SP ENERGY NETWORKS

Flexible Networks for a Low Carbon Future

Methodology & Learning Report

Work package 2.4: Integration of Voltage Regulators

August 2015

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2 Executive Summary

Automatic Voltage Regulators (AVRs) have been identified as an enabling technology to achieve the aim of improving the flexibility of the 11kV and 33kV distribution network. Their ability to regulate the voltage on a specific part of the network was recognised as being useful in mitigating against the voltage drops that can occur when networks are reconfigured.

2.1 Project background

Work Package 2 of the Flexible Networks for a Low Carbon Future project looked at various methods that could be used to improve the flexibility of the distribution network to enhance network capacity and defer network upgrades. One method that was considered was reconfiguring of networks to manage the distribution of load. This method is known as backfeeding, it is commonly used to redistribute load to enable parts of the network to be serviced or repaired. During backfeed conditions parts of the network at distance from the primary substation will experience a drop in the voltage. If this voltage drops below statutory levels action must be taken to increase the voltage. Automatic Voltage Regulators are designed to work in just such configurations so were identified as an enabling technology for network reconfiguration,

2.2 Aims and objectives

Automatic Voltage Regulators are not new technology, they are used extensively on the continent, but in the UK they are not commonly used by network designers. AVRs have been installed on the SPD and SPM networks but this has always been done on an ad-hoc basis. As part of the flexible network projects it was possible to carry out controlled tests on the AVRs as well as monitor and record the processes used by SPD and SPM from initial planning through to telecontrol and control room operation. There were four main objectives identified in meeting these aims

- Installation and monitoring of AVRs for identified flexible network test sites
- Testing of AVRs at the Power Networks Development Centre (PNDC).
- Development of an IPSA 2 AVR Model for use in system design
- Implementation of AVRs into business as usual into SPEN

2.3 Outcomes of the project

Of the three trial areas identified for the flexible networks project only one experienced sufficient voltage drop to require voltage regulators to be installed. In order to augment the learning for voltage regulators another site (Ruthin) was identified. Both the Ruthin site and the West New Hall site in St Andrews provided valuable learning into the installation and commissioning of AVRs that will be retained by the business. A standard design for the supporting pole structures was developed and this was amended following the experience of the two installations. Important developments were made in the design and construction of standard telecontrol interface hardware and software components. Part of the project involved getting AVRs from the current ad-hoc arrangements into business as usual. This process involved a useful investigation into how information is exchanged between departments and led to a number of suggestions for process improvements. The testing at the PNDC provided valuable information on the behaviour of the devices under forward and reverse power flows in the two permissible operating modes. As the installation of voltage regulators becomes more widespread the information gained during this testing regime will be used to further inform the development of the power quality and voltage policy. Finally the testing was used to validate the IPSA model of voltage regulators that was developed as part of the project.

2.4 Learning derived from the methods used in the project

There have been a number of learning outcomes as the result of the methods used in this project. From a planning perspective, a methodology has been developed for the use of voltage regulators in an automated network environment. Tools have been developed for modelling the network to select the best location for the voltage regulators. As part of the business as usual process the methodology of locating AVRs for generation connections has also been codified. The process of installing AVRs has been formalised with a standard four-pole supporting structure being developed along with installation guidelines. A standard parameterisation process, using a digital set-up application provided by the manufacturer, has been established to commission the units and store the parameters. Telecontrol functionality for the voltage regulators has been developed and the control rooms in both SPD and SPM have implemented processes to ensure that the units operate safely when connected to parallel networks. All of these improvements have been recorded as part of the business as usual process which was part of the delivery of this project.

2.5 Further developments

There is increased awareness within the industry that AVRs are a useful tool to mitigate against voltage excursion. While this project focused on the use of AVRs as an enabling technology for flexible networks the knowledge gained has meant that AVRs can be installed to mitigate voltage issues whatever the cause. Coopers, the manufacturers of the AVRs for this project, have developed a new controller module. This replaces the 3 individual control units used for this project with a single control unit. This will help simplify the installation and commissioning process making it quicker and safer. There is sufficient room in this new single cabinet to house the telecontrol equipment necessary for the remote control of the AVRs. This will do away with the need for an additional telecontrol cabinet and will further simplify the installation of the AVRs.

SPEN intend that the next generation of telecontrol communications will have increased bandwidth. The increased bandwidth could be utilised by the AVRs and it will be possible, once the system is in place, to read analogue values from the unit. This can be used to give greater visibility to network voltages and power flows as well as being used as a maintenance aid.

3 Introduction

Work Package 2.4 Integration of Voltage Regulators was one of 12 sub packages of the three main work packages that formed the Low Carbon Network Fund (LCNF) Flexible Networks for a Low Carbon Future project. Work package 2 as a whole looked at Dynamic Network Control, the objective of this work package was to improve the flexibility of the 11kV and 33kV networks to enhance existing network capacity. This was done by looking either at technological advances and cost reductions already in use on the EHV networks or at specific issues that limit network capacity. The 4 sub packages of work package 2 were.

- 2.1 Dynamic Thermal Rating of Assets
- 2.2 Flexible Network Control
- 2.3 Energy Efficiency and Voltage Optimisation
- 2.4 Integration of Voltage Regulators

Using a combination of the above techniques a target of creating 20% headroom was set. The intention was that this headroom would defer further network investment for up to 10 years based on current load growth.

The integration of Automatic Voltage Regulators (AVRs) is part of the headroom achieved by flexible network control. AVRs can be seen as an enabling technology for flexible network control, they can be used to counteract the drop in voltage that can occur when the network is reconfigured from its normal configuration to redistribute load. AVRs are not commonly used in the UK and their use as part of a flexible network strategy was considered novel enough to warrant inclusion in the LCNF bid.

The deliverables of work package 2.4 have adapted over the lifetime of the project to account for the changes in circumstance and knowledge gained during the various project activities. Of the three network trial sites chosen for Flexible Networks, only St Andrews required the use of an AVR. This led to the identification of an existing AVR installation in Wales (Ruthin) as a suitable site to augment learning. Trials of the operation and behaviour of the AVRs have been carried out at the Power Network Development Centre (PNDC) This has provided an opportunity to fully test the AVRs in controlled condition at extreme network voltages and with power flows in both directions. This provided a set of performance data that was used for validation of the IPSA model developed by TNEI under the project. The AVR installations at St Andrews and Ruthin have been carried out with the knowledge gained feeding into the business as usual program. This covered procurement installation and integration. Initial stakeholder engagement with other distribution network operators (DNOs), in particular SSE, suggested that there was no immediate desire to approach the Energy Network Association (ENA) to see if these type of units could be certified. As the project progressed it became clear there was a strong business case to have AVRs as a business as usual solution on the SPD and SPM 11kV network, mainly for generation connections[1]. The requirement to develop a 'plug and play' solution has been largely successful. The knowledge gained during the project has been disseminated internally during the business as usual process. The result is that SPEN now has a full set of tools and processes required to design, install and maintain a AVRs for flexible network control.

