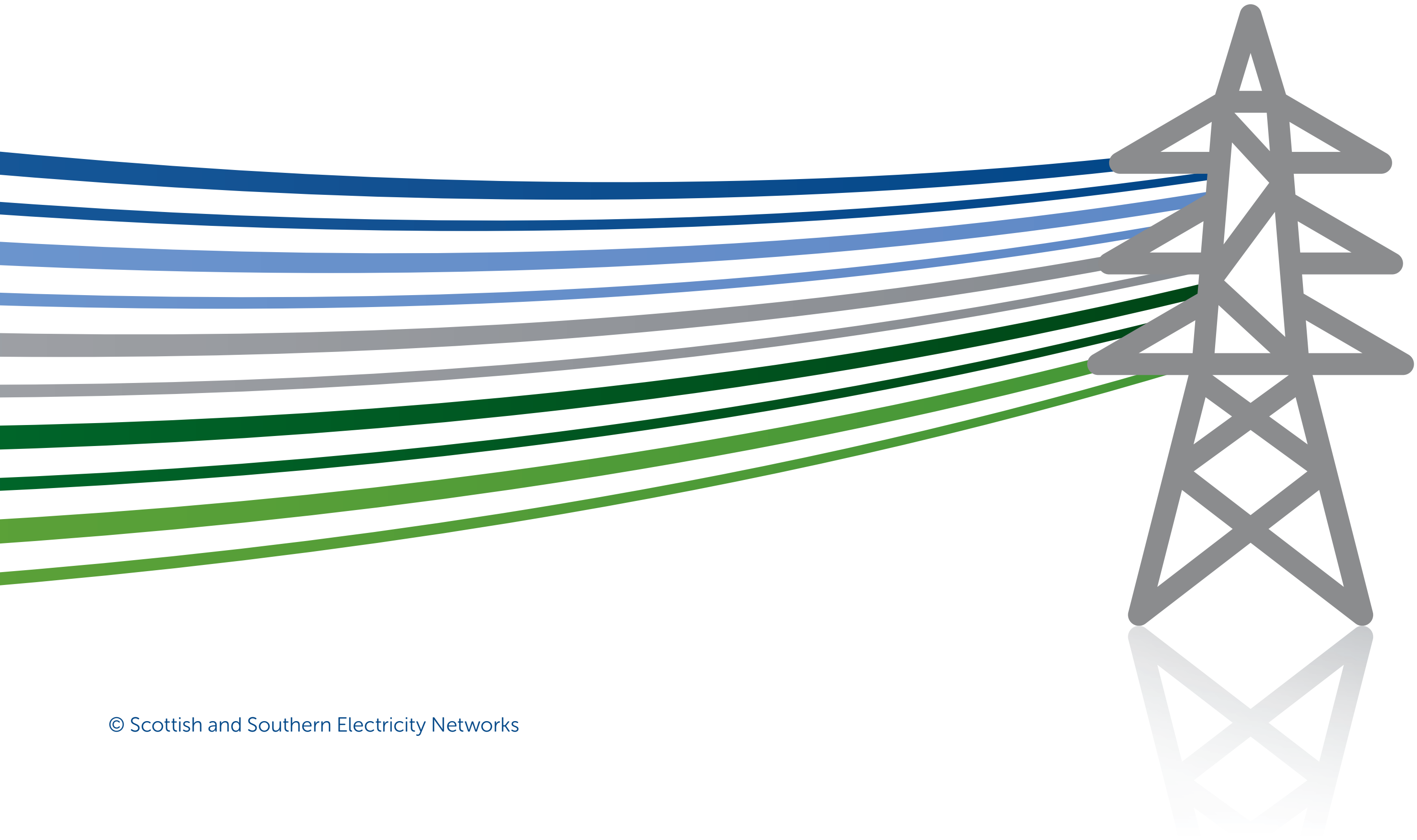
Scottish & Southern
Electricity Networks

NINES

ANM: Functional Design, Infrastructure and Comms Learning Report



1. Knowledge and learning outcome reports

SSEN has worked with University of Strathclyde to develop a suite of reports covering the main areas of learning delivered by the NINES Project.

Areas where most learning has been achieved are; the effectiveness of frequency responsive DSM, maintaining network stability in an active operational environment, and the interaction of the numerous variables on Shetland's closed electrical system.

A summary of the full suite of reports is as follows:

DSM

- DSM: Customer Impact
- DSM: Infrastructure
- DSM Network Benefits

BATTERY

- Battery: Operational Effectiveness

FREQUENCY RESPONSE

- Frequency Response: Customer Impact
- Frequency Response: Operational Effectiveness

ANM

- ANM: Functional Design, Infrastructure & Comms Report
- ANM: Operational Effectiveness

NINES

- NINES Commercial report
- NINES Knowledge & Learning Summary Report

Contents

2. Abbreviations

ANM	Active Network Management
ACG	Actively Controlled Generation
BESS	Battery Energy Storage Systems
CB	Circuit Breaker
DA	Data Access
DER	Daily Energy Requirements
DDS	Data Distribution Service
DSO	Distribution System Operator
DDSM	Domestic Demand Side Management
DMS	Distribution Management System
DSM	Demand Side Management
HMI	Human Machine Interface
http	Hypertext Transfer Protocol
LIC	Local Interface Controller
LIFO	Last-in-first-out
LPS	Lerwick Power Station
LUI	Local User Interface
NAS	Sodium Sulphur
NINES	Northern Isles New Energy Solution
OPC	Object Linking and Embedding for Process Control
RPZ	Registered Power Zone
SCADA	Supervisory Control and Data Acquisition
SGS	Smarter Grid Solutions
SHEAP	Shetland Heat Energy and Power
SOC	State of Charge
SSEN	Scottish and Southern Electricity Networks
SVT	Sullom Voe Terminal
TGO	Total Generator Output
UoS	University of Strathclyde
USM	University of Strathclyde Modelling

3. Executive summary

Scottish and Southern Electricity Networks (SSEN) has come to the end of Northern Isles New Energy Solution (NINES), a five-year implementation and trial of co-ordinated, actively-managed, energy resources on Shetland.

A need to replace existing power station plant and aims to increase the level of renewable generation connecting to the island has driven the development and demonstration of this innovative and integrated whole-energy/whole-system solution.

Critical to meeting the objectives of NINES is the Active Network Management (ANM) system, a real-time control solution that enables the co-ordination of the various elements of the NINES scheme and the Shetland system. Through active management of controllable network devices, the two high-level objectives of the NINES ANM system were to:

- Accommodate renewable generation customers and reduce reliance on fossil fuels; and
- Smooth the demand curve to minimise peaks and troughsin Shetland system demand.

An ANM system was designed to meet NINES requirements by establishing a real-time, deterministic control platform that hosted automated algorithms to monitor network parameters and control ANM elements including renewable generation, large-scale battery storage, and groups of domestic demand side management devices. The ANM platform built upon SSEN learning from the Orkney Smart Grid project, taking real-time constraint management beyond past demonstrations with multiple project partners, and collaborating to establish system constraint rules that define the autonomous management of new renewable generators against stability and operational constraints on the Shetland system.

Requirements developed over the operational stages of the trial, with operational learning informing the revision of ANM system design and configuration. The following key learning points were taken from the trial:

ANM Delivers Enhanced Hosting Capacity

Through real-time management of system stability constraints, NINES has accommodated an additional 8.5 MW of renewable generation capacity on Shetland, increasing the total renewable capacity to 12.5 MW.

This 200% increase in renewable generation capacity will reduce the energy met by fossil fuel on Shetland.

User Configuration of ANM Rules

The ANM system was initially designed to be highly autonomous, with little need for operator intervention during normal system operation. This requirement reflected a desire to maintain a degree of simplicity in day-to-day system operation. As the need to adapt constraint and scheduling rules was identified during the trial phase, SSEN engineers developed a desire to update the rules themselves, a task that required vendor support. Although all rule updates were applied during the trial, it is recognised that an overall enhanced level of user configurability is required for systems providing multiple autonomous functions on a complex network such as Shetland.

Stability Constraints: Need for Enhanced Dynamic Simulation and Testing

In the trial phase, the need for a new stability constraint rule was identified, reflecting changes to running arrangements at existing conventional generators on Shetland. In general, the implemented operational behaviour of stability constraint management acted differently from initial and emerging expectations, which was addressed in the creation of an additional constraint rule. This highlighted a recommendation for greater degree of dynamic simulation when defining stability constraint rules and actions; the initial NINES studies had only focused on ANM control actions during extreme network conditions to ensure constraint conditions were avoided. It is recommended that in future cases dynamic simulation studies behaviour during non-extreme network conditions and the interactions between and operational preferences for synchronous generators meeting system demand.

ANM coordinated Flexible Demand

ANM successfully calculated and implemented schedules for available flexible demand, both domestic-scale demand side management and the grid-scale battery storage system.

A reduction in the available flexible demand customers has reduced the system benefits of demand scheduling; however the scalable ANM control algorithm and scheme architecture allows for expansion if additional customers become available.

Changes to Battery Technology and Configuration Deliver System Value

The ANM system had a control interface established with the battery energy storage system following a revision in the battery technology deployed. Once the scheduling algorithm was updated to accommodate the round-trip efficiency of the battery technology, the full charge and discharge capability of the battery has been used to support smoothing of the Shetland demand curve.

Learning through the NINES trial stage has identified the benefit derived from the ANM scheme and opportunities for improving flexibility and value derived from the system. In Spring 2017 SSEN is undertaking a revision of the ANM platform to provide enhanced configurability to support operation in the developing Shetland system.

This reports directly answers how we managed the secure operation of the Shetland network with a high renewable penetration and contributes to the answering the question; To what extent do the new arrangements stimulate the development of, and connection to the network of more renewable generation and reduce the area's reliance on fossil fuels?

4. Introduction

In 2010, a licence obligation was put in place requiring Scottish and Southern Electricity Networks (SSEN) to present an Integrated Plan to manage supply and demand on Shetland.

The Shetland Islands are not connected to the main GB electricity network and, as such, face unique electrical challenges – but also a unique opportunity to decarbonise supply. Under the licence condition, this Integrated Plan was required to demonstrate that it had identified a solution based on the lowest lifecycle costs, taking into account its environmental obligations.

As part of the Integrated Plan submission, the consideration was to, amongst other things, the upgrading or replacement of Lerwick Power Station, the impact of third party generation requirements, the abundance of renewable energy resources and the future demand on Shetland. The factors influencing the supply and demand issues on Shetland necessitated an innovative approach to their management. However, with innovation comes the need to trial solutions before reaching an answer. As a result, SSEN originally proposed to split the implementation of the Integrated Plan into two phases:

- **Phase 1** Shetland Trial (Northern Isles New Energy Solutions 'NINES') – implementation of the infrastructure necessary to actively manage demand, generation, reactive compensation and energy storage assets. These elements were coordinated to maximise the amount of energy harvested from renewable generation while maintaining supply quality and security. In doing so, two principal effects are achieved:
    - a reduction in maximum demand; and
    - a reduction in the electricity units generated byfossil fuels.
- **Phase 2** (Shetland Repowering) – upgrading or replacement of Lerwick Power Station by SHEPD, taking into account the learning acquired during Phase 1 and, where appropriate, extending the Phase 1 technology.

NINES Elements

NINES was originally designed and developed to operate in conjunction, and integrated, with Lerwick Power Station or its replacement operated by SHEPD, and was developed with the main aim of informing the optimum repowering solution. Whilst its primary objective was to trial 'smarter' initiatives, importantly NINES has funded elements and infrastructure that are expected to endure as part of, or alongside, the new energy solution. Central to the project has been the creation of an integrated set of models designed to anticipate the impact of NINES, covering the following themes:

- Dynamic Stability model
- Steady State model
- Unit Scheduling model
- Customer demand forecast model
- System Development optimisation model
- Strategic Risk and Operational risk model
- Shetland Economic model
- Commercial model

Facilitated by modelling and practical learning, the aims of NINES have been to:

1. Undertake specific projects that increase understanding of how best to accommodate Shetland's significant wind potential on a small distribution network; and

2 Undertake specific projects that increase understanding of how the existing and known future demand on the island can be best managed on a constrained, isolated system.

