Customer-Led Network Revolution

Overview of Network Flexibility Trial Design for CLNR

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1 Introduction

A review of active network/smart grid trial design and existing relevant active network management trials and pilot programs is required to enable development of network flexibility field trials for CLNR.

This review will enable development of a suite of trial designs to enable systematic evaluation of the smart grid technologies and schemes to be implemented as part of Learning Outcome 3 and also test cells 14 and 18 from Learning Outcome 2. The trials will enable an evaluation of the possible network flexibility available as a result of the deployment of these technologies.

Methodology and assumptions are detailed in section 2. This is followed by a review of the learning required from and the network interventions/technologies and control system architecture(s) that will be deployed as part of CLNR. A review of the relevant active network/smart grid demonstration networks with a focus on the learning required and the proposed control system architecture(s) is presented in section 4. Section 5 introduces some generic requirements and evaluation criteria for network flexibility field trials. Finally, section 6 describes initial guidelines for the implementation of all field trials to be deployed as part of the investigation into network flexibility as part of the CLNR.

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2 Methodology and Assumptions

Review of literature of generic trial design; interviews with experienced researchers.

Review of design of existing active network management trials and pilot programs in the context of the following networks, where the field trials will be implemented:

- the Denwick, reception network (test cell 21);
- the Rise Carr reception network (test cell 22);
- the proposed PV cluster distribution(test cell 23); and.
- direct control of flexible customers (test cells 14 & 18).

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3 CLNR Network Flexibility Field Trials

In order to establish what previous work is relevant for the development of network flexibility field trials for the CLNR project it is important to restate the objectives of the field trials, review the overall control system architecture(s) and the new network interventions that will be deployed.

3.1 Learning objectives of network flexibility field trials

The network flexibility field trials need to enable the assessment of the extent to which the network is flexible and the cost of this flexibility [1]. More particularly the results of the field trials enable assessment of what are the most effective interventions to deliver this flexibility [1].

The network interventions that need to be assessed as part of the CLNR are as follows:

- Enhanced Automatic Voltage Control (EAVC)
- Real-Time Thermal Ratings (RTTR)
- Bi-directional Electrical Energy Storage (EES)
- Demand Side Participation (DSP)
- Integrated EAVC, RTTR, EES control system supervised by Grand Unified Scheme (GUS)

Therefore, the network flexibility trials must enable assessment of each of these new network interventions/technologies trialled as part of the project, the collaborative operation of the new network interventions (distributed control approach) and also the integrated overall control system architecture (GUS).

3.2 Summary of CLNR Network Flexibility Technology Deployment

The field trials will be developed for five areas of distribution network within the Northern Powergrid DNO region with the following network interventions deployed: -

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- Low density rural 20kV network (Denwick, Northumberland) (Test Cell 21)
    - EAVC
        - Distributed voltage monitoring
        - EAVC 1 integrated EAVC at primary transformers (TBC)
        - EAVC 3 for in-line 20kV auto-transformer voltage regulators (TBC)
        - EAVC 2 solution for 20kV/LV secondary substations (MR)
        - EAVC4 for shunt 20kV switched capacitor bank (TBC)
    - RTTR
        - 66kV OHL (GE FMC Tech)
        - 66/20kV transformers (Dynamic Ratings/MR)
        - 20kV OHL (GE FMC Tech)
        - 20kV/LV transformers (Dynamic Ratings/MR)
        - LV UGC (EATL instruments)
    - Bidirectional electrical energy storage, integrated with EAVC and RTTR to relieve voltage and thermal constraints:
        - 100kW at secondary substation (A123)
        - 50kW on LV feeder (A123)

The network interventions are illustrated diagrammatically in Figure 3-1.

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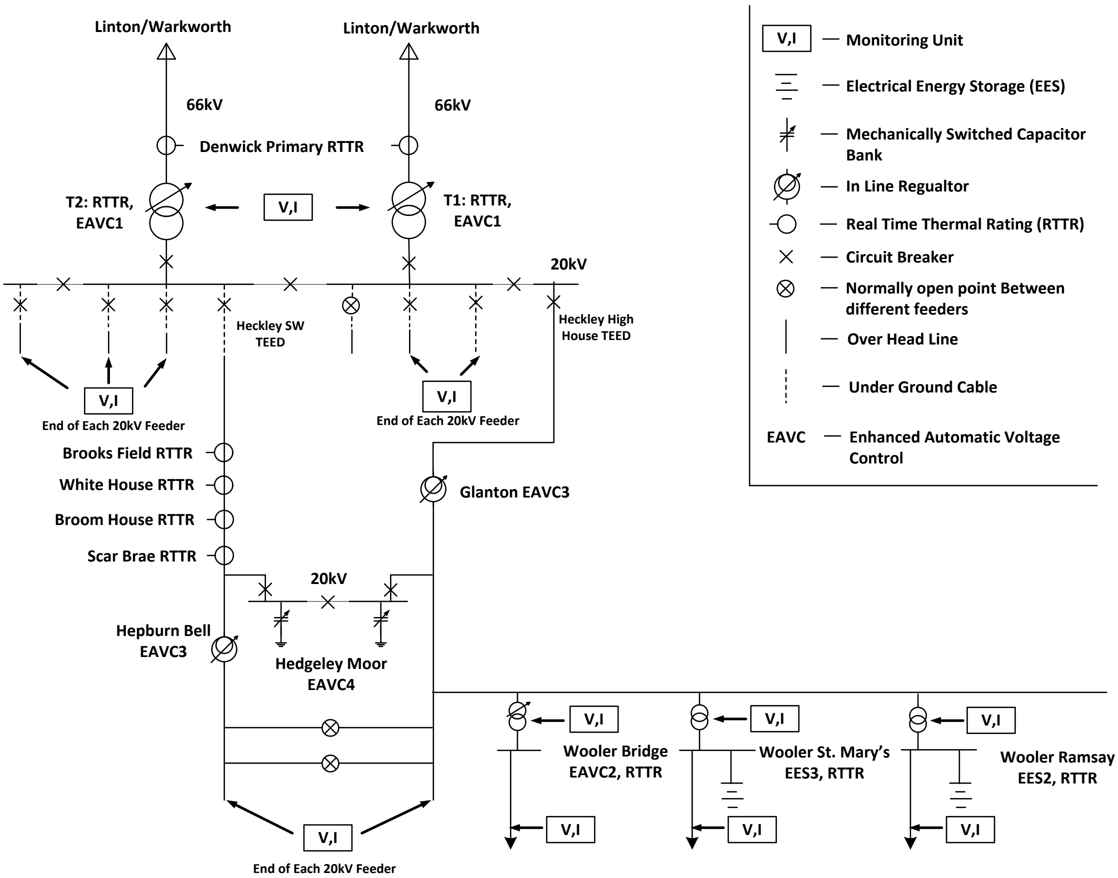

Figure 3-1: Denwick Distribution Network with network interventions

- High density urban 6kV network (Rise Carr, Darlington) (Test Cell 22)
  - EAVC
    - Distributed voltage monitoring
    - EAVC 1 integrated EAVC at primary transformers (TBC)
    - EAVC 2 solution for 20kV/LV secondary substations (MR)
  - RTTR
    - 33kV UG (EATL instruments)
    - 33/6kV transformers (Dynamic Ratings/MR)
    - 6kV UGC (EATL instruments)
    - 6kV/LV transformers (Dynamic Ratings/MR)
    - LV UGC (EATL instruments)

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- o Bidirectional electrical energy storage, integrated with EAVC and RTTR to relieve voltage and thermal constraints:
  - ▪ 2.5MW at primary substation (A123)
  - ▪ 100kW at secondary substation (A123)
  - ▪ 50kW on LV feeder (A123)

The network interventions are illustrated diagrammatically in Figure 3-2.

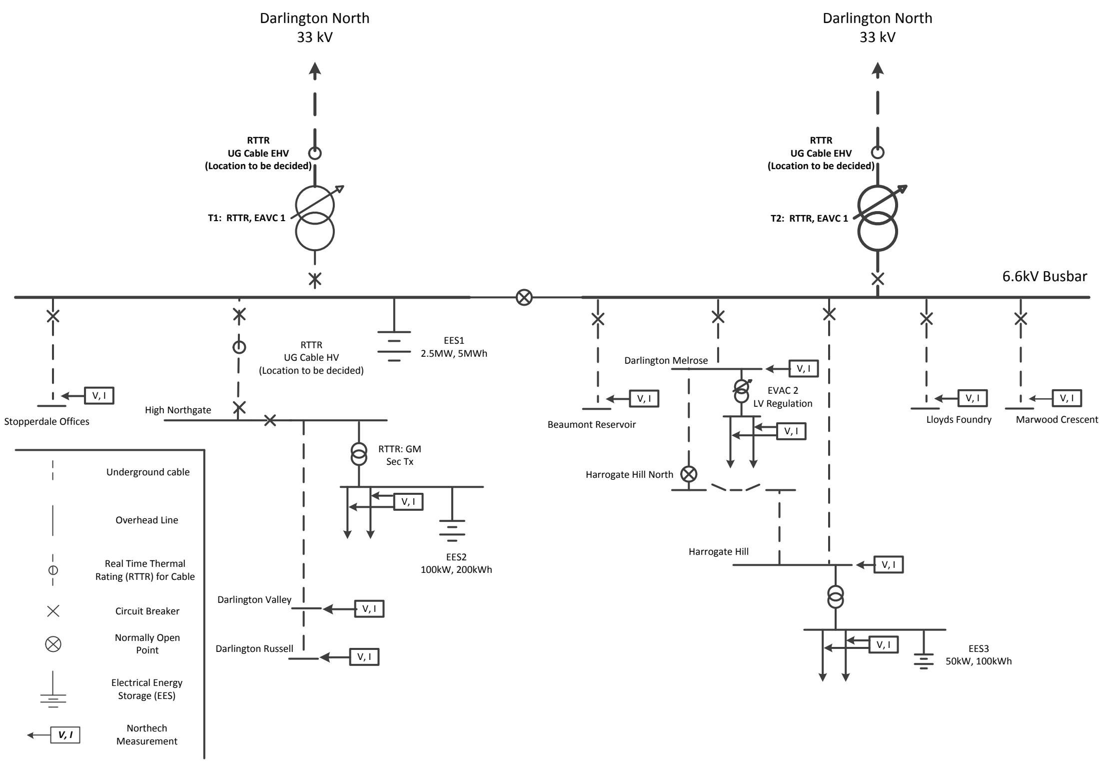

Figure 3-2: Rise Carr Distribution Network with network interventions

- PV reception networks (Maltby, Rotherham) (Test Cell 23)
  - o 1x secondary EAVC to limit voltage swing (TBC)
  - o 1x secondary storage (50kW) to clip peaks and fill troughs (A123)
- Heat pump clusters (To be confirmed) (Test Cell 14)
  - o 1x secondary EAVC 5 (TBC)
  - o 1x secondary RTTR (Dynamic Ratings/MR).
- Responsive load and generation, clustering assumed (To be confirmed) (Test Cell 18)

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- Industrial and Commercial Load
  - 1 x primary EAVC (TBC)
  - 2 x primary transformer RTTR, to generate control signal (Dynamic Ratings/MR)
- Distributed Generation
  - 2 x primary EAVC (TBC)
  - 3 x primary transformer RTTR, to generate control signal (Dynamic Ratings/MR)

3.3 Overview of CLNR Smart Grid Control System Architecture

Active control systems for power systems have been previously categorised as either centralised, distributed or decentralised. A strictly defined centralised control system would consist of a data acquisition, decision making algorithms and the control operation to take place at a single location. A distributed control system, in contrast, consists of a number of independent devices or control systems that appear to its users as a single system. In a decentralised system a problem is divided into smaller problems which are solved by a decentralised controller using local data. These decentralised controllers then interact with each other to solve the overall problem [2, 3].

