Customer-Led Network Revolution

Lessons Learned Report

Grand Unified Scheme

Active Network Management

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Executive Summary

Northern Powergrid, as part of the Customer-Led Network Revolution (CLNR) project has completed an ambitious program to successfully deliver an innovative Active Network Management system across four strategically selected network areas in the North East of England. The control system, known as the Grand Unified Scheme (GUS), manages voltages and powerflow by coordinating the actions of a number of smart grid technologies including real-time thermal rating, electrical energy storage, voltage control devices and demand-side response.

As a UK first, the project has demonstrated, on live networks, the coordinated control of a variety of active solutions and sought to evaluate the additional benefits this type of system has over discrete devices operating independently. The control system was deployed on four network areas (test cells); these consist of a rural and urban HV and LV network, and two LV areas with high photovoltaic and heat pump penetrations.

The GUS is a distributed control system with four distinct components which when operating together enable autonomous Active Network Management of voltage and power flow on the distribution network. The control system was supplied by Siemens and is based on their Power 5 (formerly Power CC) platform. The components of GUS are;

Distribution Network Applications – Distribution System State Estimation, to provide visibility of the network voltages and power flow's, and a Volt-Var Controller to manage Enhanced Network Devices (ENDs) to limit network violations, voltage or thermal, or to minimise operating losses.

Remote Distribution Controllers (RDC) – provides substation level management of one or more ENDs by incorporating real-time thermal rating and local monitoring to provide an enhanced view of the local network.

Enhanced Network Devices (ENDs) – a single network device managing itself with no wider network visibility; able to accept revised set- points from either the RDC or Central Controller. ENDs integrated into the GUS are real-time thermal rating devices, voltage control devices, electrical energy storage and demand-side response.

Network Monitoring – various devices positioned at substations and feeder end points to provide network visibility.

Communications Systems – equipment to transfer information between devices via a number of media.

The deployment of the GUS represents a significant step forward for the future use of Advanced Network Management systems to resolve voltage and thermal constraints.

A considerable amount of experience has been gained throughout the CLNR project, this report details the key challenges and learning that has been generated through the design, procurement, installation, testing and operation of the overall control system. This report is structured to group Lessons Learned with the stages of the project lifecycle to which they apply.

Sets of trials have been performed to test the system and derive learning. Through operating the system and further analysis to extend the learning, the capability of the GUS to provide benefits by co-ordinating a number of devices to mitigate voltage and thermal constraints at several points on a distribution network has been demonstrated.

CLNR has demonstrated that this type of control system can be installed on a live distribution network, following Business as Usual processes. It can provide headroom benefits above discrete devices for complex network constraints. Importantly, Northern Powergrid has developed the skills in its workforce to integrate this technology into its distribution network.

This project has demonstrated that control systems can be successfully operated outside, but linked to, incumbent Network Management Systems. This opens the door for a vendor agnostic approach to control system evolution as we move towards low carbon networks, although barriers still exist to new market entrants.

It is apparent that there are alternative control philosophies to manage network constraints. The analysis of the trials and wider learning generated within the project suggests that in the shorter term, acceptable levels of benefit can be achieved in most cases by simpler control techniques. As it stands, a centralised, hierarchical control system of the GUS type of would likely be reserved for more demanding network constraint scenarios and not be widely deployed within the ED1 price control period.

Finally, the design and deployment of the GUS control system has pushed the boundaries of innovation for equipment installed on a live distribution network and has presented considerable challenges for all involved. Northern Powergrid expresses its gratitude for the outstanding efforts of Siemens and the wider project team in delivering this system.

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.	GUS LL 2.1 GUS LL 4.1 GUS LL 4.9 GUS LL 4.10 GUS LL 7.4
2	Managing change and integrating combinations of novel technologies onto the network, required a higher degree of specialist input than anticipated. The successful development and maintenance of an Active Network Management system requires continuous involvement from the business and industry supply chain liaison. The development of failsafe applications in the control algorithms bolstered confidence in the system that permitted commissioning and testing. The development of substation controllers, configured to manage local devices are a robust and, potentially, inexpensive way to manage multiple local network devices.	GUS LL 3.1 GUS LL 3.2 GUS LL 3.3 GUS LL 4.1 GUS LL 5.1 GUS LL 6.2 GUS LL 6.3

3	Communications infrastructure and GPRS communications in particular have identified that GPRS is insufficient in most cases for control purposes, and the future roll out of smarter grid equipment is likely to be a burden for DNO's. Enhancements were made through the use of roaming SIM contracts that had a major impact in both communication service provision and reliability for little extra cost; this could be a useful opportunity for operational field engineers.	GUS LL 7.1 GUS LL 7.2 GUS LL 7.5 GUS LL 7.8 GUS LL 4.5

Glossary

ADSL	Asymmetric Digital Subscriber Line
AVC	Automatic Voltage Control
BaU	Business as Usual
BT	British Telecom
CDM	Construction (Design and Management) Regulations
CLNR	Customer-Led Network Revolution
DNO	Distribution Network Operator
DNP	Distributor Network Protocol
DSR	Demand Side Response
DSSE	Distribution System State Estimator
EAVC	Enhanced Automatic Voltage Control
EES	Electrical Energy Storage
ESQCR	Electricity Safety, Quality and Continuity Regulations
FAT	Factory Acceptance Testing
FDWH	Flexible Data Warehouse
GPRS	General Packet Radio Services
GUS	Grand Unified Scheme (Control Infrastructure)
HV	High Voltage
I/O	Input/output
ITT	Invitation To Tender
LV	Low Voltage
LCNF	Low Carbon Network Fund
LDC	Line Drop Compensation
NMS	Network Management System
NPg	Northern Powergrid
NPS	Network Product Specifications
OLTC	On-Load Tap Changer
PV	Photovoltaic
RDC	Remote Distribution Controller
RTTR	Real-Time Thermal Ratings
RTU	Remote Terminal Unit
SAT	Site Acceptance Testing
VPN	Virtual Private Network
VCC	Voltage Var Control

1 Introduction

1.1 Customer-Led Network Revolution project

The Customer-Led Network Revolution (CLNR) Project is a four-year project, led by Northern Powergrid (NPg), 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 deliver 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 balance supply and demand while deferring investment in conventional reinforcement on the distribution network and so cost effectively facilitating the transition to a low-carbon economy. The project has studied how this can achieved by trialling network based technologies and customer flexibility solutions, supervised by a control system, called the Grand Unified Scheme (GUS).

This report documents the lessons learned from the deployment of the GUS during the process of initial design, procurement, installation, commissioning, operation and maintenance and is intended to assist organisations considering implementing a similar system on the distribution network.

The report will progress through a summary of each stage of the project delivery, outlining the approaches used, novel techniques, and resulting solutions. Through this approach, the key learning is highlighted, leading the reader towards the conclusion of salient lessons learnt during each stage.

The project procured a Flexible Data Warehouse (FDWH) system to operate alongside the GUS, collecting all the monitoring and operational data into a central repository. This system was to facilitate the academic analysis and learning for the project and so differs from what would be required for Business as Usual (BaU). As a result, the lessons learnt report does not directly consider the FDWH, though it will be referred to at various points.

A significant amount of learning has been generated in deploying the communications architecture to support the GUS. This topic is included in this report.

1.2 Grand Unified Scheme

The CLNR project has successfully designed, procured, commissioned and operated an Active Network Management system across four test cells on Northern Powergrid's distribution network. The system is called the Grand Unified Scheme (GUS) as the purpose of the system is to co-ordinate (unify) the responses of a variety of systems (scheme) across a wide area (grand). The procurement was effectively started in December 2011 with the final system successfully commissioned in December 2013. The system was supplied by Siemens.

The GUS uses the following devices as inputs:

- Monitoring equipment located in primary substations;
- Monitoring equipment located in distribution substations;
- Monitoring equipment located on feeders (e.g. end of feeder);
- Real-time thermal rating of transformers, cables and lines;
- Feeder switch / circuit breaker positions, advised by the Network Management System.

The GUS has the ability to control the following:

- Electrical Energy Storage, located at a primary substation, distribution substation and LV feeder;
- Demand-Side Response of Industrial and Commercial customers and domestic customers;
- Voltage control devices located at the primary substation, distribution substation and HV and LV feeders.

Single line network diagrams for the two main test cells are included below to appreciate the scale of the control system.

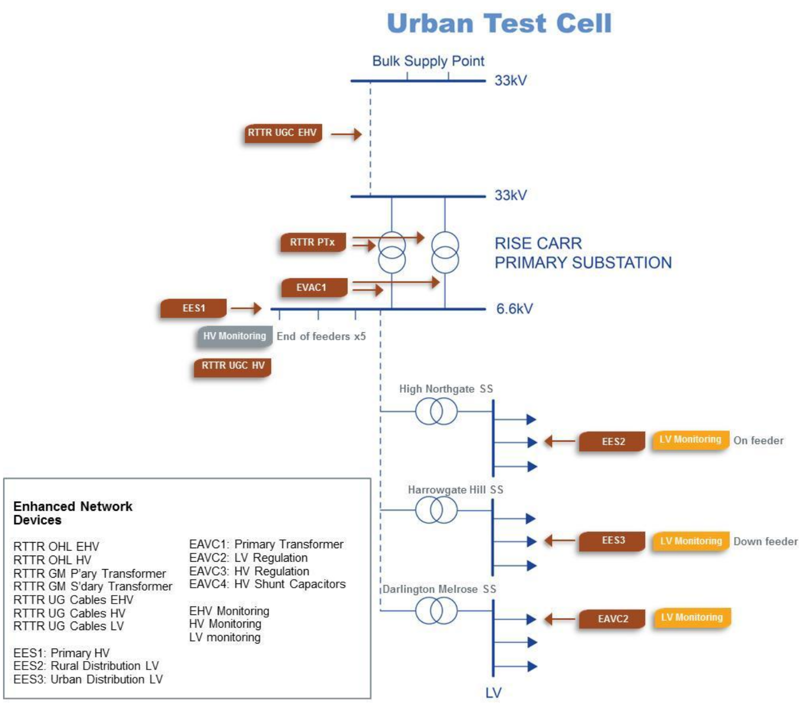

Figure 1.1 – Urban test cell diagram

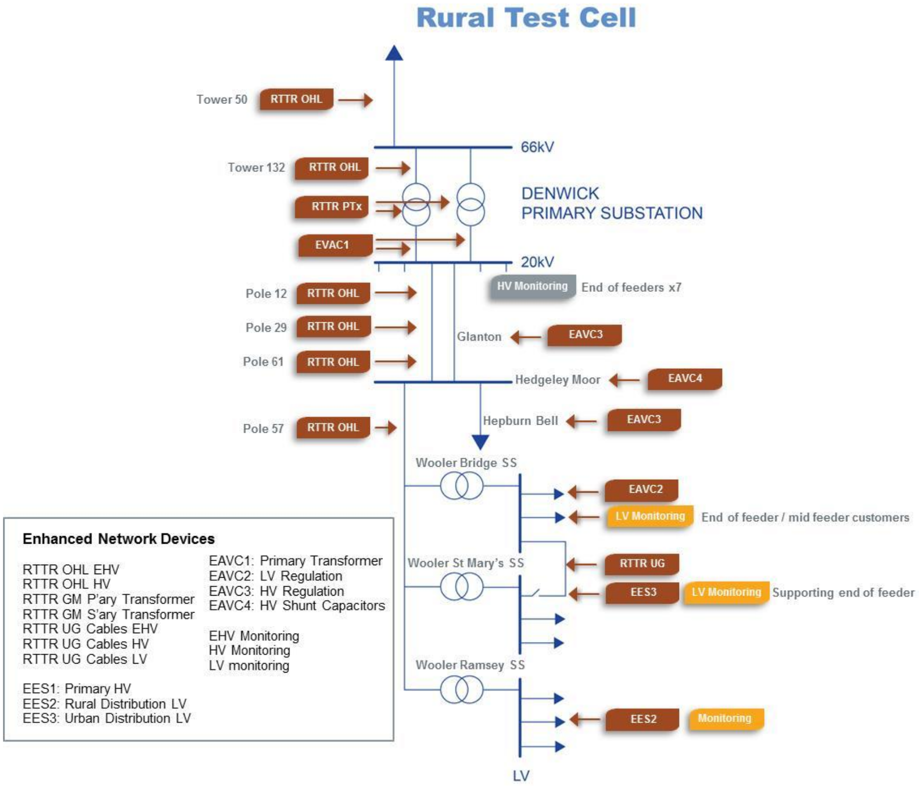

Figure 1.2 – Rural test cell diagram

1.3 Process and methodology for gathering lessons learned

Lessons learned for each of the network based technologies (GUS, EAVC, EES and RTTR) were gathered via a series of structured workshops, 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 showed learning opportunities. Lessons learned have been identified both where things may have been done differently with hindsight and as a result of the projects successes.