These models served to predict the behaviour of the energy systems on Shetland, and to validate each of the key elements of NINES as they were added. Following this validation process, these models have been used to inform the design of any replacement of Lerwick Power Station realised through the competitive process. With the successful operation of NINES, the infrastructure and knowledge to reduce the peak capacity requirement for any replacement solution to a level dependent on the particular assets connected, and the characteristics of the new solution has been determined. The NINES project assets are described below.

1. **1MW battery at Lerwick Power Station**
   A 1MW battery acts as an energy storage system on the Shetland Network. In addition to facilitating the connection of new renewables, the battery assists in optimising and stabilising the operation of the existing island network by helping to reduce demand peaks. The battery has helped to accommodate the connection a significant amount of new renewable generation that would otherwise not have been able to connect.

2. **Domestic demand side response with frequency response**
   SHEPD has worked with Hjaltland Housing Association to install advanced storage heating and water heating in 234 existing homes. These new storage and water heaters (which replaced existing traditional storage heaters) were provided through Hjaltland and ERDF funding and have been specifically designed to use a much more flexible electrical charging arrangement. This new charging arrangement is determined based upon the predicted demand, weather forecasts, availability of renewables and any other network constraints. This initial roll out was intended to help gauge the effectiveness of storage and demand side response at the domestic level.

   The heaters incorporate additional insulation to minimise heat loss and are fitted with programmable timers to allow users much better control of temperature and operating times when compared with conventional storage and water heating systems. The new heating system is designed to be more efficient, while giving the customer full control of both temperature and operating time and allowing for charging at times that best suit the network.

3. **Renewable generation**
   Shetland has some of the richest renewable resources in Europe and there is significant interest on the islands to connect a range of new renewable generators. There is a mix of wind and tidal generators currently connected that range in scale from 45kW up to 4.5MW. However, before the advent of NINES these generators could not connect to the network due to the underlying voltage and stability constraints. Connecting more renewable generation, which is unavoidably intermittent, would have exacerbated these problems.

   To address this, NINES has trialled an active network management regime which has offered renewable connections to developers. In return, they are required to give their agreement to being constrained when the system cannot accommodate their generation. The measures that have been developed and trialled under NINES are reducing this constraint by being able to actively provide demand when there is renewable resource available.

   Indeed, these arrangements could be necessary even if Shetland is to become electrically connected to the mainland at some point in the future. If a single mainland link is damaged, this could result in a prolonged outage, which would mean that Shetland would once again be electrically islanded. Therefore the prospect of and ability to constrain will remain for generators on Shetland, albeit on a less frequent basis.

4. **Active Network Management (ANM) system**
   This is the NINES project's nerve centre: it monitors the different parameters affecting the network, including embedded constraints, frequency stability and weather and manages an appropriate response. It responds to, and tunes, the models which are being developed to monitor and understand how new storage assets will behave. By creating flexible demand on the island progress has been made in exploiting and maximising Shetland's wind generation potential on an islanded basis, and in reducing the generated output from replacement thermal generation.

   A key driver for the trial has been to develop an understanding how these technologies work and interact in a real-life environment. The learning from NINES has demonstrated that in general terms (with the exception of additional renewables), all NINES technologies predominately involve energy shifting rather than energy reduction.

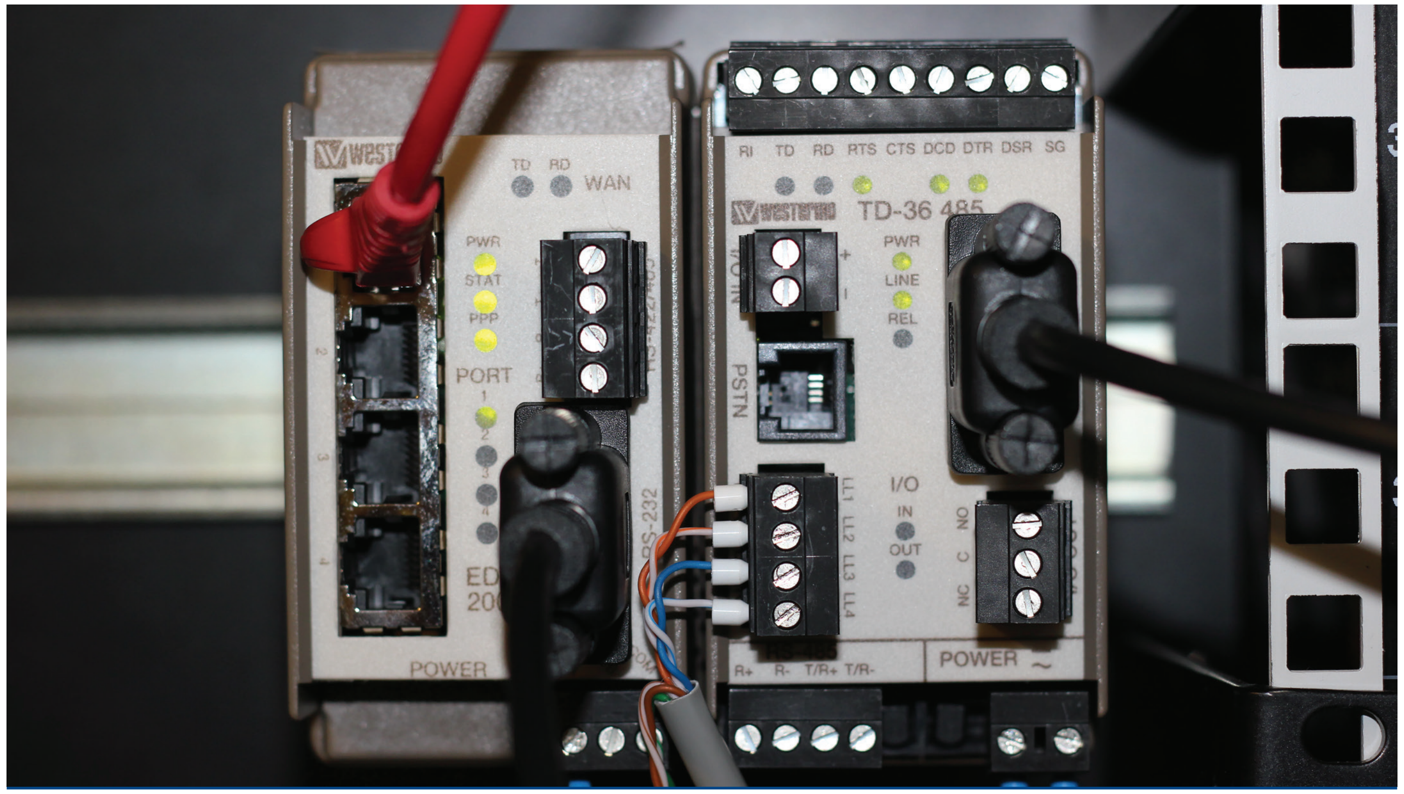
This document constitutes part of the NINES Learning Reports, a series of documents that share learning from the NINES project, presenting a summary of the work delivered and disseminating outcomes from the design, implementation, and demonstration stages of the project. This specific document focuses on the ANM element of the NINES project, reporting on the functional design of the system, and presenting the infrastructure that has facilitated the active management of the Shetland network.

The following report is one of a number of related reports undertaken by the research team, led by University of Strathclyde and focuses on the Functional Design and Requirements of the ANM system.

The document consists of the following sections:

- **Section 6** contextualises the NINES project, describing the energy delivery challenges on Shetland and motivations for the ANM element of the project.
- **Section 7** describes the requirements for the ANM system deployment, as defined at the beginning of the NINES project in 2012. The functional requirements for the ANM system are summarised and original ANM Constraint Rules are presented as defined by network modelling and simulation.
- **Section 8** presents the original specification of the ANM system, describing the system architecture, hardware, interfaces, and functional design to meet the project requirements. The rationale behind design decisions is shared in this section of the report.
- **Section 9** reflects on operational experience following ANM system deployment, the benefits dererived from the demonstration and the subsequent revisions to ANM system design. This section presents the learning achieved from implementation of supporting technologies, such as energy storage and demand side management. The operational experience that led to revisions to functional design is explained, with description of the updated requirements and implications for ANM operation.
- **Section 10** concludes the report, summarising key learning from the project in the context of future developments on the Shetland network.

In terms of Learning Outcomes, this report addresses Secure operation with high renewable penetration. What is the relationship between intermittent generation and responsive demand, including storage? To what extent do the new arrangements stimulate the development of, and connection to, the network of more renewable generation and reduce the area's reliance on fossil fuels?



5. The challenge and context

Shetland is the UK's largest electricity network not connected to the National Grid. The islanded nature of the Shetland electricity network presents a number of challenges for the integration of renewables and reducing reliance on fossil fuels for electricity supply.

The supply and balancing of the network relies on synchronous generation from the Lerwick Power Station (LPS) and Sullom Voe Terminal (SVT). The islanded network is sensitive to sudden changes in the availability of generating capacity or electricity demand, requiring sufficient synchronous generating reserve to maintain system stability.

Network constraints relating to system voltage and frequency stability limit the capacity for accommodating renewables on Shetland. The renewable resource on Shetland is some of the best in Europe. The existing wind farm on Shetland achieves an average capacity factor of 52%.

Shetland has a large proportion of space and water heating supplied by electrical storage heaters. The advanced flexibility and storage capability of modern electrical heaters, complemented by improvements in network automation, monitoring and control technologies, provides opportunity for this element of system demand to be managed in a smarter way, supporting system stability and providing ancillary system balancing services.

ANM was successfully demonstrated by SSEN through the Orkney Registered Power Zone (RPZ), an innovation project that released non-firm connection capacity for renewable generators on the previously-closed Orkney network. The project addressed thermal capacity constraints resulting in the connection of over 28 MW of renewable generation capacity at 25 different sites on the Orkney network. The Orkney ANM system is a real-time control system that regulates energy export from participating generators when it is necessary to maintain the network within operational limits. The autonomous control provided by ANM facilitates the connection of intermittent generation beyond traditional limits, exploiting the latent capacity offered due to the variable and intermittent nature of electricity demand and renewable energy exports. The nature of constraints identified on the Shetland network is different from those managed via ANM on Orkney.

Prior to NINES, the Shetland system had limited capability for control, measurement and automation of network operation, particularly regarding the integration of renewables. A SCADA system located in LPS is based upon the Serck SCX product, providing an indirect interface to the GE PowerOn Fusion SCADA/DMS system based at the SSEN Network Management Centre in Perth. SSEN identified the opportunity to use ANM as a means to accommodate additional renewable generation on Shetland, restricting export under conditions where stability constraints were binding.

The NINES project builds upon a number of projects that trialled innovative concepts including alternatives to radio tele-switching; demand-side management (DSM) and storage; markets for DSM; and Active Network Management.

The Trial Evaluation of Domestic Demand Side Management (DDSM) project trialled the deployment of new domestic storage and water heaters to six homes on Shetland, providing demand side management and fast-acting frequency response to support system operation. Schedules were frequently updated to controllers installed in each home, facilitating the issue of real-time set-points. The project delivered proof-of-concept for DDSM that informed the scope of the NINES project.