These categorisations for control system architectures can become ambiguous when one considers an actively managed power system requiring several layers of hierarchical control. For example, in the case of the CLNR concept, it could be considered that the control system is essentially centralised as the GUS controller monitors the entire system and also issues commands instructing the operation of Enhanced Network Devices (ENDs). However, within this framework the voltage control (VC) system of systems and the power flow management (PFM) system of systems operate the distribution network to achieve their individual operational goals.

Two main distribution network objectives have been identified within the CLNR project which, if achieved, mitigate the most restrictive network constraints associated with

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future distribution networks with large concentrations of Low Carbon Technologies (LCTs), microgeneration and Distributed Generation (DG). These objectives are: -

- Power flow management (PFM)
- Voltage control (VC)

Secondary objectives that have been defined thus far are: -

- Reduction of distribution network losses
- Conservation Voltage Reduction (CVR)
- Asset management (E.g. reduction in tapchange operations in aging equipment)
- Harmonic mitigation
- Dynamic power flow management <60s (DPFM)
- Dynamic voltage control <60s (DVC)

These objectives are conventionally achieved by infrastructural upgrade and renewal. However, it can also be achieved by the deployment of new network interventions, identified in the previous section, and active network management schemes which seek to maximise the utilisation of the existing distribution network infrastructure.

As part of the network flexibility trials multiple deployments of these technologies will be tested in isolation and in collaboration with other deployments. Therefore, there can be RTTR equipment deployed on an overhead line but a number of these installations can work in collaboration to form an RTTR system.

Furthermore, these systems can work in isolation or in collaboration to achieve the overall network objectives outlined earlier. However, not all of the new network interventions can be used to achieve all the control system objectives. The hierarchial control system architecture in of the CLNR system is illustrated diagrammatically in Figure 3-3.

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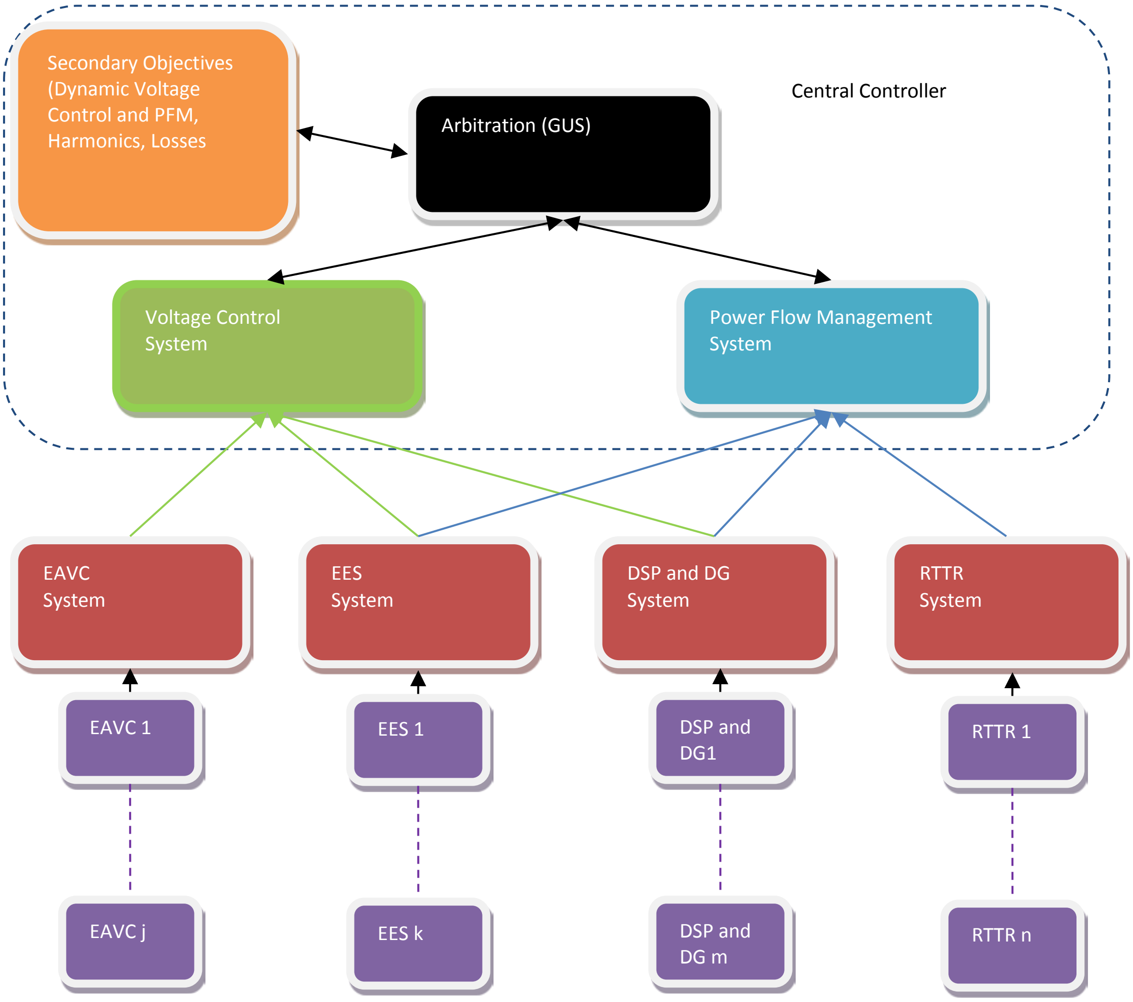

Figure 3-3: CLNR control system architecture overview

It should be noted however, that the CLNR project is not only testing new network interventions but also control system architectures. The architecture can vary from a highly distributed one, where there is no co-ordination between the ENDs to a semi-centralised/hierarchical approach as proposed in the GUS architecture. A fully centralised approach to this has been found previously to be difficult in terms of implementation and maintenance when large numbers of ENDs are part of the system.

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4 Active Network/Smart Grid Trial Review

4.1 Introduction

In order to satisfy the requirements for the design of network flexibility field trials, a review of previous active network/smart grid field trials, was carried out. This informed the evaluation of the methodologies used for field trials of relevant active network/smart grid demonstration and pilot projects.

To investigate how the trial and testing programs of these demonstration projects relates to the CLNR trial program, it is necessary to understand the network interventions deployed and the required learning outputs of the trial programs.

Previous work has been reviewed with regard to the state of the art in smart grid and active network management deployment and schemes. A number of review pieces have been completed and new projects are being completed in this area with increasing frequency [4-10]

Cognisant of the previous literature and of the control system architecture and systems proposed for CLNR, the following projects were found to be particularly relevant:

- AuRA-NMS
- SuperTapp N+ trial
- Skegness/Boston Registered Power Zone
- Orkney Registered Power Zone
- Demand for Wind
- Active control of distributed generators based on component thermal properties - Scottish Power Energy Network
- GenAVC Field Trials
- ESB Networks Smart Grid Demonstration project

In the following sections, these projects will be briefly reviewed with particular reference to the elements of their control architecture that aligned with elements of

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the CLNR, details of the implementation of the trials/pilot programs and finally a summary of what the learning objectives of the field trials were.

4.2 AuRA-NMS

4.2.1 Overview

AuRA-NMS is an autonomous regional active network management system that was developed in the UK through a partnership between several UK universities, EDF Energy, ScottishPower and ABB. AuRA-NMS can be viewed as distributed network management and control software running on a distributed hardware platform. The AuRA-NMS hardware platform including the control algorithms has been installed at a number of locations on UK distribution networks [11]. In addition to the initial work, on voltage control and power flow management, further work has included the deployment of the first distribution level EES unit to be deployed in the UK [12, 13]. The control system architecture in the context of the CLNR control system architecture is illustrated diagrammatically in Figure 4-1.