The initial proposal also considered the use of reactive power compensation in addition to voltage regulators. Early investigation concluded that these units were a mature technology, ready for business as usual adoption and therefore were not considered further in the project.

[1] *TNEI supporting document 8279-33-01-AVR Location Summary*

4 Background

Voltage regulators are specialist transformers that can be used to either increase or decrease the voltage of a network. The core of a voltage regulator is an auto transformer, this is a transformer where the primary and secondary terminals share a single winding. They are lighter and have less losses than a conventional two winding transformer. The automatic voltage regulators used for this project are also fitted with an on-load tap changer and a sophisticated digital controller. Automatic Voltage Controllers are not new technology but have not been used widely in the UK. In the past they have been occasionally used to provide voltage support in rural areas but they are increasingly being installed to mitigate against voltage rise issues caused by generation connected to the 11kV network. One of the challenges raised by the implementation of flexible network control is that reconfiguring networks in order to shift load can result in a voltage drop at the end of some long feeders. Automatic Voltage Regulators can be placed in series on long feeders to boost voltage. This makes them a cost effective way of overcoming one of the issues that may prevent a flexible network program being realised.

The overall majority of AVRs currently connected to the distribution grid are driven by generation connection applications. In these cases the installation of an AVR can remove the voltage rise constraint of a connection application and allow the generator to connect at a point in the network close to the site. The St Andrews installation is the first SPD load based connection in over a decade. There has been little information available with which to develop a justified business case for further deployment of AVRs for both load and generation connections. One of the key outputs of the knowledge gained from the field trials and the PNDC test centre is a set of procurement, installation and integration strategies. These can be used to assess the cost effectiveness of using AVRs as part of a flexible network strategy primarily for flexible network control but also to facilitate the installation of renewable generation on the 11kV network.

5 Details of Work Carried Out

At the inception of the project it was not known if voltage regulators could be successfully used for voltage management in flexible network control systems. The AVRs proved to be a suitable technology that could be applied to both generation and load connections. The field installations at Ruthin and St Andrews provided numerous opportunities for gaining the experience required to feed into the business as usual process. The business as usual process was then used to develop the policy, processes and procedures that will be used for implementing AVRs going forward. One of the stated aims of work package 2.4 was to produce a 'plug and play' AVR prototype system that could rapidly be deployed. SPEN now have a proven pole mounted voltage regulator system available from this project. They have also documented processes for installing, commissioning and controlling AVRs. This can be used to demonstrate that the 'plug and play' requirement has been met. Experience gained at the St Andrews site demonstrated that the process involved in planning, locating and installing AVRs for a flexible network control scheme took more time than for a generation connection. However, the wider Flexible Networks project has developed a methodology that will allow AVRs to be rapidly deployed once the appropriate network location has been determined. The following subsections will cover the main activities carried out for work package 2.4

A three-phase voltage regulator to support a generation connection at Ruthin was installed before St Andrews. This allowed for a focus on the installation of AVRs and in particular the development of the telecontrol requirements. This included the prototype of an interface cabinet and clarification of the radio survey procedures. During this period the three single phase AVR units for the St Andrews installation were available in the workshop for testing. The opportunity was taken to investigate alternative control strategies as well as troubleshooting the GPRS data gathering equipment that was required to provide validation data for the project. A process for locating the AVR at a suitable point on the network needed to be developed and this task was undertaken by TNEI. In addition to the location being electrically coherent it also needs to be in an area that is able to receive radio communication and in a location for which way-leaves can be obtained. In order to model the location a computer model of the AVR was developed in IPSA as part of the TNEI project deliverables. Data to validate this model was provided by data gathered as part of the testing carried out at the PNDC centre.

5.1 Knowledge Gathering/Dissemination

AVRs have been installed to mitigate local voltage issues on the SPD/SPM network as early as 2001. These projects were all one offs so there was no process in place to document the installation for future development. The initial stages of the project therefore involved internal engagement with the various stakeholders within SPEN to assess the status of existing knowledge. A list of voltage regulators existing on the SPD/ SPM network was produced and information gathered on all of these sites. The existing AVRs were all from the same manufacturer (Cooper Power Systems) and supplied in the UK by Langley Engineering. Langley Engineering was active during the project in providing background information on the use of voltage regulators and in providing technical documentation and application notes. They also participated in an AVR knowledge dissemination event held at the PNDC on 10th October 2013. Knowledge gathering continued as part of the business as usual process with information being collected and collated on an ongoing basis. This included investigation into the alternative possibilities for ground mounted units and a review of current ground mounted installations and designs[2]. Research was also carried out into the available design standards[3]. The IEEE standard on AVRs proved to be the most comprehensive; it covered all aspects of AVRs from physical design to type testing and maintenance. Further research was carried out into the various manufacturers of AVRs and an overview was produced to inform the future procurement process[4]. The Coopers AVR is fitted with a sophisticated controller and part of the process in installing the AVR

[2]TNEI supporting document 8279-28-R1-Pad Mounted AVRs
[3]IEEE - STD C57.15-2009 http://standards.ieee.org/findstds/standard/C57.15-2009.html
[4]TNEI supporting document 8279-16-R0 AVR Tank Types

was to review the manuals and produce a set of parameters for the St Andrews test site. By producing a set of parameters for St Andrews it was possible to draw up a set of standard 'base' settings and guidelines for the production of site specific settings. In addition the Coopers ProView software was also used and the suggestion that this was used as a method of archiving and programming the machines was discussed[5]. The Cooper CL6 Controller will be replaced in late 2015 by a CL7 controller and research was carried out on the operation of this unit to ensure back compatibility with CL6 controller and any new functionality that would impact on the current AVR policy[6]. Much of this knowledge gathering was undertaken as part of the business as usual process which is discussed further in section 5.6. Towards the latter part of the project the wider understanding of the operation of AVRs in the business led to a discussion of policy regarding the use of AVRs for generation as well as their use as a flexible network enabling technology. These discussions resulted in an AVR forum held on 28 January 2015 where engineers from all areas of the business came together to discuss future policy. An informed discussion on AVR policy of this type involving engineers and policy makers from all parts of the company would not have been able to take place without the knowledge gathering and dissemination undertaken as part of this project.

5.2 Installation of AVRs for Flexible Network Control

As a demonstration of the effectiveness three sites were chosen as demonstrators for Flexible Network Control. These locations were:

Whitchurch
Wrexham
St Andrews

Following assessment of the three networks, neither Whitchurch nor Wrexham were found to require voltage regulation in a flexible network control scheme and thus AVRs would not be required.

In order not to lose learning from the loss of Whitchurch and Wrexham as AVR network deployments the focus moved to the PNDC to test the AVR units.In addition an AVR installation site not directly linked to the Flexible Networks project was identified. The Tegfa/Cilgoed windfarm at Ruthin in Wales was chosen, this was a generation connection with AVR requiring telecontrol and would provide useful engineering and construction knowledge. Delays in the commissioning of the 11kV network at the PNDC meant that the network was not available for testing the AVR in the timescales originally set out in the program. The Tegfa/Cilgoed windfarm was constructed in late 2013 and was the first AVR deployment to provide feedback to the project. A two pole design was used for this site and a general arrangement drawing was created internally by SPEN[7]. Detailed design drawings for the manufacture of the metalwork were created by Line Design Technology Ltd who would later on be commissioned to provide a new four pole design for St Andrews.