This report principally documents the outcomes of the structured GUS Lessons Learned Workshops, conducted with Northern Powergrid and Siemens personnel, complemented and supported by additional inputs from specific reference sources and subsequent follow-up with key staff.

2 Preliminary Design

2.1 Overview

At project commencement, the commercial market for Active Network Management with the required functionality was in its infancy with no unified control schemes operated by the GB DNO community. A distinguishing feature of the CLNR project was to integrate a variety of network devices, most of which were relatively novel and had not themselves been procured. Therefore, the preliminary design stage of the GUS was a balance of keeping to the original project intent and understanding what the market could provide, to accurately establish what the supply community could realistically deliver in the project timescale.

The key stages of work completed during the preliminary design phase, led by EA Technology, are as follows:

- Feasibility study
- Industry consultation workshops
- Tender specification, within a formal procurement process
- Supplier consultations, within a formal procurement process

Unlike many LCNF projects of this scale, the CLNR project used a competitive tender route to procure the control system. This approach tested the market and ensured value for money.

2.2 Feasibility study

A brief feasibility study was conducted early in 2011. This highlighted that whilst DNOs may operate several isolated control systems (protection, generation constraint, voltage control and network switching), none of these either individually or combined currently provide the functional capability to actively manage the CLNR network devices. The feasibility report continued with an analysis of potential control architectures and how these could be employed to fulfil the project aims. Namely, decentralized, centralized, and distributed. The factors considered include:

- Scalability;
- Cost;
- Resilience to failure;
- Implementation of algorithms;
- Speed-of-operation; and
- Communications requirements.

This work provided a baseline against which to assess potential supplier solutions during consultations and the subsequent tender process.

2.3 Industry consultation workshops

A briefing paper was created to facilitate industry consultation on the feasibility of procuring a control system with the desired functionality. A key aim was to test market capability before heading into formal procurement, and the output of these sessions was intended to allow the project team to revise the draft technical specification if required.

The purpose of the briefing paper was to:

"…provide potential suppliers of the GUS control system with initial information on the scope and desired functions. Work to define in detail the desired functions and constraints of the GUS control system is underway and hence the information within is subject to change.

The document is intended for dissemination to third parties to enable an initial consultation process with potential suppliers. This is primarily to ascertain the feasibility of developing and commissioning such a system within project constraints."

The paper listed the key areas of intended functionality of the control system:

- Network visibility – use of monitoring from a variety of sources to assess network state;
- Calculating network set points – the desired control architecture was for the remote devices to operate independently and be centrally managed through set point control;
- Connectivity management – for a wide-area control system it is necessary for the system to either understand network connectivity (switch positions) in real-time, or be resilient to connectivity changes;
- User interface – the intended outcome for the GUS control system was to deploy an active system operated from the BaU control room;
- Practical Considerations – the need for communications, validation to ensure devices are behaving as expected, alarms and IT security.

Five leading industry manufacturers participated in the preliminary supplier workshops. Two key areas emerged as distinguishing features across the five suppliers:

- How the control system would evaluate the distribution network state;
    - Using monitoring devices to make spot assessments of network state, and
    - Using monitoring devices as inputs into a state estimator.
- How the control system would define the most suitable solution to deploy;
    - Via a set of deterministic logic blocks;
    - Via an optimisation algorithm.

At the time, some suppliers fed back to the project team that these two functional areas were polarising, dependent on which approach they had capability to deliver. Therefore, views were expressed that placing firm requirements for the inclusion of one or the other approach may preclude them from tendering.

As in any formal procurement process, the project team were keen to maximise the potential supplier pool; the specification was written in a form which is ambivalent to the specific approach for these two areas.

All but one supplier was reticent about the work involved to incorporate real-time network connectivity as an input into the control system. The reticence was regarding timescales and risk responsibility for integrating with the incumbent Network Management System (NMS). As this was previously identified by the project team as a key risk area, several options were discussed in how the control system could be kept up-to-date with network switch state, as shown in the extract from the consultation document:

"Manual updates of connectivity models will not be suitable for future wide-scale deployment; however given the timescales of the project, it is appreciated that automatic re-configuration of the control system due to connectivity changes may not be feasible. Any control system procured under the trial would need to demonstrate that an upgrade path is feasible without significant redundancy."

Suppliers were, overall, confident that they could achieve a link with NMS. As this function is an important feature for the wider deployment of such systems, the project team felt it should be included as a specification requirement.

2.4 Tender specification

A technical specification was developed between October and December 2011, which was used to describe the core functional requirements during the formal procurement process.

Using the feedback obtained from the supplier consultations, along with the project requirements, the team distilled these to a series of core requirements for the GUS to deliver, for example:

- Assessment of the current state (amount of headroom) of the distribution network relating to user defined operating limits;
- Management of specific 'test cell' distribution network areas to minimize voltage and/or thermal violations;
- Development of interfaces to a range of Enhanced Network Devices ENDs (e.g. AVC relays, energy storage)
- Management of local ENDs, including "graceful degradation" between operating modes (described later);
- Calculation and issuance of voltage and powerflow set-points to multiple ENDs;
- Interface with the existing NMS, if a connectivity model is required;
- Provision of a flexible user interface; and
- Scalability to allow multiple distribution network segments across the DNO network.

The diagram below outlines the expected configuration of GUS at this stage of technical development (November 2011 – pre-tender award).

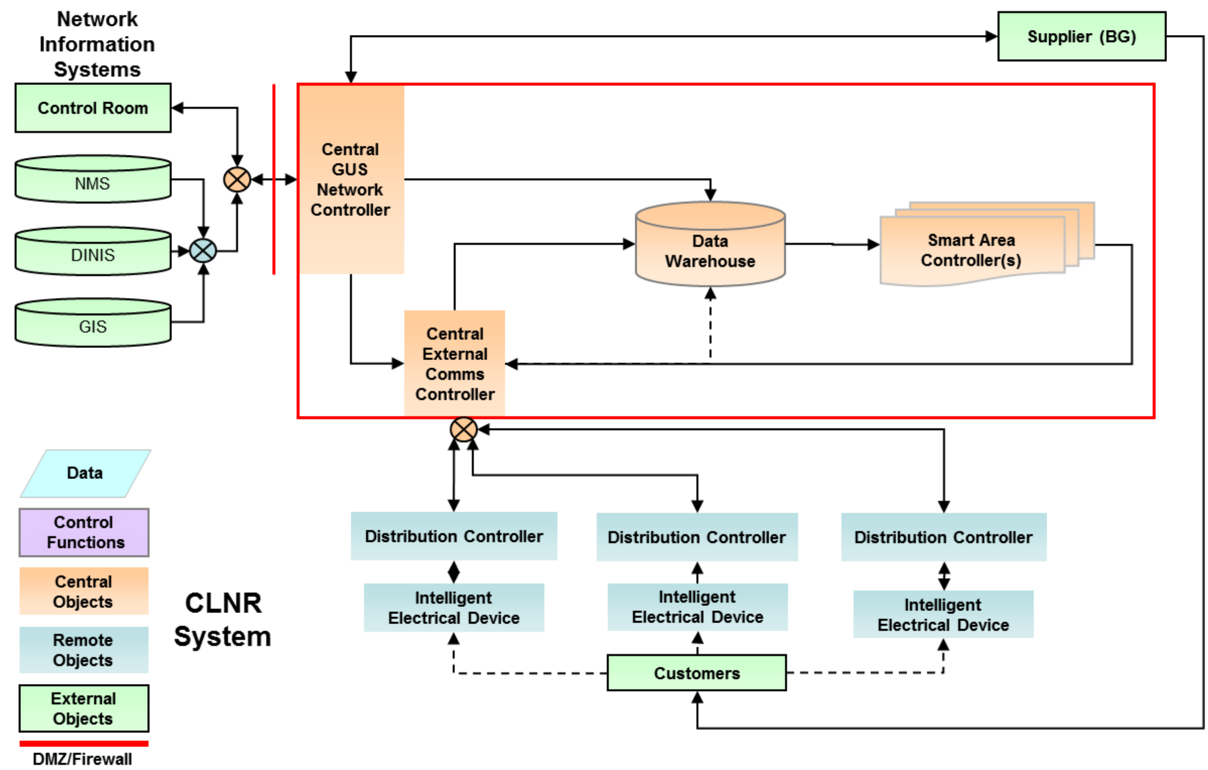

Figure 2 – Expected configuration of GUS

It is worth noting at this early stage of design there was still a considerable level of ambiguity on the details of the network devices to connect to the GUS. Whilst in the ideal scenario these would have already been purchased, the short timescales and innovative nature of the project resulted in many of the devices being purchased in parallel with GUS system competitive tender. This limited the degree of information that could be provided in the technical specification, which was understood to significantly increase the risk of delay and cost increase.

The summary statement from the technical review team from the supplier workshops review report highlights the level of maturity in the market at that point in time (October 2011).

"… it should be noted that the technology and systems employed within this type of prototype system control development is novel, ambitious, undeveloped and hence not fully mature. Developments in this technology are on-going and this CLNR project will forge the learning of smarter grid development."

Two tender specifications were developed:

- Technical recommendation for the purchase of the Grand Unified Scheme Control System; and
- Technical recommendation for the purchase of the Customer Led Network Revolution Data Warehouse[1].

[1] Available on the CLNR website project library http://www.networkrevolution.co.uk/resources/project-library/

It should be noted that the NPSs are specific to the requirements of the CLNR project and were not intended to provide a generic specification for control system applications. The Data Warehouse was purely intended to provide a data storage and query facility for the academic analysis. It was not developed as a Business as Usual system.