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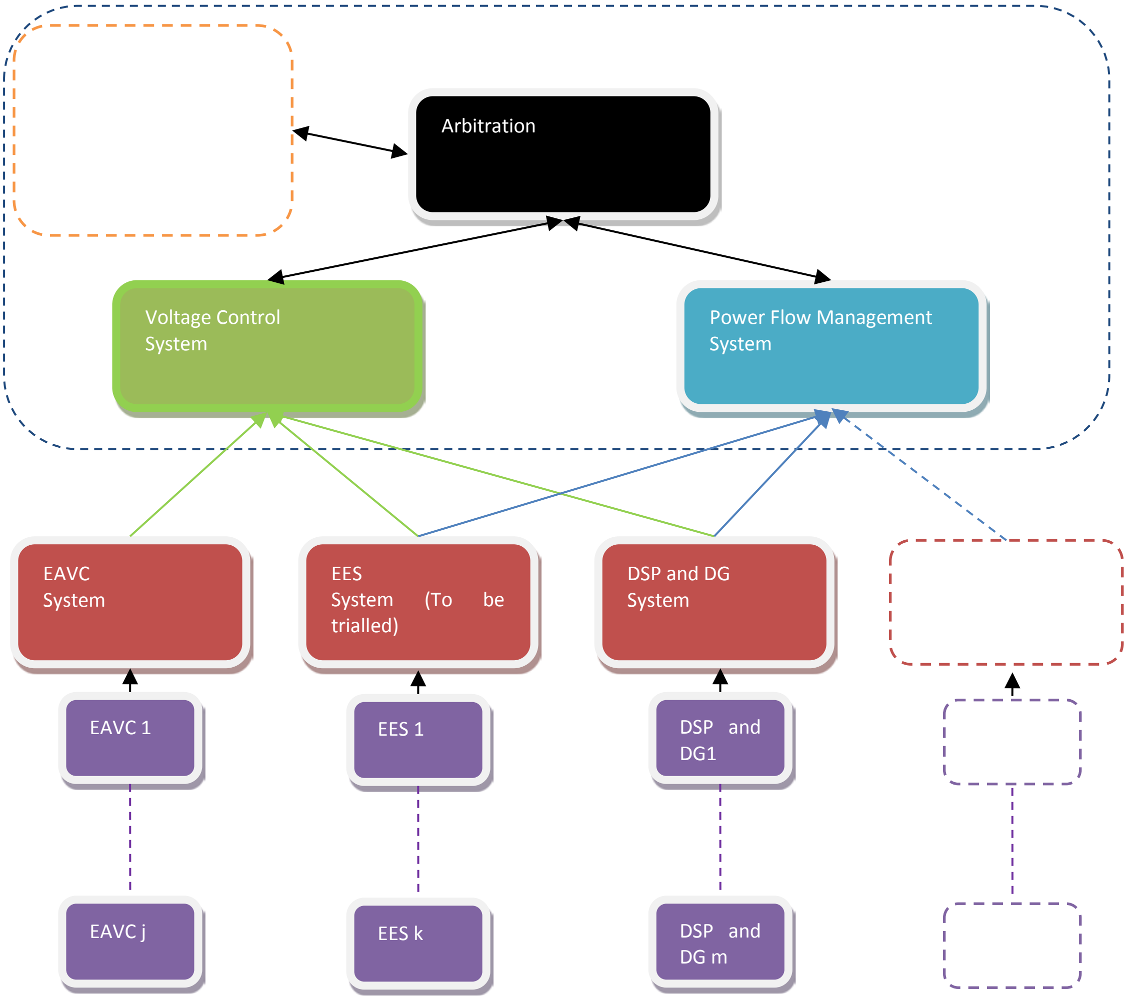

Figure 4-1: AuRA-NMS control system architecture overview

4.2.2 Testing program methodology

An initial closed-loop testing of the individual voltage and power flow control approaches was carried out using a real-time simulator developed at the University of Strathclyde. The prototype software was then passed to Imperial College for more rigorous testing, using a different bespoke real-time simulator. A testing methodology was adopted to test the behaviour of the approaches under the various network conditions and, under different conditions, assessing the performance of the approaches in the presence of: measurement errors, communication errors, and model

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errors, i.e. difference in the real impedances of lines and transformers due to errors in modelling and thermal effects.

Simple tests of the control approaches exploring the use of reduced measurements and estimates from different Distribution State Estimators (DSEs) have demonstrated the real-time integration of the control approaches with those DSEs. Testing to evaluate the DSEs, and the performance of the control approaches when using different algorithms was also completed.

The partner utilities decided to take very different approaches to the deployment of AuRA-NMS. EDF Energy was moving towards an open-loop trial deployment on the 11kV network. Industrial computer units were to be deployed at three neighbouring primary substations, with ADSL links between each site. The intention was to run each of the control approaches open-loop and in parallel to allow assessment of their individual performance.

In contrast, SP Energy Networks are currently considering a different approach: the use of the AuRA-NMS control system outputs to provide decision support in the control room. This approach enables the DNO to gain confidence in and develop their understanding of the underlying decision-making techniques used before deploying them on the network. As the functional specification of AuRA-NMS did not presuppose how network management decision-making functionality would be distributed, running AuRA-NMS's control decision-making modules in the control room is possible.

A further development of the work is the deployment of a large energy storage unit. At the time of writing the EES trial program has not begun but some work has been completed with regard to the planned testing program [12].

A key consideration of the test program is that normal network operation is not disrupted, yet the EES must produce a measureable effect so that the benefits brought to network operation can be quantified.

To achieve this, a two-stage methodology is to be adopted. During the initial stage, an incremental approach will gradually build up the power exchanges between the

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network and EES. Operation will only take places at times when a favourable network state can be relied upon.

The incremental approach will follow these first steps: local manual time-of-day operation, remote manual time-of-day-operation, automated time-of-day-operation, and voltage control at PCC.

Following successful operation in the first stage and verification of modelling results, testing will move into an operational stage. Here the operation of the ESS will adopt what will be considered to be routine objectives in the future, working to contribute to a series of benefits to the stakeholders in the electricity value chain.

During initial deployment the following modes of operation will be evaluated: -

- Automatic voltage control mode to maintain the Point of Common Coupling (PCC) within narrower voltage limits
- Charge/discharge at fixed power levels (with slow ramp rates) at fixed time of day based on knowledge of historical load profiles.

During the operational phase the following modes of operation will be evaluated: -

- Voltage control
    - tightening of voltage limits in response to windfarm measurement
    - tightening of voltage limits in response to remote-end measurement.
- Power flow management
    - supply of reactive power to wind-farm
    - supply of real power in response to thermal constraint
    - peak shaving
    - absorption of real power in response to wind-farm over-generation
    - absorption of real power in response to reverse power flow
    - loss minimisation.

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4.2.3 Learning

The control system technologies to be deployed as part of this project were initial research developments. Therefore, the primary aim of the trials during this program were to assess the operation of the control systems when they were operated in closed-loop in real time simulators and the operation when deployed in the field where they were let run in open-loop where they did not affect decision making within the distribution network. This enabled the DNOs to be become “comfortable” with the operation of the autonomous control systems prior to them becoming part of the control infrastructure of the distribution network.

4.3 SuperTapp N+ trial

4.3.1 Overview

The SuperTAPP n+ relay estimates embedded generator output and total network load based on local substation measurements. These estimates are used to optimize the voltage set point at the primary substation in order to maximize voltage headroom and accommodate extra generation capacity [14, 15]. The control system architecture in the context of the CLNR control system architecture is illustrated diagrammatically in Figure 4-2.

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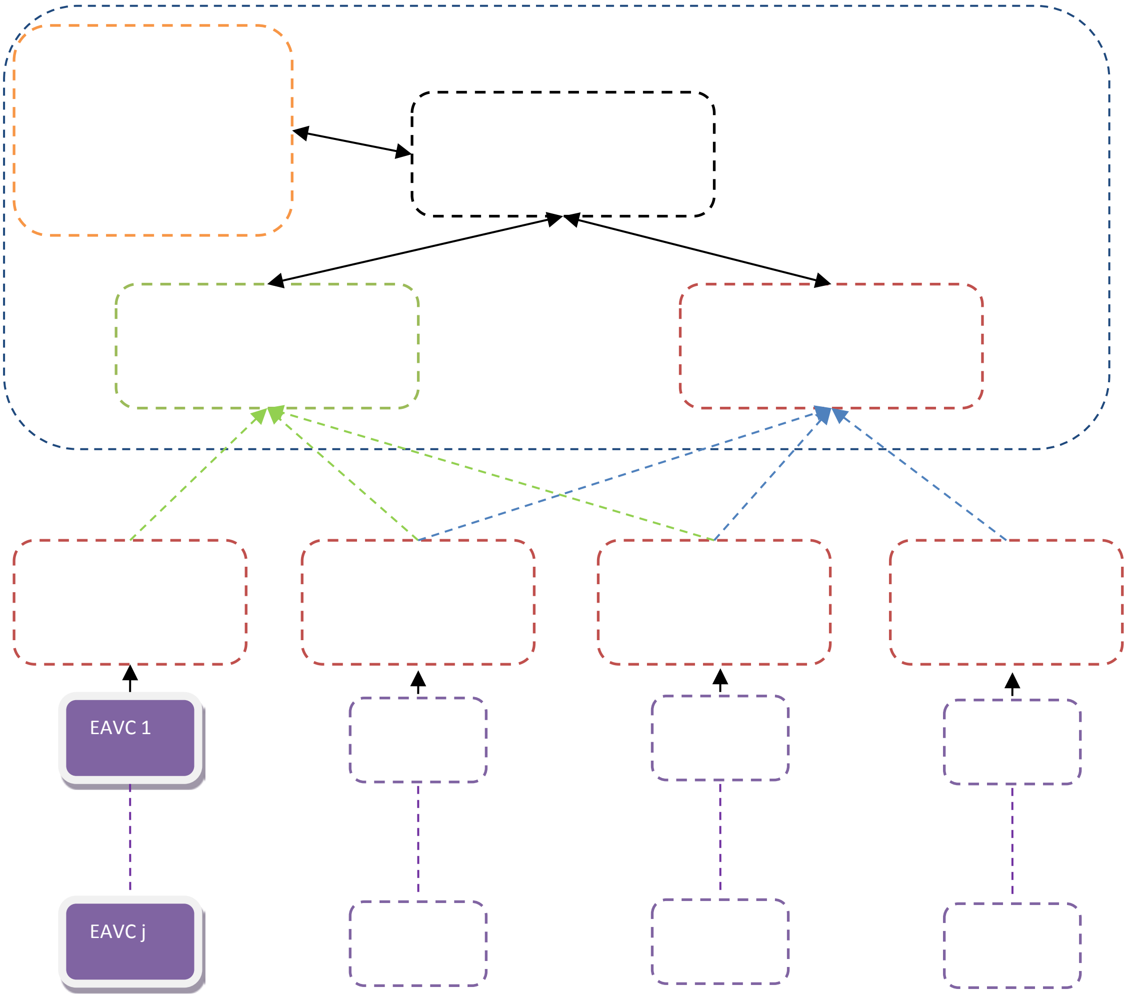

Figure 4-2: Control system architecture overview for SuperTapp N+ trial

4.3.2 Testing program methodology

The relay was first run in open-loop mode to check that was installed properly and the generator estimation was accurate. The original Voltage Control Relay (VCR) still controlled the tap changes. Further, studies investigate the additional headroom liberated by application of the control system/relay.