In addition to the pole design, important work on the telecontrol and commissioning of the units took place at the Cilgoed/Ruthin site. Telecontrol is required for all AVR installations on a main line, at a minimum the following inputs and outputs are required (as defined in SPEN policy):

An input to tap all three AVRs to neutral;
An output to indicate that all three AVRs are tapped to neutral;
An input to switch the unit between Auto and Bypass mode (so it doesn't tap back to neutral); an
An output to indicate that the unit is not in Auto mode.

[5]TNEI supporting document 8279-14-R1- West New Hall AVR Settings
[6]TNEI supporting document 8279-21-R0 - Comparison of CL6 and CL7 Controllers
[7]SP4103496 - 11kV three phase pole mounted regulator
[8]LDT-VRCP-001-V1.0 et al

These controls are important from a safety standpoint. It is highly dangerous to connect an AVR to two parallel networks with differing voltage if it is not tapped to neutral. Taking St Andrews as an example this could mean the closing of the Crail Soule normally open point while the line was being fed from St Andrews. If the AVR is not tapped to neutral the differing voltages can cause circulating currents within the unit which can result in catastrophic failure. In addition to tapping to neutral, the unit is also required to be switched out of automatic operation mode so once the unit is set to neutral it does not start to operate the tap changer. The telecontrol interface is required for the unit to be used as part of a flexible network control system as this will involve the switching of normally open points and the exposure of the AVR units to parallel networks while the system is reconfigured.

The task of designing a telecontrol interface was undertaken by a SPM control engineer. The system used an existing piece of telecontrol equipment for a Gas Vacuum Recloser (GVR). This is a pole mounted control cabinet that receives telecontrol singles via a VHF radio signal from a radio repeater at the primary substation. The primary substation is directly connected to the main control room via phone line or fibre optic cable. In addition to the telecontrol design, changes were also made to accommodate an operational policy directive requiring additional functionality for remote control capability. This is to account for a safety alert following a fatality involving the local operation of a tap changer.

This work done on the prototype unit at Cilgoed/Ruthin captured a number of important developments that will be utilised for AVRs both for flexible network control as well generation applications, these are:

- Adaptation of Gas Vacuum Recloser control design for AVR operation;
- Mapping of radio points for AVR;
- Design of interface between GVR and Cooper CL6 unit including identification of suitable latching relays;
- Creation of a Power On SCADA software patch to enable AVR to be displayed as graphic and accept relevant control signals from the control room interface.

This system was successfully installed and commissioned at the site in late 2013.

The installation of the AVRs for flexible network support at the St Andrews site offered a valuable opportunity for some additional knowledge gathering and lesson learnt as will be described below. The AVRs for the St Andrews installation were purchased and stored at SPEN's Glenrothes depot. With the units in storage for a number of months it was possible to develop and test a number of control and data gathering designs under workshop conditions. An alternative telecontrol system was developed based on the original Ruthin design (this was tested successfully in the workshop but proved not to be workable when tested on site). In addition each unit was fitted with a communication card and a fibre optic network established between the three units. This was then fed into an Envoy unit to allow operational data from the unit to be recorded and transmitted to the iHost data acquisition system. A technical note was produced covering the main learning outcomes gained from the work carried out at the Glenrothes Workshop[9]. The study into the location as described in section 5.4 of the AVR at St Andrews was completed and the process of obtaining wayleaves was undertaken. The units were successfully installed using a new four pole design. A software patch was created in order for the voltage regulator to be operated from the control room using the PowerOn System and the unit was prepared for final commissioning and operation.

[9] *8279-05-R2- AVR Testing Learning Outcomes*

5.3 Automatic Voltage Regulator IPSA Model

As part of the TNEI project funding contribution an AVR Model for the IPSA software was developed. This model will form part of the standard IPSA model library and will be made freely available to other IPSA licensees. At a fundamental level the AVR is modelled as a directional load dependant transformer. The software uses a standard AVR symbol and this can be placed in a branch between two busbars. The operation of the model is dependent on the direction of the power flow with respects to the sending and receiving end of the branch. The basic principle is shown in Figure 1.

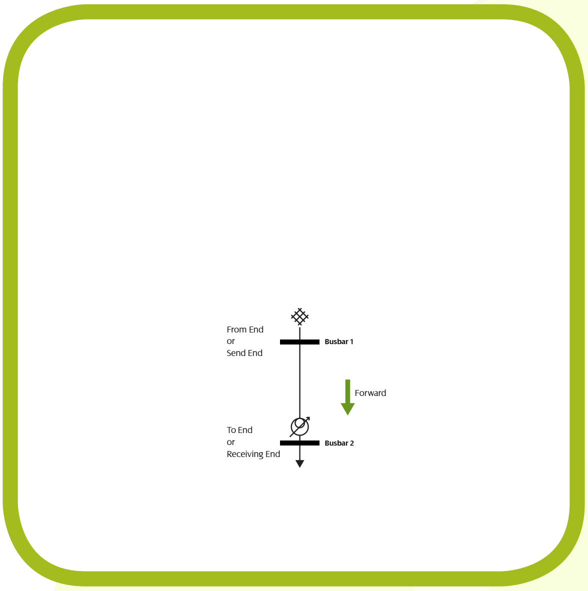

Figure 1 AVR IPSA Model

The core parameters of the model are the same as a standard transformer (rated power & impedance) with voltage regulation range being represented by a tap change function.

The model can be selected to operate in one of the six operating modes listed below. These will dictate how the unit behaves depending on the direction of the power flow.

- Forward Locked Mode
- Reverse Locked Mode
- Neutral Reverse
- Co- Generation Mode
- Normal Bi-Directional
- Reactive Bi Directional

A full description of the AVR model including a description of the above operating modes can be found in the supporting documentation[10].

[10] *8279-33-R0 -Voltage Regulator IPSA Model*

5.4 Location Modelling for AVRs in Flexible Network Control

For the St Andrews network test site, in order to facilitate future flexible network control, an AVR needed to be installed in one of the St Andrews to Anstruther circuits in order to overcome voltage issues during back feeding conditions. Figure 2 shows a high level diagram of the relevant circuits of the St Andrews and Anstruther HV networks. In normal operation the feeder 25 circuit breaker would be closed and would feed the entire network down to the Crail Soule normally open point. In order to facilitate the flexible network strategy the circuit would need to be back fed from Anstruther by opening the Grange NOJA normally open point for example and closing the Crail Soule NOP. During this back feed condition the voltage drops to below statutory limits from St Andrews Bay Hotel onwards so the AVR is used to boost the voltage. Figure 2 also shows the proposed position of the AVR on the network. A detailed report of the full modelling process is available[11] however a brief description is provided here.