6. ANM requirements

6.1 Objectives

The objectives of the ANM deployment were to:

- Accommodate customers:
  - Enable the provision of ancillary services from a wider range of customers on Shetland.
  - Allow the maximum possible amount of renewable generation to be connected and reduce the amount of fossil fuel consumption from the island's generation sources.
  - Accommodate the connection of new small generators on the network.
- Smooth the demand curve:
  - Provide network balancing by managing demand and enhance the stability of the network with new generation and storage capabilities, including the management of network frequency via ANM.
  - Smooth the net demand profile seen by LPS (reduce the difference between minimum and maximum daily demand).
- Gain an understanding of ANM and improve control interfaces:
  - Test the expanded use of ANM, building on SSEN experience in Orkney, by implementing control of connected loads and generators for network constraint management. Monitor power flow and voltage across the network and control devices in real-time to ensure that all points remain within limits.
  - Provide acceptable user interfaces in conjunction with existing systems for operators at LPS and Perth Network Management Centre.
  - Use real-time feedback from network monitoring and communication link health statuses, to modify system operation.

6.2 Functional requirements

The ANM functional requirements are presented across three areas:

- **Stability Constraint Management:** Where network devices, such as generators, responsive loads and energy storage devices, are controlled in real-time in response to prevailing network conditions. This meets the objective of accommodating additional customers while managing the network constraints that may arise following their connection.
- **Device Scheduling:** Where forecasts are used to derive and issue schedules to appropriate devices to meet the objective of smoothing the demand curve.
- **Configuration and Interface:** The requirements associated with ANM user interactions, the capability to issue manual control commands, and interfaces with other SSEN systems.

6.2.1 Stability constraint management

To provide constraint management features, it was required that the system provided automatic, real-time control of devices to maintain constraints within limits. The real-time control is defined as continuous monitoring of network parameters, checking thresholds are maintained; once constraint thresholds are exceeded, the system must calculate control actions to mitigate the constraint and issue set-points to the identified devices. Once a constraint has been mitigated, ANM must issue control signals to release the set-point of controlled devices back to the standard schedule. For generators, the standard schedule is unconstrained operation.

Constraint thresholds may be:

- Specific network measurements, such as a voltage (V) or current (I) measurement at a congested 'pinch point' on the network. A 'pinch point' can be described as an asset where there is a risk of network parameters exceeding the planning limit, for example where the power flow through a cable, overhead line, or transformer, can exceed the asset's rated capacity; or
- A stability threshold, calculated as a function of multiple measurements or device status indications.

The real-time monitoring of constraint thresholds and calculation of device set-points requires high-resolution data updates from a number of sources. This requires the ANM system to receive data from:

- Controlled ANM devices such as generators, DDSM and large scale storage devices;
- Telemetry analogue measurements of export from existing 'firm' generators on Shetland, such as Lerwick Power Station, Sullom Voe Terminal, and Burradale Wind Farm; and
- Telemetry analogue measurements of network parameters, such as current (I) or voltage (V) at network 'pinch points'.

A number of different data points must be received from ANM devices, informing the calculation of device active set-points. The ANM must receive analogues of device export/import to feed into active set-point calculation. Device status indications are also required, providing details of communication link health and each device in or out of service status. The ANM device information must also be shared with both the Shetland-based Serck and Perth-based Power-On Fusion SCADA/DMS system, with the capability to raise alarms following specified status indications.

The functions that define the stability constraint rules are presented in section 7.3.

6.2.2 Device scheduling

A fundamental requirement of the ANM system was to schedule ANM devices. The requirements for scheduling were based upon two elements: the frequent day-ahead forecasting of network behaviour, and the ongoing calculation and issue of schedules to ANM devices.

Requirements stated that the ANM system requires forecasts of MW power in each 15-minute block for the next 24 hour period for the following:

- MW energy export from wind generators (both existing and ANM-controlled);
- MW energy export from tidal generators;
- MW energy export from other ANM-controlled generation;
- MW energy demand from uncontrolled sources: i.e. all demand outside of ANM control.

The weather forecast is updated hourly and the forecast contains 24 one-hourly values for the first 24 hours, and four three-hourly values for the following 12 hours. The wind forecasting system sends a single wind power forecast to PI Shetland and is updated hourly. The ANM scheduling software requires the expected wind power production for the 24 hour period of interest in the format of 96 blocks corresponding to 15-minute intervals with forecast wind farm output in MW. PI Shetland will provide the forecast as a normalised value, expressed as a percentage, with resolution of 1 hour, or 3 hours for forecast data beyond 24 hours ahead. ANM software must convert this into the required 15-minute intervals using linear interpolation. The current measured power output from each wind farm must be used with the forecast value for one hour ahead for interpolating values for the next hour.

It was required that at least once a day, the ANM derives a 24-hour schedule of set-points for ANM controlled devices. Re-calculation of the schedule must be triggered at pre-set times or when new forecast data is received. This was specified to be capable of a resolution of every 15 minutes throughout the day and ensures the latest forecast information is informing schedules. Day-ahead availability of ANM devices must be provided to inform scheduling calculation.

The objective of the ANM-calculated schedules is to improve network performance and this must be performed within the constraints of both the network and controlled devices. For example, DDSM must deliver a daily energy requirement to customers to meet a basic heating need, and the battery is limited by the energy storage capacity, power rating and round-trip efficiency. ANM must take account of the capability of all ANM controlled devices when calculating schedules. Similarly, it must ensure that schedules do not cause network stability constraints to emerge, which would then require the real-time issue of active set-points to controlled devices, replacing the scheduled set-points.

In terms of device or group treatment, the DDSM groups that operate under a fixed schedule must be processed first. Then groups or devices with flexibility in scheduling are to be scheduled in order of their energy requirement e.g. the largest available resource is controlled before moving on to smaller resources which may be less effective.

6.2.3 Configuration and Interface

Complementing the functional requirements directly associated with the real-time management of constraints and scheduling of controlled devices, requirements were specified relating to the user interface and configuration features of the ANM system. The user interface must provide the capability for SSEN engineers to observe, intervene and re-configure elements of the ANM system and its actions.

A requirement was specified that the ANM Operations Team, consisting of SSEN engineers, could send manual control signals to ANM controlled devices. These signals will either:

- Synchronise date or time;
- Specify active set-points; or
- Specify device operational settings, such as frequency response characteristics for responsive loads.

In terms of the calculation of schedules, the operators must have visibility of the schedules, with the capability to define the resolution of schedule updates. This includes operator visibility of forecasts with the capability to update forecasts manually, allowing user experience to inform the forecasting process. The operator must be able to apply a manual reference schedule, or specify when the reference schedule is applied to devices.

Any manual schedule is not necessarily derived with reference to the limitations of devices and constraints, as described in Section 7.2.2. As a result, all manual schedule alterations must be validated by the ANM system to ensure that device constraints and energy requirements are met, and that all network and system stability constraints are met. If a manual operator intervention results in significant deviation from the active schedule, the ANM system must re-calculate new schedules for all devices.

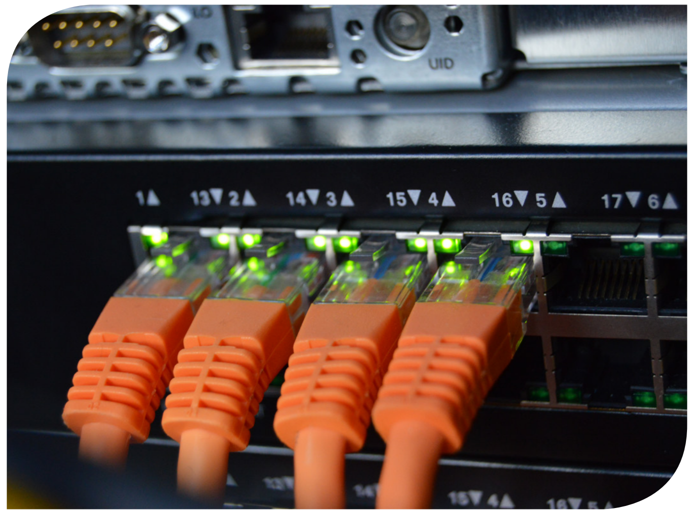
The ANM system is also required to store all forecasts, schedules, active set-points, ANM system status, and configuration data in the PI Shetland historian. This allows for the review of specific ANM control decisions and analysis of long-term trends.

6.3 Specification of ANM constraint rules

The constraint management element of ANM was required to control managed devices as a real-time response to prevailing network conditions. The need for constraint management was primarily driven by the electrically-islanded nature of the Shetland network and the network operation challenges that arise due to this status.

The accommodation of additional generators on the Shetland system, particularly intermittent renewables, introduces stability challenges to network operation as the non-synchronous renewable generators displace export from the conventional synchronous plant at LPS and SVT. The loss of synchronous generation capability, which provides system balancing and reactive support, leaves the system sensitive to sudden changes in generation or demand that cause an imbalance in supply.

An investigation performed by the University of Strathclyde, with support from SSEN engineers, identified stability constraints that may arise due to the connection of additional renewable generation on Shetland. Modelling and simulation of the Shetland network informed the specification of parameters and constants that defined each of the constraint rules. The initial constraint rules, derived from the Shetland network simulations, are:



Frequency Stability Constraint:	The key criteria for frequency stability is that the Shetland system frequency can be maintained within +/- 2% of nominal (+/- 1Hz). SSEN engineers defined the worst-case frequency stability event associated with the connection of additional renewables as the instantaneous loss of all renewable generation capability. The instantaneous loss of all renewable export will require sufficient primary frequency response pick-up from the online synchronous generators. The frequency stability constraint limits the export from additional renewables, ensuring there is sufficient demand met from synchronous generation to manage frequency deviation. Dynamic simulation of the Shetland system was performed by University of Strathclyde, investigating the worst-case frequency deviations following loss of all renewable generators, including already-connected sites. Studies simulated dynamic frequency response with the lowest-inertia, and therefore slowest-response, units at LPS in operation. Minimum demand conditions were simulated as this is the extreme case with the lowest proportion of load supplied by synchronous generation. The University of Strathclyde's modelling and simulation identified a 14.3 MW limit of instantaneous renewable generation that could be accommodated onto the Shetland system without breaching frequency limits following an outage.
Network Operation Constraint	The town of Lerwick constitutes a relatively large proportion of the electrical demand on Shetland. This means that the supply from LPS is required to meet at least 40% of total system demand to ensure that the voltage profile to the South mainland is maintained within statutory limits. This de-minimis limit of supply from LPS ensures that sufficient reactive power is supplied to the Shetland system. This requirement introduces the Network Operation Constraint, which specifies that the total exports from renewable generation and SVT must not displace LPS export below meeting 40% of system demand. Taking account of total system demand, instantaneous export from existing firm renewables, and instantaneous export from SVT, it is possible to define an instantaneous limit of additional renewable generation export that can be accommodated on Shetland.
Spinning Reserve Constraint	Similar to the Frequency Stability Constraint, it is required that sufficient spinning reserve is provided by synchronous generation to meet demand following an instantaneous outage of all renewable generation on Shetland. Spinning reserve is provided by the SVT generators, meaning that all lost energy exports from renewable generation must be displaced by the SVT generators. There is a limit of 23 MW export from the SVT site, therefore displacement of renewable generation export from SVT following outage must not exceed 23 MW. This specifies a limit on instantaneous renewable generation export such that it, in combination with the instantaneous export from SVT, must not exceed 23 MW.
SVT Offline Constraint	The gas-turbine synchronous generators at SVT provide both primary and secondary frequency response following loss of all renewable generation on Shetland. As such, SVT provides a significant contribution to the stability and operation of the Shetland system when there is high renewable output. Therefore, when SVT is off-line, not exporting to the Shetland system, all ANM-controlled generators are to be curtailed entirely to a 0 MW set-point.

The instantaneous limit of energy export from ANM controlled generators must be the minimum of the limits defined by the four constraints rules stated above.