2.5 Supplier consultations

The tender invitation received submissions from two companies. The project ran day sessions for each potential supplier to present and discuss their submission. Two independent Tender Assessment Panels reviewed the tender responses; one panel focusing on the technical aspects of solutions (EA Technology and various experts from Northern Powergrid) and another on the commercial aspects (Northern Powergrid).

Both submissions from each respective company were a combination of building on an existing platform with some additional development to meet the specifics of the project. In many respects the two suppliers offered a common solution, particularly around the voltage management functions. The most significant aspects to be developed were interfaces with energy storage and demand-side response.

The key technical discussion areas during these consultations were:

- The need for more information on the specific ENDs required to interface with;
- Clarity on the type and provision of communications at the sites;
- Form the project team, a need to understand the control decision-making approach;
- Myriad practicalities such as authorisations, site details and timescales.

As part of the procurement process, the tender assessment panels scored each submission fairly on technical merit against a scoring mechanism which considered each of the main technical areas of the control system. The final scores were submitted to the Northern Powergrid procurement team to score alongside the commercial elements. The procurement officer validated the proposals and subsequently entered into post tender negotiations with the winning supplier, Siemens. Following a 10-day stand-still period (during which no challenge was received), the formal contract was signed April 2012.

2.6 Procurement

The procurement of the GUS control system was handled in accordance with Northern Powergrid's standard procurement procedures, consistent with European public procurement Directives and their incorporation into United Kingdom legislation as the Utilities Contracts Regulations (2006). It was felt that this had been the correct approach to have taken as it allowed the CLNR project to demonstrate Business as Usual (BaU) procurement of the control system, and the associated challenges.

Within these procurement regulations, it is possible to apply an R&D exemption, as may be deemed appropriate. The feasibility study looked at the commercial offerings of a range of suppliers, indicating that there would potentially be a strong market from a cross-section of suppliers. The R&D exemption was therefore not pursued.

It was also felt that a competitive procurement route would also yield additional learning as it more closely replicates the conditions of a BaU deployment.

Overall, the project team found that the market readiness of such control systems was lower than would be perceived from manufacturer's brochures and discussions.

The procurement of the GUS control system was processed via the Achilles utilities vendor database, with there being three main stages to this:

- An e:Qual stage, where a series of specific questions were tabled, to establish the capability of the candidate suppliers, as organisations;
- The subsequent issue of a formal Invitation to Tender (ITT), to a sub-set of these candidate suppliers;
- The receipt and evaluation of the Tenders received.

The completion of the procurement process led to the award of the contract to Siemens.

2.6.1 Early contractor involvement

With regard to technical ability, suppliers naturally have a wealth of knowledge that they can bring into projects at an early stage. This was particularly evident with Siemens, having vast experience on a global scale. The procurement route followed, although fair and competitive, effectively prohibits significant involvement of a potential supplier at pre-tender stage.

Projects such as CLNR are funded to push the technical envelope; however, noting the risk aversion in how LCNF projects are governed, it is not prudent to push the envelope too much. During preliminary design, it can be difficult for a DNO to fully appreciate the level to which they are seeking a small enhancement of existing market ready solutions (low risk) or more radical changes which require new approaches (high risk). Early supplier involvement helps DNOs fully understand the time and cost implications of pushing for novel or complex features.

2.6.2 Sequential nature of deployment

The program for CLNR dictated that specification and procurement of END systems was in parallel with the GUS control system. This created a large amount of uncertainty from the control system supplier perspective at procurement stage and we understand this uncertainty was close to preventing suppliers from bidding.

Pushing risk onto a supplier does not remove the risk from the project.

During development of the control system, not having details of the specific equipment to interface with increased the timescales and meant the project could not achieve design freeze according to the program.

Conversely, had the project procured all the ENDs before progressing with detailed design of the control system, there would have been an immediate effect on the project program due to the sequential nature. However, in hindsight, this effect would likely have been the same or less as the delays incurred due to the ambiguity.

It should be noted that the project intended to procure "off-the-shelf" END devices as far as possible. It was therefore not practical to specify the interfaces before procurement selection as this could have committed END suppliers to a development program, which would increase cost and risk.

Our recommendation for future projects of this nature is to ensure that all devices required to interface with a control system are known. Regardless of the impact on delivery timescales, the time is likely to be won back in reduction of further issues and this also leads to a more orderly and controlled delivery.

2.6.3 Provision of test samples

When specifying equipment that will ultimately be integrated into a control scheme, it is prudent to request a spare or loan unit to be provided along with any technical documentation describing the function and interfaces. This assists the supplier to efficiently develop their systems and allows testing as early as possible.

2.7 Lessons learned during specification and procurement

The following key lessons learned are related to the specification and procurement phases:

GUS LL 2.1 A control system operating on the HV system must be resilient to connectivity changes, either by automatically detecting and adjusting for connectivity changes, or by integrating the system with the Network Management System.

GUS LL 2.2 Consulting with a range of suppliers before tender submission within a formal procurement route provides feedback on market capability and whether the scope is achievable.

GUS LL 2.3 A procurement mechanism that allows early contractor involvement will allow the involvement of specialist skills onto the project earlier and assist in de-risking the implementation.

GUS LL 2.4 Ensuring all components of a control system are specified in detail is an essential step before designing a control system. Although this can dictate that delivery is sequential, it is likely to lead to a reduction in delays overall.

GUS LL 2.5 The provision of test samples of smart grid components greatly assists in the development of interfaces and de-risks the commissioning process.

3 Design Elaboration

Post contract award and now with Siemens on board, the project entered into a design elaboration phase aimed at achieving design freeze. It was understood that the tender specification was limited in technical content, mostly due to limited detail for the END devices due to the parallel procurement process. The tender submission process placed significant weight on the prospective supplier's plans for finalising a design and delivering the working system within the short time-frame the project programme allowed.

Siemens developed a comprehensive series of workshops involving a wide range of their technical experts on individual aspects of the GUS. The overarching format for each workshop involved Siemens presenting their outline proposal to the project team whilst raising areas for further agreement.

It was clear that Siemens' existing products provided a firm SCADA baseline for which to develop the additional functionality required by CLNR. The proposal was to train the project team in Siemens' SCADA platform (Spectrum Power 5) to allow all project stakeholders to understand the current capabilities as a starting point, and subsequently, the most efficient way to build in the additional functionality on top. It was felt that discussions would be convoluted if all stakeholders were not familiar with the existing system, with the potential for decisions to be flawed. This approach worked very well and is a firm recommendation for all future similar projects.

The workshops were intended to allow Siemens to move the project forward through the development of formal functional specifications. The workshops were:

- Workshop 1: Project introduction and approach;
- Workshop 2: Design of END interfaces;
- Workshop 3: Design and application of Remote Distribution Controllers;
- Workshop 4: Spectrum Power 5 introduction training;
- Workshop 5: Enhancing Spectrum Power 5 to meet project requirements;
- Workshop 6: Design of the Data Warehouse.

The workshops were essential in bringing the project stakeholders together in the early stages of the project. It was clear that there were concerns' regarding the interfaces to END devices as it was still not possible to firmly provide all interface details. There was also concern over the interface to NMS as Northern Powergrid were in the process of updating the system and it transpired that the new version did not have the ICCP interface support, which was intended to be used by Siemens.

While Siemens delivered a comprehensive suite of design workshops, the timing precluded a number of the third party suppliers from involvement. Those contracts were not awarded before the workshops commenced. In the instances where there were no supplier specifications available for a particular END, the project team made informed decisions, on the basis that these may be refined, once the particular supply contract was in place.

Overall the design elaboration phase was an iterative process rather than heading towards a fixed date design freeze. A significant amount of flexibility was required from Siemens and all other project stakeholders to support the continuing development. This created a difficult project management environment with many complex interactions with other parts of the program.

It became clear that there is a lack of standardisation or common approaches in this area. Many of the issues, queries and decisions were generic in nature which undoubtedly other DNOs have faced during their own projects. It was felt there would have been limited benefit consulting with other DNOs as this project was relatively unique at the time. The general level of knowledge and awareness in this sector has increased dramatically in recent years. A key recommendation now would be to set up a forum to consult with and inform other DNOs before, during and after project delivery.

Through CLNR and other LCNF projects, the industry has created a solid foundation of knowledge to inform future delivery practices and process. To ensure this knowledge is succinctly accessible to DNOs in the future it would be of benefit for DNOs, along with other key stakeholders, to reach common understanding of information requirements and develop a best practice guide for delivery and integration of ANM.

As a general note, as far as possible the project team kept the delivery aligned to how a system would be developed and implemented in a Business as Usual context. There were two main derogations from this:

- Communications: the project used public communications and accepted the risk of unavailability of bandwidth;
- Resilience: the project did not specify resilient systems, apart from the connection to existing UPS systems where necessary at primary sites.

The CLNR project was not intended to trial communications systems, however the project generated a significant amount of learning in this area, discussed in section 7.

Detailed thought will be required by the DNO on how they intend to grow their network communications infrastructure to support ANM within BAU. Implementing suitable connections for the required bandwidth and resilience is likely to require a suite of several site specific options seamlessly integrated. It will require considerable effort to design, agree and deliver such a network.

3.1 Lessons learned during design elaboration

The following key lessons learned are related to the design elaboration phase:

GUS LL 3.1 A design approach involving a series of workshops where the design is jointly developed between the supplier and client is an efficient method to achieve design freeze.

GUS LL 3.2 Control systems can be complex and in order for a client to be comfortable with the inner workings it can be necessary to attend substantial training courses.

GUS LL 3.3 For innovative systems where learning occurs as the project progresses, an agile project management approach can be beneficial, where specific priority areas are focussed upon to completion.

GUS LL 3.4 Consultation with other DNOs should be undertaken before embarking on a novel control system design. Due to the innovation funding, there is now considerable experience across the DNO sector.

GUS LL 3.5 It is recommended that DNOs and suppliers jointly develop a best practice guide as the starting point for standardising control system practices across the industry.

4 Deployment and Integration

One of the most challenging aspects of the project was the integration of the GUS control system with the wide range of third party devices required to provide information or act upon new system set-points. This section will discuss the approach and notable lessons learnt progressing through to completion of the factory acceptance tests.

The simplified GUS data flow diagram below shows the range of devices connected.