The modelling process involves building an accurate physical model of the 11kV network and populating this with loading data, either measured or estimated. The diagram in Figure 2 shows a high level representation of the network, in reality the network required the modelling of 172 transformers, 686 lines and 808 separate bus bars. This is a complex network model and would have been very challenging to create using conventional techniques. The task was greatly simplified by a facility in IPSA that allows for a network model to be generated using Geographical Information System (GIS) data. SPEN has a GIS representation of its 11kV networks and this was used to generate an accurate model from the 33kV primary substations down to each individual 400V low voltage distribution transformers. This model was then populated with equipment rating information supplied by SP.

The next step was to model the loading in the network so that the power flows and therefore voltages would provide an accurate representation of the real network behaviour. The overall loading on St Andrews and Anstruther HV feeders was known from 30 minute data recorded in the SPEN load database system and values of maximum annual demand recorded on ground mounted secondary substations were available. Assumptions were made in modelling the loading of pole-mounted substations based on a proportion of the transformer rating. Loads at secondary substations were initially scaled to match these values consistent with SPEN best practice guidelines. Once detailed load data from the additional monitoring equipment installed on primary and selected secondary substations was available, this was used to refine the loading model. Final validation was carried out by comparing the calculated and measured voltage profiles which provided confidence in the load modelling assumptions applied.

[11] *7640-01 Flexible Networks Series Voltage Regulator Modelling R1D3*

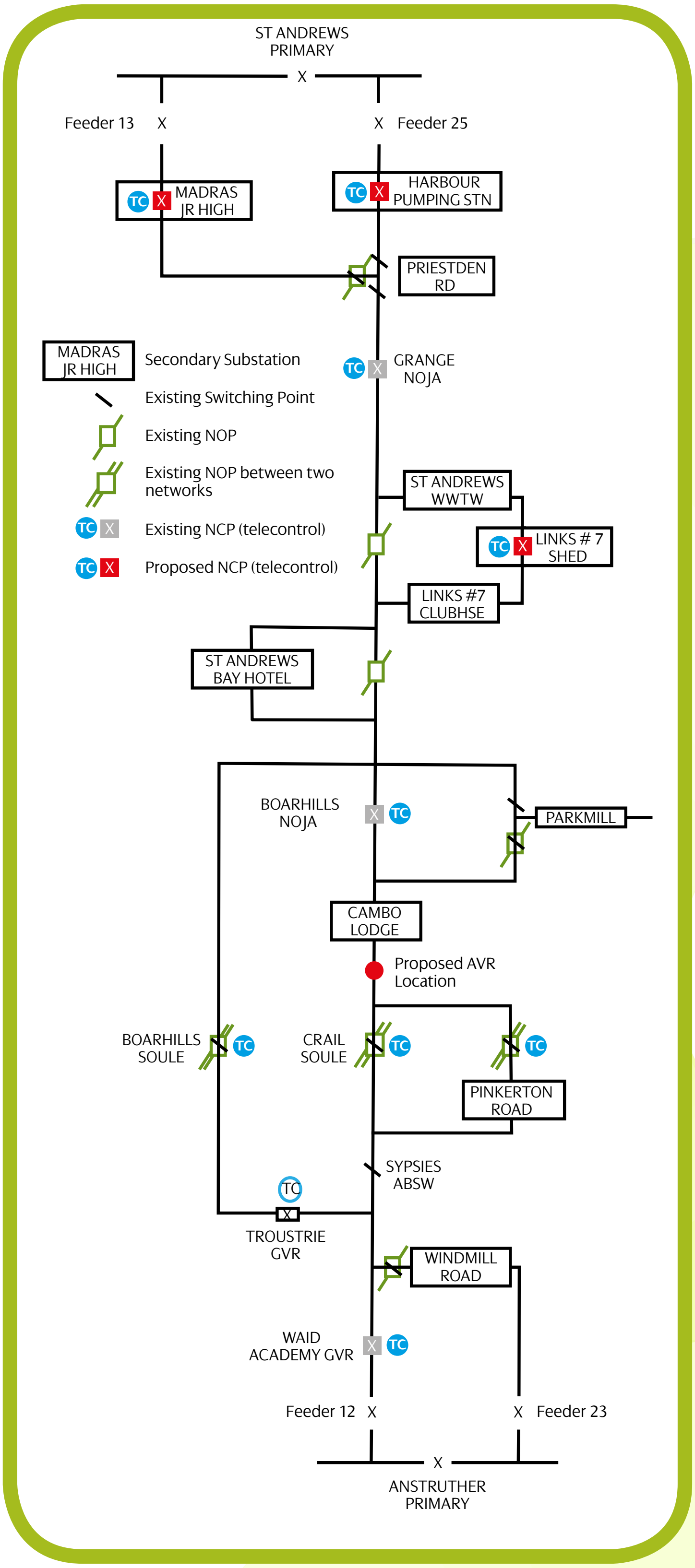

Figure 2 St Andrews - Anstruther 11kV Secondary Network

Once the validated network model had been built work could proceed on selecting a suitable location. A number of base case and test case scenarios were modelled which are detailed in Table 1 below.

Table 1 Base and Test Cases

Case	Configuration	Results / Comments
Base Case 1 – Intact by St Andrews, feeder 12 supplied by Anstruther	Feeder 25 supplied Load at F12 = 1.265MVA	Load at F25 = 3.336MVA
Base Case 1 – Backfeed Anstruther to Grange NOJA	Feeder 25 backfed from Load at F12 = 3.653MVA	Load at F25 = 1.042MVA
	Under voltage occurs from Cambo lodge to Grange NOJA	
Base Case 2 – Intact 25 supplied by St Andrews, feeder 12 supplied by Anstruther	Feeder 13 and part of feeder Load at F12 = 1.265MVA	Load at F13 and F25 = 2.872MVA
Base Case 2 – Backfeed Anstruther to Grange NOJA	Feeder 25 backfed from Load at Anstruther = 3.653MVA	Load at St Andrews = 0.913MVA
	Under voltage occurs from Cambo lodge to Grange NOJA	
Test Cases Without an AVR		
Test Case 1 – Backfeed	All feeder 25 backfed from Anstruther at feeder 25 NOP	Under voltage of 0.824pu occurs
Test Case 2 – Backfeed feeder 25 to Links No. 7 Sheds GMS	Feeder 25 backfed from Anstruther to Links No. 7 Sheds GMS	Under voltage of 0.940pu occurs at links No 7 shed NOP
Test Case 3 – Backfeed feeder 25 to Harbour Pumping Station GMS	Feeder 25 backfed from Anstruther to Harbour Pumping Station GMS	Under voltage of 0.881pu occurs at harbour pumping station NOP
Test Cases With an AVR		
Test Case 1 – Backfeed to Grange NOJA from Anstruther with AVR	Feeder 25 backfed from Anstruther to Grange NOJA	All Voltages within limits, AVR loading 102 Amps
Test Case 2 – Backfeed ALL feeder 25 with AVR	Feeder 25 backfed from Anstruther to St Andrews primary	AVR loading at 240 Amps. Not a viable operating scenario.
Test Case 3 – Backfeed ALL feeder 25 with AVR	Feeder 25 backfed from Anstruther to St Andrews primary	Some minor under voltages on Anstruther feeder 12 AVR loading 188 Amps
Test Case 4 - Backfeed feeder 25 to Harbour Pumping Station GMS with AVR	Feeder 25 backfed from Anstruther to Harbour Pumping Station GMS	All Voltages within limits, AVR loading 144 Amps

Test Case 1 with the AVR located at Cambo Lodge was considered to be the optimum location in terms of maximum load transfer without resulting in network undervoltages. Once this was chosen it was then possible to provide an area of location between pole 87 and pole 125. This gave the network engineers sufficient flexibility to choose a location for which there was radio reception for telecontrol for which they could obtain wayleaves.