4.3.3 Learning

Field trials of the SuperTAPP N+ were undertaken to demonstrate: -

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- Demonstrate that the SuperTAPP N+ generation estimation algorithm is accurate
- Explore the relay's capabilities on different network designs and with different mixes of distributed generation [14, 15]

4.4 Skegness/Boston Registered Power Zone

4.4.1 Overview

Dynamic line rating (DLR) has been applied for load management and protection of a 132kV double-circuit line between Skegness and Boston (North East of England) thereby enabling a larger penetration of wind generation. The rating of the line is calculated dynamically from local weather measurements to co-ordinate allowed generation automatically. As a back-up system, in case for some reason the windfarm power output is not reduced on command by the control system, a relay is available to initiate tripping of the wind generators [16]. The control system architecture in the context of the CLNR control system architecture is illustrated diagrammatically in Figure 4-3.

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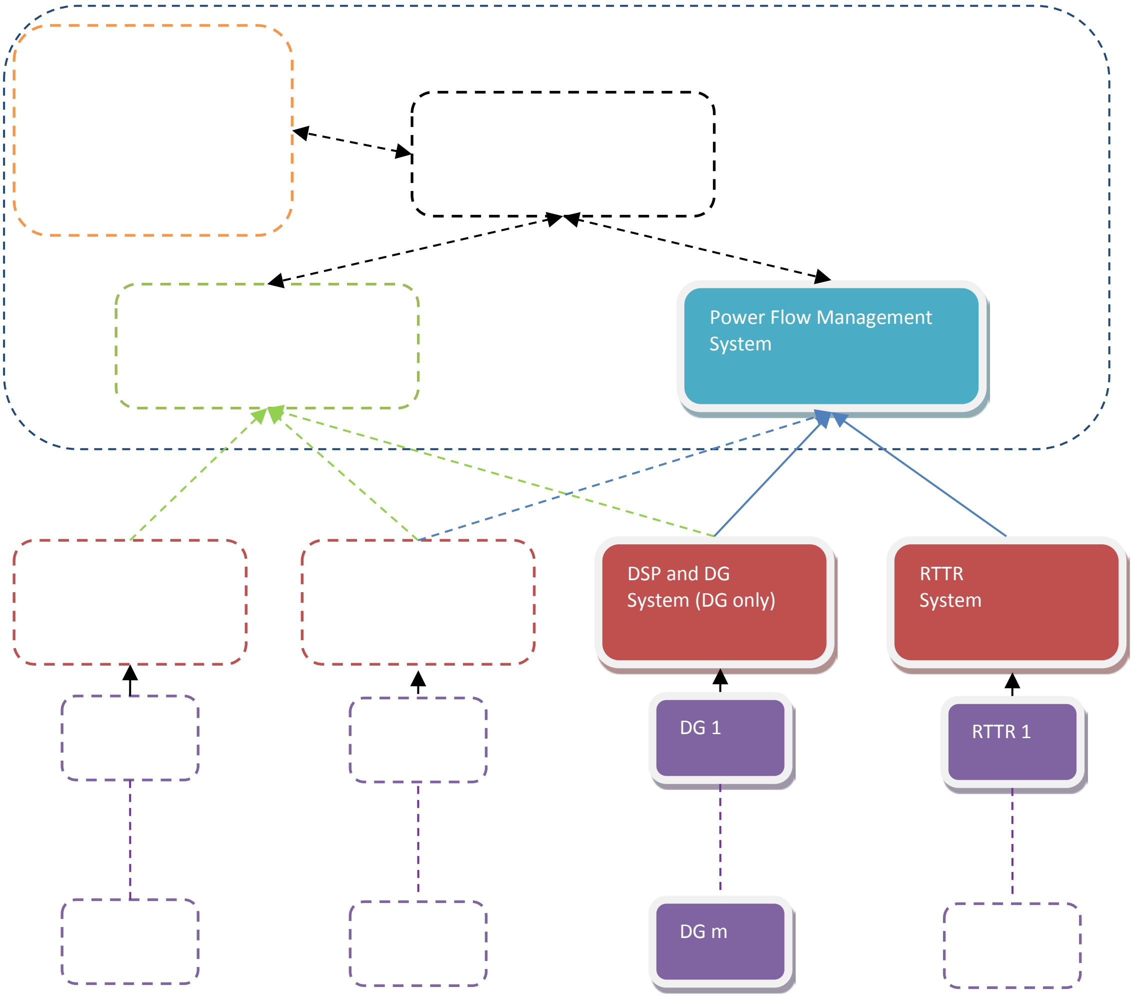

Figure 4-3: Boston-Skegness control system architecture overview

4.4.2 Testing program methodology

Two DLR enabled relays were commissioned in Skegness in March/April 2008. The relays were installed into wall-mounted cubicles. Each cubicle has also a data logger installed which captures the data from the weather station and outputs from the relay. A Power Donut™ is used to record current flow through the conductors and also measure the temperature of the conductor. This enables validation of the conductor models in the DLR enabled relays.

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4.4.3 Learning

The testing program enabled validation of the models, developed and implemented in the DLR enabled relays, of the overhead line conductors. This would allow the DNO to get confidence in the operation of the relays to implement the final system which would curtail wind turbine generation real power export if the conductors exceeded their dynamic line rating.

4.5 Orkney Registered Power Zone

4.5.1 Overview

This project features the deployment of an active management scheme to facilitate increased connection of renewable and distributed generation to part of the North-Scotland distribution network. The active management scheme ensures that thermal operating limits are not violated by curtailing DG units connected under the auspices of the scheme [17, 18]. The control system architecture in the context of the CLNR control system architecture is illustrated diagrammatically in Figure 4-4.

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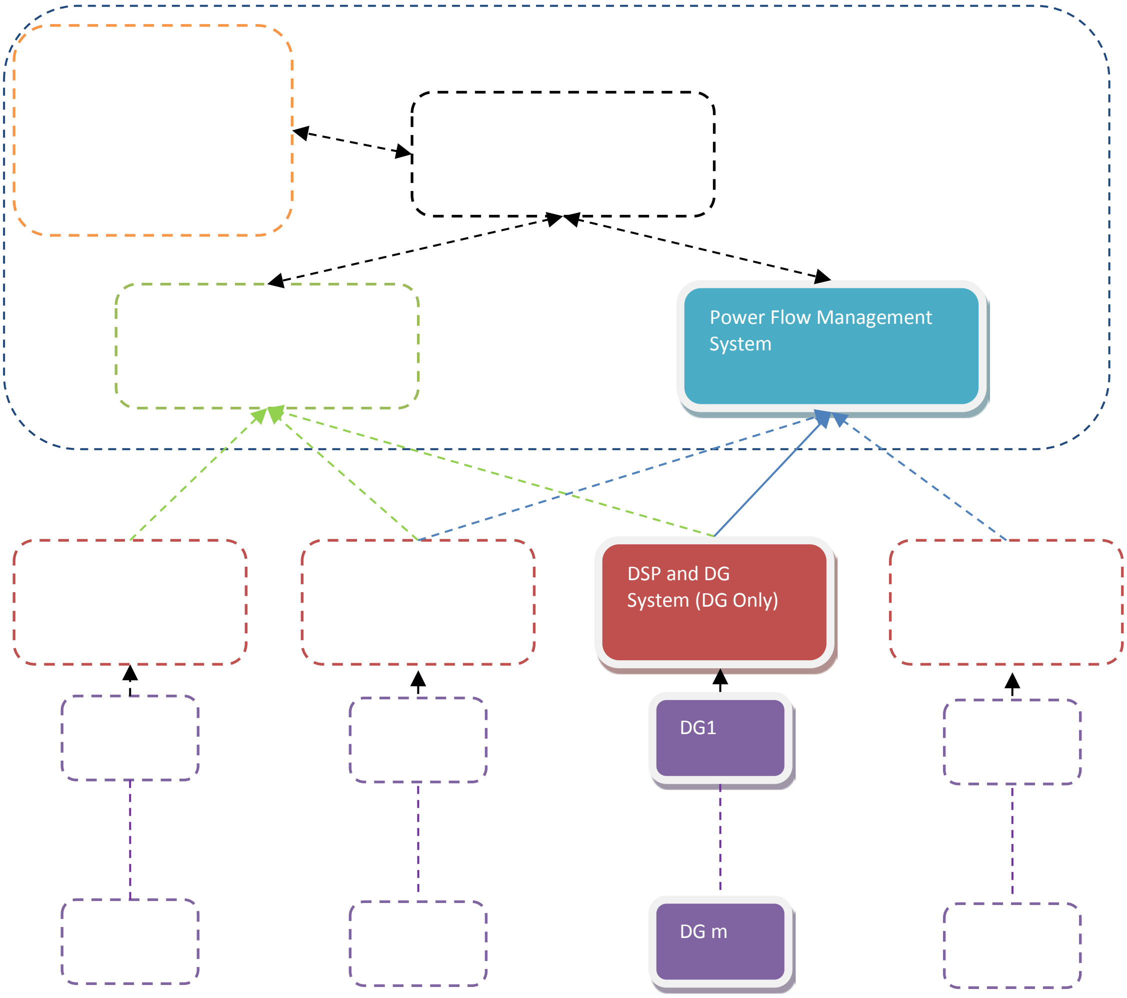

Figure 4-4: Orkney Registered Power Zone (RPZ) control system architecture overview

4.5.2 Testing program methodology

An initial trial period confirmed the ability of the system to regulate the output of a generator (windfarm) to an acceptable degree of accuracy. A closed-loop control trial, to test communications and control logic on Programmable Logic Controllers (PLCs) was completed and verified initially. The active network management scheme has been fully tested and commissioned and has successfully implemented trim instructions with the two participating generators several times since going online [17, 18]. Further testing sought to investigate the following.

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- Verification of logic control (output regulation, loss of communications, local and remote lockout/enable)
- Verification of communications solution
- Integration of active network management scheme with wind turbine/windfarm controllers
- Verify PLC capability and interoperability
- Measurement of communications and control system and generation response times

4.5.3 Learning

The trials sought to demonstrate the operation of a power flow management system deployed on Orkney. The project is ongoing, the initial system consisted of two generators under the control of the scheme. Initial trials demonstrated the operation of the generation curtailment management system. Further trials verified measurements, integration of windfarm curtailment and PLC capability. Subsequently, full closed-loop operation was implemented and is ongoing. Thus, this trial demonstrated the operation of the system.