The initial ANM constraint rules considered the management of other NINES controllable devices to avoid generator curtailment actions. Such an approach would mitigate the curtailment of renewable energy export and maximise renewable output on Shetland. Requirements considered the following controllable devices to maintain the constraint limits:

- **Domestic Demand Side Management (DDSM): approx. 4.2 MWh:** An estimated 750 houses would be provided with new electrical space and water heaters, releasing controllable electrical demand and providing sub-second frequency response. In addition to alleviating generator curtailment, this DDSM capability can be scheduled at times of low demand to smooth the overall demand curve. Both capabilities present potential to support the constraint rules and mitigate generator curtailment.

- **Large-scale Demand Side Management: 135 MWh:** Inclusion of the Shetland Heat Energy and Power (SHEAP) community heating scheme to provide demand-side management capability and manage the system demand curve. Similarly to DDSM, managing overall system demand can adapt the loading curve to provide periods of high demand during periods of increased renewable export capability. Both large-scale DSM and DDSM must be managed within bounds that ensure customer's heating needs are met and not adversely affected.

- **Battery: 6 MWh:** Use of the grid-scale battery to import power during forecast constraint periods, and export power at peak demand times. During the initial requirements specification, a 6MWh sodium-sulphur battery was proposed. It was not planned that the battery would provide fast-acting frequency response.

Prior to the connection of additional renewable generation, no steady-state power-flow (i.e. thermal) constraints occurred on the Shetland system; existing conventional generation was used to manage voltage constraints, reflected in Network Operation Constraint (see above). It was identified that the connection of additional renewable generation could cause thermal or voltage constraints to emerge, although this would depend on the generator connection location. Hence, the ANM system was assigned the requirement to accommodate multiple generator, multiple constraint autonomous control, in a manner that mirrors the ANM system demonstrated as part of the Orkney Smart Grid Project.

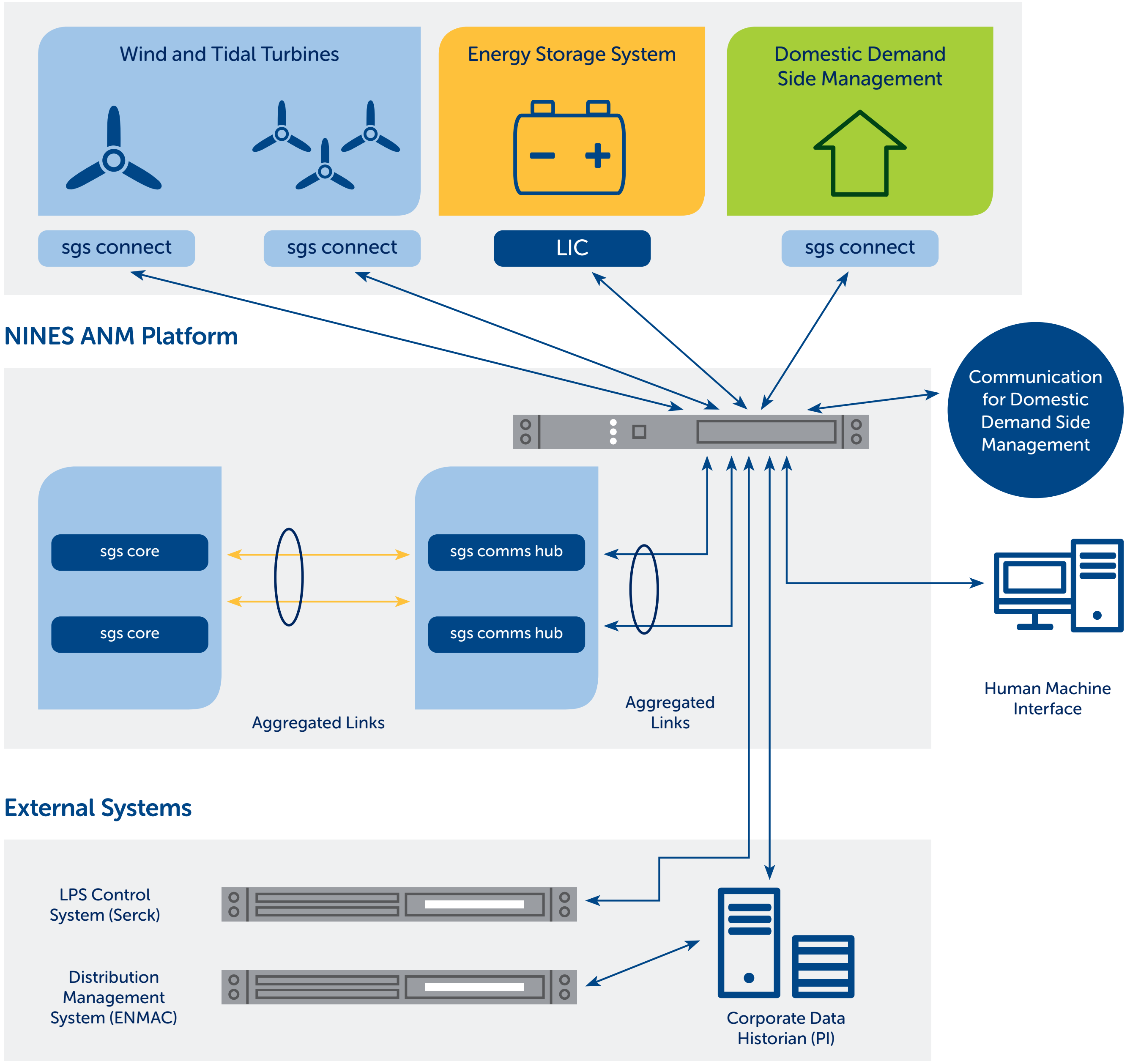
Since the original design, the system has evolved and the original assumptions are no longer valid for all constraint cases. A new constraint rule was developed and implemented. Similarly, modifications were made to original constraint rules, with operating margins and constants updated to reflect operational experiences; these are discussed in further detail in Section 9.3.

7. ANM functional design

The ANM functional design was specified such that the requirements stated above were met. Following a period of operation and learning, revisions were made to the functional design, which are discussed in Section 9. The ANM system was supplied by Smarter Grid Solutions.

7.1 ANM System Architecture

The ANM System architecture for NINES was designed using a well-understood model that has been successfully deployed in several other locations, notably on Orkney where over 25 MW of generation is under real-time ANM control. Figure 1 shows the logical architecture of the NINES ANM system and the links to external devices under ANM control.



7.2 ANM platform

The ANM system on NINES is a modular platform consisting of centralised and distributed components. This system was designed to enable scaling, allowing new devices such as generators to connect without the need for disruptive modifications to the whole system. It is important for NINES to ensure that the system can adapt to future demands. The centralised component of the NINES ANM system comprises a communications gateway, sgs comms hub, connected to an application host, sgs core, via a real-time data manager based on an open standard for publish-subscribe data distribution.

The distributed component, sgs connect is located at each device under ANM control sgs connect performs local control and fail-to-safe functions. Examples of failures and responses for generator control are summarised in the table below.

Table 1: Summary of sgs connect fail-safe responses.

Failure	Response
Loss of communications to sgs comms hub	sgs connect implements a fail-safe response of fully curtailing the controlled generator export to zero. Following restoration of the communications link, the generator is automatically released by sgs connect to the appropriate ANM export set-point.
Controlled device not responding to set-point	A two-stage approach of escalating actions is carried out, designed to avoid tripping the generator Circuit Breaker (CB) unless absolutely necessary: When the ANM system issues a set-point to a generator, sgs connect starts a pre-configured duration timer. If this timer expires and the generator export remains greater than the set-point, the sgs connect enters an 'unloading' state. Whilst sgs connect is in the unloading state a zero export set-point is issued to the generator. The generator is required to reduce its output to below 2% of the total rated export capacity within another pre-configured time period. If the generator does not achieve this, the metering CB is tripped to remove the generator from the network.

Non-functional requirements for the NINES ANM system called for it to be resilient to single point of failure and to provide a robust, reliable platform. The design decision was made to configure the NINES central ANM component using four servers, hosting two instances of sgs comms hub and two instances of sgs core. The four servers are configured such that one sgs core and sgs comms hub are in active control with the other sgs core and sgs comms hub on hot standby.

All four of the platform servers share an in-memory real-time database. This database is the mechanism by which data can be exchanged between all participating servers in the NINES ANM system. Data may only enter or leave the ANM platform via the active sgs comms hub. This design feature was taken to provide improved resilience and security. Resilience is increased by allowing all four servers access to data in real-time using the shared in-memory database, meaning that if one server were to fail, the standby would seamlessly be promoted to main without disruption to ANM control. Additional resilience to single point of failure is designed as part of the ANM solution; the ANM platform uses multiple stacked switches with automatic failover, link aggregation technology along with multiple network interface cards across IT network connections to reduce the risk due to failure network links. The sgs core and sgs comms hub servers are specified with redundant power supplies and are in turn protected by an Uninterruptable Power Supply (UPS).

7.3 Communications and interfaces

In specifying interfaces, open standards were taken as the preferred approach over proprietary protocols. The ANM interfaces adopted protocols and standards used by SSEN to ensure smoother integration and understanding of design and operation.

The sgs comms hub is the gateway that facilitates all data exchange between controlled devices, the ANM algorithms and operational systems that exist at LPS (Serck, PI and PowerOn Fusion). As the NINES system needs to communicate to a wide variety of devices all using different protocols, the sgs comms hub is designed to be largely agnostic towards which communication protocol it can use. This gives a great degree of flexibility when choosing the best protocol that suits the controlled device. This design also ensures future controlled devices can be added without the need to be constrained by which protocols are supported.

7.3.1 Local interface controllers

Local Interface Controllers (LICs) are installed at the location of each device that is controlled by the ANM system. Each LIC consists of the sgs connect distributed element of the ANM system. The LICs provide a dedicated interface to the proprietary control system of the relevant device. The LICs each include a Local User Interface (LUI) that provides some limited functionality (e.g. this may be a dedicated touch screen panel or it may be some LEDs and switches). The LICs are configured to provide the relevant functionality for the device in question. This functionality includes the following:

- Collection of data;
- Passing of set-point data, operating parameters, schedules and commands;
- Disable/Enable command;
- Fail-safe logic (used in the event of communications problems).

For NINES, the Controlled Devices fall into 3 groups:

- Power Producers: generators that provide power to the network (i.e. Large Wind Turbines and Small Wind Turbines);
- Power Prosumers: devices that can provide power to the network or consume power depending on the configuration of the device (e.g. the Battery Energy Storage System);
- Power Consumers: demand customers that can be controlled in some way (e.g. DDSM and the SHEAP thermal store).

7.3.2 ANM to DDSM element manager

The DDSM Element Manager facilitates two-way communication between the ANM system and controlled devices in the DDSM category. The NINES ANM system is designed to communicate with controlled devices such as demand and generation to perform its network management functions, including scheduling of demand and management of system stability on Shetland.

The ANM interface to the DDSM Element Manager is facilitated through sgs comms hub, using the DNP3.0 protocol over IP. DNP3.0 was identified as meeting data transfer requirements, while supported by both sgs comms hub and the DDSM Element Manager. The sgs comms hub is the Client, establishing connections and making DNP3.0 requests, and the DDSM Element Manager is the Server, accepting a connection and responding to requests from the sgs comms hub.

7.3.3 ANM to PI

SSEN uses OSIsoft PI to provide data archival, retrieval, and display functions for operators and engineers. SSEN has an instance of PI for their entire network in Scotland, known as PI Power Systems North. A new, dedicated instance of PI, known as PI Shetland, has been installed to support the NINES project.

The ANM interface to PI Shetland is facilitated using sgs comms hub. The interface between ANM and PI is facilitated using OPC. OPC (Object Linking and Embedding (OLE) for Process Control or Open Connectivity) is a standard established by the OPC Foundation task force to allow applications to access process data in a consistent manner. OPC operates in a client/server model and supports remote data exchange over the network using DCOM (Distributed Component Object Model). OPC was chosen on NINES as the communication protocol as OSIsoft support the reading and writing of data tags in PI using OPC as the access protocol, thereby allowing the ANM system and PI to exchange data. The OSIsoft PI OPC Interface is an OPC Data Access (DA) COM Interface for bi-directional communication between an OPC DA Server that supports v1.0a and 2.05 of OPC DA standard and an OSIsoft PI System.

