Customer-Led Network Revolution

Lessons Learned Report

Enhanced Automatic Voltage Control

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Glossary

ADSL	Asymmetric Digital Subscriber Line
ASHP	Air Source Heat Pumps
AVC	Automatic Voltage Control
BaU	Business as Usual
BS	British Standards
BT	British Telecom
CDM	Construction (Design and Management) Regulations
CLNR	Customer-Led Network Revolution
COSHH	Controls for Substances Hazardous to Health
DNO	Distribution Network Operator
DNP	Distributor Network Protocol
DSR	Demand Side Response
DSSE	Distribution System State Estimator
DVSF	Distributed Voltage Sensitivity Factors
EAVC	Enhanced Automatic Voltage Control
EES	Electrical Energy Storage
EHV	Extra High Voltage
ESQCR	Electricity Safety, Quality and Continuity Regulations
EV	Electrical Vehicles
FAT	Factory Acceptance Testing
FDWH	Flexible Data Warehouse
GRP	Glass Reinforced Plastic
GPRS	General Packet Radio Services
GUS	Grand Unified Scheme (Control Infrastructure)
HV	High Voltage
ISU	Isolated Supply Unit
I/O	Input/Output
ITT	Invitation To Tender
kVA	Kilovoltamperes
LL	Lesson Learned
LV	Low Voltage
LCNF	Low Carbon Networks Fund
LDC	Line Drop Compensation
MCB	Miniature Circuit Breaker
MR	Maschinenfabrik Reinhausen
MVA	Megavoltamperes
NEDL	Northern Electric Distribution Ltd
NMS	Network Management System
NPg	Northern Powergrid
NPS	Network Product Specifications
OLTC	On-Load Tap Changer
OSR	Optimal Solutions Report
PLC	Programmable Logic Controller
PV	Photovoltaic
RDC	Remote Distribution Controller
RMU	Ring Main Unit

RTTR	Real-Time Thermal Ratings
RTU	Remote Terminal Unit
SAT	Site Acceptance Testing
SLD	Single Line Diagram
ST	Single Tender
VEEEG	Validation, Extension, Extrapolation, Enhancement, Generalisation
VPN	Virtual Private Network
VVC	Voltage Var Control
YEDL	Yorkshire Electricity Distribution plc

1 Executive Summary

The Customer-Led Network Revolution (CLNR) project has successfully pioneered trials of Enhanced Automatic Voltage Control (EAVC). One of a number of smart solutions being trialled through Northern Powergrid's Low Carbon Networks Fund (LCNF) CLNR project, EAVC solutions perform in a similar way to traditional Automatic Voltage Controllers. However, the key differential is that EAVC's voltage setpoints can be adjusted remotely through a communications channel by an Active Network Management system, such as the Grand Unified Scheme[1] (GUS). As a result of the wider control, voltage is regulated at strategic points for the benefit of the network as a whole. This addresses the problem of conventional AVC schemes operating independently with no interaction with the network, beyond a local busbar measurement.

Several design options were considered for each of the EAVC solutions within the CLNR project, with final decisions concluding that some of the schemes were going to interface with existing on-site control devices. The definitive solutions trialled as part of this project were:

- On-load tap changing distribution transformers
- Primary AVCs with the ability to accept voltage setpoints from a remote source
- In line regulators, applied at HV and LV
- A shunt capacitor bank.

All solutions have been resilient and are still fully operational on the network.

Lessons learned for each of the network-based technologies were gathered throughout the project via a series of structured workshops. The workshops were complemented and supported by site visits and follow-up with key personnel to reflect on the progress of the project and any aspects which challenged or offered learning opportunities.

The highlights from the project and the analysis performed on the data from the trials concluded that:

- The innovative voltage control solutions trialled in CLNR have shown greater headroom than conventional practices to allow increased connections of load or generation, whilst maintaining compliance with statutory voltage limits;
- Northern Powergrid has built significant expertise to be able to apply novel voltage control solutions, such as on-load tap changers on distribution transformers, in a Business as Usual context;
- The academic analysis provided key outputs regarding headroom achieved and observations on which solutions work better and where;
    - HV/LV distribution transformers with OLTC which operate based on local measurements can allow additional connections of Low Carbon Technologies (LCTs), such as heat pumps (HPs), electric vehicles (EVs) and solar photovoltaics (PV);
    - HV/LV distribution transformers with OLTC operating under a wider control scheme can allow more connections of LCTs;

[1] Grand Unified Scheme: An Active Network Management system that was created as part of the CLNR project.

- The HV regulators in the CLNR project, operating in conjunction with a wide area control scheme, could increase allowable HP and EV connections significantly, but would have no benefit for additional connections of generation. This was due to the regulator design being voltage boost only, which cannot mitigate voltage rise. Regulators with both boost and buck capability provide benefits for demand and generation LCTs;
- Shunt connected capacitor banks can be used to increase connections of demand based LCTs (e.g. HPs and EVs), however cannot offer network benefits for generation connections as they serve to only boost voltages. The location of capacitor banks is an important factor in determining the benefits.

This report presents the lessons learned relating to the implementation of EAVC systems on the HV and LV network, both where the project has been successful and where, with the benefit of hindsight, a different approach could be adopted for future implementation. The key outputs are presented in the relevant sections, and fall within the following topics:

- Design, Specification Development and Procurement
- System Integration and Supplier Liaison
- Health and Safety
- Site Selection, Logistics, Installation and Construction
- Commissioning
- Training, Skills, Operation and Maintenance.

Although not specifically included in this report, but as a result of the learning and experience gained during the CLNR project, a new voltage control policy is being developed to allow, where the economic case is justified, inclusion of the new technologies and techniques in the network.

The three key lessons learned are listed in the table below:

Item	Details	Reference
1	Early engagement with Health and Safety stakeholders and working groups proved highly beneficial. The identification of hazards and the mitigation measures to reduce risk has been well received by our Health and Safety colleagues, the network control engineering and technical services departments and the wider industry stakeholders. Integral safety features and procedural adherence enabled successful trialing of prototype equipment.	EAVC LL 6.1 EAVC LL 6.2 EAVC LL 6.4 EAVC LL 8.3

2	Managing change and integrating combinations of novel technologies onto the network, required a higher degree of specialist input than anticipated. Technical services key personnel are essential to the successful integration and development of enhanced voltage control and advanced control systems, the development of both in parallel is not advisable for future projects of such scale. Confidence in new technology is realised from experience with it, an amount of expert thinking time to consider all outcomes is required and is not avoidable.	EAVC LL 4.4 EAVC LL 4.5 EAVC LL 4.6 EAVC LL 4.7 EAVC LL 4.9 EAVC LL 8.2 EAVC LL 8.3
3	Communications infrastructure and GPRS communications in particular have identified that GPRS is insufficient in most cases for control purposes. The future roll out of smarter grid equipment such as transformers and regulators, plus the additional physical size required for them and the associated monitoring of networks is likely to be a burden for DNO's. The integration of substation controllers, configured to manage local devices and cope safely with communications loss is a robust and, potentially, inexpensive way to manage enhanced voltage control devices.	EAVC LL 5.2 EAVC LL 5.3 EAVC LL 7.1 EAVC LL 8.3

2 Introduction

The Customer-Led Network Revolution (CLNR) project is a four-year project, led by Northern Powergrid, trialling Smart Grid solutions on the distribution network as well as creating smart-enabled homes to give customers more flexibility over the way they use and generate electricity. The results will help the industry to ensure the electricity networks can handle the mass introduction of solar PV panels, electric vehicles and other low carbon technologies.

The objective of the CLNR project is to understand five Learning Outcomes, which are:

- Learning Outcome 1 – What are the current, emerging and possible future customer (load and generation) characteristics?
- Learning Outcome 2 – To what extent are customers flexible in their load and generation, and what is the cost of this flexibility?
- Learning Outcome 3 – To what extent is the network flexible and what is the cost of this flexibility?
- Learning Outcome 4 – What is the optimum solution to resolve network constraints driven by the transition to a low-carbon economy?
- Learning Outcome 5 – What are the most cost effective means to deliver optimal solutions between customer, supplier and distributor?

The CLNR project aims to understand the value of the different solutions in terms of being able to defer or avoid investment in conventional reinforcement of the distribution network, and so facilitating the transition to a low carbon economy while minimising costs. The project has studied how this can be achieved by incorporating three network based technologies: Enhanced Automatic Voltage Control (EAVC), Real Time Thermal Ratings (RTTR) and Electrical Energy Storage (EES); in addition to customer flexibility solutions.

This report documents the lessons learned about EAVC from the process of initial design, through commissioning, to operation and maintenance and is intended to support organisations considering implementing EAVC on the transmission or distribution network.

2.1 General description of Enhanced Automatic Voltage Control (EAVC)

Northern Powergrid has successfully trialled several EAVC solutions whose function, although similar to traditional Automatic Voltage Controllers, differs in that voltage setpoints can be adjusted either locally by a Substation Controller, or remotely by an Active Network Management system – the Grand Unified Scheme (GUS) – which controls and receives network information from various smart solutions included in the CLNR project.