4.6 Demand for Wind

4.6.1 Overview

Demand for Wind is a research and development project which seeks to investigate the ability of demand side management to address the variability in large scale and small scale wind power generation. To enable this investigation, a demand side management system, where household modems communicate with a control centre using web enabled technology, was implemented [19].

Household electricity usage was monitored, and control signals are regularly retrieved, causing automatic switching of loads (e.g. water heating) and an advisory signal to be updated, prompting the household user to manually switch loads on or off (e.g. dishwasher) as they desire. The control centre determines whether there is a surplus of

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wind power, and regularly updates the control signals for each load being automatically controlled [19]. The control system architecture in the context of the CLNR control system architecture is illustrated diagrammatically in Figure 4-5.

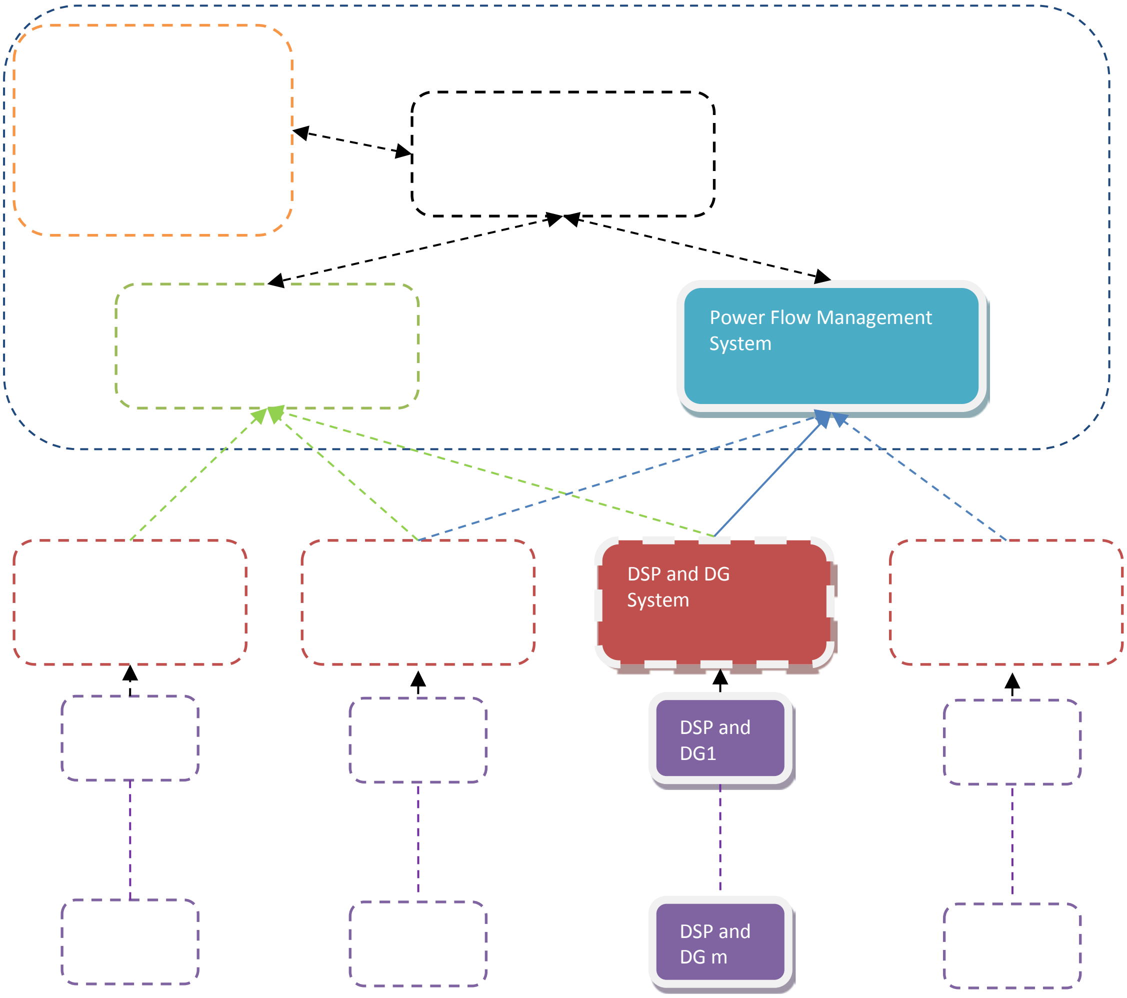

Figure 4-5: Demand for Wind control system architecture overview

4.6.2 Testing program methodology

70 participants had registered for the pilot scheme who had their energy monitored. At the time the trial was conducted wind penetration levels in the UK were and still are relatively low and situations of excess wind power are rarely if ever encountered.

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Therefore, high wind scenarios were simulated in the Durham University Smart Grid Laboratory [20] and the output of this synthesised the operation of windfarm that required the assistance of demand side management to manage power flow.

4.6.3 Learning

Preliminary demand side management carried out through the web site with has been demonstrated, including calling on demand side management using synthesised control system inputs to the demand side management system.

4.7 Active control of distributed generators based on component thermal properties - Scottish Power Energy Network

4.7.1 Overview

The work was carried out in the UK as part of a collaborative project aiming to realise the "Active control of distributed generators based on component thermal properties". This was a collaborative project including Parsons Brinckerhoff, Durham University, Scottish Power Energy Networks (SPEN), AREVA T&D and Imass, part-sponsored by the UK Government's Technology Strategy Board (TSB) which sought to investigate the potential to exploit the dynamic thermal capability of distribution system equipment [16, 21, 22]. The control system architecture in the context of the CLNR control system architecture is illustrated diagrammatically in Figure 4-6.

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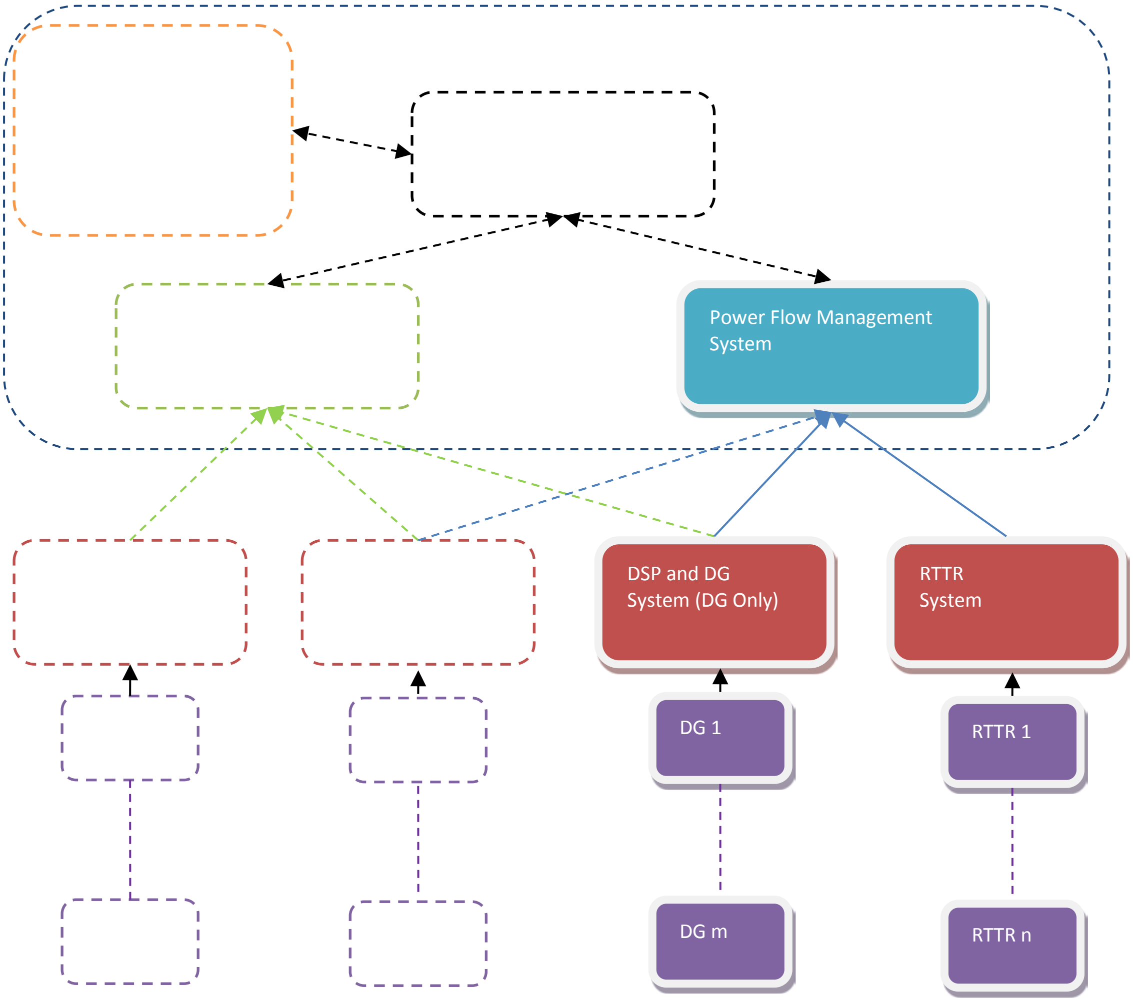

Figure 4-6: Active control of distributed generators based on component thermal properties control system architecture overview

4.7.2 Testing program methodology

Initial testing consisted of a prototype active thermal controller installed in open-loop mode on a section of Scottish Power Energy Networks" distribution network. Thermal state estimation techniques allow the dynamic thermal rating of components, which are not directly monitored within the power system, to be estimated. Thermal state estimations facilitate the precise and reliable assessment of environmental conditions whereby a minimal amount of meteorological monitoring allows the thermal state of

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components within a wide area to be assessed. This was validated for the field trial network through the comparison of estimated and monitored component operating temperatures [23].

This was followed by a closed-loop analysis using a the site information will be performed offline via simulation to demonstrate the potential benefits of different control strategies for controlling multiple distributed generation (DG) schemes. Finally, a full closed-loop system featuring Dynamic Line Rating (DLR) technology integrated with generation curtailment strategies is proposed [24].

4.7.3 Learning

Initial open-loop trials with extra measurements on the network enabled validation of the thermal state estimation algorithm. closed-loop trials, using offline and online simulation tools, enabled investigation of the operation of an integrated DLR and multiple DG management algorithm. The final, full closed-loop active network management system trials will demonstrate the operation of the DLR systems increasing the throughput of renewable energy through existing infrastructure.