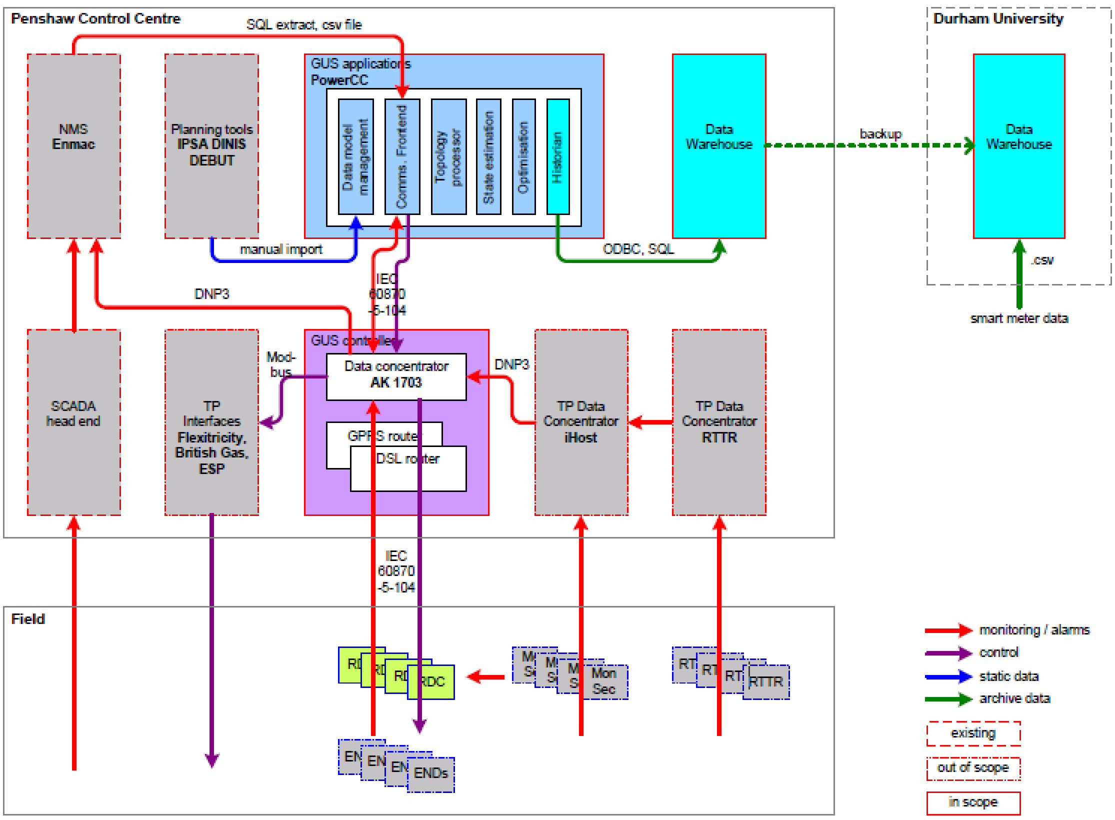

Figure 3 – GUS control system data flow diagram (courtesy of Siemens)

The control system consists of a series of components based on Siemens' Spectrum Power 5 SCADA platform. Siemens have previously deployed the Spectrum Power 5 system at over 200 sites across Europe, ranging from management of transmission networks to radial supply points from wind farms. Therefore, the core system is not a new development and already had certification for the appropriate international design standards. This was beneficial in building confidence in the deployment of the system and gaining authorising signatories within Northern Powergrid.

System Element	Description
Central Controller & Applications	The Spectrum Power 5 SCADA platform providing applications for distribution network analysis (DNA), visualisation, data model management and archiving.
Central Processing unit	The Siemens SICAM 1703 ACP AK platform acting as a front-end processor and data concentration unit for the central controller.
Remote Distribution Controller	The substation and remote site controller built on Siemens SICAM 1703 ACP platform.
Signal Function Device Map	Definition document defining the data flow through the GUS system.
Data Warehouse	An Oracle database platform to provide off-line network data for analysis by the academic team.

Table 1 – GUS control system components

Completion of the control system design was a multi-layered process, beginning with high-level abstract functionality and progressively increasing in detail down through each layer, from types of application, mapping data flows, all the way to individual data points. Joining all the dots requires a suitably skilled and collaborative partnership between all stakeholders (particularly designer and design authority). The design workshops had provided the details for the first layers, allowing Siemens to produce the functional specifications. This part of the design inherently relies upon the ability of the DNO to provide accurate distribution network data, and timely approvals from the various facets of the business. The successful deployment of any ANM scheme will be reliant upon the quality of DNO information and guidance. The major work streams for completing the specifications were:

- Providing an electrical network model with sufficient detail;
- Defining the control system graphical user interface;
- Finalising the implementation of GUS operation modes and how ENDs operate in each mode;
- Definition of all interfaces;
- Definition of the GUS IO schedule;
- Specification of the factory and site acceptance testing;
- Throughout, consideration of operational safety.

4.1 Network model

The state estimation function required an accurate representation of the distribution network for appropriately modelling distribution power-flows and calculating voltage levels. Developing robust network models with sufficient accuracy for the four test cells in the CLNR project represented a significant piece of work. Any ANM system using a state estimator will encounter the same scale of work, namely, generation of network electrical models and defining graphical representation unless existing design systems are in good shape.

The distribution network is regularly reconfigured for outages and faults, managed with the use of a Network Management System (NMS), therefore, when on separate platforms, these systems will need to synchronise network configuration switch data in near real-time. At Northern Powergrid there were several nuances which further impacted this work and likely to be mirrored other DNOs. The NMS network model has connectivity but not electrical data, as current operations do not require the functionality.

In Northern Powergrid the HV network model for design purposes is held in the DINIS format, this contains electrical data and HV network switches. As expected, this format was not readily usable by Siemens for import into Power 5, so it was decided to convert the DINIS data to IPSA, using the converter provided within the IPSA software. This presented the project with a significant rationalisation exercise to create sufficiently accurate network models in IPSA that corresponded with the network in NMS. The DINIS to IPSA conversion process did not carry through network switches, and component naming conventions were not aligned with NMS, so it was necessary to manually import the data into the GUS platform and build in further extensive validation checks. Siemens have the ability to automate this process but for four networks the time investment to set this up was not feasible.

To quantify the DNO work involved, the Denwick test cell model (two HV feeders and half a dozen LV networks), when simplified, had in excess of 2000 bus bars. The work took a team of two approximately four months to complete. Further on-going work was required to maintain the models in line with actual network developments over the project trial period.

A clear recommendation is for DNOs to establish a common format across their systems to facilitate seamless data transfer. This would reduce the work involved to maintain several network models across conventional NMS, future ANM schemes and design tools.

The project felt that providing the state estimator with the most accurate model that could be provided was important. A key learning point was that it would have been beneficial to simplify the model significantly.

4.2 User interface

Incumbent NMS for each DNO has a particular look and feel. Although this system was to be provided by a different supplier it was important to mimic as far as possible the existing user NMS interface. This approach provides benefits such as reducing the learning curve, limiting training requirements and reducing the likelihood of user errors. In addition to the initial scoping effort, the implementation requires thorough review prior to commencing of site based commissioning works. The work includes manually verifying each part of the single line diagram display of the network model and associated system analogues. It is slow and arduous work requiring two skilled control engineers. Given the current scarcity of control engineering resources in most DNOs, this amplifies the difficulty in planning and executing the work without adversely impacting the delivery schedule.

4.3 Operating modes

The GUS is a complex control system which takes input from and manages a variety of discrete devices. It is important to ensure that the system:

- Operates safely and as expected during failure scenarios;
- Allows the operator to gain confidence in the system, given the novelty;
- Provides the data to allow the project to achieve learning (which may not necessarily be required for BaU).

To support these goals, GUS was developed to have five defined operating modes to enable implementation of the hierarchical architecture under test. The table below presents the high-level philosophy for each mode. The design team then had to agree the implementation of these modes for each connected device.

Mode	Description
Central	Power 5 manages the test cells based on a wide-area view and sends out voltage and power set points.
RDC	Each RDC is managing the local site based upon local monitoring. The RDC sends passive control interventions to the END. Status and intervention data is sent to the Power 5 Controller.
RDC+	Test mode for the CLNR trials. The Power 5 behaves as if managing the test-cell. The RDC remains in RDC mode and does not react to commands. This effectively allows the operator to check what action the system proposes without it being passed to the device. This was useful for confidence building.
END	The Device acting autonomously on its default settings without any interference from the RDC or Power CC.
Safe	Inhibits all interventions and place the End is default mode. This mode can be set either for individual sites, test-cells or the whole GUS scheme.
Loss of Communications	This mode was to define how the system would implement gracefully degradation across the devices if communications were lost.

Table 2 – GUS control system operating modes

The parallel procurement of ENDs in the early stages of the project prevented the definition of the operating modes and data transfer across all devices during the design workshops. The work took place later through direct consultation with each supplier, followed by subsequent agreement with Northern Powergrid stakeholders. Due to the novel technical nature of the work, this became quite a protracted process. Taking the Energy Storage systems as an example, the definition of operation modes required clear definition for Northern Powergrid's Protection, Telecoms, Safety, and Network Design experts to accept and allow its operation. To complete this work the project required extensive liaison and cooperative working with the equipment supplier who were interfacing to an external control system for the first time in the UK.

4.4 Interface definition

4.4.1 Interface with END devices

To provide control of the ENDs, it was required to develop twelve unique third-party device interfaces for forty-five physical devices.

The initial market assessment informing the project bid suggested all the END devices would be available 'off-the-shelf'. The project found, at the time of going to market in late 2011, the supply chain was more embryonic than anticipated. It proved difficult to purchase all the ENDs, despite in many cases manufacturers having products listed in catalogues. A number were still in the later stages of prototyping.

As a high level view, the Technology Readiness Level (TRL) of the END devices was reasonable high so as to ensure smooth installation and testing, however, as a system, the TRL was significantly lower. Integrating the equipment under a single common control scheme was more time consuming than expected.

The interface development work for an ANM broadly separates into three categories of integration:

- Network Monitoring;
- ENDs;
- NMS and similar operational systems.

Northern Powergrid have policies outlining the stages and work involved with introducing new SCADA / telemetered control systems, used by their primary engineering teams. These, where appropriate, were followed by the project. When the devices interfacing are market ready products, at TRL 8+, then this process is robust. To integrate new/prototype devices, there is no policy coverage and essentially each one requires a multi-discipline review to ensure the implementation covers the required functionality and fails safe. The categories of functionality to be covered include:

- Operational controls, ensuring operational safety in all feasible circumstances;
- Measurement parameters, ensuring the right data is recorded to facilitate project learning;
- Communication practicalities, ensuring consistent timestamps, synchronised time across devices and handshaking arrangements;
- Generation and transmission of alarms back to the control room;
- Protection, ensuring protection systems are appropriate for each network component.

It is required that several staff disciplines are involved to either define their requirements, or approve the proposals before implementation. This involves considerable engagement with system design, protection, safety and telecommunications representatives.

For the GUS, to help simplify the process, industry standard protocols were used such as DNP3 and IEC 60870-5-104. Similar to the experiences from many projects, adopting a standardised protocol gives a level of comfort but does not guarantee a smooth process to integrate equipment – there are many interpretations of how to adopt standard protocols. There would be benefits for DNOs to collaboratively produce a suite of application guides to inform the industry of a common interpretation of frequently used standards such as DNP3. This could reduce time and cost to configure equipment, and de-risk communication issues.

As it stands there is no single communications protocol that is suitable for all distribution operational applications. The path is set for a number of protocols to be used for smart grid applications. Although the standard IEC 61968, partly under development, and the Smart Grid Architecture Model, proposed by work funded under the European Commission, are important developments in this area.

4.4.2 Interface with NMS

The GUS requires live data on the status of HV network switch positions from Northern Powergrid's NMS. This enables the state estimator to understand the current electrical network configuration before predicting power-flows. It is a critical piece of information; if the GUS electrical network model does not reflect the actual configuration then power-flows and hence subsequent optimisation proposals will be incorrect.