An EAVC device may be instructed to change its output voltage even when voltages at that node are within limits due to a remote communication from another part of the network. This is shown in Figure 1 where the yellow and the dotted red lines represent (a) the output of an EAVC device whose setpoint was remotely changed after the Timer period had elapsed and (b) the output that a standard AVC would provide under the same network conditions with only localised operation mechanisms, respectively.

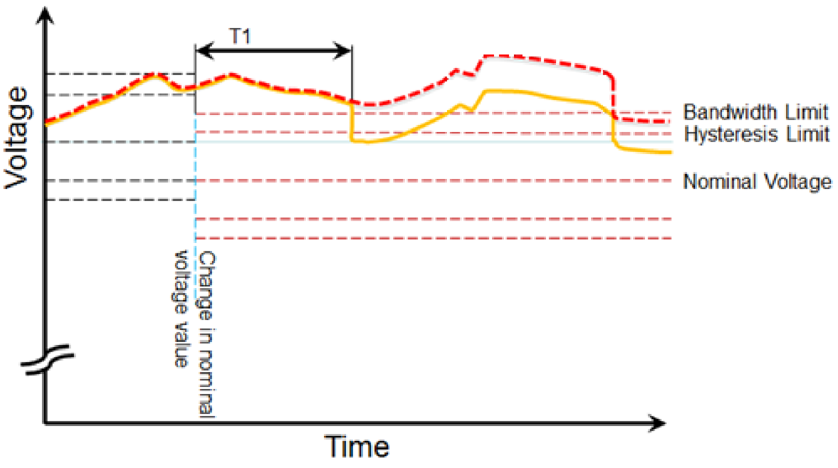

Figure 1 – EAVC Voltage Regulation Function

The ability for voltage set points to be remotely configured represents only a small change in operating philosophy for an AVC device yet it allows it to be influenced by a wider control scheme. The feature is also available in existing commercial products.

2.2 Process and methodology for gathering EAVC lessons learned

Lessons learned were gathered via a series of structured workshops which were complemented and supported by a series of site visits.

The Lessons Learned Workshops allowed personnel specialising in all aspects of the project – ranging from procurement to health and safety, commissioning and project management – to reflect on the progress of the project and any aspects which challenged or offered learning opportunities.

Sections 4 to 9 below highlight the outcomes of the structured EAVC Lessons Learned Workshops. These outcomes are reinforced by additional inputs from specific reference sources and subsequent follows-up with key CLNR project staff

3 Enhanced Automatic Voltage Control Overview in the CLNR Project

This section presents the background for the locations where EAVC systems were commissioned, their current deployment status and the voltage control benefits that they can bring to the network.

3.1 Implementation and network applications

Five EAVC schemes were identified for trials in four of the Northern Powergrid network test cells as part of the CLNR project. These are presented below:

- **Primary Substation**
  - **EAVC1: primary transformer with OLTC.** Control at Primary Substations is a well-known area for DNOs. The CLNR project has trialled its interaction with downstream nodes; in order to understand the interoperability of further control in the network, solutions were implemented at Denwick Primary Substation in Denwick and Rise Carr Primary Substation in Darlington, both of which are located in the North East of England.
    - Denwick Primary Substation has two oil immersed 20/25MVA (ON/OFN), 66kV/22kV transformers incorporating On-Load Tap Changers (OLTC) with a ±10.5% voltage range in fifteen 1.5% steps.
    - Rise Carr Primary Substation has two oil immersed, dual ratio, 15MVA, 33/11.5/6.4kV transformers, incorporating On-Load Tap Changers (OLTC) with a -15% to +4.5% voltage range in fourteen 1.5% steps.
- **Distribution Substation**
  - **EAVC2: OLTC on HV/LV (distribution) transformers.** The introduction of generation into a Low Voltage distribution network can lead, during periods of low demand, to reverse power flow through the Distribution transformer resulting in voltage rising above statutory limits. To investigate solutions to these issues at distribution substations, transformers with OLTC were implemented at Mortimer Road, Wooler Bridge and Darlington Melrose, located in the North of England.
    - Mortimer Road consists of an in-door substation connected to the Photovoltaic Test Cell. The substation has an 11kV supply connected to a close-coupled 800kVA 11,000V/433V transformer in delta star formation.
    - Wooler Bridge consists of an in-door substation in the Rural Test Cell. The substation has a 20kV supply connected to a close-coupled 500kVA 20,000V/433V transformer in delta star formation.
    - Darlington Melrose consists of an outdoor substation connected downstream of Rise Carr primary substation in the Urban Test Cell. It has a 6.1kV supply connected to a 500kVA 6100/433/250V transformer in delta star formation.
- **HV Feeder**
  - **EAVC3: HV in-line regulator.** In-line voltage regulators can boost or buck the voltage along a feeder to compensate for any voltage drop due to demand or voltage rise as a result of generation. Modern voltage regulators can also cope with bi-directional power flows. For CLNR, existing regulators were used at Glanton and Hepburn Bell, both boost only, and both located in the North East of England on the Rural Test Cell.

- Glanton has a Bush 10 MVA Regulator capable of providing 10, 1.25% incremental steps to the input voltage of 20kV; with a maximum output voltage of 22.5kV.
- Hepburn Bell has a Bush 5 MVA Regulator capable of providing 10, 1.25% incremental steps to the input voltage of 20kV; with a maximum output voltage of 22.5kV.

- **EAVC4: HV switched capacitors.** Capacitor banks compensate for reactive power on the circuit, which can reduce voltage drops, particularly for long spans of overhead line. For CLNR, an existing switched capacitor bank was used at Hedgeley Moor on the Denwick HV system in the Rural Test Cell. It consists of two banks of three capacitors that increase/decrease the network voltage by switching capacitance in stages, controlled by an AVC relay.

- **LV Feeder**
  - **EAVC5: LV feeder regulation.** LV regulators can manage voltages on individual LV feeders. They can be located along a low voltage feeder or connected to a disparate LV feeder in a distribution substation. The EAVC5 solution was implemented at Sidgate Lane in Hexham using an in-line voltage regulator with EAVC installed on a feeder that formed part of the heat pump test cell i.e. a high proportion of the customers connected to the feeder had heat pump installations, and therefore, volt drop at the end of the feeder was a potential concern.

EAVC1, 2 and 4 were based on existing voltage control devices, the upgrade works included changing the AVC relay to a type that could accept remote set points and installing a substation controller. For EAVC2 and 5, new assets were installed.

Figure 2 below provides an overview of where the EAVC devices fit into the overall context of the HV and LV distribution system.

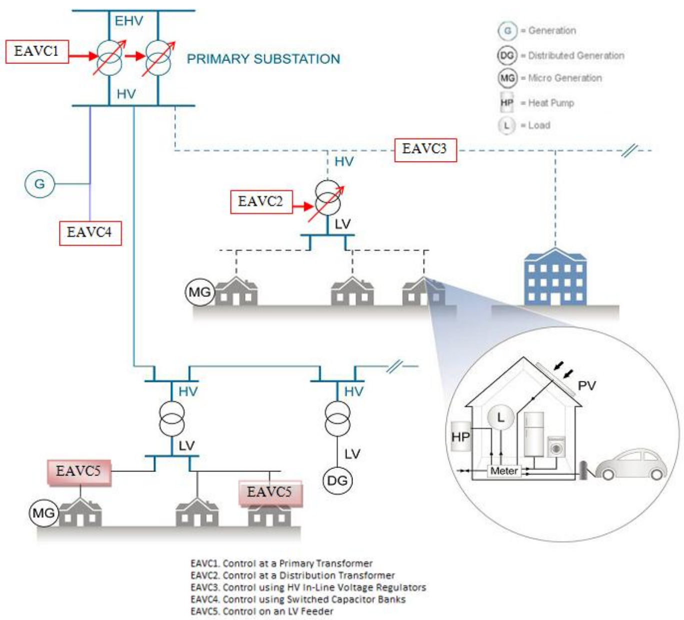

Figure 2 – EAVC Trial Solutions at Different Nodes of the Distribution Network

3.2 Current status of Enhanced Automatic Voltage Control deployment in the CLNR project

The CLNR project has pioneered successful trials of all five EAVC device types mentioned in section 3.1. All solutions have been resilient and are still installed and fully operational on the network. All were installed and commissioned on the network in October 2012 (EAVC5) and throughout 2013 (EAVC 1-4) with trials and analysis being carried out from installation and through 2014. Data from various network trials have been captured and used to inform academic studies to help understand the benefits of the solutions. The equipment has operated as expected and when remotely controlled by the Active Network Management system, has responded according to the voltage limits imposed by GUS.

4 Design, Specification Development and Procurement

4.1 Design

The EAVC design phase was initiated in April 2011, when EA Technology was tasked to commence work on "Design of EAVC Solutions". This phase produced the design solutions for the five different EAVC schemes, and addressed:

- System components;
- Control philosophy, which incorporated network measurements, response times, and coordination with other devices and failure responses;
- Interface requirements such as the connection to the network and the connection to other systems;
- Ancillary systems such as monitoring, device protection and the impact of the solution on system protection and secondary supplies;
- Operation and maintenance such as operational procedures, safety and the impact on maintenance;
- Environmental impacts such as COSHH, noise and disposals.