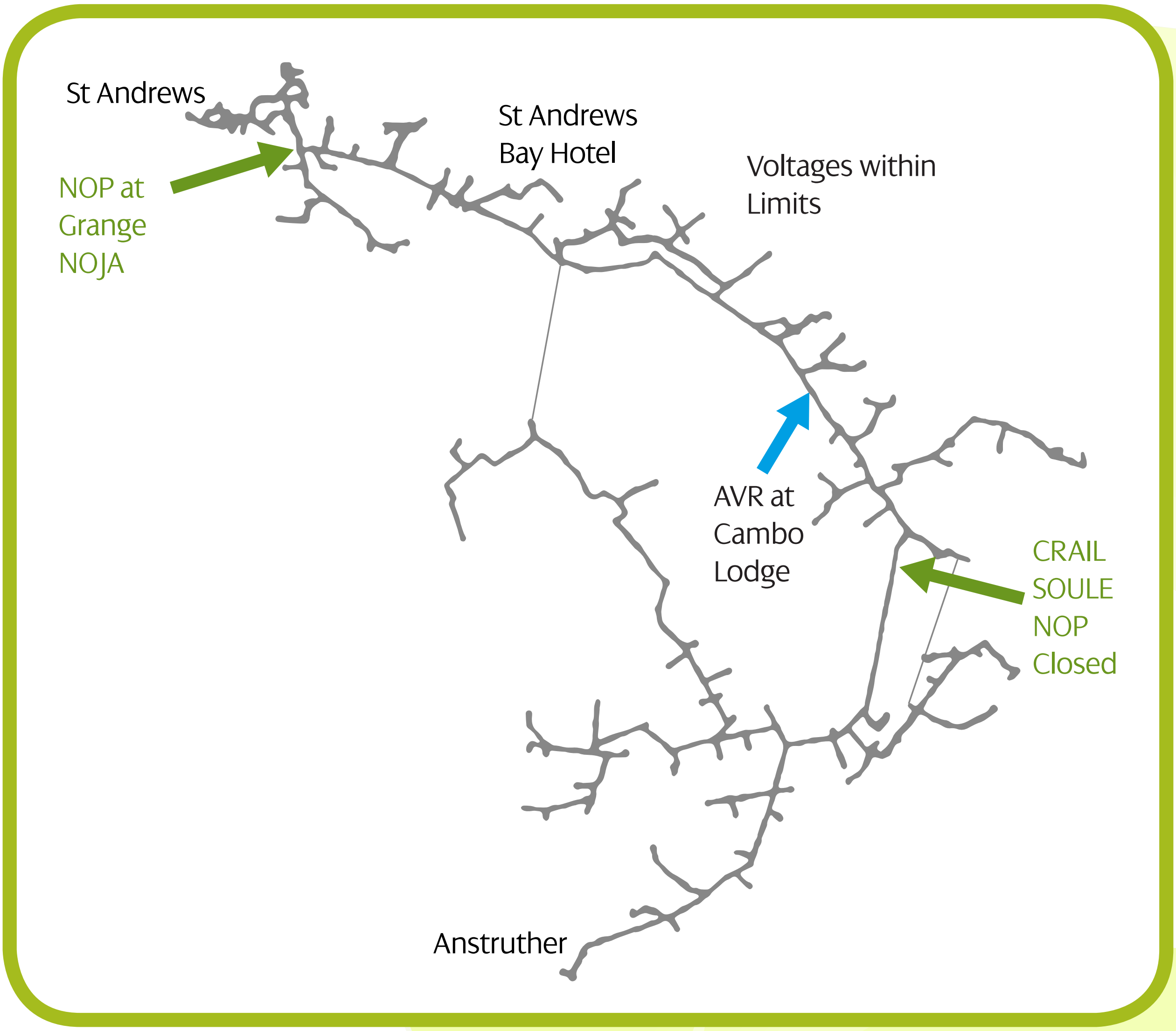

Figure 3 Final Location for AVR at St Andrews

5.5 AVR testing at the Power Network Demonstration Centre

- Testing of the AVRs at the Power Network Demonstration Centre (PNDC) commenced in June 2015 and concluded in July 2015. The PNDC has three Cooper 200A AVRs permanently installed on their 11kV network in a closed delta formation. A set of test procedures were developed[12] to demonstrate the behaviour of the AVRs in various configurations and at extreme network conditions. The tests undertaken demonstrated the control modes and configurations defined in the SPEN voltage policy document. These were: Set voltage – forward and reverse power flow;
- Bandwidth – forward and reverse power flow;
- Time delay – forward and reverse power flow;
- Line drop compensation resistance and reactance – forward power flow, and
- Control operating modes – forward power flow;

Tests were also carried out in the reverse power sensing control feature. These were;

- Bi-directional – forward and reverse power flow
- Co-generation – forward and reverse power flow

The initial set of tests allowed for the behaviour of the AVR to be recorded in controlled conditions and provided valuable information of the control parameters at the extremes of network conditions. Of particular interest was the use of line drop compensation. This function allows a AVR to control the voltage at a point in the network remote from itself. This is not a function that has been used by SPEN before. Having the ability to test this will give the network planners confidence that it can be used on a live network.

The tests of the reverse power sensing control feature were important as these produce a different behaviour of the AVR depending if the unit is operating in Bi-directional or Co-generation mode. Both modes are permitted according to the SPEN voltage control policy but behave differently when the power flow is reversed. This test was conducted using set up shown in Figure 4 where the AVR is connected to the grid at the source side and a synchronous generator on the load side. This set up allowed for the power flow through the AVR to be regulated in both directions. The results of the distributed generation test are shown in Figure 5. The results will be used to provide visual examples of the two control modes described in the voltage regulation policy document.

