relay would act as the "master" whilst the other AVC relay would "follow". However, control schemes have evolved from master-follower scheme to allow more sophisticated control by using Circulating Current, Line Drop Compensation, Negative Reactance and Transformer Automatic Paralleling Package (TAPP) methods.

Modern AVC relays need to provide increased flexibility to improve voltage control as well as providing dynamic controls to allow for changing network conditions. For example, when embedded generation is connected on the network, additional signalling will ensure that the contribution from the generator is included in the overall AVC scheme. Additionally older type AVC relays exhibit technical limitations regarding their ability to adjust the network conditions and allow reactive power absorption by transformer tap staggering (the aggregated reactive power absorption could be used to mitigate power flow issues in the transmission network during periods of low demand).

The trial area for Network Equilibrium incorporates substations that have a variety of different AVC relay technologies. Table 5-1 and Table 5-2 below provide a list of BSPs and Primary Substations with their associated AVC relay manufacturer and model.

Table 5-1: BSP AVC Relays

Bulk Supply Point	AVC Relay
Radstock Main	GEC MVGC01
Bridgwater Main	Alstom KVGC202
Street	GEC MVGC01
Exeter City	Alstom KVGC202
Totnes	GEC AVE5
Woodcote	GEC MVGC01
Taunton Main	GEC MVGC01
Bowhays Cross	GEC MVGC01
Tiverton	Fundamentals SuperTAPP n+
Exeter Main	Alstom KVGC202
Paignton	Alstom KVGC202
Sowton	Reyrolle SuperTAPP

Table 5-2: Primary AVC Relays

Primary Substation	AVC Relay
Nether Stowey	GEC MVGC01
Staplegrove	GEC AVE5
Lydeard St Lawrence	Siemens MicroTAPP
Waterlake	Siemens MicroTAPP
Colley Lane	Siemens MicroTAPP
Tiverton Junction	GEC AVE5
Tiverton Moorhayes	Alstom KVGC202
Marsh Green	Alstom KVGC202
Dunkeswell	GEC MVGC01
Millfield	Alstom KVGC202

As can be seen from the lists above, the AVC relays installed at the different sites range from an early GEC AVE5 electro-mechanical relay through to the latest Fundamentals SuperTAPP n+ numerical relay. Figure 5-1 to Figure 5-6 show pictures of the different relay technologies installed at WPD substations.

Figure 5-1: AVE5 AVC Relay

Figure 5-2: MVGC01 AVC Relay

Figure 5-3: KVGC202 AVC Relay

Figure 5-4: MicroTAPP AVC Relay

Figure 5-5: Reyrolle SuperTAPP AVC Relay

Figure 5-6: SuperTAPP n+ AVC Relay

To comply with the full requirements of the SVO method, an AVC relay must exhibit two fundamental features:

- Communication – a protocol, preferably DNP3, to allow communication with WPD's NMS; and
- Hard Voltage Limit – overall voltage range to prevent the system from inadvertently moving outside of limits.

In addition, they must also exhibit at least one of the following features:

- Fine Control – ability to receive specific voltage target settings; or
- Settings Control – ability to receive signals to change to different group settings.

In addition to the requirements of the SVO method, any new AVC relay to be used on the WPD network must also exhibit the following features:

- Tap Stagger – ability to create a deliberate stagger of taps between two transformers to control reactive circulating current and maintain voltage control;
- Line Drop Compensation – feature to maintain remote voltages by adjusting sending end voltage with respect to current; and
- Embedded Generation Perception – ability to incorporate signals from embedded generation to control the overall system voltage.

Table 5-3 below provides an overview of the AVC relays' functionality. The relays listed are those that are already installed in WPD substations with the exception of the A-Eberle REG-D, SuperTAPP SG and MR TAPCON.