It was established early in the design solution project that the entire CLNR smart network schemes would be controlled via an Active Network Management system named the Grand Unified Scheme (GUS), but due to the fact that the GUS was also at its early development stage the design of the smart network solutions would help form its design.

The early design efforts derived the overall control philosophy for voltage control, considering the need to co-ordinate actions and prevent hunting for serial connected devices. This work, informed by market research, shaped the view that:

- An EAVC is an enhanced form of automatic voltage control due to its ability to have its setpoint value changed over a communications channel by, for example, an Active Network Management system;
- The AVC relays would be proprietary items, possibly with minor modifications, and it would be required for the ANM control system (GUS) to include a local controller to interface with the relay.

The interface between the GUS control system and EAVC devices was considered at length, as it has significant design ramifications. It was decided that the best approach would be to procure a proprietary AVC relay and place the development of the interfaces with the GUS control system within the scope of the control system supplier.

The subsections below describe the options that were considered and adopted for each of the EAVC devices for the CLNR trials.

4.1.1 EAVC1 – Voltage Control at the Primary Transformer

When producing the design solution document, a number of potential options were researched. First of all, consideration was given to what parts of the primary AVC scheme needed to be enhanced to become suitable for the CLNR project. It was determined that heavy current assets such as the primary transformer and its OLTC are reliable and trusted equipment for transforming and varying the system voltage and therefore did not require replacement. Conceptual models were thought about with this in mind.

The final solution concluded that operating a standard AVC scheme with an enhanced functionality of the local controller was the most appropriate option. This considered enabling the AVC to control the voltage around a variable setpoint, which could be decided by the GUS and received via a communication link, but it meant the existing relays needed to be replaced. Further research of different relays showed that both SuperTAPP n+ and MicroTAPP relays could receive pulse commands over serial interfaces or digital signals between digital I/Os that could increment or decrement their setpoint by a pre-determined value. It was also reported that the SuperTAPP n+ could, with development, receive a setpoint value over a communications link. This would involve no changes to primary plant and existing relays could be used maintaining all standard functions but enhanced by the addition of accepting new setpoints from the control room system.

Furthermore, the option was discussed to add an additional backup solution, as a precautionary measure, to mitigate the risk when introducing new systems and equipment. A piggyback main/standby option was implemented to allay concerns.

4.1.2 EAVC2 – Voltage Control at the HL/LV (Distribution) Transformer

Due to a lack of off-the-shelf options to automatically control the output voltage of a distribution transformer, three conceptual models were presented for consideration.

The options included:

- a new distribution transformer with an OLTC incorporated;
- a HV regulator between the existing Transformer and the Main Ring Unit; and
- a LV regulator installed between the existing transformer and the LV distribution fuse board.

The preferred design solution was to replace the transformer, including the addition of an AVC relay that could accept remote variable voltage setpoints, due to its similarity to existing AVC schemes already used at primary substations. However, it was uncertain if such a device could be procured in time for the CLNR trials. Various manufacturers were consulted; distribution transformers with OLTC were, at the time, at prototype stage with Areva T&D and Maschinenfabrik Reinhausen. The former device was not developed beyond the prototype stage and the latter was at the early stages of development with a UK transformer manufacturer.

Procurement of regulators was not favoured due to:

- Space restrictions that would make, in particular, installation with close-coupled equipment impractical and therefore the solution would be limited to substations with discrete components; and
- Installation at substations with discrete components would bring potential protection issues as the additional impedance from the regulator would reduce the fault current 'seen' by the Ring Main Unit.

It was not until after the design solution stage and the writing of the technical specifications that it was found that Maschinenfabrik Reinhausen had carried out successful trials in Germany and were therefore able to supply a distribution transformer with an OLTC. After extensive research and enquiries with the major suppliers of voltage control equipment it was determined that Maschinenfabrik Reinhausen were the most suitable suppliers of such equipment; therefore EAVC2 would be procured using Northern Powergrid's Single Tender (ST) process.

4.1.3 EAVC3 – Voltage Control Using a HV In-Line Voltage Regulator

Three options were considered for the HV in-line voltage regulators in an effort to procure the optimum design solution.

The options included:

- Single phase modern in-line voltage regulators in open or close delta formation with:
  - Individual controllers for each phase;
  - One controller for the three regulators.
- Use of the existing in-line brush transformers with Ferranti OLTC voltage regulator units able to boost the voltage by 12.5%.

The final design concluded that the existing regulators were suitable for the CLNR project. The feeder demand was too high for standard (short lead time) single phase regulators and there was insufficient time to order bespoke units that could cope with the required demand. The solution involved keeping the HV in-line regulators in service and installing modern AVC relays, capable of communicating with the existing Ferranti OLTC. The AVC would receive voltage setpoints from the GUS and operate the OLTC, providing the EAVC scheme. This produced a low cost solution when compared with other solution which may involve the installation of new heavy current assets and it was similar to the EAVC solution at the primary.

4.1.4 EAVC4 – Voltage Control Using HV Switched Capacitors

The HV switched capacitor selected for the CLNR trial at Hedgeley Moor on the Denwick HV system was a modern ground mounted type, with two banks of three capacitors each controlled by a modern AVC relay and a Programmable Logic Controller (PLC).

The design solution for EAVC4 was simply to connect the GUS to the existing control setup. The capacitor bank at Hedgeley Moor had a modern MicroTAPP voltage relay, however through investigation it was determined that this relay did not have the features to allow it to interface with a local GUS controller. A new relay was required (SuperTAPP n+).

4.1.5 EAVC5 – Voltage Control on an LV Feeder

Control of voltages for individual LV feeders may be necessary for areas of non-homogenous demand and generation. The design stage highlighted that there were three conditions that lead to voltage issues on LV networks:

- Large amounts of generation on the HV network or adjacent LV networks, leading to high voltage levels supplied to the distribution substation;
- Large demands on the LV network, leading to high feeder voltage drops; and
- Large amounts of distributed micro-generation on LV networks, leading to voltage rise on the LV feeder.

As such, EAVC using LV switched capacitor banks and in-line single and three phase LV voltage regulators were considered.

Capacitors are normally used to raise voltages that have been lowered due to reactive losses. In this context, to address voltage rise issues, it was concluded that using capacitors to control voltage at LV would be of limited value;

Commercially available regulators for LV applications were either pole mounted units (single phase or three phase), ground mounted three phase units or small discrete units. In terms of device selection, the pole mounted devices would preclude their use on most urban circuits, in terms of the form factor and a lower rating. There are a number of fixed tap regulators which are intended for conservation voltage reduction applications; ground mounted units of up to 800kVA were available at the time.

Smaller 20kVA single phase regulators were available. These would provide flexibility, as they could be installed on rural and urban networks due to the ability to be pole or pillar mounted. It could also overcome most network voltage scenarios by just targeting areas likely to suffer from voltage issues, however, the cost of installing multiple devices (one per service) along with the associated interruptions required at each service would be too expensive and disruptive.

For the purpose of the CLNR project it was concluded that a 3 phase ground mounted regulator, with sufficient capacity for an LV feeder (around 200kVA) and a simple one step buck or boost setting, was the most attractive option. Furthermore, the installation was thought to be simpler as a single regulator could be used to regulate the voltage of multiple customers.

4.2 Specification development

A series of specifications were developed to allow procurement of the voltage control solutions. These can be found in the CLNR website project library.

4.3 Procurement

The following sections describe the specific equipment procured for each EAVC system.

4.3.1 EAVC1 – Voltage Control at the Primary Transformer

The primary transformer and its OLTC were not required to be procured, existing assets were being used. However, the additional instrumentation required for the EAVC1 schemes included:

- Communications equipment;
- An EAVC panel; the layout can be seen in Figure 3 and its components are outlined in Table 1;
- An individual relay for each transformer (duplicate components were needed for each site).

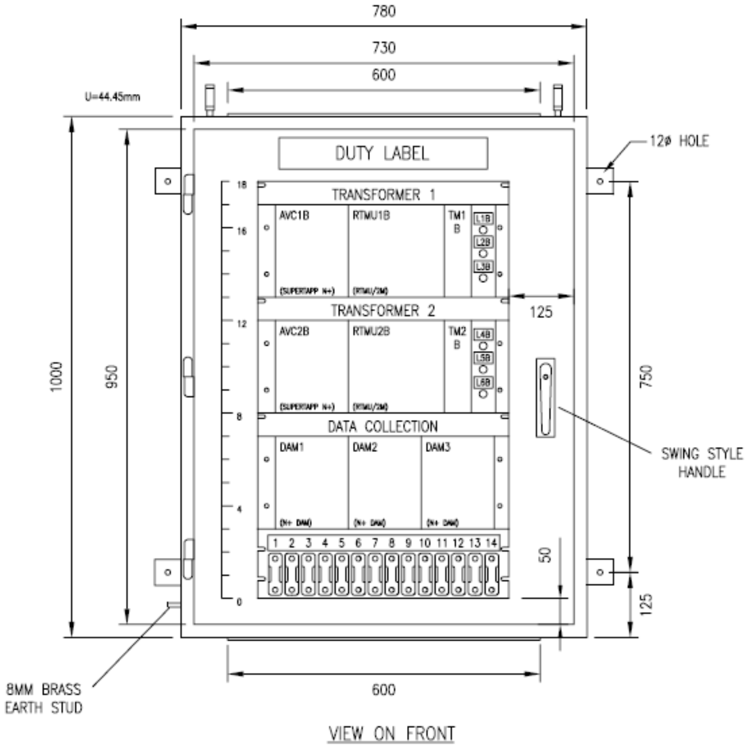

Figure 3 – Layout of EAVC Panel

Table 1 EAVC Panel and components

Component	Manufacturer	Model
EAVC Relay	Fundamentals	SuperTAPP n+
Data collection modules 1,2 & 3	Fundamentals	n+ DAM
LED indicator - Tap freeze applied (Tx_1)	-	CML
LED indicator - Tap Change Lockout (Tx_1)	-	CML
LED indicator - Tap Change In- Progress (Tx_1)	-	CML
LED indicator - Tap freeze applied (Tx_2)	-	CML
LED indicator - Tap Change Lockout (Tx_2)	-	CML
LED indicator - Tap Change In- Progress (Tx_2)	-	CML
Transformer Control and Monitor Unit (Tx1)	-	RMTU/2M
Transformer Control and Monitor Unit (Tx2)	-	RMTU/2M
Test Module (Tx1)	Siemens	2RMLGO2
Test Module (Tx2)	Siemens	2RMLGO2