There is an ISO protocol available to provide this master-master connectivity between control systems, outlined in IEC 60870 Part 6 Inter-Control Centre Communications Protocol (ICCP). However, as this connectivity was being scoped Northern Powergrid were in the process of an upgrade to their NMS. The planned delivery of GUS would have required development of connectivity mechanisms to both the existing and then the subsequent updated version of NMS. A simpler approach was taken to provide HV switch configuration data: a script would run on the NMS switch state database every five minutes, producing an output text file. The file contains two data fields: HV switch asset number and status (open or closed). The exported file is then exchanged between the two systems using an SFTP (SSH File Transfer Protocol) client mechanism. It was considered important that the GUS receives real-time updates of connectivity from NMS; however, as the cycle time for the GUS control loops was five minutes, matching this periodicity was deemed appropriate.

As the GUS has a connection to the internet, when considering a connection to a safety critical system, security is a major concern. As the GUS and NMS operate in separate security zones, a jump server was used to pass the file from the NMS DMZ to the GUS DMZ. This gave a three-stage process of firewalls to provide a secure connection. As in this case, where an ANM system is separate to the core NMS it will require definition of the following:

- Security – implementation of a suite of methods to prevent breaches;
- Data contents – configuration of consistent shared data fields;
- Data transfer arrangements – data update arrangements (e.g. polling and update frequency);
- Performance – the processing capability of the systems that generate and transfer the data;
- Connectivity – communications protocols to be used.

At some sites, it was also required to pass alarms directly back to NMS rather than the initially planned route of through GUS. Additional RTUs were installed with Radius (microwave link) connections. The NMS was configured for these additional alarms by setting up a drop down menu leading to a separate alarms page on the main operations screen in the NMS interface specific to CLNR test cells.

4.4.3 Time synchronisation

Clearly, maintaining clock synchronisation between the disparate devices is an important requirement. The project specified the connection to Northern Powergrid's Network Time Protocol (NTP) server as common clock signal to synchronise devices. This system uses UTC time but it later transpired not all devices could carry out the manipulation to local time. This can be corrected manually but in the UK this presents a problem at seasonal adjustment times.

4.4.4 Stakeholder engagement

The introduction of the GUS into the network control room and at network sites represented a significant new direction, touching on many of the major facets of the business. The project team understood the importance of engaging all stakeholders and perceived this as a two way process, that their views counted and they had a real opportunity to shape the outcome. The project delivery team then worked to provide clear direction and ensure any concerns or opposition are addressed. The development of a clear stakeholder strategy for dissemination of information and management of changes to operations is a vital part of successful delivery. Key points of the engagement strategy were:

- Formation of a Technical Group for detailed design review;
- Formation of a stakeholder working group;
- Regular updates to stakeholders during delivery;
- Joint development of an Acceptance Strategy;
- Development and delivery of staff training.

The formation of working groups is a method of engaging a wide range of stakeholders and facilitating discussion and accountability. In the detail of delivery it can become easy to expect everyone to understand the reasoning for actions, or become de-sensitised to the potential level of changes to individual roles/teams. The development of a working group is also beneficial in avoiding divergence between project team thinking and the expectations of the wider business.

The roll-out of GUS involved numerous internal stakeholders; the table below shows the scale of this activity:

Role	Involvement	Preliminary Design/ Tender	Detailed Design	Commission
Director of Field Operations	Strategic direction and approval	X	X	X
Head of Protection and Technical Services	Strategic direction and approval	X	X	X
Head of System Strategy	Strategic direction and approval	X	X	
Head of Safety and Training	Strategic direction, Operation requirements and approval	X	X	X
Head of Network Planning and Design	Strategic direction and approval	X	X	
Head of Telecommunications	Strategic direction and approval	X	X	
Standards and Policy Manager	Strategic direction and approval	X	X	
Control Operations Manager	Strategic direction and approval	X		X
Network Projects Manager	Strategic direction of integration with NMS and approval	X	X	
Control Engineer	Network	X	X	X
Protection Engineer	Equipment selection, design settings, testing requirements and witness		X	X
Telecommunications and SCADA Engineers	Equipment specification, install, commissioning	X	X	X
Field Engineers	Site surveys and field operations		X	X

Table 3 – Internal stakeholder engagement

The sites for the installation of GUS and the ENDs were determined at bid stage. A verification exercise was undertaken early in the project to ensure that appropriate learning could be generated and there were no major restrictions on the use of these sites. Across the four test cells a mix of supply side variances (e.g. heat pumps, solar PV, storage heaters) and network type variances (e.g. dense urban, long overhead rural) are provided.

To complete the wider control scheme, the project required installations at seventy sites, sixteen being at substations. Equipment was installed at 66kV, 20kV, 6kV and 415V.

4.5 Enabling works

Site installation particulars were verified to provide the supporting documentation to allow sub-contractors to accurately scope and plan to deliver the schemes. For seventy sites, a significant amount of time is needed to arrange and conduct site surveys to verify suitability of proposed sites and identify any difficulties due to legacy equipment. Schematic diagrams and associated site works packs were produced to allow progression.

Early involvement of the projects Safety Health and Environment (SHE) managers allowed identification of the types of mitigation actions the project needed to consider at the sites. The CLNR project delivery team had significant direct support from SHE, ensuring a number of mitigation steps were designed in from the start, particularly around control modes (local ability to lock the control), site access arrangements (CLNR sites were restricted) and training requirements for field staff.

An induction pack was created to remind site staff of health and safety issues and inform them of the overall objectives, the programme of works and how their works fits in with others to allow co-ordination. The main body of the induction pack was generic and then augmented for each individual / group to clarify how their work supports progress.

4.6 Installation practicalities

Commencement of the GUS site installation works was dependent upon the progress of works for installing new END and network monitoring devices. The sequential nature of this activity naturally caused timescale pressures. The CLNR installation work spanned over ten different companies which creates a project management challenge.

Combinations of smart grid enabling equipment are in their infancy and many products are often not rationalised, for instance, it is usually necessary to install additional RTUs for a monitoring device rather than the device having this functionality integrated. For sites with multiple pieces of equipment, space can be a restricting factor. Smart grid technology is developing reasonably quickly and the real-estate needed is reducing however substation space will continue to be a constraining factor at many sites.

For many installation activities under CLNR, a single contractor was used. In these cases, this greatly assisted the project in having a single point of contact, minimising project management resource needed from the core project and gave a continuity of engineers on site.

4.7 Control of hardware and software

To accurately test the system in the factory it is necessary to mimic as far as possible the equipment required to interface with the control system for each test cell equipment configuration. This requires an accurate and controlled database of equipment installed as part of each site. The database requires information on firmware version, configuration settings, database settings, baseline reference and authorizing staff for each item of equipment. This records the build standard of the overall installations and allows control as updates are rolled out. Once the control system is live, as nuances are discovered and updates patched, the management of this baseline is critical to keep track of the situation.

Configuration data for novel schemes does not currently have a home in a DNO, so it is initially necessary to develop a system for project purposes. A process is then needed to hand the information over at project completion. There are a number of established software configuration management programmes available for this purpose, both commercially and open-source. Alternatively, spreadsheets can be easily developed.

4.8 Lessons learned during deployment and integration

The following key lessons learned are related to the deployment and integration phases:

GUS LL 4.1 Successful deployment of an ANM requires significant and continuous involvement of DNO personnel. The state of the market is not appropriate to manage through supply contracts, many details must be worked through during implementation.

GUS LL 4.2 The network models used within state estimators should be as simple as possible. The benefits of additional accuracy that may be gained through a complicated model may be lost in the increased effort required to configure and maintain the model.

GUS LL 4.3 Developing a network model with sufficient detail and accuracy is a considerable task.

GUS LL 4.4 Defining a common format for network data across DNO systems would facilitate easier data transfer and reduce the maintenance burden.

GUS LL 4.5 The use of standard protocols provides a level of comfort with the knowledge that it will be possible for two devices to communicate; however, there are many interpretations of implementation and design work is usually necessary.

GUS LL 4.6 There would be benefits for DNOs to produce a suite of application guides to inform the industry of a common interpretation of frequently used protocols.

GUS LL 4.7 A simple method exists to extract switch status, and many other parameters, from NMS using a simple script running on data contained in the NMS reports database which had little impact on normal system operation as delivered on our test cells.

GUS LL 4.8 Where devices are required to operate using local time zones, they should be specified to accept signals from a time server and automatically adjust for seasons locally where needed.

GUS LL 4.9 The number of roles within a DNO that need to be engaged with is large. The formation of Working Groups to engage all internal stakeholders at appropriate points is beneficial.

GUS LL 4.10 Early involvement of Health and Safety personnel allows the early identification of mitigations so they can be designed in at the outset.

GUS LL 4.11 It is important to keep track of installation parameters and record changes to systems, to enable version control of design documents.

5 Testing Strategy

DNOs rightly have a conservative approach to introducing new equipment on their network, it is therefore important the systems undergo comprehensive testing. A foundation of this work requires the connection of reference systems in the factory. CLNR was a cutting-edge project incorporating a mix of advanced prototypes, turnkey, and legacy equipment from suppliers in the UK, Western Europe and North America. While all parties involved with GUS delivery made every effort to assist, share information and work together, the integration of new technology to legacy equipment presents significant technical challenges.

A key learning point is to ensure the control system supplier is provided with fully functioning test samples for each device. This is likely to require stipulation in supply contracts. Where it is a legacy device, it would be prudent to obtain a spare for off-line testing or agree an alternative approach.

The Factory Acceptance Test (FAT) is usually the first significant opportunity to witness implementation of the specification and additionally presents the client with a valuable opportunity to develop their understanding of operation. It is worth clarifying the two key objectives at this stage of delivery; firstly to verify the supplier is producing what was specified, and secondly, as a result of testing, to confirm the equipment is suitable to pass to the next stage of delivery – typically installation on the network. The importance of gaining approval from the appropriate senior managers in the business of testing proposals cannot be understated. Novel systems such as the GUS involve greater levels of automation than is typical on a DNO network. Therefore, the testing activities required will be more comprehensive than for minor upgrades to standard issue equipment.

The initial plans were for a comparatively straightforward sequence of factory acceptance tests before more in-depth site acceptance tests to verify functionality. As the complexities of integrating the GUS with the various devices became apparent, this philosophy was deemed too simplistic. The GUS provides a level of automation not previously experienced on the electricity supply network and so it naturally presents a level of discomfort for authorising managers. A staged release plan was required.

As part of the Working Group approach, senior technical and safety stakeholders developed a six-stage acceptance strategy, to alleviate safety concerns. This broke the FAT into stages of functionality aligned with the individual test cells – starting with the simplest and gradually increasing complexity as confidence grew. For a complex system dependent on network analogues to drive decisions, there are limitations in validity of what tests can be achieved off-line. It therefore becomes important to have a clear and considered approach with defined success criteria at each stage. Outlining how each stage builds on previous results to progress to acceptance or rejection of system functionality. The tests must include sufficient stress testing to assess how the system will react to potential abnormal conditions. These stress tests should directly identify those tests aiming to verify that the system fails safe. The failsafe tests greatly assisted in growing the confidence of safety, network control, and protection teams on the increased levels of automation.