The PI OPC Interface is installed and configured by SSEN to act as an OPC client. A compatible OPC server is installed by SGS on the sgs comms hub servers with the tags configured to allow bi-directional data exchange. The SGS OPC driver ensures that any changes flowing downstream from PI are reflected in the clustered database and conversely pushes ANM changes upstream to PI through the OPC server.

The communication exchange between PI and sgs comms hub has proven to be a reliable. Initial setup of the interfaces was time consuming due to the many PI data points that required configuration on both sgs comms hub and PI.

7.3.4 ANM to serck

LPS Control System (Serck): LPS has an SCX6 SCADA control system manufactured by Serck. Data is exchanged between the sgs comms hub and Serck using the DNP3 protocol.

The ANM system obtains status information for all existing generators from Serck. This includes the status and power output of all LPS generators, SVT export and Burradale wind farm.

The LPS Control System provides the primary HMI to the system operator for the business as usual functionality of the ANM system.

7.3.5 ANM to human machine interface

The ANM Human Machine Interface (HMI) provides a secondary user interface to the ANM system for configuration (e.g. when new controlled devices are being commissioned), testing, and backup purposes. The LPS Control System, Serck, provides the primary HMI for the ANM system. The ANM system is designed to be highly autonomous and operate without regular intervention from operators with the exception of:

- Commissioning new generators;
- Adjusting the margins of the Constraint Rules;
- Setting upper limits for storage devices;
- Inputting uncontrolled demand forecasts, fixed schedules and schedule calculation triggers.

The HMI communicates to sgs comms hub via hypertext transfer protocol (http) using a RESTful web service.

7.4 Design specification

7.4.1 Constraint management

7.4.1.1 Software Application

The constraint management functionality is provided through deployment of a constraint management application (sgs power flow) hosted on sgs core, supplied by Smarter Grid Solutions, the ANM system vendor. This application regulates the production or consumption of power against the constraint rules described in Section 7.3. The active set-points that are triggered and issued by the constraint management function take priority over all schedule set-points calculated in the device scheduling function. In application, the constraint management function solely manages generation device-types on the Shetland network.

Rationale: The constraint management functionality provided by the application is consistent with the tried-and-tested ANM philosophy applied to the Orkney Smart Grid. The use of a demonstrated and verified solution provided confidence in the deployment of constraint management functionality within the NINES project.

7.4.1.2 Principles of Access

Due to the need to control multiple generators, a Last-In First-Out (LIFO) approach is taken to allocating spare network capacity. By this approach, ANM-controlled generators are curtailed in the order in which they contracted to connect: for example the most recent generator to contract will be the first to be curtailed, while the next-most recent will only be curtailed if the most-recent has been fully curtailed.

Rationale: This approach to allocating capacity provides higher priority to the first generators to contract for connection. LIFO reflects the conventional approach to capacity allocation for traditional firm generator connections, providing rationale for application of this specific principles of access philosophy. This was also reflective of the LIFO allocation demonstrated on the Orkney Smart Grid, therefore continuing an existing process within the Commercial and Connections team at SSEN.

7.4.1.3 Constraint management philosophy

A series of escalating thresholds are applied to maintain ANM-controlled generators within the constraint limit, which is dynamically changing based upon prevailing network conditions. Four thresholds are defined, which are specified as a percentage of the constraint limit. The thresholds are defined as:

- **Global Trip:** Exceedance of this threshold will immediately disconnect all ANM-controlled generators. Within NINES, this threshold was not set, as the immediate disconnection of all ANM controlled generation would exacerbate any stability concerns on the islanded Shetland network.
- **Sequential Trip:** Exceedance of this threshold will disconnect ANM-controlled generators, following the LIFO priority stack, with a configurable delay in between each disconnection. ANM-controlled generators are sequentially disconnected until the combined ANM-controlled generator export falls below the Trim threshold. A Sequential Trip threshold was not set within NINES for the same reasoning as Global Trip as described above.
- **Trim:** Exceedance of this threshold will trigger a calculation of the necessary set-points to be issued across all ANM-controlled generators, such that the combined export will fall below the reset threshold. The calculation of set-points follows the LIFO priority order.
- **Reset:** If the total export across all ANM-controlled generators falls below the reset level, while ANM-controlled generators have an active set-point less than their rated export, the ANM will release the set-points by a pre-configured amount, at a specified time delay between releases.

The thresholds are presented in Figure 2. The use of escalating thresholds allows SSEN to employ an appropriate degree of control over participating generators and devices, reflecting the proximity of network operating conditions to the constraint limit. By initially applying granular curtailment, the participating generators are offered access to a greater volume of available network capacity; it is only when network conditions move closer to the constraint limit, before curtailment actions are taken, that escalating action of disconnecting devices is taken.

Where thermal power-flow constraints are identified at pinch-points on the network, the above process is used to manage power flows against a fixed constraint limit, reflecting the thermal capacity of the circuit. In this case, only ANM-controlled generation associated with the power flow constraint will be curtailed or disconnected following a threshold breach. This approach to constraint management ensures generator export is only interrupted or curtailed in cases where it will have an effective impact on constraint mitigation. Once generation connection applications were received, power-flow constraints were not identified, therefore this functionality is available, but was not utilised.

In the case of stability constraint management, the derivation of both the Constraint Limit and the ANM-Controlled Generation export level uses live analogue telemetry data from the Shetland network, via Serck, and direct analogues from ANM-controlled devices. Given the stability implications of immediately disconnecting generators from the islanded Shetland system, the Trip thresholds are not configured for management of the stability constraints. The power system application and the configuration of the different thresholds as all envisioned in the patents (UK and international) that cover this method.

Figure 2: ANM Thresholds

7.4.1.4 Real-time control rationale

The constraint management application processes each constraint limit in sub-second timescales, identifying breaches of constraint limits, and where necessary calculating and issuing device set-points. This process is time-bounded to occur every 600 ms, ensuring fast-acting response, always within the time frame (real-time and deterministic) following observation of a threshold breach.

This fast-acting response ensures the real-time operation of the system, providing confidence that actions will be calculated and issued in fast time-scales as the network nears an insecure state. The enhanced confidence allows SSEN to reduce operating margins and release greater volumes of hosting capacity to generators.

A key element of the ANM functionality is that live network measurements feed directly into the deterministic derivation of the Constraint Limit, there is no application of load-flow network simulation or optimisation. This approach to functional design is driven by a requirement to ensure fast-acting, real-time control, with consistent and deterministic outputs. Risks associated with alternative approaches, such as integration of a load-flow, or optimisation, based solution, include the removal of time-bound solutions and ultimately increasing latency to control actions.

7.4.2 Device scheduling

The NINES ANM system produces schedules to direct the operation of controlled devices including domestic loads and battery energy storage devices. The scheduling functionality is implemented through the sgs balance scheduling application.

In the scheduling application device operation schedules are calculated according to the specified objectives for the ANM system and will be based on the available forecast data. Forecasts are received for various elements of the power system on Shetland, including wind power, tidal power, and demand.

The scheduling has three main objectives, to be achieved while maintaining operation within practical limitations of the device.

1. Alleviate constraints;
2. Lop peaks in the demand profile;
3. Fill troughs in the demand profile.

Schedules are recalculated on all devices due to the interaction between different devices and the different rules and objectives driving the scheduling. Some devices may be configured to use a manually-defined fixed schedule. This is controlled in the ANM HMI, where each device/group can be configured to receive the set-points automatically calculated by the scheduling application or be assigned a user-defined fixed schedule. When schedule calculations are initiated the software will compile all of the latest available information. This includes the latest forecasts and the most up-to-date information collected from controlled devices or other systems, e.g. Energy Stored and Energy Required. Issuing of fixed schedules is a manual input process and will over-ride any calculated schedules. Fixed schedules do not considered the levels of energy available unless a manual calculation has been performed by the operator.

Triggers on the system will initiate a recalculation of the schedules. Triggers include:

- Pre-set times or intervals, configured in the ANM HMI by the operator;
- When new forecasts are received.

Newly calculated schedules are implemented immediately and this applies no matter the reason for the recalculation trigger. This is independent of any broadcast calculation times entered by the user. Operators still have the ability to amend calculated schedules or impost a reference schedule at any time.

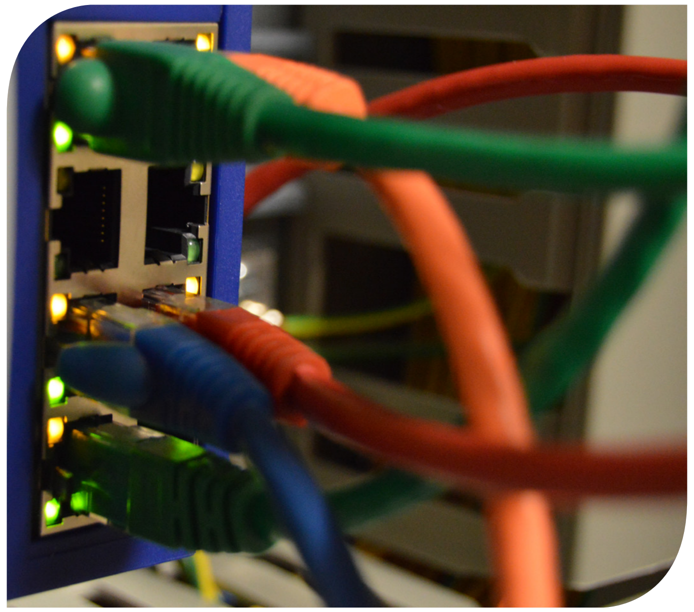
The ANM software has access to forecasts of power outputs and demand (See Section 7.2.2), from the next 15-minute time slot to 24 hours ahead, i.e. 96 values. The ANM software also has data on the current conditions. This provides the "live" and forecast data required in the scheduling calculations.

Schedules produced have 96 values covering all 15-minute time slots in a day. Schedules are issued and applied immediately upon calculation. The schedule calculation is therefore based on the current values and the forecasts for the subsequent 95 time slots. For example, if schedules are re-calculated at 05:07 then the calculation for each time slot will be based on data as shown in Table 2, with settings used immediately and for the next 24 hours. If schedules are re-calculated again then the settings used in the calculation are all revised.

Time Slot Start Time	Source Data	Time the Settings are Actually Used
00:00	Forecast Block 76	Next Day from 00:00 to 00:15
00:15	Forecast Block 77	Next Day from 00:15 to 00:30
Remains same until ▼		
04:45	Forecast Block 95	Next Day from 04:45 to 05:00
05:00	**Current Values at 05:07**	**Immediately upon issue until 05:15**
05:15	Forecast Block 1	Today from 05:15 to 05:30
05:30	Forecast Block 2	Today from 05:30 to 05:45
Remains same until ▼		
23:45	Forecast Block 75	Today from 23:45 to 00:00

Table 2: Example of schedule calculation and use timing

This prevents any problems that might arise with the immediate application of a schedule where the instructions for the current time slot are actually based on the forecasts for the same time the next day. This approach also lets schedule recalculation be used for the immediate scheduled (but non-real-time) alleviation of constraints that may arise as conditions deviate from what was forecast.



8. Operational experience and revisions to functional design

The following section outlines the NINES ANM operational experience and resultant revisions to functional design across the trial period.

8.1 New generator connections

8.1.1 Operational experience

Once the Shetland system was opened to ANM connection applications, SSEN received applications for a total of 15.2 MW of generating capacity, across 8 different sites.

Following the issue of connection offers, SSEN has contracted 8.545 MW of renewable generation for managed connection via the ANM system. This consists of:

- 8 MW of non-firm wind generation;
- 0.545 MW of non-firm tidal generation, reflecting the world-first connection of a tidal array that exports to the grid.