The chosen relay was the SuperTAPP n+, designed by Fundamentals Ltd and sold under license by Siemens. This is a new relay with the same basic functionality as the on-site relay (MicroTAPP) but with additional properties, particularly regarding communications. The SuperTAPP n+ was chosen based upon its similarity to the relay currently used, and its capability of providing all of the requirements outlined within the specification document. This relay was connected in parallel with the existing MicroTAPP AVC schemes and a switch was made available on site and in the control room to allow users to toggle between the MicroTAPP and SuperTAPP n+.

Although the implementation of two separate (main/standby) control systems can be confusing; Northern Powergrid mitigated the risks associated with the piggyback system by posting adequate labelling on site with associated instruction sheets and ensuring Control staff were made aware of the differences between the schemes.

Future EAVC schemes would be unlikely to be subject to these restrictions.

4.3.2 EAVC2 – Voltage Control at the HL/LV (Distribution) Transformer

The majority of equipment for the EAVC2 trials was procured from Maschinenfabrik Reinhausen (MR) as they were the most suitable supplier for the technology, having a device in the advanced prototype stage. The transformer was supplied by EFACEC (Northern Powergrids contracted transformer supplier). For each site (Mortimer Road, Wooler Bridge and Darlington Melrose) the same fundamental components were procured; however, different power, connection configurations etc. were selected on a site-by-site basis. The important characteristics of the equipment procured for trials have been provided for each site in

Table 2 which is an excerpt from the equipment specification provided by the manufacturer.

Table 2: Equipment Procured for Trials

	Mortimer Road	Wooler Bridge	Darlington Melrose
Transformer			
Manufacturer	EFACEC	EFACEC	EFACEC
Standards	ENA-TS 35-1	ENA-TS 35-1	ENA-TS 35-1
Type of transformer	Separate winding transformer	Separate winding transformer	Separate winding transformer
Rated power of transformer	0.8MVA	0.5MVA	0.5MVA
Rated voltage of transformer phase/phase	11kV	20kV	6.6kV
Range of regulation	±8%	±8%	±8%
Number of steps	8	8	8
Step voltage	220V	400V	132V
Phases	3	3	3
Output Voltage	400V	400V	433V

	Mortimer Road	Wooler Bridge	Darlington Melrose
Output Current	1067A	666.7A	666.7A
Type of cooling	ONAN	ONAN	ONAN
Total mass	3030kg	2610kg	2300kg
Oil	1245 litres	1120 litres	890 litres
On-Load tap changer			
Manufacturer	MR		
Model	OILTAP LIII200D-40-09 09 0		
Ambient temperature	-30 to 50^{0}C		
Control Circuit (voltage)	230VAC 50Hz		
Relay			
Manufacturer	MR		
Model	TAPCON 230 Expert		
Parallel operation	CAN-Bus		
Supply Voltage	88 – 265 VAC/DC		
Physical serial interface	RS232/RS485		
Interface protocol	DNP 3.0		
Auxiliary voltage	60VDC, 15VA		
Dehumidifier			
Manufacturer	MR		
Product	MTraB Maintenance Free Dehydrating Breather		
Analogue output signal	4….20mA(-40…..80^{0}C)		
Supply voltage	230VAC		
Rated current	0.6A		
Protection Class	IP55		
Control Panel			
Supplier	Fundamentals		

4.3.3 EAVC3 – Voltage Control Using a HV In-Line Voltage Regulator

The existing HV in-line regulators (3-phase brush transformers with Ferranti OLTC units) were kept in service for the CLNR project. Only modern voltage relays with their required additional components discrete to the relay and EAVC panel, capable of communicating with the Ferranti OLTC and receiving variable voltage setpoints from the GUS were procured. The characteristics of the voltage relays and EAVC panel are as per described in section 4.3.1.

4.3.4 EAVC4 – Voltage Control Using HV Switched Capacitors

The existing HV switched capacitor located at Hedgeley Moor supplied by Denwick Primary is a modern ground mounted type, with two banks of three capacitors each controlled by a modern voltage relay and a PLC. However, the existing relays were not compatible with the GUS and therefore relays were replaced with a modern type with additional discrete components. The characteristics of the voltage relay are as per the description in section 4.3.1.

4.3.5 EAVC5 – Voltage Control on an LV Feeder

In the scheme of the CLNR project, the LV Feeder EAVC solution was a fairly simple and low cost item. The constituent components required to implement the scheme were:

- Container / housing for the regulator (Glass Reinforced Plastic);
- A voltage regulator;
- Point of isolation;
- An LV fuse-board;
- A control module or local controller;
- Instrumentation (VTs & CTs);
- Communication equipment.

Northern Powergrid purchased a GRP housing separately from the regulator, based upon the expected footprint once additional protection systems and ISUs were integrated. Furthermore, Northern Powergrid determined the best method of providing communications, based upon the interfacing options of equipment and the location of the site (and whether there was any existing communication equipment). The other components required were selected and procured independently, at Northern Powergrid's discretion. Table 3 gives an overview of the equipment procured for the Sidgate Lane three-phase LV in-line regulator scheme, including a brief description and additional comments.

Table 3 - Table of constituent components required for EAVC using a three-phase in line regulator

Manufacturer	Model	Description	Comments
EMS (UK) Limited	PowerStar	A ground mounted voltage optimiser for in-line installation to a three-phase supply	Configured to provide voltage optimisation by connection arrangements. Provides one regulatory function and a bypass mode.
		Supply-side isolator	Allows regulator to be isolated
		Load-side isolator	Allows regulator to be isolated
		Fuses for protection	At outgoing LV feeder (400A) and load-side of regulator (200A) for protection discrimination purposes
	Glass Reinforced Plastic	External housing for regulator	Provides appropriate environmental protection
Nortech	Envoy	RTU: The Envoy platform provides communication to remote locations with a built in GRPS or 3G option. It incorporates the Linux operating system and therefore provides a base onto which control and monitoring applications can be developed	The system was integrated with an ADSL direct-line broadband connection not the GPRS or 3G
NA	NA	Firewall	Providing cyber security
NA	NA	Modem	For communications
ND metering Solutions	Rail 350V Retro –Fit Multifunction Meters (x3)	Monitoring of outgoing LV fuse board feeders	Additional monitoring installed as part of the trial. Not required in BaU
Novus	DigiRail-4C	Channel Digital Input/Counter Module: Modbus I/O	Interface between Envoy RTU and temperature sensors
		Power Conversion System, 220-240VAC to 10 – 15VDC	Converts power supply to that supported by monitoring equipment

4.4 Summary of design, specification development and procurement lessons learned

EAVC LL 4.1 It was a pre-requisite of the project bid that the solutions should use readily available equipment. However, it was found that ascertaining market readiness through literature searches was inaccurate. A number of manufactures claimed to have products that would carry out the functionality of an EAVC scheme which were only at the prototype stage.

EAVC LL 4.2 The EAVC3 and EAVC4 products were an adaptation of existing equipment and mimicked the control gear of the EAVC1 scheme, apart from the need to piggyback the relay. This provided continuity to the project by using the same product for a number of applications.

EAVC LL 4.3 No physical tap position indicator is provided on the MR OLTC used on the CLNR project but visual indication is provided on the Tapcon 230 relay and is available while the transformer and relay are energised and de-energise. Future requirements may consider providing a means of identifying the current tap position on the tap changer unit itself.

EAVC LL 4.4 The EAVC design principle of varying the setpoint of a voltage control device was proven to work. The method used allowed the dead-band to move with the setpoint, which may not have been the case with other solutions.

EAVC LL 4.5 Extra protection functionality, such as runaway functions – e.g. an overvoltage trip mechanism, was implemented along with the relays standard protection functions to comply with company standards.

EAVC LL 4.6 Due to the novel approach of modifying the setpoint at the Primary Busbars and the use of new (and at the time unapproved equipment), it was deemed prudent to piggyback this with existing proven devices. The new relays were shown to operate reliably. Now there is more confidence in the new device type, it is unlikely this method would be necessary for future deployments.