It is important the testing strategy is agreed during the initial stage of the project as it has significant impact on both delivery timescales and skill sets required. The testing strategy should give suitable consideration to:

- The overall philosophy of the FAT and SAT, a view of what system aspect is tested, where and how;
- Provision of test configuration and network equipment required for tests;
- Success criteria for each test stage, in particular, distinction between tests which prevent progression to the next stage and those which are mopped up in, for example, issue lists;
- Understanding of the limitations of testing at each stage due to the inability to replicate site conditions (e.g. lack of real analogues);
- Categorisation of tests, distinguishing between test which require client witnessing or if self-certification is acceptable;
- The appropriate approval process for test scripts, who holds the responsibility to develop them and the timescales for their delivery;
- The need for strict version control of software and database upgrades and modifications;
- Resourcing requirements and logistics, different disciplines may need to witness specific tests, which may not fit into the supplier program.

The usual way of working is for the testing plans to be developed by the supplier and approved by the client. For a complex system this process can be iterative. It is recommended that an initial strategy is jointly discussed so the supplier has a clear direction of which tests are most important to the DNO.

Figure 4 shows the high-level testing strategy. A significant amount of concern regarding the control system was the novelty of the autonomous control of ENDs, which in some cases were novel themselves. The GUS system was designed to be able to operate in an Open-Loop mode (i.e. to centrally monitor the network, and retain all ENDs in local control), which allowed it to be installed and operated on the network to assist proof of the full end-to-end functionality. This provided a natural approach, and avoided a significant amount of type testing to allow full autonomous control.

As a blanket summary, the control modes of GUS were effectively, off, local and central. The project team, working with Siemens devised an additional control mode, RDC+. This allowed the central controller to enact full autonomous control whilst the remote devices were prevented from performing control requests. This allowed the project team to capture what actions the control system was requesting, without them being acted upon. This was an essential feature in obtaining overall approval as it built confidence in the system – control engineers had more clarity on why decisions were being made. Operating in RDC+ mode for a period of time and being able to sanity check control decisions was a key risk mitigation to switch the system into full autonomous mode.

A stage gate at the end of each phase allowed the project team to review progress before commencing the next phase of work. The open-loop commissioning stage was an extension of tests carried out in the factory but with real network analogues used by the state estimator.

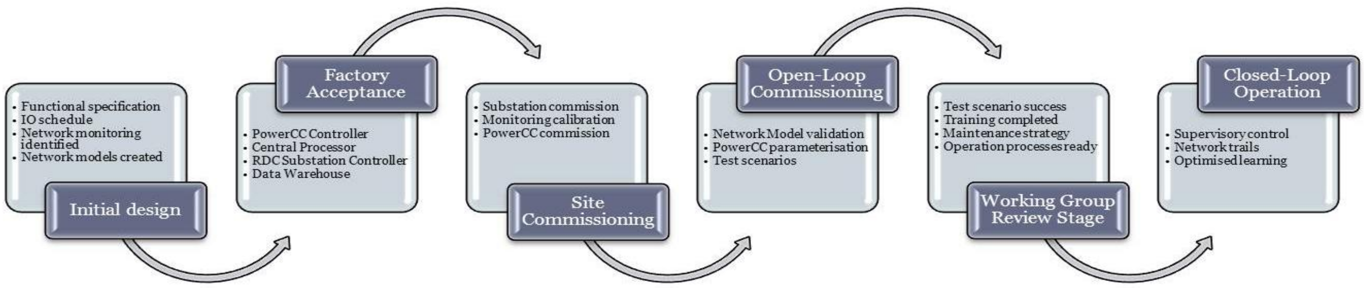

Figure 4 – Overall testing strategy

5.1 Factory acceptance testing

Post design, the FAT comprised of five stages, progressively testing the interfaces to ENDs, functional testing in various control modes and then progressing to a system FAT. The project team have reflected that the FAT phases in reality had limited value as it was not possible to adequately replicate site conditions.

With the benefit of experience an alternative option for commissioning the central control system would be to build and fully test all safety related functionality in the factory and then progress to site installation, where the system can be thoroughly tested and more issues could be identified. During our approach the project team found that site commissioning tests uncovered additional issues that were not identified during the FAT – time may have been saved by uncovering many of the issues in one process to allow them to be managed earlier. It is noted the Technology Readiness Level (TRL) of each individual component, including the control system, may be high, integrating components together on this scale lowers the TRL considerably.

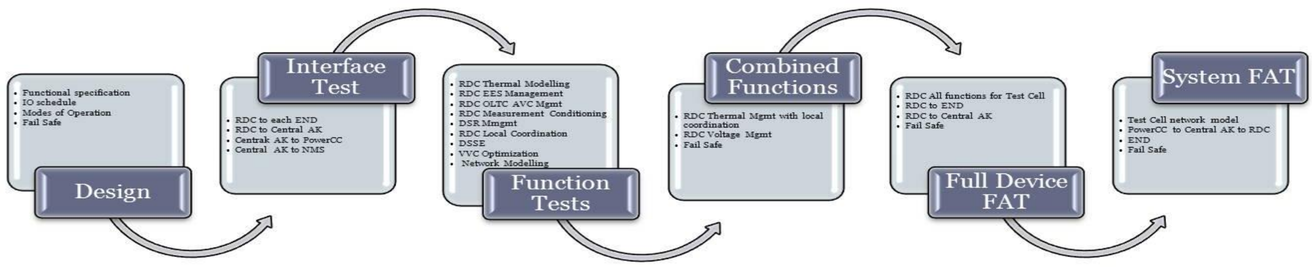

Figure 5 – FAT testing strategy

'Open sessions' were held after the early FAT process to allow stakeholders to visit the test labs at Siemens and witness particular functionalities in operation. This improved confidence in the early stages, provided a sense of openness and gave the opportunity to raise concerns.

5.2 Site acceptance testing

From a DNO perspective, the novelty of the technology led to the requirement for increased preparatory work and resourcing during tests. At any site for the CLNR project there were at least two new systems – a new END or an enhancement to existing assets, such as RTTR to an existing transformer, and a new GUS component.

The GUS was installed as a separate stand-alone system operating in parallel to NMS. Part of the acceptance strategy was to test the passing of alarms through the legacy SCADA system to ensure that critical issues are passed to the control room via a conventional route in real time – the 'GUS desk' may not be manned permanently. Some complexity was necessary as it was not desired for all alarms to be sent via SCADA. Some work was undertaken to define which alarm events would be handled through the GUS and which would also require passing through SCADA/NMS.

5.2.1 Preparatory works

The configuration of ANM involves a number of areas of the DNO business. As a result, there is considerable work to produce all the supporting documentation and organising the range of skills for test days. The main streams of work are:

- Site visual inspection by NPG and Siemens engineers;
- Site acceptance packs – test scripts, site drawings, IO schedule, test certificates for each third-party device and electrical installation details;
- Review of Power 5 network diagrams and GUI;
- Validation of network monitoring devices and end-to-end checks of the database;
- Network outage requirement review;
- Completion of operational training (required before site acceptance);
- Production of operation guides;
- Holding of the SAT Workshop to obtain the Go / No Go decision in advance of acceptance tests.

The site acceptance pack content was the foundation for gaining support and approval to progress to acceptance testing on site. The delivery team worked in partnership with Siemens to draft the document format and salient content, agreeing success criteria and the scope that could be pragmatically achieved. This minimised the review cycle and avoided any surprises in missing or overly demanding tests.

It is recommended that test script descriptions are simplified so as to be quickly understood by all approvers.

Where a project is planning tests on the system or work requiring control room operators, Northern Powergrid use a process of booking that resource in advance using the 'network outage' process. There is a lead time associated with this, depending on other projects underway, which must be considered during planning. The schedule for the SAT had to be agreed two months in advance.

The deployment of innovative equipment onto a live distribution network has inherent risks which must be carefully managed. As part of the CLNR project delivery, which encompassed GUS, a range of training and support documentation was required to be delivered before equipment could be commissioned. The main requirement was based on field operational staff who may be required to interact with the equipment during an outage. The scheduling impact was that the ENDs at each site had to be commissioned onto the network and operational, meaning all associated training and documentation delivered, before the GUS team could begin the SAT works.

The SAT Workshop functioned as part training and part health and safety risk assessment and approval. The objective was to step through the SAT plan for each site with representatives from each discipline to make sure risks, equipment and issues are fully considered before the work was carried out on the network. It also worked to smooth the path forward by ensuring everyone involved had been briefed and was familiar with other team members' responsibilities before the works started on site.

The remaining work preparing for the SAT focused on checking the sites are installed as expected and all software and equipment is ready, to avoid any surprises on the day of testing.

5.2.2 Testing process on site

The successful completion of the SAT for the control system requires a multi-disciplined team of test engineers both at the network site and in the network control room and therefore coordination and scheduling is important. Siemens led the sequence of testing on site in coordination with the Northern Powergrid Senior Authorised Person (SAP) and the project delivery team providing the engineers to operate the network equipment; authorise site access and witness results. For the GUS, the SAT process required engineers for the following disciplines:

- Protection;
- Expert for the particular END;
- Control system supplier design engineer;
- Network control;
- Telecommunications;
- Senior Authorized Person.

An open telephone conference platform, operating continuously during commissioning, was used to allow remote engineers to readily discuss activity and issues.

The diagram below outlines a typical sequence of tests completed during the SAT at each site:

- Visual inspection installation to construction drawings;
- Test communications data link;
- Communication checks;
- Time synchronisation;
- Software uploads to RDC and GUS;
- Testing of acquisition data:
    - Monitoring signals;
    - Control signals;
    - Alarms.
- Fail-safe devices operation;
- RDC to Power 5:
    - Operating modes;
    - Operating scenarios;
    - Alarms;
    - Fail safe.
- Stress tests.

In most cases the thorough testing of each site could be completed between one and two days.

5.3 Lessons learned during testing

The following key lessons learned are related to the testing phase:

GUS LL 5.1 Inclusion of an operating mode specifically for test purposes (RDC+ mode) can simplify testing and reduce the time needed for operators to gain confidence in the system.

GUS LL 5.2 The specifics of the testing strategy should be discussed between the client and supplier early during the design stage to give the supplier a clear understanding of the tests most important to the DNO.

GUS LL 5.3 Rather than testing as much as possible in the factory, it is beneficial to perform a reduced set of tests and then install the system onto the network, operating passively, to allow debugging in a live environment. This assumes the ability exists to remotely configure devices.

GUS LL 5.4 Developing a site testing pack that clearly states the tests and the success criteria is vital to obtain buy in, especially from stakeholders who are not involved with the project on a daily basis.

6 Operation

6.1 General

The GUS control system has been operated over many months and confidence has been built up in its operation. As confidence has increased, the control system was given gradually increased levels of autonomy over network devices:

- Initially the GUS control system was operated under direct supervision;
- Successful commissioning tests of operating modes and switch off functions allowed the GUS to operate in listening mode without supervision;
- Supervised operation of the system in RDC+ mode (where the GUS acts as though connected devices are operational and sends commands, but the RDC ignores them), showed over a period of time that decisions were as expected;
- Initial operation of the system in closed loop mode (GUS both makes decisions and acts on them) was supervised and the number and type of devices that were operational were limited;
- Trials were conducted to test the system over a range of circumstances by, for example, reducing thresholds to drive out specific actions;
- A period of gradual reduction in the amount of supervision over the system until unsupervised overnight operation was acceptable.