The contracted ANM generation has increased the connected and contracted level of renewable generation capability from around 4 MW to 12.5 MW.

8.1.1.1 Curtailment assessments

In the processing of applications, the SSEN planning process evaluated the operational impact of each generator connection, studying the emergence of any thermal or voltage constraints. In all cases, the connection of prospective generators did not result in the emergence of thermal or voltage constraints. This negated the need for the 'pinch-point' constraint management functions of ANM, solely managing stability constraints.

Each generator connection application resulted in a curtailment assessment study, the outputs of which were issued in the connection offer as an annual estimate of export curtailment due to ANM constraint management. This approximation of curtailment has provided SSEN customers with an indication of export interruption and supports the commercial planning of the generation development. The curtailment assessment study requires modelling assumptions regarding ANM system configuration and wider network operating conditions, which are all subject to change. Although conservatism is built into the study, the outcomes are supported by guidance highlighting the approximate nature of curtailment estimates.

In each curtailment assessment, estimates of annual generator curtailment were compared to the equivalent estimate of unmanaged site production. In the lowest-curtailment case, a generator was approximated to experience a 31% reduction in annual exports. In the worst case, a generator was estimated to experience an 83% reduction in exports due to ANM curtailment. In the higher-curtailment cases, generators did not proceed with connection to the Shetland network. It should be noted that the quoted curtailment figures are estimates derived from desktop forecasting studies and not derived from operational ANM data.

8.2 ANM platform

8.2.1 Operational experience

During the early stages of the project it was envisioned that the ANM system would be highly autonomous and require limited input from operators. This resulted in fixed autonomous rules, built-in to the ANM application, that required supplier support for major revisions; SSEN engineers were only able to update the values of constants and margins within ANM constraint functions, rather than update the functions.Through operational experience it became apparent that a more configurable approach was required, driven by the need to change constraint functions and SSEN Operator desires for greater levels of manual intervention. The rationale behind the revision of constraint functions is discussed in Section 9.3.

Operational experience highlighted a similar lack of flexibility in the Scheduling Algorithm, where autonomy and limited operator intervention were initial requirements. This application was fit for purpose during the trial deployment and while it was initially designed to be algorithmically simplistic for the purposes of the trial, improvements have been recommended to improve user configuration as the application becomes part of the business-as-usual system operation.

The need for enhanced configurability and user configuration has been a vital learning outcome from the trial. The revised requirement has not impeded the functional operation of the ANM scheme during the trial, though it had slowed down the implementation of functional updates. Updates to scheme configurability have been proposed as part of an upgrade to the NINES system following completion of the trial.

8.2.2 Revisions to ANM platform

A new version of the ANM platform will be installed in Summer 2017 and provides greater degree of flexibility and operator configurability to the NINES ANM system.

The new platform provides the capability to host optimisation algorithms, which is expected to improve the utilisation of the flexible load on the network and provide a greater level of scalability for any future requirements that may arise. This is of particular importance due to the ongoing Shetland Futures consultation process. Any new connection to the system can be integrated in to the ANM system, and SSEN will maintain a high level of control and visibility over the electricity system.

The new platform also includes the following functionality enhancements:

- **Dynamic ratings**, ensuring change in ANM thresholds is only undertaken when stable operation is maintained;
- **Network topology detection**, allowing autonomous update to ANM control rules following validated change in network topology;
- **Communications monitoring;**
- **Bad data detection**, triggering alarms or fail-safe actions following receipt of erroneous measurements.

The upgraded ANM platform will provide a revised HMI. This will provide NINES ANM system users with greater visibility, configurability and manual control options than was envisaged as necessary at the beginning of the project.

During the project, the in-memory real-time database within the ANM central controller was updated. Under stress testing of the system , the databased technology originally applied did not meet the expected perform levels. While functionally acceptable, under stress testing the stability and performance of the database did not meet requirements and was at risk of causing ANM system down-time. Although the failed cases studied in testing would not manifest themselves in the day-to-day production environment, future scaling-up of the ANM system functionality may not have been possible. The revision involved application of a database technology that utilises the publisher-subscribe, Data Distribution Service (DDS). This technology provides the ANM platform with dependable, high performance, scalable data exchange while retaining the real-time nature of the system.

8.2.2.1 Revision to real-time constraint management application

The ANM platform upgrade will include a revision to the Real-time Constraint Management Application. The revision will provide significant performance and configurability enhancements over the sgs power flow application currently utilised by the NINES system. This is achieved through the use of an new application framework. Performance tuning means that a single instance of real-time constraint management application is able to control many more devices while maintaining the time-bounded deterministic operation requirement. The core features of the application framework, in terms of the control actions, thresholds, operating margins, and principles of access have enhanced configurability, allowing specification of more complex constraint triggers and actions.

8.3 Constraint rules

Following commissioning of the NINES system, once ANM-controlled generators were introduced to the system, operational experience led SSEN engineers to identify improvements to the constraint rules, which had been implemented as described in Section 8.4.1.

Following review of operational experience, a number of interrelated reasons were identified that informed the update of constraint rules:

- Changes to the unit running order at LPS; and
- Validity of initial modelling assumptions and test scenarios.
- A new constraint rule CTR4 was added to the ANM system, described in Section 9.3.4

8.3.1 Changes to the unit running order at LPS

LPS has been the main source of electricity on the Shetland Islands since the 1950s. There is a requirement to expand the current capacity of the site. In addition to the need for expansion, there are a number of other considerations for the replacement of LPS including:

- the plant does not comply with modern-day emission limits
- there is a limited availability of land at the current site
- it is in close proximity to residential buildings which influences the technology type that can be implemented.

Original plans were for a replacement site to be built by 2017 and until that time, operate the generating units within LPS at a level that would ensure emission standards were maintained to agreed derogation limits, while ensuring capacity for renewable generation and contractual arrangements at SVT are met.

Due to delays in the approval, and therefore construction, of a new power station on Shetland, the operational regime at LPS has been adapted to maintain the units for a longer period of time. The change promotes the use of newer, but larger, B-Station generators over the older and smaller A-Station engines.

The use of larger generating units has limited the flexibility of LPS to reduce export to the 40 % minimum level defined in the original constraint rules. The Power Purchase Agreement with SVT was reduced significantly to accommodate this modification to system operation.

8.3.2 Early modelling assumptions and test scenarios

Modelling and analysis of the NINES system was performed in 2011/12, informing specification of the constraint rules. A summary of early modelling studies was published and can be found on the NINES Smart Grid Website. The constraint rules as determined in the early stages of the project were based on initial modelling assumptions, and were intended to be improved and revised as uncertainties became clearer and operational experience was gained.

A number of modelling assumptions were made regarding the expected running arrangements of the system, some of which were later found to be erroneous:

- That under periods of high renewable export LPS would be able to flexibly reduce export to meet 40% of the demand at any time.
- The turbine model of SVT was based on standard models available in Power System modelling software. Details of the SVT turbines were not made available for modelling purposes by the owners of the plant.
- Dynamic simulations focused on system behaviour during extreme conditions, with little investigation of ANM actions under normal system operation.

The Network Operation Constraint Rule (CTR3) was derived based upon the assumption that LPS would be able to reduce export at a fast response rate to allow renewable exports on the Shetland system, with the constraint rule ensuring this would not fall below meeting 40% of system demand. Due to the reasons established in section 9.3.1, LPS is not able to commit units to achieve as low as 40% of system demand during low demand conditions on Shetland. The constraint rule assumes a fast-acting response of export reduction at LPS to enhance hosting capacity for renewables; however, this response is not as fast-acting as that from SVT. As is described in section 9.3.3, this was found to risk undesirable implications for the SVT generator.

Simulations performed to define the stability limits of the system were based upon a dynamic model of the Shetland system. It was not possible to gather transient response data for all synchronous generators, with no available information for the generating units at SVT. It was necessary to use a generic generator model to represent the SVT units in dynamic simulations. With more dynamic characteristic information unavailable, the use of generic generator model was deemed suitable for the modelling given the operating margins that would be added to stability constraint mananagement for operational conservatism.

The purpose of the dynamic modelling was to identify the operational bounds for the Shetland system with greater penetration of intermittent renewable generation. The simulations studied a worst-case stability scenarios of the sudden loss of all wind from the system, defining limits for the volume of renewables that could be accommodated onto the network. The dynamic modelling only modelled the outer bounds of system stability and did perform detailed simulation of normal system operation and system response to ANM control actions across all constraint rules.

Key learning from the project has identified that a wider range of dynamic modelling activities when defining the constraint rules would have allowed simulation of the system response to ANM control actions under normal system operation, identifying the need for revised constraint rules.

8.3.3 Operational experience of constraint rules

The Frequency Stability Constraint Rule (CTR1) was derived by University of Strathclyde in the early stages of the project, identifying a maximum renewable export limit of 14.3 MW to maintain frequency stability. From operational experience, it was observed that CTR1 was never the binding constraint resulting in curtailment. The reason for this is that the current contracted export capacity of renewables on Shetland is less than the 14.3 MW export threshold.

The role of the Spinning Reserve Constraint Rule (CTR2) is to ensure that SVT carries enough spinning reserve to meet demand in the event that all wind exports are lost. Shetland Operations engineers have negated the rule due to concerns over its performance on the system.

The Network Operation Constraint Rule (CTR3) assumes that, for the purposes of accommodating renewables, LPS can provide fast-acting export reduction to 40%. As described in the previous two sections, the site cannot meet this lower export limit and does not provide the same speed of response as SVT. As such, when renewables export increases, it is SVT export that has fast-response reduction. The result of this is, as more renewable export is accommodated onto the system, if LPS cannot respond quickly with reduction in export, SVT exports may reduce below contracted minimum conditions and risk protection operation. This condition led to the introduction of CTR4, the (Generation) Asset Protection Constraint.

8.3.4 Revisions to constraint rules

Following a period of operation and a review of the constraint rules, SSEN defined and implemented an additional constraint rule, described as the Asset Protection Constraint, or CTR4. The Asset Protection Constraint ensures that renewable generation exports do not cause excessive displacement of SVT export by limiting the production from ANM controlled generation.

The Asset Protection Constraint uses an analogue measurement of export from SVT to determine the difference between the site instantaneous export and site contractual minimum-take export limit, where the latter is configured by the ANM operations team via Serck. The total permissible ANM-controlled generator export, i.e. the constraint limit, is equal to this difference between instantaneous and minimum-take export from SVT. The continuous, real-time nature of ANM control ensures that the ANM-controlled generator exports are maintained such that it does not replace the fast-acting SVT export beyond limits.

The application of the Constraint Rules have been critical to the accommodation of new renewable generation sites on the Shetland system as they set the 'safe', extended operational bounds for new generation. The rules, as initially specified, revised and currently implemented, have enabled the managed connection of multiple renewable generators. While the project identified need for refinements of the rules to reflect the changing characteristics of the Shetland system, a resultant template now exists for future adaptation of the system to facilitate any further changes to the network. The update to the system will enable the operator to implement new constraint rules, however based on the learning from this project, they should not be implemented without a period of in-depth modelling and analysis of the network to understand the impact of new constraint management rules.

8.4 Flexible demand and demand response

8.4.1 Reduction in availability of flexible demand

A full assessment of the DDSM scheme is provided in Learning Reports 1.1 – 1.4.

The original design for NINES included the ANM control of:

- 750 DDSM Homes (4.2 MWh);
- 6 MWh energy storage device;
- 135 MWh SHEAP thermal store.

For a number of reasons, once the ANM system was in operation the planned volume of flexible demand was greatly reduced to:

- 234 DDSM Homes;
- 3MWh energy storage device.