EAVC LL 4.7 The development of the Active Network Management system in tandem with the EAVC scheme added complexity to the design. Although working sequentially would have led to delays, being able to specify the interfaces in detail would likely have reduced the overall development time.

EAVC LL 4.8 The number of roles within a DNO that need to be engaged with innovative designs is large. The formation of Working Groups to engage all internal stakeholders at appropriate points is beneficial.

EAVC LL 4.9 The parallel working to finalise the designs between EAVC and GUS systems meant that it was not possible to understand the full requirements at the time of site evaluations. Enhancements to communications, protection and safety systems had to be incorporated at later stages.

5 System Integration and Supplier Liaison

5.1 System integration

The system integration of the EAVC systems addressed three distinct but complementary aspects:

- The integration of the various component sub-assemblies of the EAVC systems themselves;
- The integration of the complete EAVC systems with Northern Powergrid's distribution network; and
- The integration of the complete EAVC systems with the wider CLNR project, its associated technologies and the GUS control system.

5.1.1 Integration of the EAVC Systems

For continuity purposes, the Nortech Envoy (RTU) was deployed extensively throughout CLNR sites for monitoring and communications purposes. Due to its ability to handle a number of different communication protocols, the unit enabled the integration between other systems to become more consistent. The supplier of the SuperTAPP n+ relays had, previous to the CLNR Project, developed an interface to the Envoy, which enabled the successful communication between the EAVC schemes, monitoring devices and the GUS controller.

At sites there was significant additional communications infrastructure (Envoy RTUs, Network Switches, BT Routers) which are not commonly seen on distribution sites. The communications medium used was predominately ADSL. Initially GPRS was used with roaming SIM cards from Telefonica (Spanish Telecommunications Company) which selected the strongest carrier at any given time. Despite the roaming capability there were still gaps in data transmission. GPRS remained the communications medium for some monitoring schemes where there was no easy alternative. Overall the experiences have proved that GPRS is inadequate for real-time control schemes due to data gaps and latency (some messages were received many hours after the event). ADSL provided a more consistent communication medium and data reliability was proven to be satisfactory, although there were some reliability issues with equipment, in particular the resilience to power outages. GPRS use was kept to a minimum and only used where ADSL was not feasible (e.g. link boxes and some substation monitoring).

Uninterruptible Power Supplies (UPS) were shown to improve communications resilience, which raises the question on whether IT/Telecoms equipment has the reliability required for distribution network applications.

During integration at Primary locations (EAVC 1), alarms were channelled from MicroTAPP or SuperTAPP n+ relays through to the SCADA RTU depending on Network Control requirements. The 'piggyback' methodology, resulted in alarms being mapped from both SuperTAPP n+ and MicroTAPP devices; the newly deployed SuperTAPP n+ was unable to deliver all required alarms.

5.1.2 Integration with the Northern Powergrid Distribution Network

At Primary locations, the main/standby arrangement of the two relay types created additional complexity. It was necessary to ensure that the units assisted each other and operated without conflict. An example included sending a tap freeze command that would affect both units – it was necessary to ensure that both could be frozen remotely and both could be frozen from a single local switch.

For the deployment of the distribution level OLTC's (EAVC 2), all three installations featured a bespoke safety design regarding placement of the control panels (TAPCON 230 controllers). The control panel location, GRP fabrication and the installation of a ballistic blast wall were deployed to create a form of separation between Operators and the OLTC.

As the transformer and OLTC were a new piece of (prototype) equipment, additional safety measures were introduced. This included implementing a pressure baffle which would disconnect the supply to the transformer if internal pressures of the system rose above 0.5 bar atmospheric pressure. Also, an overvoltage relay was installed that would cut the supply to the tap changer motor in the event of high network voltages.

AVC devices feature configurable time delays to prevent rapid tapping and co-ordinate with other series connected voltage control devices (usually between bulk supply and primary transformers). The EAVC2 tap delay timings needed to align with current systems. To this end, they were set at 150 seconds, compared to existing settings at the primary of 120 seconds. Following on from the co-ordination between bulk supply and primary transformers, this provides the opportunity for the primary to address high or low volts issues for a wider area and reduces the possibility of hunting between the devices.

5.1.3 Integration with the GUS Control System

At the time of implementation, the automated management of voltages by a central controller is a novel concept for operators of distribution networks. Particularly with the use of public communication networks, there was natural concern that EAVC devices could be given 'unusual' settings which would remain if communications were lost. The graceful degradation philosophy was to be applied to all controlled assets and in the instance of EAVC devices is provided by the time delay settings within the AVC relay itself. In the event of communications loss, the AVC relay would apply a default set point and would gradually revert to this over a period of time.

Significant effort was expended to develop the interfaces between the EAVC devices, the GUS control system and the Business as Usual NMS. Additional equipment was required to convert signals and protocols, which are one-off requirements due to the unique nature of innovation projects.

The project had a preference for the use of DNP3 where it could feasibly be provided. In order to maximise the potential market for the procurement of EAVC devices, the specifications gave the caveat that other protocols may be acceptable provided they are mainstream and non-proprietary. The project was not specifically seeking to develop learning in this area. As mitigation, the tender for the GUS control system included a system integrator role and a selection criterion was on the ability to interface with a range of protocols.

Depending on the local configuration of the sites, the communication protocols used for EAVC devices were:

- DNP3 over a serial connection between the Envoy and GUS local controller;
- CanBus (or a variant) between the AVC relay and the Envoy;

An additional voltage safety feature was built into the local GUS controller which ensured that commands from the central system were within a sensible range. Erroneous values were not passed to the EAVC devices.

The project also highlighted that common interface specifications are needed for BaU roll-out of these solutions. Ensuring plug-and-play interoperability will require very detailed specification of interfaces, which many suppliers may find restrictive. Specifying the protocol alone is not adequate to ensure a smooth integration process.

Suppliers provided a lot of in-kind support to assist Northern Powergrid in developing and implementing the interfaces between EAVC devices (and other smart grid equipment) and the GUS control system. Much of the liaison with suppliers and subsequent development work was completed by the control system supplier (Siemens). The levels of support expected (unknown at procurement stage) should be clarified to allow suppliers to price appropriately.

5.2 Summary of system integration and supplier liaison lessons learned

EAVC LL 5.1 The use of Uninterruptible Power Supplies was shown to improve the reliability of networking (IT) equipment.

EAVC LL 5.2 Failsafe methods have been devised and implemented for all centrally controlled equipment. This reverts setpoints to a default value when communications are lost. In the instance of the AVC relays, the time delay settings allows for graceful degradation to avoid rapid changes in voltage.

EAVC LL 5.3 The use of public communication networks and commercially available networking equipment does not provide acceptable reliability for wide area control systems in a Business as Usual context. It was learnt that for trial purposes, where operation of remote systems is not safety critical, ADSL is generally acceptable for real-time operational data transfer.

EAVC LL 5.4 It is important to develop strong working relationships with vendors in order to secure system stability and reliance. I.e. maintenance needs ongoing supplier support in order to keep kit working – Suppliers are the ones with the knowledge of how their equipment works and (in theory) the man power to get it in the field.

EAVC LL 5.5 Considerable amounts of technical support were required from suppliers to interface equipment with the GUS control system. This should be defined early so suppliers can price it into quotations appropriately.

6 Health and Safety Lessons Learned

6.1 Health and Safety policy

Additional health and safety policy and procedural documentation has been developed to allow EAVC devices to be installed as Business as Usual activity within Northern Powergrid. Along with training material for Operations Staff a guidance document/risk assessment document has been generated for the installation of EAVC2 schemes: *“Secondary Transformers with on load tap changing capability - Operations Guidance and Site Training Record”*.

The project conducted a significant amount of training and familiarisation across the business. This covered a proportion of the staff within each relevant business function – it was not possible to achieve complete coverage in the timescales. The large scale of training and familiarisation activity to adopt new technologies to cover the entire business became apparent.

6.2 Access to substations

Access to substations fitted with EAVC devices is being controlled through Network Control procedures and restricted access notifications are posted. Access to all transformers with OLTCs is restricted (as per company policy) and was extended to incorporate EAVC2 equipment at distribution sites. Signage was created for access doors and panels and the facility to freeze taps remotely from the transformer was provided.

All locations have signage indicating that EAVC devices are fitted as part of the CLNR trial and systems must only be operated by staff with the relevant updated authorisation codes.

All maps were updated with the relevant information and contact names and numbers, and revised network diagrams have also been introduced to all substations that have been affected by the CLNR networks.

It is worth noting that although high value items of equipment were installed at distribution sites, the project did not experience any unauthorised access or theft. Normal precautionary measures such as fencing and warning signs were installed as deterrents.

6.3 Solution design for safety

A number of safety related features were added to the design for the EAVC schemes:

- A main/standby arrangement was implemented on the primary AVC relays due to concerns over a new type of relay being deployed. This was implemented so that in the event of a suspected fault, the scheme could be reverted back to a Business as Usual state. This lessened the training requirements as it was only necessary to inform field staff on the operation of the changeover switch;
- Separation is necessary between the tap changers and the control panel. This was done either by erecting blast resistant walls or separation by distance as site conditions dictated;
- A protection device was fitted to the distribution transformer with OLTC to isolate the supply if the pressure rose above a threshold. This was to mitigate against possible overheating, noting the device was at prototype stage at the time of procurement.