4.8 GenAVC

4.8.1 Overview

Econnect/Senergy have developed a method for active control of distribution networks. The method has been embedded in a commercial product, GenAVC, which is now in operation at various sites in the UK. As the voltage at the generator reaches the network operational limits the distributed generation output must be constrained. Lowering the voltage at the primary substation allows more power to be generated, without the voltage upper limits being reached. This would therefore increase the throughput of renewable energy from a windfarm. However, this must be controlled dynamically, with full knowledge of the network state, to maintain the voltage at other nodes of the network above the lower voltage limits.

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The control system architecture in the context of the CLNR control system architecture is illustrated diagrammatically in Figure 4-7.

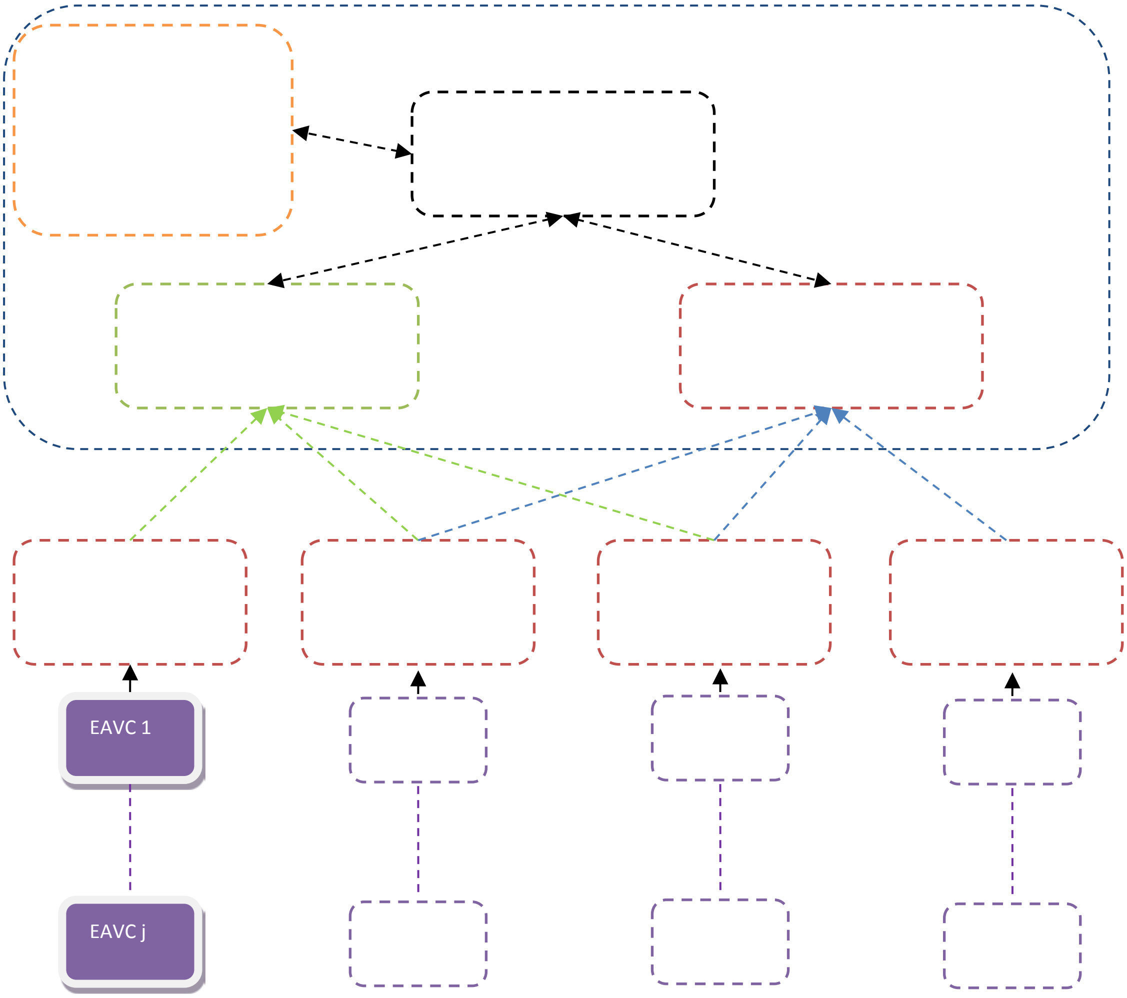

Figure 4-7: Control system architecture overview for GenAVC trials

4.8.2 Testing program methodology

The GenAVC relay/control system was deployed in a number of locations as a commercial product with results available detailing its operation.

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4.8.3 Learning

The results from the trials demonstrated the success of GenAVC at maintaining the whole network within operational voltage limits. In addition, these trials facilitated estimation of the capacity for additional generation that could be connected to a network using this method. The field trials were also used to verify the state estimation algorithm used within the GenAVC controller. Furthermore, the field trials were used to establish the additional headroom that was available due to the deployment of GenAVC. In this case, the term headroom refers to has been adopted to refer to the space between the upper (or lower) estimate limit and the upper (or lower) voltage operational limit of a node respectively

4.9 ESB Networks Smart Grid Demonstration Pilot

4.9.1 Overview

ESB Networks is leading this smart grid demonstration project which includes four core strands:

- Distribution Connected Windfarms & MicroGeneration
- Smart Green circuits.
- Smart Meter Customer Behaviour Trials
- Electric Vehicles [25]

ESB is carrying out this project in conjunction with the Electric Power Research Institute (EPRI) and the Electricity Research Centre (ERC) at University College Dublin. Specifically the project includes:

- Integration and management of wind on the distribution system through:
    - Voltage/Var optimization of wind output.
    - Management of voltage rise caused by wind generator through a voltage regulator.
    - Optimum sub-station design for generator connections.

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- Development of smarter greener networks through design and active operation to optimize efficiency and utilization.
- A comprehensive smart meter customer behaviour trial.
- A grid assessment through demonstration, to understand the impact of clustered Electric Vehicles on the low voltage network.

The control system architecture in the context of the CLNR control system architecture is illustrated diagrammatically in Figure 4-8.

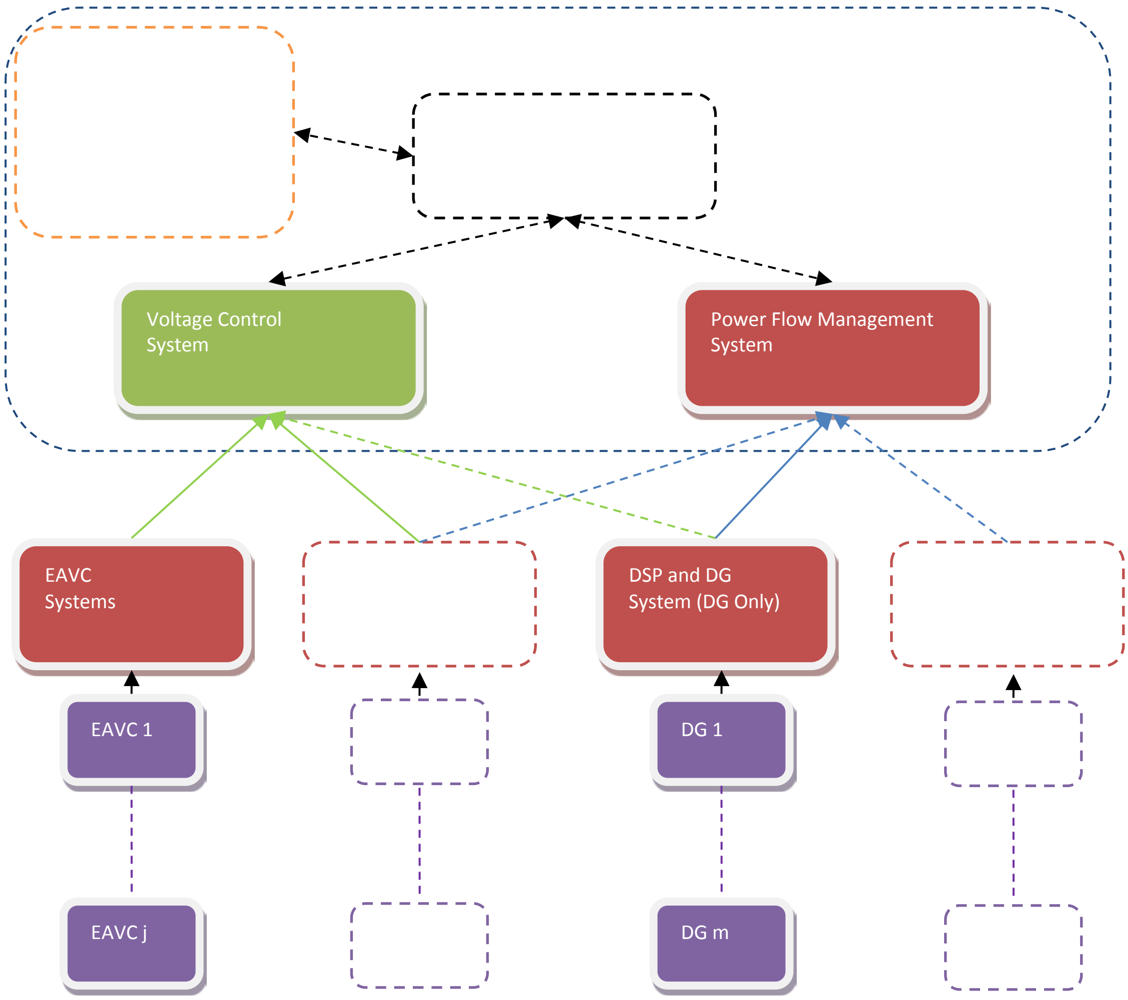

Figure 4-8: Control system architecture overview for ESB Networks Smart Grid Trial

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4.9.2 Testing program methodology

The testing program for integration and management of wind on the distribution network will look at a range of operation modes where the overall VAr output of the windfarms can be optimised while remaining within the voltage rise limitations required for coupling with demand customers.

Voltage regulators (Boosters) have been extensively used in Ireland to manage voltage drop caused by long heavily loaded networks. ESB Networks are testing the use of these voltage regulators to manage voltage rise for distribution network connected windfarms. This is currently being trailed with high resolution monitoring equipment installed to test the operation of the booster and transformer tap change devices in response to the variable windfarm output.