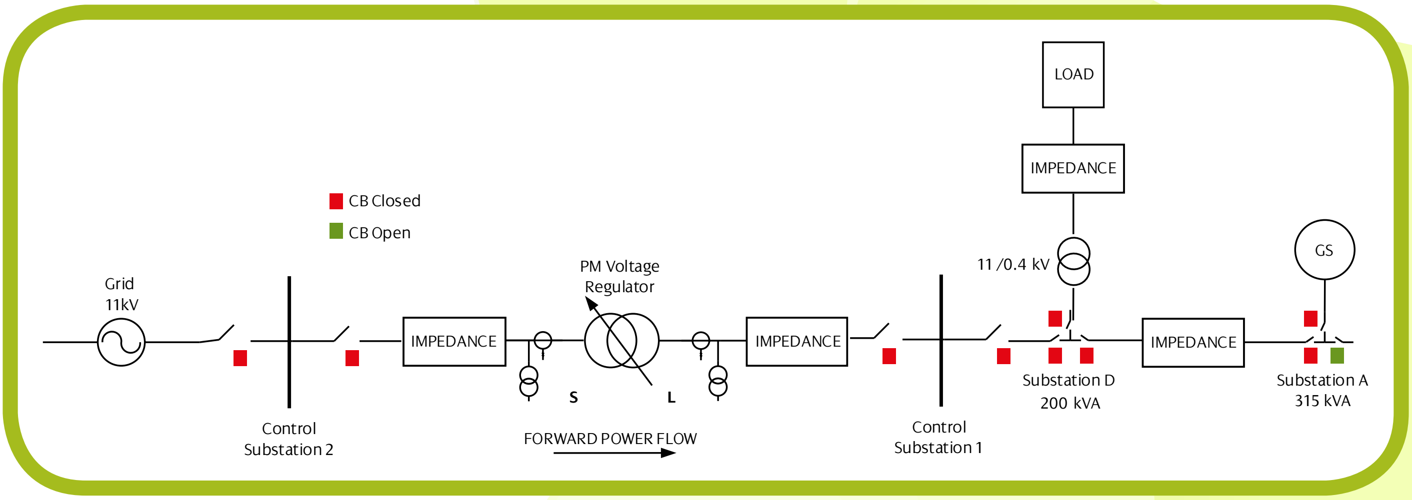

Figure 4 Distributed Generation Test Set Up

[12] *PNDC Test document PNDC/SPEN-002/MS-01*

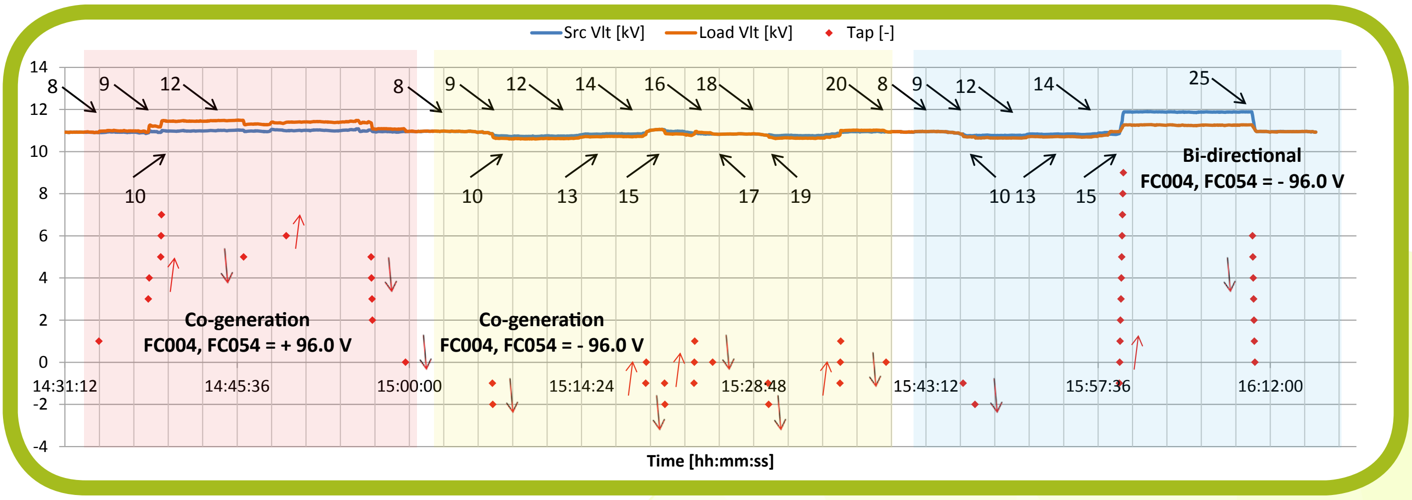

Figure 5 Plot of a Distributed Generation Test

5.6 AVRs into Business as Usual

Business as Usual describes the final stage of the work package where the knowledge and the lessons learnt through implementing the method were documented and disseminated in such a way as to inform SPEN policy and processes going forward. To manage this process a virtual folder structure was created and the following 11 subject headings were chosen.

- Voltage Regulation Policy
- Design Guidance
- Procurement Specification
- Construction Documents
- Commissioning Guide
- Telecontrol Guidelines
- Linesman's Manual
- Maintenance Policy
- Asset Data Model
- Field Operation Instructions
- Control Room Procedures

The intention was that at the start of the process each of these files would contain whatever existing documentation was held by SPEN on the relevant subject. Each category had a manager assigned to it and during the later part of 2014 TNEI conducted interviews with all the main stakeholders. This allowed for the gathering of information and any documentation. The process was kept on track by holding a fortnightly AVR BaU review meeting. This approach meant that at the end of the process a SPEN employee with no knowledge of AVRs would be able to easily locate the documentation on a particular policy or process. A short overview of each of the above headings is provided below.

5.6.1 Voltage Regulation Policy

Previous reference to AVRs was made as part of the quality of supply, system voltages and voltage regulation document[13]. The latter part of this document deals with voltage regulators providing a description of open and closed delta configurations as well as policy on design and operation. As part of the business as usual process voltage regulation policy was discussed and the regulation document was amended to include the following 2 clarifications.

Multiple Regulators: The policy document clarified that there is only to be one voltage regular on a main circuit. Additional devices can be situated on spur lines. Where devices are located on main lines which from part of the a ring or interconnector the devices shall be designed so that they can be bypassed or configured to operate in the reverse direction to ensure operational flexibility.

Rating and Fault Level Capability: The policy confirms that the standard rating for a regulator on the 11kV and 33kV networks will be 200A. The policy clarifies that the fault current level of the unit should be calculated as 25 times the nominal rating of 200A (5kA). It notes that this is less than the maximum fault current level on both the 11kV and 33kV networks. It goes on to point out that as the majority of these devices will be placed on rural networks they will be subject to much lower fault current ratings. Where system fault levels exceed the 5kA limit larger units can be deployed if economical.

During the business as usual program questions were raised about the policy of installing voltage regulators for generation connections. As part of stakeholder engagement it was found that unlike SPEN some DNO's did not allow for the connection of AVRs to facilitate intermittent generation connections. The current SPEN policy document allows for such connections. This has led to an ongoing debate within SPEN leading to an AVR forum held on 28th of January 2014. The forum discussed the issues around installing AVRs for generation connections and agreed that they were more complex than previously thought. Policy in this area is still under discussion and while there is a place for AVRs in facilitating renewable energy generating projects they must be subject to appropriate design guidelines.