6.4 Summary of Health and Safety lessons learned

EAVC LL 6.1 DNOs have existing mechanisms to restrict access to sites based on authorisation codes. This mechanism can be used to restrict access to sites which contain novel equipment to those with appropriate familiarisation and training necessary to safely work in the area.

EAVC LL 6.2 The existing mechanisms to protect site operators from the risks associated with tap changers need to be extended to distribution sites where OLTC are installed. The project installed control panels (to freeze taps) at safe distances, or where this was not feasible, blast screens were erected.

EAVC LL 6.3 A significant amount of familiarisation and training activity is required to ensure new equipment is dealt with safely in all circumstances. This must cover a wide variety of staff roles and business functions.

EAVC LL 6.4 Deploying novel equipment on live distribution networks requires a thorough safety review. Ancillary safety equipment is often necessary to provide a safety backstop, which may not be required once there is more confidence in the technology.

7 Logistics, Installation and Construction Lessons Learned

7.1 Space restrictions

The CLNR project aimed to derive learning from the deployment of a variety of equipment across a network area. This led to the installation of many pieces of equipment at individual sites. An overall observation, perhaps expected within a nascent market, is that it is necessary to install additional equipment to provide ancillary functions, such as communications modems and signal converters.

The space requirements should lessen once manufacturers can be given a firm steer on the enduring functionality required by DNOs. This will allow them to rationalise discrete components by integrating functions.

7.1.1 EAVC1 – Voltage Control at the Primary Transformer

Primary sites usually have switching rooms which can be used to house additional equipment. Installing EAVC at a primary site will generally involve the replacement of existing equipment which can ease space constraints. Also, old analogue type control equipment is generally larger than the new control equipment used in AVC schemes. Figure 4 shows the new EAVC panel installed at Rise Carr Substation.

Figure 4 – EAVC panel at Rise Carr Substation (after installation)

7.1.2 EAVC2 – Voltage Control at the HV/LV (Distribution) Transformer

The space restriction for EAVC2 installations is not due to the heavy current equipment or the addition of the control equipment, although this does need consideration. The main concern for space is the operational restriction requiring a physical separation of the operator control panel and heavy current device; this requires the installation of door interlocks and/or physical separation.

7.1.3 EAVC4 – Voltage Control Using HV Switched Capacitors

Switched capacitor banks are generally large bulky units that need to be situated in large outdoor substations or, as in the case of the Hedgeley Moor site, a purpose built structure.

Figure 5 – Hedgeley Moor Switched Capacitor Bank (left) external and (right) internal

7.1.4 EAVC5 – Voltage Control on an LV Feeder

EAVC5 installations will either require additional room within a distribution substation compound or a separate enclosure if it is situated along the length of a feeder.

Regulators have a large footprint once they are integrated with protection and isolation systems and housed within a suitable container. Availability of space will therefore be critical in determining whether schemes are practical. Figure 6 shows the installation of the voltage regulator at Sidgate Lane substation.

Figure 6 – Substation extension at Sidgate Lane

It can be seen that the new installation is not visible above the substation fence height and does not appear in the eye line of the neighbouring residents.

7.2 Installation and construction

The construction and installation phase was straightforward and completed with few issues. The following sections draw out specific points from each of the sites.

7.2.1 Distribution Transformer OLTC: Wooler Bridge

An ‘EAVC Panel’, consisting of a modern relay and separate monitoring and communications equipment, was installed on an external wall of the substation compound and secured with a standard ‘C’ (level 2) barrel lock. In addition a high security, anti-tamper lock with cloaking device was fitted with a standard ‘C’ (level 2) padlock as well. By installing the EAVC panel external to the building, operating the OLTC via the switches on the EAVC panel is carried out ‘remotely’ from any switchgear and heavy current assets, in-line with Northern Powergrid’s standard safety procedures. This is presented in Figure 7

Figure 7 – Wooler Bridge substation and external mounted EAVC panel with double locking mechanism

A panel in the side of the substation building was created to enable a synchronous generator to be connected onto the LV board (busbars) (Figure 8). This meant that customers experienced only a brief interruption in supply whilst the transformer tails were replaced. Before energising the new transformer, the generator was re-synchronised with the mains power.

Figure 8 – Wooler Bridge - cavity secured with panel created in side wall to allow synchronous generator to be connected to busbars

A power supply for the CLNR equipment was taken from one of the outgoing LV feeders and connected onto an MCB, shown in Figure 9 (left).

Figure 9 – Wooler Bridge – (left) MCB for CLNR equipment, supply taken from teed junction on outgoing LV feeder way (right) ADSL broadband line for communication equipment

A fixed communications line was provided by BT, allowing an ADSL broadband connection for communication devices, shown in Figure 9 (right).

Within the substation, the LV board was on the opposite side of the compound to the transformer (in a close-couple configuration with the RMU) connected via an Isolated Supply Unit (ISU). An emergency tripping unit was connected to the HV switchgear, providing the transformer with surge protection. Both of these are shown in Figure 10.

Figure 10 – (left) Isolated Supply Unit (ISU), (right) Surge protector

7.2.2 Distribution Transformer OLTC: Darlington Melrose

Darlington Melrose is an outdoor substation and due to the unfamiliarity of the equipment being installed, it was decided that additional safety precautions would be provided by housing the equipment within a steel lined purpose built container. The footprint of the new transformer with container was larger than that of the existing transformer; therefore the concrete plinth supporting the existing transformer had to be extended. A trench was excavated to bury connections between the control unit and transformer. An additional plinth was created to support the control unit (EAVC panel, etc.). This is shown in Figure 11 and Figure 12.

Figure 11 – (left) Existing plinth, (right) extended plinth created to support Efacec transformer and container

Figure 12 – (left) Trench for connections to control unit, (right) concrete plinth created for control unit

A padlocked drop box containing the control unit (ISU, emergency tripping unit, EAVC Panel and GUS equipment) was then positioned onto the concrete supporting plinth, shown in Figure 13.

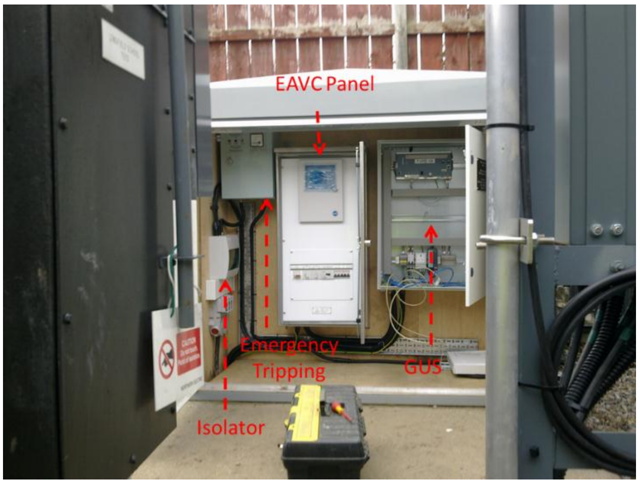

Figure 13 – Dropbox containing control unit (ISU, emergency tripping unit, EAVC Panel and GUS equipment)

7.2.3 Distribution Transformer OLTC: Mortimer Road

A number of customers with photovoltaic (PV) panels are connected to the substation at Mortimer Road. Connecting a synchronous generator to the LV busbars whilst replacing the transformer to minimise the interruption to supply was not an option as these systems have been shown to trip out with reverse power flows. It was decided that, on completion of the CLNR project, the substation would revert back to the original setup, utilising the standard distribution transformer. For this reason, the existing assets were left in place and the substation was extended to allow new equipment to be installed alongside. A concrete supporting plinth was created for the new equipment at the back of the existing substation, shown in Figure 14 and Figure 15.

Figure 14 – Existing indoor close-coupled equipment within substation compound

Figure 15 – Concrete plinth created behind existing substation to support new equipment

New heavy current equipment including an LV board, transformer and close coupled RMU were installed at the Mortimer Road site. Furthermore, this allowed the old building to be used to house additional CLNR equipment at a different location.

7.2.4 LV Regulator: Sidgate Lane

A site-survey was undertaken to determine the configuration of how the regulator was going to be connected into the existing LV network. A number of spare ways within the substation LV distribution board were identified. It was proposed that a spare way on the LV board would be used to connect the regulator, and another, to power ancillary equipment. To mitigate the risk of faulty equipment disconnecting customers, a 4-way LV link-box was installed, enabling customers to be supplied from one of two outgoing feeders from the LV distribution board. This enabled the regulator to be easily switched into or out of the circuit and minimised customer interruptions whilst installations were carried out. A 'smart' link-box was installed to provide end-of feeder-monitoring for the trial analysis and to provide voltages to assist the GUS for wide area control. The location of the link-box and end-of-feeder monitoring is shown Figure 16 and Figure 17.