The SHEAP thermal store was not integrated into the ANM system due to the two third parties involved in the development of the store being unable to come to commercial arrangement. ANM control of the SHEAP thermal store would directly benefit specific generators under ANM control, mitigating curtailment. The provision of services from the SHEAP thermal store to ANM-controlled generators would be facilitated by the ANM system, however creating commercial arrangements between the parties was not within the remit of SSEN, whose role was as a facilitator in the process. The other parties were not able agree suitable commercial arrangements that would allow the SHEAP thermal store to participate in the ANM system and mitigate generator curtailment.

There was a reduction in the number of DDSM home participants in the trial due to a change in circumstances led to several project partners pulling out as the project start date approached. In 2013, work was carried out to identify a suitable method to replace the 500 Shetland Islands Council customers that were part of the original NINES DDSM proposal. Through the development of a suitable method, it was determined that an Open Market Model was the best approach to recruit additional DDSM customers. A change request submitted to Ofgem in October 2013 outlined a proposal to produce an Open Market Model that could be used to recruit 500 additional customers.

The proposed DDSM solution was designed and developed to complement the SHEPD Integrated Plan submission, where control and scheduling of the devices would form part of the enduring operation of the proposed new power station.

Following on from the rejection of the original Integrated Plan submission and the obligation on SSEN to run a competitive process, SSEN believes that recruitment of these customers would now sit better with an aggregator or similar party. As SSEN has no direct control over the potential solution(s) which may come out of the competitive process, there is no certainty on how the DDSM would fit into the overall solution.

8.4.2 Operational experience

The reduction in availability of flexible demand resources did not trigger updates or alterations to the objectives, requirements or functional design of the NINES ANM system. This reduction in the volumes has an impact on the bounds of the network support services that can be provided by the scheduling element of the NINES ANM system.

The reduction in volume and effectiveness has not directly impacted the total additional capacity of renewable generation accommodated on Shetland through ANM. The approximation of MWh real-time capacity that could be leveraged, derived through curtailment assessments, was based upon conservative assumptions of ANM operation. The curtailment assessment studies did not model the benefits of flexible demand that ANM-controlled generators could benefit from. During early stages of the project there was uncertainty regarding the capacity of flexible demand and it was therefore deemed least-risk to exclude flexible demand from calculations Therefore, generator expectations for available network capacity was not based upon the provision of curtailment support from flexible demand.

8.5 Battery

8.5.1 Change to battery technology

The project procured the first-grid scale battery storage system for the UK. Three tenders were submitted, each proposing a different battery technology: Sodium Sulphur (NAS); Vanadium Redox; and Zinc Bromide. The contract was awarded to S&C Electric for a 1 MW, 6 MWh NAS battery. The technology had been used widely in America and Japan with in excess of 300 MW installed capacity at over 215 sites. NINES was the first installation in the UK and only the second in Europe.

Two weeks prior to the scheduled energisation of the battery, SSEN were informed of a battery fire at a NAS installation in Japan. In late 2012, a decision was made by SSEN, informed by external consultants, to seek an alternative solution to the NAS battery due to the safety case associated with the chosen site location.

The alternative solution had to be sized to fit the existing housing building for the NAS battery. The technology selected was a valve regulated lead acid battery. Lead-acid batteries have a lower energy density than NAS batteries – 30 Wh/kg vs 218 Wh/kg respectively – this increased the battery footprint by a factor of 5. Due to the battery housing constraints, the energy storage capacity of the battery was reduced to 3 MWh.

Implications of this were that there was less energy flexibility available to support the network operation. The warranty for the battery decreased from 15 years to 5 years or 1500 cycles. The capability of the alternative solution was not as great as that originally specified and therefore expectations of the battery had to be adjusted.

8.5.2 Operational experience

As detailed in Section 8.4.2, the battery is scheduled to:

1. Lop peaks in demand;
2. Fill troughs in demand;
3. Minimise curtailment.

The battery was installed in February 2014. The ANM-calculated schedules for the battery were applied to the battery from early 2015. Following several months of operational experience, a number of learning points were used to inform system configuration improvements, which are discussed in more detail in Section 9.5.3. A list of operational observations are presented overlay:

- At first, the battery did not reach full charge regardless of the 8 hour charging window. There was not a distinct charge and discharge energy requirement set for the device in the ANM system. The battery scheduling algorithm was configured with a single fixed energy requirement of 3 MWh, not reflecting the greater amount of energy required to charge the battery fully once losses are taken into account and the reduced rate of charge as full charge is reached.

- Analysis of a short operational time period, comparing demand data against battery operation, identified apparent inaccuracies in the battery schedule. It was noted that the battery was not always being used to minimise demand peaks at the highest demand periods of the day.

Further information on the battery can be found in Learning Reports 2.1 – 2.3.

8.5.3 Revisions to battery scheduling algorithm.

SSEN analysis discovered that the battery was only utilising 66% of its capacity. The consequence of this was that by not fully discharging the battery, less energy would be required to fully recharge the battery. This decreases the controllable demand available to ANM, and limited its contribution to scheduling objectives.

The energy requirement of the battery was initially configured within ANM as a constant 3 MWh, assuming a 100% round trip efficiency. In practice, a little more than 4 MWh charge is required and more than this when the battery requires an equalisation charge. Furthermore, the battery does not charge at full rated power for the full charge cycle; instead following a step-down charging profile with the maximum rated power decreasing when the battery reaches 80% state of charge (SOC) and again at 90% SOC. As this was not defined within initial requirements, the ANM system did not account for these operational characteristics; this resulted in the ANM schedule assuming the battery has taken a greater level of charge than is the case. This has led to a number of instances where the battery has not been fully charged. It should be noted that in these cases the battery was still able to operationally support the wider Shetland system but it was not operating at its full capability.

The ANM system does evaluate the battery SOC when a schedule re-calculation is triggered. In cases where the battery has not been fully charged, this action will increase to SOC to 100%. The frequency of this calculation has been increased to half-hourly during the night-time charging period, resulting in a noticeable improvement as the ANM schedule fully charges the battery on a regular basis.

8.6 Element manager

8.6.1 Operational experience

The DDSM is scheduled using device data sent from Element Manager to the ANM system. Element Manager aggregates the available capacity from each of the available storage devices and sends a single value back to the ANM system via a LIC. This value is then used in the scheduling calculation. Operational experience identified inaccuracies in the reporting of device availability from Element Manager.

Element Manager transmits a '% Devices Reporting' figure to ANM which allows the scaling of DDSM controllable load based upon availability of devices. During testing, it was discovered that the '% Devices Reporting' figure only provided an indication of the number of devices, and not an accurate volume of available capacity due to variation in sizes of devices in each group. It was not possible to provide an indication of individual device rating through Element Manager.

One source of inaccurate device reporting was communications to individual appliances. To address the problem of intermittent communications with DDSM appliances in the home, when the Daily Energy Requirement (DER) is not received from an appliance, Element Manager uses the last known 'good' value received from that appliance. It was found that when a customer switches off an appliance, for example during summer when heating is not required or if the property is unoccupied for a period, the last received good value continues to be used, although the actual DER is zero, as the appliance is switched off.

This was found to create an artificially high DER for each appliance, which during the summer months can overestimate the availability of up to 80% of heaters. The aggregated Group DER was correspondingly inaccurate.

It was decided not to pass the group DER availability back to the ANM as the value was not believed to be accurate enough to positively inform the scheduling calculation. This resulted in the ANM system attempting to schedule DDSM assuming all devices are available for control. During operational experience, a conclusion was reached that an incorrect value would have been more appropriate than not passing the value back at all.

8.6.2 Revisions to ANM-to-DDSM Element manager interface

To address the '% Devices Reporting' issue, a user-configurable value is provided in the HMI to allow the operator to update the settings accordingly in the next system upgrade. This allows the operator to manually approximate the percentage of devices available, reflecting seasonal trends in customer demand behaviour.

Despite both sgs comms hub and the DDSM element manager using DPN3.0, initial attempts to achieve communications between the two were unsuccessful. After thorough investigation and analysis, a driver issue with a third-party vendor was found to be the cause. A change to the driver software was implemented and this allowed both systems to communicate and operate within the design specifications.

A key learning outcome from the ANM and Element Manager experience was that a designated systems integrator, or a supplier designated as prime, would have helped improve the efficiency of implementation, testing, and trouble-shooting.

8.7 DDSM scheduling

8.7.1 Operational experience

During the trial, it was found that on occasions the scheduling application was assigning flexible load to DDSM units during peak load periods. This scheduling was contradictory to the project requirements of flattening the demand curve through DDSM. It was identified that this issue emerged from the deterministic nature of the scheduling application, which is based upon a single pass algorithm. The algorithm characteristics meant that it does not review status once the energy has been assigned across time-steps, to check if this is the best or optimal solution. A step in the algorithm assigns available demand to the next time slot when limits are reached. For example, the target value of 183 kWh is to be assigned in the low demand period when only 100 kWh is available; the schedule will assign 83 kWh to the next time step, which may also be a peak load period.

The demand must be assigned to the next available time period to ensure that customer energy requirements are met. The scheme operates in such a way as mitigating the risk that the customer energy requirement is not met is a priority of the ANM scheme. This operational approach was identified as, on occasion, resulting in unused DDSM capacity, which could be assigned to a low demand period. A simplified example of this is provided in the table below:

Table 3: Assigning available demand to a trough, with peak load occurring in next time step
*Total demand to be assigned is 183kWh

The operational implications of this are covered in the DDSM suite of Learning Reports 1.1 – 1.4.

Time	Target Value* (kWh)	Demand Value (kWh)
04:45	100	70
05:00	83	90
05:15	0	88

8.7.2 Revisions to scheduling algorithm

The new ANM platform enables Optimisation algorithms to be hosted for scheduling applications. This is to improve the utilisation of the battery device and includes the potential to improve DDSM group scheduling.

Integration of third party optimisation software into the new ANM platform enables a new day ahead scheduling application. This allows the ANM platform to create and distribute schedules to devices connected to the NINES network. This new scheduling application will resolve a number of issues currently experienced with the single-pass scheduling algorithm used for the battery storage device.

The new scheduling algorithm will:

- Avoid scheduling demand during peak times;
- Create energy storage schedules that result in a full charge and discharge cycle within a 24 hour period with independent charge and discharge energy ratings;
- Utilise the % devices reporting data point to scale domestic demand side management accordingly;
- Automate the data transfer of previous days demand from PI for use in the day ahead scheduling application.

8.8 Vulnerabilities and security concerns

It is important that appropriate efforts are made to protect the confidentiality, integrity, and availability of the NINES ANM system and its data. Security of the NINES ANM platform was considered from the requirements and design stage. During the design of the NINES ANM system the approach was to integrate security requirements from the beginning. This also extended to the software development lifecycle, the emphasis is to mitigate the risk of introducing vulnerabilities as early as possible. The system is hardened to reduce the attack surface, making it significantly harder for an attacker to gain access. The design decision to keep the real-time data exchange between sgs core and sgs comms hub isolated from the rest of the network ensures data is not exposed to any external network node. This design also increases stability and thus availability of the ANM platform. Local firewalls are in place on sgs core and sgs comms hub that drop all unwanted traffic, reducing the risk of successful attack by reducing the attack vectors available.

To test the security of the production build of the NINES ANM servers, vulnerability scans were conducted. These scans look for potential weaknesses in the system that a threat could expose. The vulnerability scans were conducted by SGS's security team and by the owner acceptance testing team at SSEN after the servers were on site and fully tested. The results of the vulnerability scans demonstrated that the security architecture of the ANM platform as deployed at LPS met the required standards by both SGS's internal team and SSEN's security team as acceptable to the risk profile of the deployment.

The ANM servers are located in dedicated, secure, locked server rooms within Lerwick Power Station (LPS) where access is restricted to a small group of Operations personnel.

To gain access to LPS itself, there is an imposing large sliding iron gate at its entrance, which is opened once the identity of any visiting parties and purpose of the visit is known. Visitor access controls are in place on arrival at reception and all visitors must be accompanied at all times when on-site.