5.6.2 Design Guidance

This section looked at what processes the system designers used to model the AVRs on the network. An interview was held with representative of the Competition in Connections department. He was responsible for dealing with generation connections and had a documented process for locating the units to mitigate against the voltage rise caused but the connection of generators. It was clear from the discussions that the competition in connections department held the most up to date model of the SPEN 11kV network due to the level of generation connections it handles. However they did not always have visibility of AVRs being installed for load applications. It was suggested to SPEN that in order for voltage regulator policy to be adopted universally there will need to be visibility of all AVR installations at the early design stage through both sides of the business. Changes of the SPEN business structure to a district structure will take place this year. This should allow the design manager of each district to have an overview of AVRs installed for both load and generation. The IPSA model that will be developed for this project will be presented to the network designers. This event will also be used to remind of the use of AVRs as part of Future Network Control.

[13] *Internal SP voltage policy ESDD-02-008 Issue 2 updated to Issue 3*

5.6.3 Procurement Specification

At present all AVRs on the SPEN network are Cooper Power System units supplied by Langley Engineering. In future these will have to be sourced under a competitive tender by the SPEN procurement department. While carrying out research into the Cooper CL6/7 controller it became apparent that the controller could be used on tap changers and transformer tanks from other manufacturers. In discussions held during the fortnightly AVR forum it was suggested that the Cooper CL6/7 controller should be kept as standard and that the tap changer and transformer tanks could be subject to competitive tender. The reasoning behind this was as follows:

- CL7 controller was available in a single unit able to control up to 3 tanks;
- A standard telecontrol interface for the CL6/7 has been developed, procuring a new type of controller would incur additional engineering costs;
- If there is not telecontrol available the unit has to be operated manually procuring a new type of controller would require additional training to be undertaken to familiarise technicians with the new operation;
- Parameter programming and storage can be standardised using Cooper Proview software.

Using the list of compatible voltage regulators from the CL6/7 manual a technical note was produced on all the manufacturers. Where available, weights and dimensions were provided and web address of all the manufactures were provided for easy reference for future procurement activities[14].

5.6.4 Construction Documents

The installation of the AVR at St Andrews provided an opportunity to review the current design for a pole mounted voltage regulator. Previous AVR installations were carried out using two pole structures which were approved for low risk weather conditions. St Andrews is subject to harsher weather conditions so a more robust design was required. Line Design Technology were commissioned to create a four pole design and produced a general arrangement as well as details of structural metal work[15]. The four pole structure was successfully installed at St Andrews. In discussions held at the AVR fortnightly meeting it was decided that the 4 four design would become the standard regardless of the prevailing weather conditions.. A process is also underway to give the metal work standard stock numbers to simplify the procurement process.

5.6.5 Commissioning Guide

The focus of this section was to look at how parameters for the AVR were generated and loaded into the units prior to commissioning. To date, as there has not been a large scale roll out of these units, this has been done on an ad-hoc basis. The creation of the parameters for the St Andrews regulators provided an opportunity to review the process. Inputs to the parameter process are primarily from the unit name plate, parameters generated by the modelling and by location of the units on the network. The data recorded by the asset database was amended to make sure that the nameplate data and other plant parameters was available in the SAP asset register. It was also suggested that a formal method of recording the output of the modelling process was adopted. Currently the parameter set is generated by the same department that is responsible for protection settings. A paper copy of the parameters is given to an automation-technician to manually program into all three controller units.

[14] TNEI supporting document 8279-16-R0 AVR Tank Types
[15] Line Design Technology drawings LDT-131-VR-4IL-001-GA & LDT-131-VR-4IL-003-V1.1

This method is not ideal as it is prone to manual error in the data entry process it is also difficult keep accurate records of the settings of each unit. It has been suggested that the Cooper Proview software be used to generate parameter sets in the office which can then be downloaded into the unit using a laptop or a USB stick/ memory card onsite. By using this method the configuration files generated by the software will provide a record of the unit settings and the risk of incorrect data input is reduced.

5.6.6 Telecontrol Guidelines

It is a requirement for safe operation of AVRs that the tap changer is set to neutral and the unit is taken out of automatic operation before it is bypassed. Damaging circulating currents in the shunt winding can occur when this happens which can lead to catastrophic failure of the unit. Consequently it is recommended that all units are fitted with telecontrol to switch to neutral and take the unit out of automatic operation. This is especially true of units connected to facilitate flexible network control that are located near a normally open point. A telecontrol interface was developed and commissioned for the Ruthin installation that will be adopted as a standard unit for new and existing units. The current VHF radio network used by SPEN has limited band width and as such there is only limited control of the AVRs. An updated UHF network with increased bandwidth is planned for the future which will allow more operational data to be downloaded. This could be utilised in a performance rather than time based maintenance scheduling.

5.6.7 Linesman's Manual

The linesmen responsible for installing the St Andrews regulators were asked for feedback on the process. They responded that both the metalwork and poles arrived correctly and that the drawings for the 4 pole design were fit for purpose. There were no particular difficulties that would require changes to the linesman's manual. They did note that the pilot pin support bar was not required as the St Andrews installation was on short poles. It has been suggested that this item is listed as optional for long pole installations on the drawing.

5.6.8 Maintenance Policy

Under the SPEN maintenance policy AVRs are classed as tap changers and as such have an annual minor inspection and a six yearly service (removal from site for servicing). AVRs have an existing maintenance policy document[16] and this was reviewed during the fortnightly AVR forum review meetings. The only change that was suggested was that the annual review also included taking a record of the number of tap change events. The Cooper manual notes that the maintenance interval can be based on the number of tap events rather than being time based. Taking an annual reading of the tap events will indicate if a service is required before the 6 year interval. It will also provide additional data to inform future maintenance policy which may in the future be duty rather than time based. In addition to the maintenance policy it was also decided that the maintenance be carried out by external contractors.

5.6.9 Asset Data Model

Iberdrola use SAP data management system to manage their assets. The current SAP data model was reviewed and a number of changes suggested. Additional nameplate data fields were added so the unit data for parameter set up was available to the protection engineers. Data fields to record the frequency of tap change events were also added to facilitate a duty based maintenance program in the future.

[16] *EATON Coopers maintenance manual Tran-10-122 Issue 2*

5.6.10 Field Operation Instruction

As the majority of the Automatic Voltage Regulators on the network are not under telecontrol it is necessary for a technician to attend site to ensure the unit is in neutral during times when the network needs to be reconfigured. Normally overhead pole mounted equipment is either turned on or off using an insulated pole. The AVRs can present an unfamiliar operational interface as they are not common on the network and are operated from a control panel rather than manually with a pole. The roll out of the new telecontrol design will result in less operation needing to be carried out in future however manual operation will still occasionally be required. A review of the available training and operational instructions within SPD/ SPM showed that both needed updating. Short training videos viewable on handheld devices have previously been used by SPEN to demonstrate operation of various items of plant. A video showing how to tap the AVR to neutral and switch it out of automatic operation will be produced. In addition operation of AVRs will be included as part of switching training and it was suggested that the AVRs installed at the PNDC could be used as this is located next to the SPEN training facility in Cumbernauld.