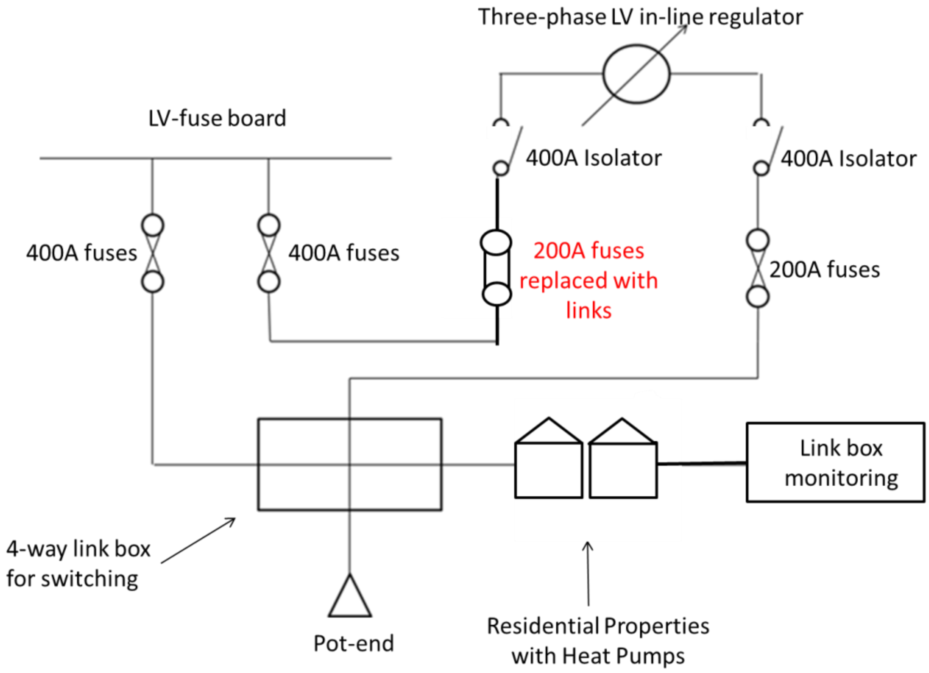

Figure 16 – Substation schematic indicating regulator connection

Figure 17 – Left- four way link-box. Right - End of feeder monitoring link box.

Once the configuration of the system was decided, the ancillary equipment, including communication equipment and measurement devices were installed. A spare feeder way within the existing LV board was used to provide an LV supply to four cabinets which were wall mounted inside the substation compound. Individual cabinets were installed to contain the CLNR equipment (metering devices and RTU), the communication equipment (ADSL broadband connection, modem and firewall) and the GUS equipment. A 240V socket for interrogation and testing purposes was also added. Additional LV fuses were provided between the existing substation LV board and the four wall mounted cabinets to provide more sensitive protection for all ancillary equipment; an additional wall mounted cabinet was provided to house these fuses.

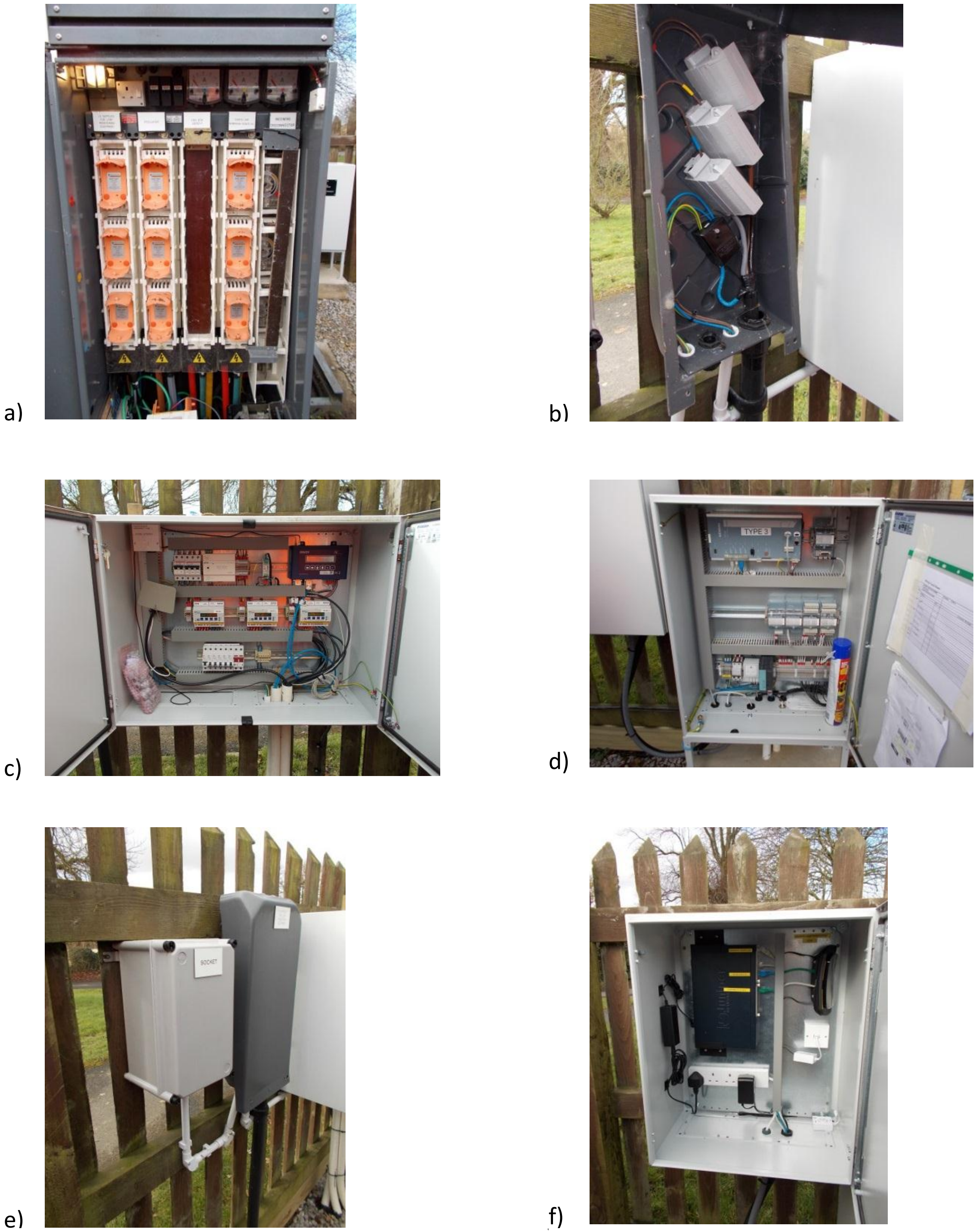

Figure 18 – a) Existing substation LV fuse-board. Spare way (far left) used to power ancillary equipment b) Cabinet containing three phase fuses for ancillary equipment protection c) CLNR monitoring equipment d) GUS equipment e) 240v power outlet, f) communication equipment

Once ancillary equipment was implemented and connected, the regulator was installed on site along with additional equipment required for protection (Figure 19).

Due to the size of the regulator, it had to be installed on land adjacent to the existing substation. A way-leave agreement was made with the local authority, to request a substation extension for the duration of the trial. The terms of the agreement specified that the fencing and housing for the regulator could be no higher than the existing outdoor substation. Once the agreement was made, the substation was extended.

Figure 19 – PowerStar regulator. On the left of the device the two Castell keys can be seen. On the right of the device LED indicators display "Savings", indicating the output supply is regulated or "No Savings" indicating the output supply and input supply are equal i.e. no regulation.

A concrete plinth was formed and the regulator was delivered to the site along with its GRP housing. Care should be taken when selecting the GRP enclosure ensuring it is of adequate size for the unit and supporting apparatus.

7.3 Summary of site selection, logistics, installation and construction lessons learned

EAVC LL 7.1 Space restrictions for new equipment are likely to be a significant barrier for mass roll-out of many smart grid solutions.

EAVC LL 7.2 Synchronous mobile generators can limit the disruption experienced by customers, but are unreliable where micro-generation causes intermittent reverse power flows.

EAVC LL 7.3 A simple LV feeder voltage control scheme can be created using a fixed tap regulator and a bypass switch.

EAVC LL 7.4 Deploying novel and innovative equipment requires a degree of flexibility. Installing additional ducts and over-specifying cable trays proved beneficial in dealing with any unforeseen equipment requirements.

8 Commissioning Lessons Learned

8.1 Commissioning of Enhanced Automatic Voltage Control

Testing and commissioning was carried out in stages, taking a risk-averse approach by gradually building confidence in the EAVC devices and control systems. Details of the overall commissioning process, in line with the GUS control system, can be found in the ANM Lessons Learned Report, in the online project library.

The project mainly used a single installation contractor, supported by a common set of staff from Northern Powergrid. This provided consistency and staff became familiar which helped to de-risk and speed up installation works. During the testing phase, staff became very familiar with the unique characteristics and quirks of individual devices. When moving onto another site with similar equipment, the project team knew what to expect.