4.9.3 Learning

ESB Networks are using this smart grid pilot programme primarily to gain familiarity with the new network interventions to enable windfarm based generation. Various modes of operation will be considered for both the voltage/VAr windfarm control strategies and the deployment of boosters to enable connection wind turbine based generation.

4.10 Discussion

The projects detailed in the previous sections have trialled elements of an active network/smart grid that are closely aligned in terms of implementation to those proposed as part of the CLNR.

In particular, the trial network interventions implemented as part of the AuRA-NMS project are very close to those proposed as part of CLNR. In contrast to CLNR, where it is the expressed intention to deploy “off the shelf” network intervention technology, the network interventions deployed are bespoke technologies developed as part of the project.

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In the SuperTapp N+ trials an existing commercial product is tested and trialled. This project however investigated only a single EAVC component. This is similar to the situation with the GenAVC trials with additional work in these trials used to validate the operation of the state estimator.

The Skegness/Boston registered power zone is an ongoing project which has been operating continually for a number of years. It includes a RTTR and a capability to curtail generation if required. This however, has not been greatly tested as the windfarm generation in the area as yet has not increased enough to require any curtailment.

In contrast, the Orkney registered power zone has a system that regularly responds to changes in the network by curtailing generation where required but does not feature RTTR.

Demand for Wind utilises Demand Side Participation to manage to a synthetic increase in wind generation. This methodology could be useful when synthesising inputs to some of the clusters proposed in Test Cell 14 and Test Cell 18.

The Scottish Power Energy networks project is an ongoing project which has been operating continually for some years now. It includes a RTTR and a capability to curtail generation if required. The field trials demonstrating the closed-loop operation of this system are currently in the design phase and this should provide some useful information on the concerns regarding the closed-loop operation of active network management.

The focus of the ESB Networks project from a point of view of network flexibility is on voltage/VAr control of windfarms and the utilisation of boosters to enable the connection of DG to distribution networks. The field trial program with regard to the testing of the boosters should be particularly interesting from the point of view of CLNR.

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5 Generic network flexibility trial design

5.1 Introduction

It should be noted that during the initial rollout of the trials design document suite and the rollout of the trials themselves that trial designs maybe changed, added to or deleted. The aim of the trial design process is to be comprehensive but it is likely that trials may be added to, removed or changed during the trial roll out.

5.2 Safety and Risks

Safety to people and equipment is vitally important in the design of the field trials. The trial design must ensure that Northern Powergrid delivers its moral obligations to the public and to staff, which will secure its requirements with respect to the Electricity Act 1989 (as amended) (the Act), the Electricity Safety, Quality, and Continuity (ESQC) Regulations 2002, and the Electricity at Work (EAW) Regulations 1989, by laying out the way in which Northern Powergrid will implement and carry out each of the trials proposed.

The possibility that a trial might result in mal-operation or faults appearing on the distribution network should be considered. Moreover, it should be noted that some field trials may not be carried out due to technical/operational/constructional issues.

5.3 Equipment Assessment

Prior to the design of any of the individual field trials, it is essential to assess the new technology to be deployed and any limitations they may have. It is also important to assess the existing equipment in terms of their capabilities. Furthermore, it is also necessary to investigate the condition of this equipment and assess whether the field trials may seriously impact on the lifetime of any component of infrastructure. In particular, this would apply to equipment that urgently needs replacing or might be close to its existing design limits.

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This might also be a factor if a field trial resulted in an infrastructural component being operated in a way that is likely to greatly diminish the lifetime of the component. Depending on the nature of the component, the component should be replaced or alternatively the field trial should be altered so the non-standard operating regime is not encountered.

5.4 Benchmarking

Prior to implementation of any field trials the smart grid test distribution networks would ideally be monitored with the full complement of monitoring equipment installed and operational without any new network interventions and control operational. This will enable benchmarking of the operation of the distribution networks under investigation. The benchmarking process enables the following: -

- Evaluation of existing network in comparison with smart distribution network
- Establish bounds of existing operation allowing investigation of mal-operation or failure of smart grid equipment
- Validation of models

Data for this benchmarking process will come from the monitoring/verification data acquisition system as well as the data acquisition associated with the implementation of the control loops/systems.

5.5 Evaluation of network flexibility

The evaluation criteria used to evaluate the trials are as follows: -

- Headroom
- Ensure system operates within network constraints;
- Resilience and reliability;
- Scalability and flexibility;
- Communications requirements;
- Network losses;
- Cost and complexity

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6 CLNR Trial Implementation

The following sections detail some initial proposals for the implementation of the field trials as part of the CLNR.

6.1 Procedure and process

A process does not exist at present for the signing off of a field trial within the CLNR project. A process is proposed in which Northern Powergrid will always be required to approve the trial. In addition, the field trial may also require the approval of the smart grid technology vendor or contractor to ensure that the field trial proposed is in line with the capabilities of the smart grid component. The field trial proposal should consist of the following as a minimum: -

- Detailed description of the field trial, including expected learning
- Proposed schedule

This is illustrated diagrammatically in Figure 6-1.

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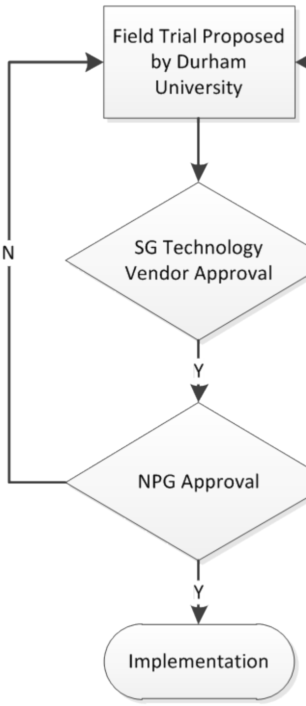

Figure 6-1: Process flow chart for approval of CLNR field trials

During development of the field trial design documents it is important to be cognisant of the field staff required to implement a field trial. Northern Powergrid project management staff need to ensure that these requirements are fed into the field trial design documents. Field staff will be required to implement some of the field trials, as components need to be physically switched or equipment will need to be attended to.

Following completion of each field trial, a review meeting with all relevant parties for the collaborating partners and/or contractors should be held to ensure that all learning, intended and unintended, is captured. This should be used to inform and shape the design of the remaining field trials.

6.2 Fault conditions

Previous trials and pilot schemes of smart grids have under fault conditions reverted back to normal/standard operation. This methodology ensures that security of supply is

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maintained and that customers do not suffer unduly from the implementation of the trial. It is proposed that this methodology is used in these trials also.

A complication may occur if multiple trials are taking place simultaneously. Furthermore, as stated previously, this project does not only consider individual/autonomous new network interventions but it also seeks to look at distribution network control system architectures as described in section 3.3. Therefore, it is proposed where this occurs that the action of the system/systems during a fault should be specified clearly prior to the field trial. If it is proposed that elements of the pilot network should continue in operation post-fault this needs to be approved explicitly by Northern Powergrid.

6.3 Data and specifications required

See Appendix A.

6.4 Network flexibility field trial networks

It is intended that the network flexibility field trial networks at Denwick, Rise Carr, Maltby and the Test Cell 14 and 18 networks will feature some of the LCTs that will drive the requirement for greater flexibility in distribution networks. These are: -

1. Load (new LCTs e.g. heat pumps and EVs)
2. Microgeneration (PV etc.)
3. Distributed generation

These networks therefore provide an insight into the load and generation composition of future distribution networks and may impact on the operation of the network. However, as the concentrations of these disruptive technologies will be small, their impact will be small and as the networks have been identified as relatively well reinforced it is unlikely that there would be existing issues.

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6.5 CLNR Field Trial Design Approach

6.5.1 Objective of CLNR Field Trials

The primary objective of the trials, LO3 work and LO4 work is evaluation of headroom for deployment of load and generation LCTs. Simulation is useful for investigation of future scenarios, configurations and deployments of network interventions. These simulations however require validation from trials in the field. Moreover, trials are particularly valuable in evaluating the dynamic operation of the network intervention and their collaborative operation. This is due to simplifications and assumptions made in simulation regarding the operation of complex network interventions devices, communications, real volts and amps, real customers and variations and inconsistencies from real devices and people. Therefore, the trials will enable investigation of these complex dynamic systems by isolating individual device/customer behaviour and investigating specifically the interactions.

6.5.2 Methodology

Trials are broken down into four basic stages:

1. Baseline
2. Voltage control trials
3. Power flow management trials
4. Integrated system trials

Baseline

Baseline trials can provide baseline data for either voltage control, power flow management or integrated system trials.

Voltage Control Trials

As the networks under investigation have been chosen to be robust and the quantities of disruptive technologies will be small, to meaningfully evaluate the impact that

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network interventions enabling network flexibility and the large scale deployment of the disruptive load and generation technologies identified earlier, the voltage setpoints and/or limits should be changed.

Two approaches have been identified to enable this: -

1. Artificial/proxy voltage limits that will be imposed during the trial.
2. Movement of position of the tap-changer to increase/decrease voltage for trial purposes.

It is proposed to, in the majority of cases, apply artificial/proxy voltage limits to be used as this limits the possibility of customers power quality being adversely affected. If specific trials require deployment of specific network conditions to create an actual voltage issue on the system this would require further consultation with Northern Powergrid.

Voltage control trials are broken down into three further sub stages:

- *Autonomous network intervention control* - In this stage each individual network intervention e.g. EAVC or EES is assessed for their impact on voltage control (on LV networks this can be either three-phase or single phase operation). This enables investigation of the capabilities of a device with local knowledge. Where network interventions exist in loosely coupled network locations, trials will be carried out in parallel.
- *GUS single network intervention control* - GUS control of each individual network intervention to investigate the operation of the device under GUS control. This enables investigation of the capabilities of device with global knowledge. In this case global means in the GUS monitoring area. In all cases open loop control will be trialled and evaluated prior to closing the loop. This can begin as soon as GUS is available. Where network interventions exist in loosely coupled network locations, trials are carried out in parallel. Lower voltage network interventions will be carried out first, where the lowest numbers of customers are involved, with higher voltage network interventions involving the largest numbers of

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customers carried out last. This has the added security in that open loop trials are carried out for longer in these cases. Minimum and maximum limit voltages, which are narrower than the statutory limits, will be implemented in the control systems to enable investigation of the dynamic operation of the network interventions without risking damage to the distribution network or customer equipment.