5.6.11 Control Room Procedures

The policy towards the control of AVRs has been developed by the control engineers in the SPM control room in Prenton. They had the first telecontrol devices on the network and developed system to ensure the units were not connected to a parallel network unless they were tapped to neutral. A Technical Limitation Record (TLR) is attached to any normally open point to warn if an AVR needs to be tapped to neutral prior to switching. This system will be adopted by the SPD control room for the St Andrews regulators and the other regulators that will be coming under telecontrol.

6 The Outcomes of the Project

The project has resulted in a raised the awareness of voltage regulators throughout all areas of business within SPEN. The two operational sites and the PNDC tests allowed information to be gathered on the operation of AVRs for both load and generation connections as well as, in the case of the PNDC tests, at the extremes of network operating conditions. Although the original aim of the project looked at AVRs as an enabling technology to facilitate network reconfiguration the raised awareness also resulted in the business looking at the company's policy in regards to the installation AVRs for renewable generation connections. AVRs can be used to facilitate the connection of renewable energy projects by reducing the extent of voltage rise caused by generation connections. This has allowed generation projects to connect without the need for network upgrades. Most of the tools and techniques developed for the load based AVR connections are applicable to generation based projects. The use of AVRs to facilitate renewable generation connections can be seen as an unforeseen benefit of the project. Discussions within SPEN are ongoing as to the development of policy towards the use of AVRs for renewable energy projects. The data and knowledge gained during this project has proved invaluable in informing these discussions.

7 SPEN Required Modifications to the Planned Approach during the Course of the Project

The Project Delivery section of the full submission document set out some milestones to be achieved by Work package 2.4 during the project. The completion of these milestones was updated as part of the change submission. These milestones are presented below with the revised dates in red.

Completion of detailed design specifications. Q3 1012
Procurement of voltage regulator sets. Q4 2012 (Q1 2014).
Completion of prototype testing at the PNDC. Q2 2013 (Q2 2014).
Installation and verification of packaged device. Q3 2013 (Q2 2014).
Completion of packaged device network testing. Q2 2014 (Q2 2015).
Development of a functional specification suitable for certification. Q3 2014 (Q2 2015).

The initial set dates for activities happening at the PNDC had to be revised due to delays in the commissioning of the PNDC network.

The inital proposal was to develop a functional design specification and, along with the involvement of other interested DNOs, to put forward an AVR for certification by the Energy Network Association (ENA). Initial research showed that the existing IEEE[17] standards were very comprehensive and the development of a functional design specification and ENA certification was not required. According to the original project plan, activities focused on the AVR installations at St Andrews, Wrexham and Whitchurch.. A generation led connection for Ruthin windfarm in the SPM region was identified which provided additional learning given the removal of the requirements for AVR installation at Whitchurch and Wrexham (following detailed analysis). The AVRs installations provided valuable engineering learning outcomes in terms of installation and telecontrol. With the St Andrews AVR installation there were a number of unrelated project delays that moved the network testing deliverable. A prerequisite for carrying out location modelling for the AVRs was the need for detailed data from the primary and secondary substations. Delays in the installation of network monitoring equipment meant that the location modelling was delayed. Once the relevant data was received the report on location modelling for St Andrews was completed in early Q3 2014. The voltage regulators had already been procured and installation proceeded fairly quickly. The units were installed and energised by early Q4 2014. It was not possible to get the units under full telecontrol at this time as there was a business as usual upgrade happening to the PowerOn control system. The unit was able to be put under telecontrol in early Q1 2015 and the St Andrews units were able fully commissioned by the end of Q1.

[17] *IEEE-RTD C57.15-2009*

8 Business Case and Plans for Rollout

This project has shown that the use of Voltage Regulators as an enabling technology for flexible networks is justified. An increase in demand would normally trigger the reinforcement of the 11kV network. This would involve additional cabling and the installation of a secondary transformer. By reconfiguring the network at certain times it is possible to utilise unused capacity and defer the need for traditional reinforcement work. This report describes how it is often necessary to install voltage regulators on a reconfigured network to mitigate against voltage excursions.

The business case for the use of voltage regulators rests on the difference between the cost of a traditional upgrade and that of installing voltage regulators. As part of the flexible networks project deliverables a Cost Benefit Analysis for voltage regulators was prepared. This identified the cost (per kVA) for traditional reinforcement and that of installing a set of voltage regulators.

8.1 Business Case for 11kV networks

A generic cost of £225/kVA has been allocated for 11kV reinforcement which includes a secondary transformer and additional 11kV cabling. The cost of the installation of a set of voltage regulators as part of normal business has been calculated at £122,200 which equates to £87/kVA as calculated in the CBA. The potential amount of capacity that can be released by this project is 1400kVA. Based on the above figures the financial benefit for this project is:

Base Cost	£225 x 1400 = £315,000
Method Cost	£87 x 1400 = £121,800
Financial Benefit	£193,200

8.2 Plans For Roll Out

A number of activities carried out during this project have meant that in future these tasks can be carried out a significantly less expense. The main area of these savings are in network modelling, engineering and project management. The project required that the demonstration network be modelled in terms of voltage profile and AVR locatoion. This allowed for a number of techniques and tools to be developed that can be used to carry out this work much more efficiently for future projects. The documentation of the installation process for AVRs for the project has allowed for the generation of standard plans and procedures. This means that in future the installations of AVRs on the network will be a more efficient process.

9 Lessons Learnt for Future Innovation Projects

The process of implementing the AVRs into business as usual was particularly successful. As a large organisation SPEN has a vertical structure with many specialist departments. This does not lend itself to business as usual activities which require a more horizontal approach through all the disciplines. By implementing business as usual the interactions between the various departments became clearer. It was possible to identify aspects of information exchange and working practices that could be improved. The business as usual approach showed that there is a clear line running through from design, procurement, installation, commissioning, control and operation and maintenance of plant. It was clear that this process is technology neutral and will be used in the near future as SPEN start to install STATCOMs on the distribution network for voltage support.

10 Project Replication

Work package 2.4 has produced sufficient knowledge so that if a future Flexible Network Solution required an AVR there are well documented tools and processes to allow it to be modelled, located, installed, commissioned, controlled and maintained. The business as usual process has resulted in a suite of documentation being available to provide information to SPEN employees at every stage of the process.

The concept of the virtual folder structure and the regular forum meetings used to manage the business as usual process was shown to be successful and is being implemented for future projects. SPEN are in the process of installing STATCOMS on the distribution network. These units are new to SPEN and pose similar challenges in terms of design procurement, installation and operation as AVRS. The business as usual process will be used from the inception to ensure that these units can be successfully integrated into the business.

11 Planned Implementation

The AVRs installed at West New Hall will continue to provide valuable data as they are used to provide voltage regulation during times when the network is backfed from Anstruther, The development of the telecontrol hardware and software for the AVR has allowed for a standard design to be rolled out to a number of existing units on the network. The result is that these units can now be controlled remotely. They do not require site access to switch to neutral in times on network reconfiguration.

12 Contact details

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