As a summary, the control modes used for each successive commissioning phase were:

- Local Control: the EAVC device was tested to ensure correct standalone operation. This was usually the device operating with a default voltage set point, mimicking conventional AVC relay operation;
- RDC Mode: the substation Remote Distribution Controller (RDC) maintains default set points on the EAVC devices. The GUS control system operates in listening mode so the network models can be verified;
- RDC+ Control: this was a specific operating mode for the GUS control system for testing purposes. The GUS control system sends out set point commands but the RDC ignores them, allowing operators to check the control responses are sensible;
- Open Loop Control: the GUS control system operates in listening mode and advises the operator of proposed changes for manual authorisation;
- Closed Loop: the GUS control system remotely manages the EAVC device through voltage set point control.

This phase-by-phase approach was beneficial for the overall project and allowed confidence in the systems to build.

8.2 Summary of commissioning lessons learned

EAVC LL 8.1 Suppliers of EAVC equipment were unaware of the scale of commissioning rigour applied by Northern Powergrid due to the added complexity and novel nature of the GUS control system. In future more clarity on testing is required to allow suppliers to plan and cost appropriately.

EAVC LL 8.2 Using a common integration team meant staff could become more familiar with each piece of equipment and what to expect from testing.

EAVC LL 8.3 Where novel equipment is not formally approved for Business as Usual roll-out, testing must be very thorough to be satisfied that it is safe in all expected operating modes.

9 Training, Skills, Operation and Maintenance Lessons Learned

9.1 Training and skills

It was required that personnel were trained to work in the substations housing some of the EAVC systems. Given the geographic area and 24 hour coverage required, it was necessary to train around 40 members of Northern Powergrid staff. Internal ISO accredited processes were used, supplemented by demonstrations from MR Fundamentals for the EAVC2 TAPCON 230 relay. Training and assessment was aligned with the BaU process at Northern Powergrid where authority is sub-divided to permit access, operation and working on the network asset.

It was noted that the requirement for training all maintenance personnel to work with the TAPCON 230 relay and EAVC2 (distribution transformer OLTC) would involve considerable time and cost. Considering future roll-out of EAVC devices, there is a strong preference for integrating the EAVC2 training into the standard training schedule to increase the number of trained personnel progressively.

A number of typical measures were taken to ensure the EAVC systems were only accessed by appropriately trained and authorised personnel.

9.2 Operation and maintenance

The CLNR project has endeavoured to operate both existing and new EAVC systems in a state which is as close to BaU as possible. In the case of the CLNR EAVC systems, the project team retained a level of control so as to monitor the technology and perform the necessary trials, measuring the performance of the EAVC systems against the anticipated benefits to the distribution network. All EAVC systems remain operational at the time of writing and have been demonstrated operating as part of an autonomous intelligent substation and under control of the Active Network Management system.

- Primary Transformer OLTC: Selection of the main/standby systems (SuperTAPP/MicroTAPP) can be toggled remotely via tele-control and physically on site. As the SuperTAPP device was similar to existing equipment there were no new operational procedures required. It remained paramount that signage was clear so operatives would know which AVC system was being utilised. Redundancy was factored in to afford network control the ability to apply a safe mode; once applied, the AVC would revert to its default setpoint and continue to tap if necessary.
- Distribution Transformer OLTC: Normal operating practice stipulates that operatives shall not be in close proximity to a transformer with OLTC capabilities during the tapping process. Appropriate signage was used to inform site personnel to contact control and freeze taps before entering any substation with distribution level OLTC equipment installed. Existing operational authorisation codes were supplemented to allow tap operation of HV OLTC transformers, whilst not in possession of codes for primary tapping operations. Network control had the ability to apply a safe mode; which would freeze the OLTC taps.
- HV Regulators and Capacitors: Installations were similar by design to primary sites, in that they applied similar equipment to existing AVC systems. When instructed to operate in safe

mode the system reverted back to their original default setpoint and continued to tap as necessary.

- LV Regulator: a bypass switch system was implemented to allow the regulator to be taken out of service. As there is the potential for the input and output switches to be configured such that the regulator would be shorted, a Castell key system was used to interlock the switches. Signage was used to inform operatives of a regulator located on the LV feeder route and instruction was provided to ensure regulation was switched off before bypassing the system.

The HV connected voltage control devices required no new maintenance regime as these are covered under Northern Powergrid's existing maintenance regime.

For the distribution transformer with OLTC, the manufacturer's recommendations for maintenance of the OLTC switching mechanism are an inspection after 2 years or 50,000 operations, whichever occurs first.

The manufacturer of the regulator (PowerStar®) recommends that inspections and electrical insulation tests are carried out once every 5 years.

Initially, there was concern regarding the amount of tapping operations that LV connected devices would perform. Load flows are more aggregated at primary sites which provides smoothing of the voltage profile. The more rapid changes in LV load flows could lead to excessive tapping. On this basis, the dead-band of the distribution transformer OLTC devices was set to 3%. This allowed the voltage levels to move around within the 3% band without leading to a tapping operation. With this setting the device operated very few times which raised the issue of trial validity. As a result, the dead-band was reduced to 1.5%.

As an operational example, Table 4 shows the tap operations for the distribution transformer OLTC devices up to September 2014. Note: all taps were reset to zero at the outset.

Table 4 OLTC Tap Operations up to Sept 2014

Site	Total taps
Wooler bridge	1287
Darlington Melrose	655
Mortimer Road	929

The 1.5% dead-band setting has provided a rich dataset with which to analyse the performance of the devices.

9.3 Reliability

The project team have not experienced any specific failures of EAVC equipment and all the physical aspects of the functionality have performed as expected. There are no reliability concerns in this regard. Clearly assets need to be operated for many years before an understanding can be gained on failure modes and overall reliability.

There have, however, been various failures of the communications systems and glitches in the interfaces. Suppliers have been requested to provide support on a number of occasions to deal with a random set of issues.

9.4 Summary of training, skills, operation and maintenance lessons learned

EAVC LL 9.1 Ongoing supplier support is needed to maintain equipment in working order. Particularly for novel equipment, it is necessary to rely on supplier support for detailed technical knowledge and site support. Complex equipment should be procured as both an asset and a service.

EAVC LL 9.2 A maintenance restriction was placed on the distribution transformer OLTC of two years or 50,000 taps due to the prototype nature of the tap changer.

10 Benefits

A series of academic analyses have been performed to assess the headroom benefits that EAVC solutions provide. These can be found in the CLNR website's project library[2].

[2] http://www.networkrevolution.co.uk/resources/project-library/

11 Conclusions

The Customer-Led Network Revolution (CLNR) project has successfully pioneered trials of Enhanced Automatic Voltage Control (EAVC). The EAVC design principle of varying the voltage setpoint of a control device via an Active Network Management system was proven to work throughout the five EAVC trials covering from Primary and Distribution Substations to HV and LV in-line voltage regulators.

The EAVC concept of remote configuration of voltage set points was demonstrated on existing assets such as primary transformers, HV regulators and shunt connected HV capacitor banks. This involved maintaining the heavy duty equipment whilst replacing the voltage control relay and installing further control and communications equipment. The installation of a new voltage control relay type provided, imposed extra challenges to the project as it was required to maintain the original equipment and install a main/standby switch-over arrangement.

The CLNR project team installed three distribution transformers with OLTC capability, developing the expertise and processes to install these units in a Business as Usual context. These units were procured as prototype units; now with nearly a year of continuous operation, Northern Powergrid has built confidence in these units.

An in-line regulator on an LV feeder was installed to investigate a potentially inexpensive method of controlling the voltage on individual LV feeders. A device intended for industrial conservation voltage reduction schemes was installed that offers a fixed voltage boost. This was installed with automated bypass switches to enable a simple 0% or 2% voltage boost to the feeder. The device, along with all other EAVC devices, and many other smart grid solutions, were integrated into a wider Active Network Management system.

All deployed solutions were market ready apart from the Distribution Transformer with OLTC which was at prototype stage at the time of the trial. Additional mitigations were installed to ensure safety of the public and Northern Powergrid staff.

For future practical deployment of voltage control solutions deeper into the distribution network, the key points are:

- Separation is needed between operator control panels and the physical tap changing device;
- Overhead line applications will generally require way-leave agreements plus a bespoke structure to accept the weight of regulators;
- Capacitor banks are large items that are only feasible in exceptional circumstances;
- The housing of LV regulators requires a large footprint once integrated with the protection and isolation systems.

A number of safety related solutions were implemented in order to safely operate some EAVC systems:

- Implementation of restricted access procedures and training.
- Installing blast walls to separate control panels from tap changers;
- Deployment of a pressure activated switch system to disconnect a transformer in the event of malfunction.
- Developing an interlock system to avoid parallel connection of in-line regulators;

A series of activities were undertaken to bed the solutions into Business as Usual – despite the trial nature of the project, the systems are deployed on a live network. Additional Policy and procedural documentation has been developed along with training courses on the safe operation of the equipment.

Communications systems have been overall problematic across the CLNR project, GPRS was found to be unreliable for control purposes and ADSL, although a reliable service, is marred by the reliability of network equipment. Significant efforts were made at the outset to ensure the safe operation of equipment in the event of communications failure – these features were relied upon frequently.

To conclude, the CLNR project has successfully demonstrated the use of novel voltage control equipment that has been tried and tested to operate satisfactory. Academic studies have furthered the extent of the trials conducted on the CLNR test cell networks to indicate the EAVC devices deployed offer real alternatives to conventional reinforcement for voltage issues.

Customer-Led Network Revolution

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