Table 5-3: AVC Relay Function Overview

	Fine Control	Group Setting	DNP3 Comm.	Hard Voltage Limit	Tap Stagger	Line Drop Comp.	Embed. Gen.
Fundamentals Super TAPP SG	✓	✓	✓	✓	✓	✓	✓
Fundamentals SuperTAPP n+	✓	✓	✓	✓	✗	✓	✓
MR TAPCON ISM	✓	✓	✓	✓	✗	✓	✓
A-Eberle REG-D	✓	✓	✓	✓	✓	✓	✓
Siemens MicroTAPP	✗	✓	IEC60870-5-103[2]	✓	✓	✓	✓
Alstom KVGC202	✗	2 Groups[3]	RS232[4]	✓	✗	✓	✓
Reyrolle SuperTAPP	✗	✗	✗	✓	✗	✗	✗
GEC MVGC01	✗	✗	✗	✗	✗	✓	✗
GEC AVE5	✗	✗	✗	✗	✗	✗	✗

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[2] MicroTAPP uses IEC60870-5-103 communication protocol which does not interface with WPD's NMS

[3] Only 2 Group Settings are available in the KVGC202 limiting the performance of SVO

[4] KVGC202 use RS232 as the protocol which does not interface with WPD's NMS

The GEC AVE5, GEC MVGC01 and Reyrolle Super TAPP have a number of functional limitations due to the technology available when they were manufactured. Due to these limitations they do not possess the features required for SVO implementation.

The Alstom KVGC202 has the ability to enable two group settings, however the type of communications protocol and inability to receive fine control points mean that it is not suitable for SVO implementation.

The Siemens MicroTAPP AVC relay, despite not being able to receive fine controls, can be configured to have up to six group settings by using auxiliary (Arteche) relays that can be directly controlled by the existing SCADA system. Therefore, the MicroTAPP can be considered for SVO implementation with some additional auxiliary relays and wiring. However, it is worth noting that future manufacturer support for MicroTAPP relays has now ceased.

The Fundamentals SuperTAPP n+ model is able to support the full requirements of the SVO method, however it has one particular disadvantage in that it cannot support tap stagger.

The A-Eberle REG-D, Fundamentals SuperTAPP SG and MR TAPCON AVC relays possess the all the functionality required for SVO. These relays are currently not on the WPD approved relay list but are under consideration for use on the WPD network.

A selection of these relays, subject to approval, will be implemented where required for the SVO selected substations.

Further details of the relays and the functionality can be found in Appendix C. The individual substation reports in Appendix F detail the specific installations and the modifications required to enable SVO.

5.3 AVC Panel

AVC relay panels can be configured and constructed in many different ways with preferences for panel design changing over the years. Electro-mechanical AVC relays, such as the AVE5, can still be found in substations over 40 years old. This type of relay will normally be installed in separate panels along with a number of auxiliary relays to provide time lags, checks, controls and alarms (see Figure 5-1). Replacement of these relays is likely to require complete replacement of the entire front facia of the panel (or replacement of the entire panel itself) due to removal of relays and complete re-wiring of the panel.

More modern AVC panel designs incorporate numerical relays (such as the MVGC01, KVGC202, MicroTAPP etc) that have a vast number of functions embedded within. Therefore this reduces the amount of auxiliary equipment compared with electro-mechanical relays. Should a numerical relay require replacing, it is much less onerous from a practical installation point of view as there will be fewer auxiliary relay interfaces.

The selected substations for Network Equilibrium contain a number of different panel designs which would require modification to allow SVO to be implemented. Descriptions of the anticipated modifications can be found in Appendix D.

6 Next Steps

Following on from this report, the SVO element of the project will enter the build phase. This will require a rolling program of 8 BSP’s and 8 Primary sites, consisting of Site design approval, equipment specification and delivery and installation.

The first site is scheduled for the final design sign off and approval in April 2016, equipment delivery in June 2016 and the installation in July 2016. The program will then continue to roll out the remaining 15 sites with completion targeted for summer 2017.

A report on the “Trialling and Demonstration of the SVO Method”, SDRC-5, is due for submission in April 2018.

7 Risk Register

The Risk Register is detailed in APPENDIX I

8 Appendices

Appendix A – BSP Scoring Matrix
Appendix B – Primary Substation Scoring Matrix
Appendix C – AVC Relay Report
Appendix D – AVC Modification Options
Appendix E – Sample SVO Designs (Waterlake substation)
Appendix F – Substation Investigation Reports
Appendix G – SVO Technical Specification
Appendix H – SVO DNO Workshop Minutes
Appendix I – Risk Register