Power 5 has the ability to optimise the network based on a range of parameters and there was naturally some tweaking of these parameters over a period of time based on the projects goals. For example, if reduction in losses is entered as a benefit, then the system would generally attempt to operate at lower voltages, where lowering the voltages does not lead to the breach of voltage limits. Therefore when losses parameters were set the system, as might be expected, drove the primary to bottom tap. On analysis of the monitoring data and the state estimator output, on which the decision was made, it was shown that lowering the voltages across the system did not lead to a breach of voltage limits. It was therefore the correct decision to make based on the optimisation parameters that Northern Powergrid entered into the system.

The Power 5 system can optimise the network based on losses minimisation, risk of thermal excursion and risk of breach of voltage limits. Each of these has their own set of parameters and thresholds to allow the system make optimal decisions. The project experiences have highlighted that the configuration of such systems, in particular in being able to balance risks and rewards of a number of operational parameters, is an important consideration. In our example, voltages were reduced which increases the risk of voltage excursion – careful setting of parameters to proportionately balance the benefit of losses reduction and increased risk of excursion is needed. Consequently to avoid any nervousness, the system was not set to optimise for losses.

As previously noted, the RDC+ mode was an essential part of allowing the team to gain confidence.

As a result of operating the system over a period of time, the project team have confidence that the control methods within Power 5 are robust; all decisions were explainable.

There remains concern over the resilience and maintenance requirements for such systems, in addition to the expertise required, which is not ordinarily resident in DNOs, as such there may be some reticence to deploy this type of system at the present time; it represents a considerable change to the way DNOs manage their networks today.

The Remote Distribution Controllers installed in the substation to control the local devices performed extremely well and Northern Powergrid has a high level of confidence in this equipment from a BaU perspective. The equipment was found to be very reliable and feature rich, for example, the RDC contained backup safety features such as voltage limits – should the central system issue a wayward voltage set point, the RDC would not action it if outside the locally set limits.

6.2 State estimation

The state estimator seeks to understand the powerflow and voltages for the network based on:

- A network model, to understand connectivity and electrical characteristics such as impedance and rating;
- A customer model, to understand demands on the network; and
- Measured data.

There are myriad parameters to configure the model and the algorithm used to estimate the powerflow is complex. The system uses the three inputs above and attempts to converge on a solution. The Power 5 system allows the user to view the estimated powerflow and voltage at any node of the network. Some exercises were conducted whereby a measurement was excluded from the calculation. Overall the state estimator produced accurate results. As an operational example to highlight the importance of state estimator configuration, in one case the communications temporarily dropped out for the load measurement of a distribution transformer. The state estimator reverted back to the model and derived a larger load value for the transformer; as a result Power 5 in the next control cycle deployed the energy storage system connected to the transformer to reduce the demand. It was discovered that in the configuration for transformer load measurements, a higher scaling factor was needed for static values.

It was highlighted that the maintenance required to keep the model up to date was substantial. Issues were also apparent with the state estimator being robust to connectivity changes; however, it should be noted that the root causes of the issues are not necessarily the state estimator – the network model may have been incorrect.

It was noted that for future projects it would be beneficial to install and commission the state estimator earlier in the overall scheme. This would have allowed it to be debugged and for the model to be adjusted earlier in the process. Commissioning of a state estimator generally takes six to nine months.

6.3 Remote configuration

Although perhaps obvious, a key operational benefit of the GUS system was the ability to remotely configure devices. This allowed changes to firmware and configuration settings to be made without visiting site and greatly assisted the project to run trials in a timely manner.

This also provided benefits in being able to debug issues. For example, the operator can change voltage set points and force the EAVC device to tap which is useful for end-to-end testing of the AVC relays and all associated communications infrastructure.

6.4 System stability

The GUS control system was operated with an update periodicity of five minutes. It was set to this frequency as it is achievable it aligned with the shortest thermal time constant of connected equipment (overhead line). The rate also provides inherent stability as all downstream devices within the period would have settled into their operating state if it changed in the last cycle.

AVC relays are operated with time delays to give upstream devices the opportunity to correct voltage issues first as a means of preventing hunting and minimising taps. The five minute rate of the GUS allows for these time delays to expire between each control period.

6.5 System redundancy

The GUS control system was specified as a non-redundant system. For trial purposes this is acceptable as it was not to be operated on constrained networks and the project would cope with short delays whilst issues are addressed. The Power 5 system is designed with redundancy (and scalability) in mind and there are various levels of failure security that can be opted for.

For future systems, redundant systems would likely be specified to include dual servers and hot standby functionality.

6.6 Control room interface

The GUS front end (user interface) was installed in the control room to facilitate operation and ensure appropriate access control. It is separate from the BaU NMS and therefore required additional hardware such as desks and display screens. As ANM schemes are anticipated to be part of the future of DNO operations, careful consideration is needed to the transition plan.

In the short term, for innovation projects and limited BaU roll outs, the desire will be to include these schemes within the existing NMS front end. For suppliers of control systems, this could be a barrier as access, working knowledge and, in most cases, assistance from the incumbent supplier of the NMS is required.

It is recommended that DNOs define a strategy for how they will develop their systems in a transparent way that improves market competition.

6.7 Lessons learned during operation

The following key lessons learned are related to the testing phase:

GUS LL 6.1 The GUS control system can be used, and has been demonstrated, to optimise networks based on risk of thermal constraints, risk of voltage constraints and reduction in losses.

GUS LL 6.2 Maintenance requirements and reliability remain a key concern for consideration of wider roll-out of advanced wide area control schemes.

GUS LL 6.3 Substation controllers, configured to manage local devices are a robust and, potentially, inexpensive way to manage multiple local network devices.

GUS LL 6.4 State estimation has been demonstrated on four network areas to be an accurate method of estimating voltages and powerflow's with limited monitoring data.

GUS LL 6.5 The configuration and maintenance of a state estimator is a non-trivial task, it is recommended to install the system in listening mode as early as possible to allow more time for fine tuning.

GUS LL 6.6 Full remote configuration of devices is an essential requirement for smart grid technology.

GUS LL 6.7 DNOs will need to define a strategy for how they will allow new control schemes from various vendors to infiltrate in the control room environment.

7 Communication Systems

This section is not specific to the GUS control system – it describes the wider communications architecture rolled out for all network technology.

Northern Powergrid's telecoms team specified and implemented the telecommunications network used to facilitate the GUS control system and all other communications systems under CLNR. This approach was taken for two main reasons:

- It is policy that parts of the NPG network can only be operated or accessed by either direct employed telecommunications team members or NPGs third-party ICT contractor;
- Secondly, use of competent and trusted internal staff would de-risk and simplify the delivery of a crucial element of the project.

7.1 Communications media

The CLNR project aimed to use the most cost effective communications solution available in each case. The project was not seeking to specifically test different communications mechanisms. A blend of public and private methods was used:

- Fixed line ADSL;
- GPRS;
- Microwave links.

Initial installations of monitoring equipment used GPRS connections. Surveys were carried out beforehand to ensure coverage was acceptable. There were concerns over bandwidth, reliability and latency issues; however the cost and practicality outweighed this in the early project stages. Once installed, gaps in data recording were evident and as a short term measure, enhanced antennae were used. Although this improved the reliability of data transfer, it became clear this would not be a suitable media, considering the real-time nature of the control system.

At busier sites the amount of data that was planned to be generated and required to be transferred to the project Data Warehouse, in some cases at one minute sample rates, was significant. Although GPRS (3G) can have sufficient bandwidth, the bandwidth level is variable and dependent on others' usage (voice traffic holds priority in GSM). It was decided to install fixed line ADSL connections to all substations where it was intended to house new equipment.

Installing fixed lines in substations took the project over nine months. The delays were mostly due to the drawn-out sequential process followed by the service provider. Missed appointments could delay progress significantly. All appointments had to be attended by Northern Powergrid personnel for substation access which was a drain on resources. Five appointments were necessary for each of the 16 sites: quote, survey, fit, termination and router installation.

It was previously required for all 'hot sites' to install isolators, this is now not necessary if the local BT exchange is connected by fibre optic rather than copper cables.

For remote sites (e.g. end of feeder monitoring) it would have been disruptive and expensive to install fixed lines, so GPRS was used. In some cases the local authority was engaged to seek permission to install GPRS antennae in street lighting. Roaming SIM cards were used that can hop between carriers. In reality, the cards only change carrier when they have lost the connected signal, they do not hop to find the 'best' carrier. This feature does, however, provide some security against communications outage. At the time, it was not possible to buy a roaming SIM card from the UK as these were fixed to a particular carrier. The project procured SIM card from Telefónica Spain which allowed roaming onto all major carriers in the UK. Telefónica also provide as standard a web portal to check the status of the connections and signal strength – this proved a useful tool.

This learning has potential benefits for fault restoration personnel – they would not have to carry multiple mobile 'phones if roaming SIMs were used.

Primary substation sites had existing microwave links for BaU SCADA. The burden on this system was not added to apart from bringing back alarms to NMS.

7.2 Communications architecture

Communications security is a major concern, particularly where public communications systems are to be used. This concern is twofold: potential breach to access the smart grid equipment and potential breach into Northern Powergrid's core network.

The architecture to maintain a high level of security is shown in **Error! Reference source not found.**.