- *Collaborative GUS control* - Step wise integration from the lowest voltage network interventions up to the highest. As an example of this philosophy collaborative control begins with LV connected EES and HV regulators at Denwick. The final collaborative system at Denwick would therefore feature EES2, EES3, HV/LV OLTC transformer, Glanton HV regulator, Hepburn Bell HV regulator, Hedgeley Moor capacitor bank and Denwick 66/20kV transformers. Minimum and maximum limit voltages, which are narrower than the statutory limits, will be implemented in the control systems to enable investigation of the dynamic operation of the network interventions without risking damage to the distribution network or customer equipment.

The capability of these networks to provide this flexibility will be evaluated using the criteria established previously: -

1. Headroom
2. Ensure system operates within network constraints
3. Resilience and reliability
4. Scalability and flexibility
5. Communications requirements
6. Network losses
7. Cost and complexity

It is not envisaged that voltage control evaluation will be substantially affected by seasonal issues. However, in the case of the PV cluster network (Maltby) it would be preferable to have the majority of voltage control field trials be conducted in the summer. Similarly, for the rural and urban test networks it would be preferable to have

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the majority of the field trials conducted in the winter when load is likely to be high and voltages are lower across the distribution network.

Power Flow Management Trials

In the case of power flow management field trials, to meaningfully evaluate the impact that new network interventions could make to enabling network flexibility and the large scale deployment of the disruptive load and generation technologies identified earlier, a different approach to that proposed for voltage control is required. A number of candidate approaches have been considered: -

1. Artificial limits to be imposed
2. Assume conductor/network element is different to that installed e.g. let RTTR equipment use a model for a 95mm^2 Al cable when in reality a 185mm^2 Al cable is utilised within the distribution network.
3. Scaling of results from monitoring systems prior to their submission to control system/GUS.
4. Reconfiguration of the network for trial purposes to force outside limits?

The fourth approach is not advised as it may result in damage to equipment and therefore may result in customer disruption. The first option is preferred as this is likely to be a safer option and is less likely to incur human error.

The capability of these networks to provide this flexibility will be evaluated using the criteria established previously.

Power flow management trials are also broken down into three further sub stages:

- *Autonomous network intervention control* - In this stage each individual network intervention e.g. EES or DSP are assessed for their impact on power flows. This enables investigation of the capabilities of a device with local knowledge. Where network interventions exist in loosely coupled network locations, trials will be carried out in parallel.

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- *GUS single network intervention control* - GUS control of each individual network intervention to investigate the operation of the device under GUS control. This enables investigation of the capabilities of a device with global knowledge. In all cases open loop control will be trialled and evaluated prior to closing the loop. This can begin as soon as GUS is available. Where network interventions exist in loosely coupled network locations, trials are carried out in parallel. Lower voltage network interventions will be carried out first, where the lowest numbers of customers are involved, with higher voltage network interventions involving the largest numbers of customers carried out last. As previously, this has the added security in that open loop trials are carried out for longer in these cases.
- *Collaborative GUS control* - Step wise integration from the lowest voltage network interventions up to the highest. As an example of this philosophy collaborative control begins with both LV connected energy storage units at Rise Carr and local RTTR ampacity calculations. The final collaborative system would therefore feature at Rise Carr EES1, EES2, EES3, and DSP integrated with RTTR ampacity calculations from across the distribution network.

It is envisaged that power flow control evaluation will be affecting by seasonal issues as RTTR for example is greatly affected by seasonal variation and therefore it is advised where possible to deploy in each of the four seasons as a minimum.

Integrated system trials

- *Voltage constrained scenario* - Voltage control and power flow management systems will be operated in parallel. Ampacity ratings and voltage targets will be set in order to investigate scenarios where the additional headroom available due to power flow management system results in a voltage condition that requires mitigation. This approach enables investigation of the interactions between the power flow management systems and the voltage control systems.

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- *MVA constrained scenario* - Voltage control and power flow management systems will be operated in parallel. Ampacity ratings and voltage targets will be set in order to investigate scenarios where the additional headroom available due to voltage control results in a violation of a thermal limit that requires mitigation by the power flow management system.

The overall approach is illustrated diagrammatically in Figure 6-1

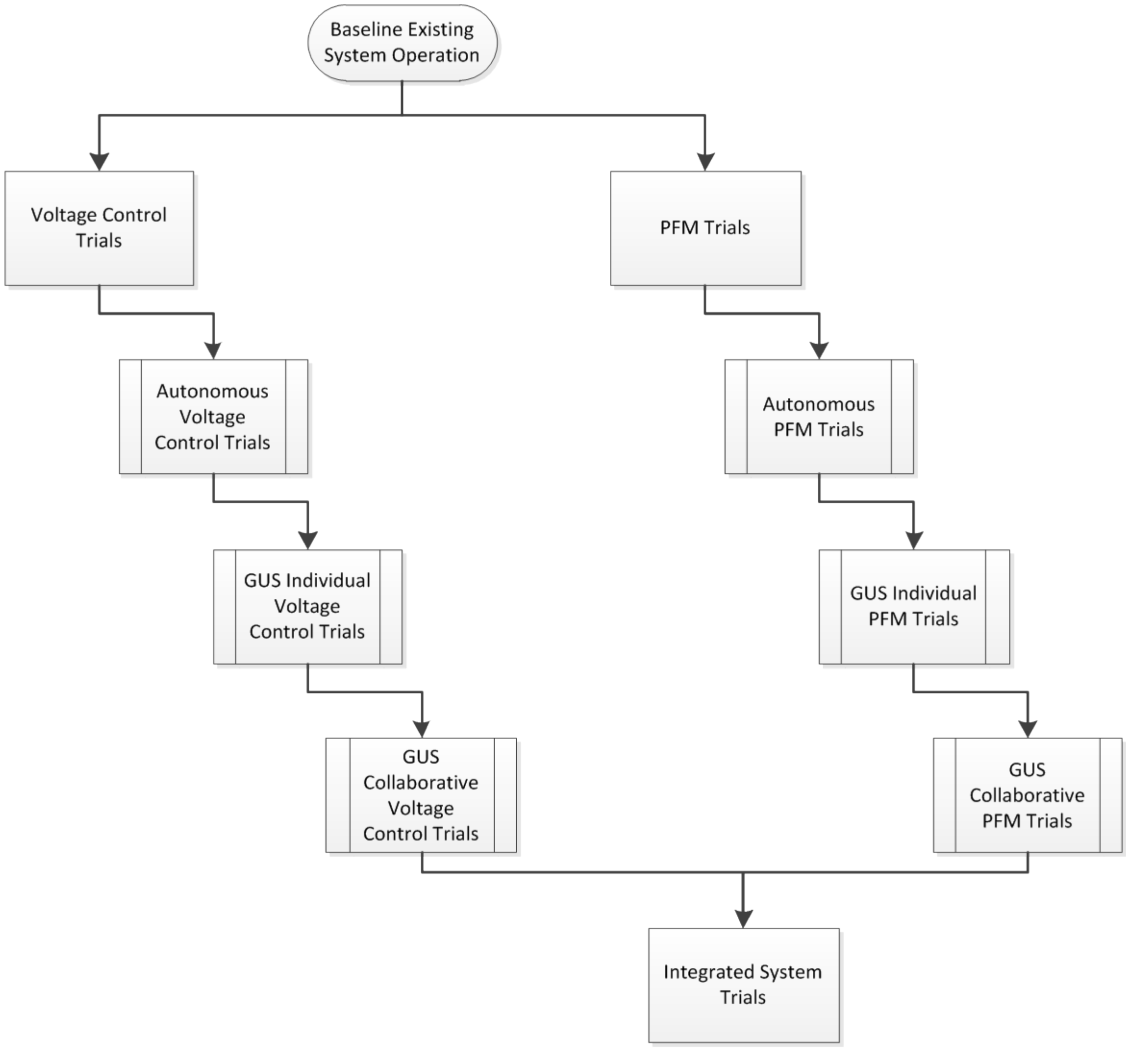

Figure 6-2: Field trial flow chart

Trials will be designed to minimise change to the existing network. This enables NPG to have confidence with trials and minimises system configuration work for each trial. This should also benefit efficient use of time with the network.

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In addition, if the operation of the network is close to the existing capacity of the network this approach will also reduce the simulation work that will be required as this approach will ensure that the system remains within existing operational boundaries for many of the trials.

This will enable use of steady-state models to enable simpler field trials, in many instances, as the dynamic operation of the system will be well understood from previous real data from SCADA and the baselining field trial.

The field trial design and rollout philosophy also enables validation of dynamic models of individual network interventions on the network when they are operated using local or global knowledge. This enables development of dynamic system models incorporating collaborative operation of network interventions, in which all system models have been validated, prior to deployment of the full collaborative GUS system on the distribution network.

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Appendix A – Durham University Data requirements for design of Field Trials

Northern Powergrid

1. Schematics of the relevant areas of the distribution networks indicating the location and connection of each network component referred to in the "Shopping List" document. In addition, the network flexibility equipment required for TC14 and TC18 also need to be included in the shopping list and detailed in terms of connection and location.
2. Detailed impedance data of the relevant distribution networks.

Northern Powergrid/EA Technology

1. Detailed data/information on all equipment used in the trial. This includes existing equipment (e.g. regulators, capacitor banks etc.) that may be used in any of the field trials. Where data sheets etc. are not available e.g. in the case of equipment that has not been purchased then the specification or latest draft version of the specification for the equipment will be adequate to progress the field trial design work.
2. Monitoring equipment needs to be grouped into: -
    1. Monitoring and verification
    2. Inputs to control system/schemes

    This grouping is required. Monitoring equipment needs to be calibrated and signed off operational prior to benchmarking process.
3. Commissioning dates for each item of new equipment and the commissioning of revised control arrangements for existing equipment is a critical factor in the design and scheduling of the trials.

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4. Definition of END operation and control to be defined: -
    1. level of remote access/remote control will be available to the operator
    2. Co-ordination and priority of control actions and ENDs (particularly important when the smart grid components are not operating under the control of GUS and in a distributed control)
    3. What level of autonomy does each of the ENDs have.
5. The intelligence/authority of the smart grid scheme is distributed throughout the smart grid. The capability of the smart grid to move this intelligence is to be defined.

Northern Powergrid/British Gas

1. Detailed information on the volumes, location and connection arrangements of direct control load and generation and details of the control system (e.g. GUS) interface.

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