The main entrance and other parts of the LPS site are covered by CCTV, which is continuously monitored by Operations personnel.

At the remote end (where the sgs connects are located) my understanding is that these are typically installed in newly built, dedicated small out-buildings which are padlocked and protected by electronic intruder detection systems.

The key risks identified were categorised as:

- Loss of Personal Data;
- Loss of System Data;
- Interference with the supply of Electricity to DDSM Customers;
- Intrusion in to the SSE Network from DDSM equipment in the Field.

An example of some of the security requirements identified through the original Six Homes Trial of DDSM are as follows:

- Audit Changes;
- Develop Code Using Approved Coding Guidelines;
- Encrypt Data Over Public Networks;
- Restrict Ability To Configure ANM;
- Restrict Access To Authorised Users;
- Verify Message Integrity;
- Verify Message Source;
- Warn on Invalid Inputs;
- Segregate Networks;
- Lock Accounts on Multiple Failed Logins.

The ANM system was designed to manage risk by meeting the above requirements.

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10. Conclusions

9.1 Constraint management

The deployment of ANM through NINES has more than doubled the volume of renewable generation on Shetland, taking the contracted renewable capacity to 12.5 MW.

The trial of the ANM solution on the Shetland Isles has presented a great deal of learning for all project partners. The islanded nature of the Shetland system and the resultant need for stability constraint management has driven the innovative trial of ANM to accommodate renewable generation. The resultant doubling of renewable generation capacity on Shetland will significantly improve the displacement of fossil fuel generated electricity.

The requirement for fast-acting and robust control to maintain system stability informed design decisions to deploy real-time detereministic rules-based control. Establishment of fail-safe responses ensures system stability is maintained during periods of ANM outage or device non-compliance. Including control system redundancy with spinning reserve has ensured enhanced ANM scheme availability, mitigating the risk of fail-safe outage for ANM-controlled generators.

Constraint management has required monitoring of a wider range of network parameters, and introduced the higher-resolution logging of operational network and ANM system data. Not only does this provide greater visibility of network behaviour to operational engineers, but supports future planning activities, allowing SSEN to maximise use of existing network assets and increase hosting capacity for new customers.

Operational experience during the trial phase identified the need for an additional constraint rule, reflecting changes in existing generator operating characteristics that defined the original constraint rules. This experience serves to highlight the changing developments on networks and the need for constraint rule revision to reflect these changes. Limited flexibility within the ANM system for users to re-configure constraint rules has resulted in vendor support to add or edit rules; it is recommended that greater flexibility is built in to such constraint rules to allow an enhanced degree of user control.

Planned updates to the ANM platform, building on learning from the NINES trial, will introduce greater degree of flexibility for SSEN users to configure constraint management rules. This allows SSEN to adapt the ANM constraint rules to meet the changing needs of the Shetland system.

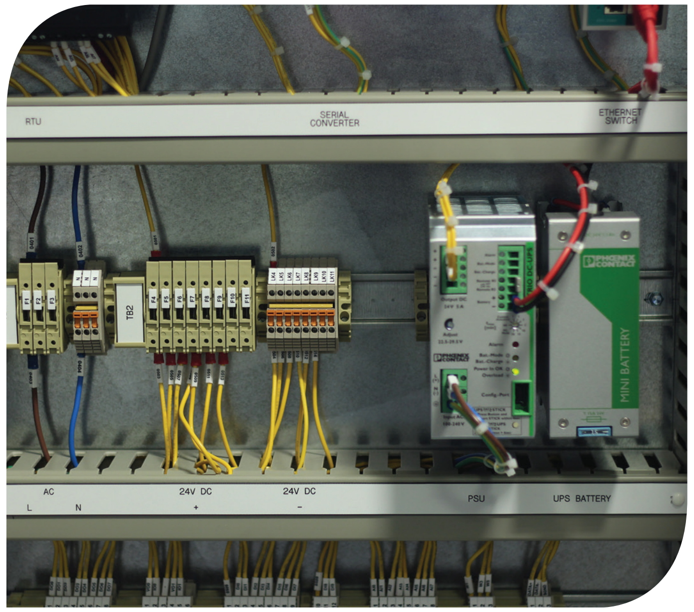
9.2 Device scheduling

The NINES ANM system has successfully established a scalable platform for monitoring and control of grid-scale battery storage and distributed domestic DSM devices across Shetland.

The scheduling of DDSM groups and grid-scale battery storage on Shetland required ANM applications and infrastructure to provide monitoring and control to domestic device level. Establishment of the ANM Element Manager enabled control of DDSM groups of aggregated domestic devices, whilst direct communications were established between the ANM system and larger devices, such as the energy storage system. The protocol-agnostic design of the sgs comms hub gateway has provided a scalable platform which will allow expansion of the ANM system to incorporate additional devices in future.

The demonstration of ANM scheduling observed successful control of the energy storage system and DDSM devices . The operational availability of DDSM devices was found to be lower than anticipated, with resultant implications for the load-curve balancing objectives of scheduling; greater visibility of DDSM device availability has been identified as a improvement to better gauge the effectiveness of DDSM.

Changes to the volume and type of devices available to the scheduling algorithm, through revision to the battery type and lower volume of available DDSM devices, was found to impact the effictiveness of ANM schedules, but not the ANM scheduling capability. This reflects a scalable solution that can adapt to the changing nature of the Shetland system.



When defining battery storage schedules to smooth the daily demand curve, operational experience highlighted the importance of an accurate value of round-trip efficiency. By not taking this value into account, the battery was found to not provide the expected level of smoothing to the demand curve. Following update of device characteristics within the scheduling algorithm, reflecting the round-trip efficiency of the battery, a greater level of smoothing was identified in the demand curve.

As with constraint management rules, the scheduling algorithms were subject to minor revision following operational experience at the trial stage. Enhanced configurability of scheduling rules, rather than fixed-rules was identified as a future requirement of the system, providing capability for users to have greater influence over scheduling. The HMI was initially designed for little day-to-day user interaction, however operational experience has recommended a more configurable user-to-ANM interface that allows setting of schedules and specification of scheduling rules. Planned revision of the ANM platform will provide the enhanced functionality to allow SSEN user configuration of rules and resultant schedules.

9.3 Contribution to learning outcomes

This report has addressed 3 of the 8 learning outcomes. A short summary is provided to demonstrate how the learning from the ANM functional design, implementation and trial has contributed to each Learning Outcome.

LO1: How can a distribution system be securely operated with a high penetration of renewable generation?

The ANM system provides a centralised control solution for all ANM managed elements on the Shetland system. The ANM platform supports the network operators in balancing the Shetland system effectively, and during periods of high wind on the system, constraint rules ensure that the network remains in a safe and secure state at all times. Flexibility in configuring constraint rules, reflecting developments on the network, was found to be critical for a scalable solution.

The trial of the system has demonstrated that significant additional renewable generation can be added safely to the system and adjustments made accordingly depending on other factors such as available demand, and the export from conventional generation plant. Full dynamic simulation of normal operational conditions, as well as constraint conditions, is required to validate any future creation of, or updates to existing constraint rules.

LO2: What is the relationship between intermittent generation and responsive demand, including storage?

- Effectiveness of frequency response demand side management;
- Maintaining network stability in an operational environment;
- Interaction of numerous variables on a closed electrical system.

The ANM platform provides a crucial link between the intermittent generation, and responsive demand in overall system management. While it has been demonstrated that the initial calculations ,requirements and anticipated storage and flexible demand did not result in the ideal outcomes for maximising renewable generation and reducing demand peaks, operational experience has provided guidance as to how that can now be addressed. Updates have been made to the scheduling algorithm in order to ensure that the value of the battery is realised in minimising demand peaks. This is in line with other operational updates to the functional design of the system as a result of learning during the trial.

LO6: To what extent do the new arrangements stimulate the development of, and connection to, the network of more renewable generation and reduce the area's reliance on fossil fuels?

Without a system for controlling generation and responsive demand on the island, it was not possible to facilitate the connection of any new renewable generation due to stability and frequency constraints on the network. The ANM system and wider NINES project components has more than doubled the volume of contracted renewable generation on Shetland.

The current ANM platform and configuration provides the capability to control generation within Shetland system limits and is future proofed to the extent thatthe constraint rules can be altered as operational characteristics or commercial arrangements develop in future. Additional devices to support the connection and operation of renewable generators, such as battery storage systems, can be integrated onto the ANM platform with bespoke control rules reflecting operational and commercial arrangements to further enhance the operation of the Shetland systems against the objectives.

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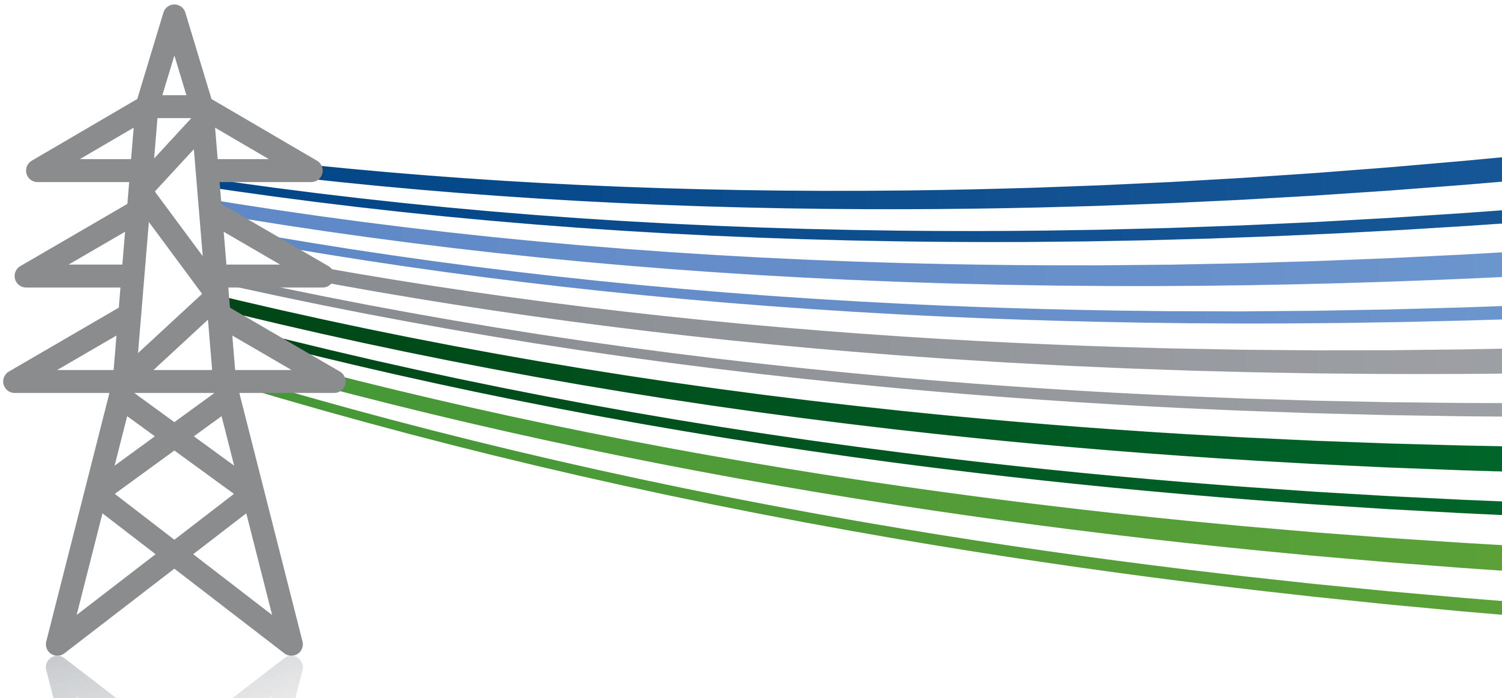

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