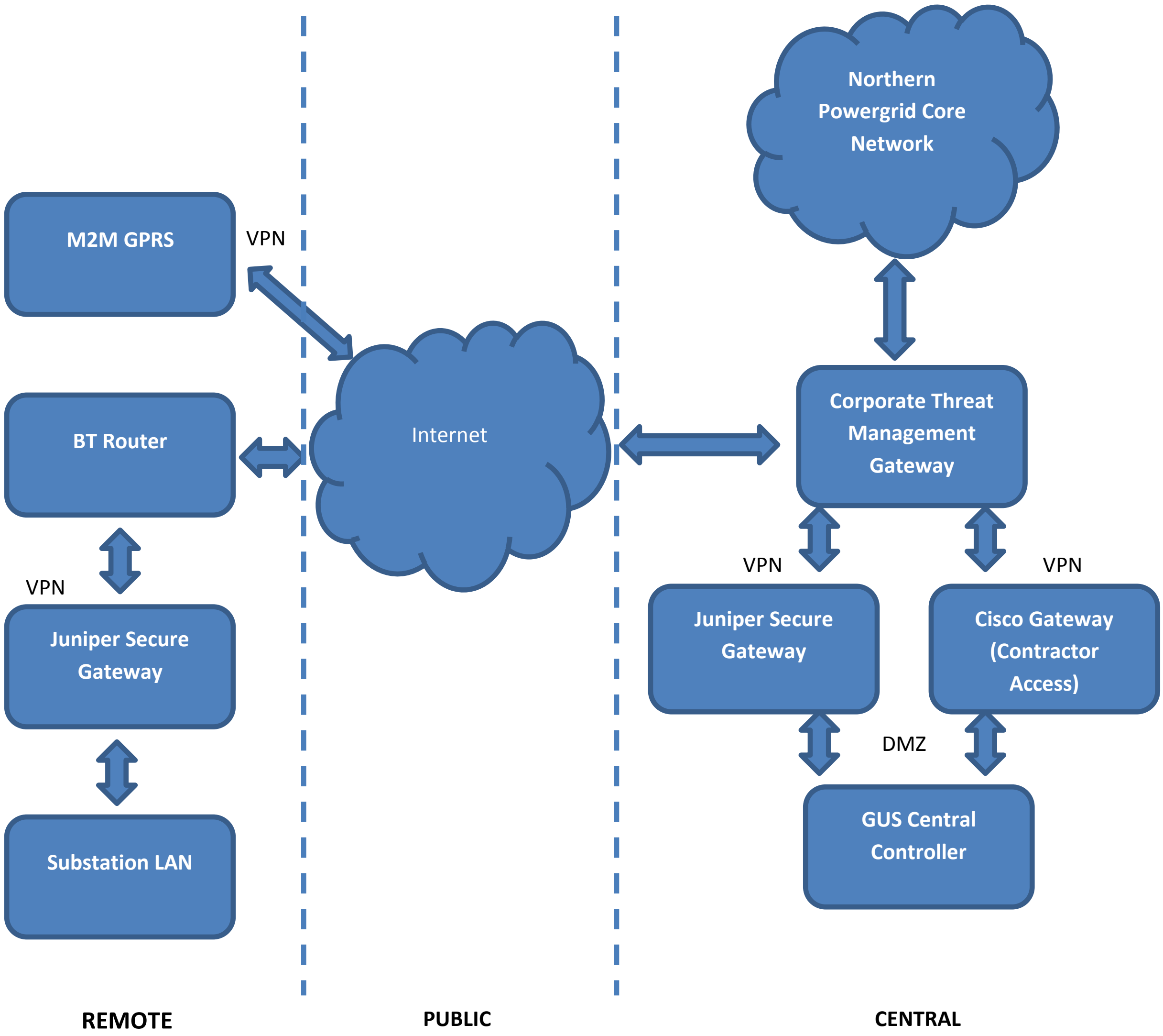

Figure 6 – Communications

The central control part of GUS operates within its own Demilitarised Zone (DMZ) before connection to the 'untrusted' wide area network. Virtual Private Network (VPN) tunnels were used throughout on public ADSL and GPRS connections to provide the connectivity between individual substations and the central system.

Standard business ADSL broadband was provided by BT at substation sites. As an extra, the project procured the use of a static IP address, which the Juniper switch is only configured to accept.

The project installed dedicated communications cabinets at each substation with the BT (broadband) router and secure gateways installed. The secure gateways provided the VPN functionality and setup the firewall for the substation LAN. The secure gateway (Juniper switch) applies a further layer of security by limiting which devices can talk together. The modular nature of the design at substations (separate devices) allowed the project team to easily debug faults and setup issues as it was easier to test and isolate the faulted component. Rationalisation of the footprint of communications equipment will be required going forward, as wall space was often limited in substations.

It is noted that the hierarchy of control in the GUS process data from remote devices centrally. Alternative communication systems (e.g. microwave mesh) open up the prospect of greater emphasis on local area control.

7.3 Reliability

The project witnessed reliability issues with using GPRS early in the project, as was expected. For passive components (monitoring) where the data is only intended to be used for off-line analysis, and where 99% reliability is not required, GPRS connections can be a cost effective communications media. It is essential for the remote devices to have the ability to buffer and locally store data so communications do not need to be near real-time.

The CLNR project intended to use public communications systems and it was therefore understood at the outset that backup systems to ensure system safety in the event of communications loss was a key requirement. As part of the testing strategy, a significant amount of time was spent on testing system functions for communications loss.

Overall, it was noted that the reliability of the communications systems was acceptable for the project purposes but, from the perspective of the need for high resilience for a smarter grid, reliability was poor. The project installed communication links in over 70 locations; maintaining the systems became a continuous activity. The issues encountered were a mix of the inherent issues with public communications systems (outages) equipment resilience issues. As examples, the equipment would often fail to restore after a power outage and would require a re-boot, or a security patch would be installed and configuration settings would be lost, requiring further effort to re-commission the system. Many of the issues were attributed to the fact that the system was not in a stable state as additional equipment was being connected and software updates were being applied.

Consistent with other projects, the project has learnt that communications equipment reliability is far less than power system assets. The wide-scale deployment of communications systems by DNOs, regardless of method chosen, will require significant resource to develop and maintain the systems.

7.4 Lessons learned on communications systems

The following key lessons learned are related to the testing phase:

GUS LL 7.1 Fixed line connections can take many months to install with the need for repeated site visits.

GUS LL 7.2 GPRS was found to be unreliable in most cases for control purposes.

GUS LL 7.3 Wherever GPRS is used, it is necessary to ensure that devices can buffer data to avoid data loss.

GUS LL 7.4 Use of street lighting infrastructure to house GPRS antennae has been proven to be effective in improving signal strength.

GUS LL 7.5 Roaming SIM cards, procured from foreign providers, have been used to improve the reliability of GPRS. Providing Field Engineers with roaming SIM cards could be beneficial to maximise signal coverage.

GUS LL 7.6 The use of separate devices as opposed to integrated devices for communications equipment allows easier fault finding and debugging of issues.

GUS LL 7.7 For critical applications the use of public communications infrastructure is unlikely to provide the required level of resilience. Communications methods which are owned and operated by the DNO (e.g. licensed microwave radio) are favoured.

GUS LL 7.8 The reliability of communications equipment is poor compared with power assets, and in a smart grid future will become a major burden for DNOs.

8 Network Applications and Benefits

8.1 Benefits of an integrated approach

The GUS control system has been demonstrated to manage a variety of smart grid technologies. Regardless of whether the system can actually release headroom within a network, there is a benefit in having network technology managed consistently, independent of the manufacturer.

In this context, the specific cases where the GUS control system has demonstrated benefits:

- Providing improved set points for devices such as AVC relays, based on multiple remote measured points (substation and feeder ends);
- Allowing the network to operate to higher utilisations due to the use of real-time thermal rating equipment;
- The co-ordinated management of series voltage control devices to avoid hunting and limit the potential for devices to race to top or bottom taps;
- The minimisation of losses through the effective linking of remote monitoring measurements with voltage control set points;
- Maximising the benefits of Energy Storage devices by ensuring the state-of-charge is appropriate for the time of day;
- Calling real power dispatch (Demand-Side Response and Energy Storage) in response to a (simulated) real-time thermal rating derived constraint on a primary transformer;
- Understanding the effect of reactive power on the circuit and using the Energy Storage devices to compensate.

The learning derived by developing the integrated approach in CLNR can provide a consistent method of integrating smart grid technology onto the network through the use of a common substation controller. The failsafe mechanisms built into the substation controller in particular could form a standardised method of ensuring the safe management of devices from a range of manufacturers.

8.2 Network headroom benefits

A series of academic studies have been conducted on the additional headroom that can be extracted from networks, in addition to the discrete operation of smart grid technologies. These can be found in the learning library for CLNR.

There are a variety of control options, with varying complexity levels, which can be used to release headroom on circuits. The GUS control system, as a type of solution, would be reserved for the more complex of issues and where it is required to extract the maximum capacity from existing circuits. The CLNR project has allowed Northern Powergrid to design, install and operate a system on the upper end of complexity, with the associated commercial risks, to fully understand the implications of operating such a system on a wider scale. There are however, simpler methods of control that may be more appropriate in the shorter term and these will be investigated through the ED1 period.

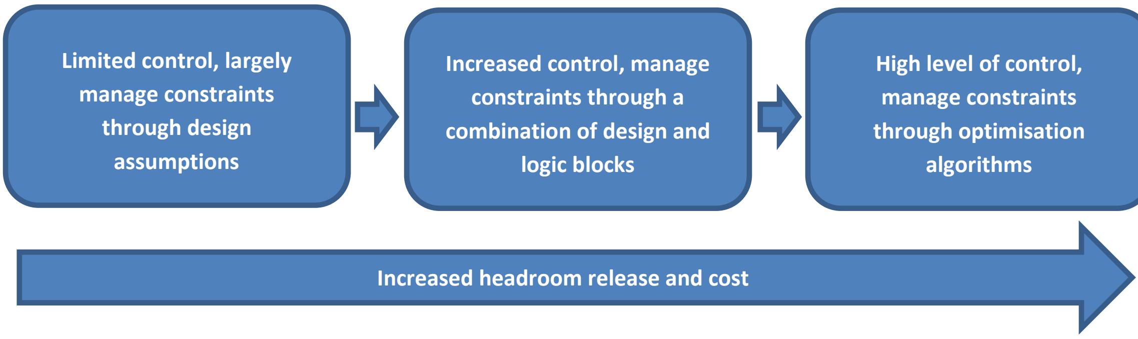

Figure 6 – Control options

Where DNOs are routinely faced with complex powerflow problems and, perhaps, also have more pointed losses incentives, then the GUS type of control system will become necessary. Now, as a result of CLNR, Northern Powergrid has more confidence in what this type of system can provide and, more importantly, how it can be installed and operated.

As noted above, the particular benefits of the GUS control system is in the integration and management of smart grid technologies. As it stands, elsewhere in the CLNR project it has been identified that Energy Storage is beneficial but expensive and Demand-Side Response is beneficial but further work is necessary as there are reliability concerns and willing customers are likely to be scarce. For voltage control, the system has been shown to infer significant advantages over existing mechanisms (primary fixed set point), however there are a number of mainstream improvements that can release voltage headroom with very little additional cost or complexity.

Therefore, our opinion at present is we believe there is a limited need in the short term to progress forward with advanced central control systems such as the GUS for BaU purposes, however there are a number of main stream improvements that can release headroom with lesser cost and complexity.

9 Conclusions

The CLNR project has successfully designed procured, commissioned and operated an advanced Active Network Management System: the GUS control system, as a first of its kind on GB distribution networks. The CLNR project has demonstrated that complex wide area control systems can be procured via a competitive tender process and they can be successfully installed as separate systems, and integrated with, existing Network Management Systems. The system has been shown to provide co-ordination of real-time thermal rating, voltage control, energy storage and demand-side response systems. Several trials were run, simulating network issues such as voltage constraints and powerflow levels above asset ratings, to test the system and understand the additional benefit that this type of control system can bring to distribution networks.

The procurement has been completed within an ambitious timescale of less than two years from contract award.

This report presents lessons learned, both where the project has been successful and where, with the benefit of hindsight, a different approach could be beneficial for future projects. The key outputs of this report are the lessons learned which are presented in the relevant sections, and fall within the following topics:

- Preliminary Design, Supplier Consultation and Procurement;
- Design Elaboration;
- Deployment and Integration;
- Testing Strategy;
- Operation;
- Communication Systems; and
- Network Applications and Benefits.

The CLNR project procured a variety of network technology in parallel and many of the lessons learned relate to the maturity of the market and the lack of firm interface specifications. For deployment of future control systems it is recommended that suppliers are engaged earlier in the process to allow full scoping of the project based on the suppliers' core offering.

Substantial learning was generated regarding the testing strategy. An alternative strategy is proposed for future deployments, where the passive elements of the control system are installed first to allow debugging of the data transfer from monitoring systems and the central control system. As a result of a comprehensive testing and commissioning process, Northern Powergrid have developed sufficient confidence in the GUS control system to manage constraints on the network, although it is noted the system has a high maintenance requirement.

To conclude, the benefits that the system can derive are discussed. The GUS control system can release incremental benefits over discrete devices; it is noted that wider rollout is unlikely to be pursued by Northern Powergrid until complex powerflow problems and smart grid solutions become mainstream.

Customer-Led Network Revolution

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