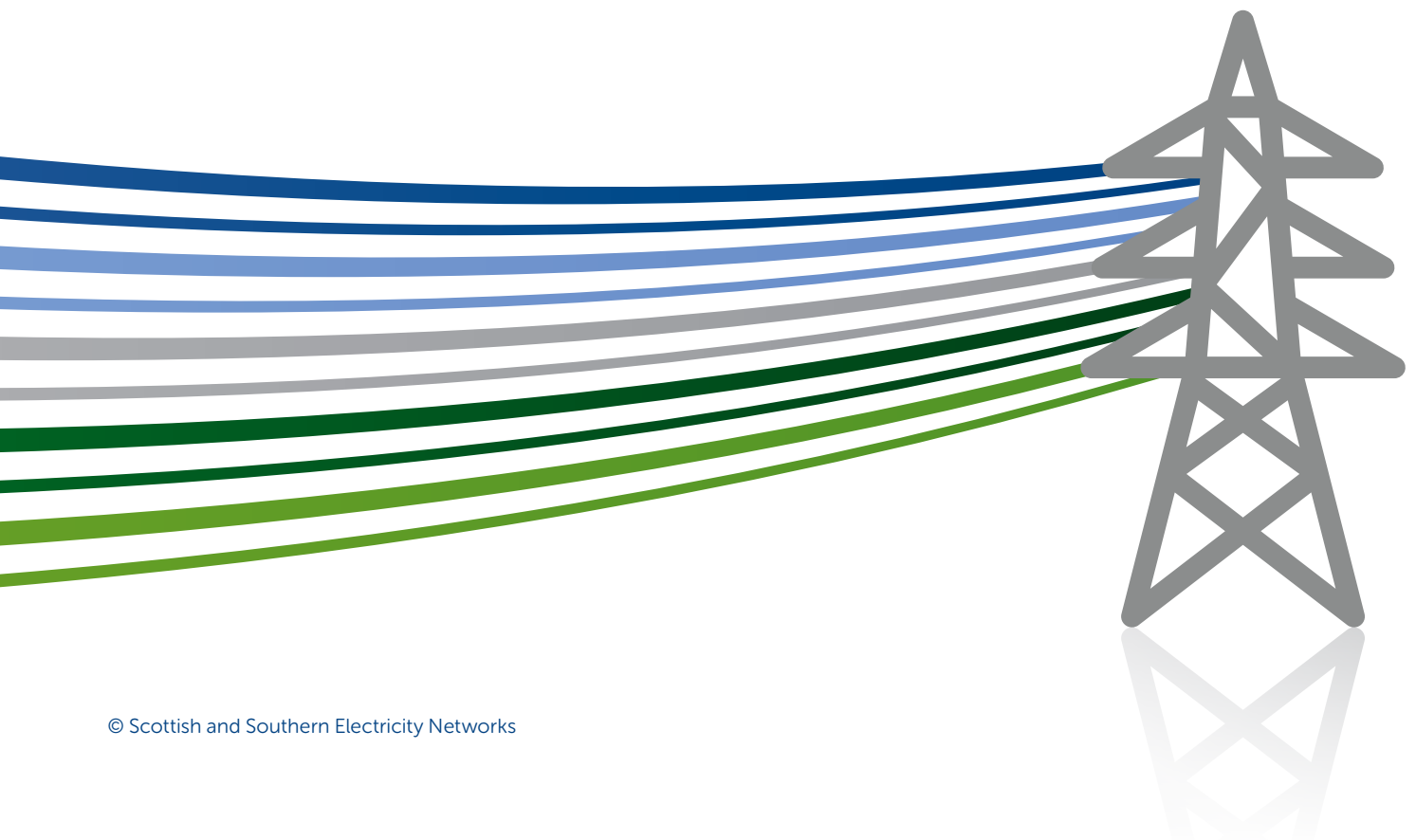




NINES

# Project Closedown Report

April 2017





## Prepared by

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## Acknowledgement

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This project could not have delivered the learning outcomes derived from this initiative without wide-ranging support from our customers, necessary for virtually all aspects of the project including Demand Side Management, Active Network Management and renewable generation connections, either directly through the installation of equipment within their homes or businesses, or indirectly through the installation of equipment on their street.

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# 1

## Project background



# 1. Project background

During the DPCR5 Price Control settlement, a licence obligation was put in place which required Scottish Hydro Electric Power Distribution (SHEPD), part of Scottish and Southern Electricity Networks (SSEN), to present an Integrated Plan to manage supply and demand on Shetland.

The Shetland Islands are located 130 miles from northern Scotland and have a population of 23,200 with electricity demand varying between 11 and 47MW. 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 DPCR5 licence condition, this Integrated Plan was to be presented to the Authority by 31 July 2013 and SHEPD was required to demonstrate that it had identified a solution based on the lowest lifecycle costs taking into account its environmental obligations. This solution also offered SHEPD

the opportunity to trial solutions, individually and in combination to maximise their effect, with the aim meeting the original objectives and to provide learning outcomes and processes which could be replicated by other DNO's across the UK.

As part of the Integrated Plan submission SHEPD considered, amongst other things, the upgrading or replacement of Lerwick Power Station, the impact of third party generation, the abundance of renewable energy resources and the future energy demand on Shetland.

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 has record breaking capacity factors of 52%. When SHEPD initially approached this issue the network topography was the key issue, with no interconnector, the maximum amount of energy used on Shetland each year sets a limit for the maximum amount of energy that can be generated in each year:

- Shetland annual electricity consumption - 225GWh
- The island's energy use also sets a limit for the maximum that can be generated at any moment in time:
  - Winter maximum demand - 47MW
  - Summer minimum demand - 11MW

Despite significant renewable resources, before NINES just 7% of all consumed energy was produced by renewables. If a mainland link was available, which is still a future possibility, further generation capacity could be exported and peak

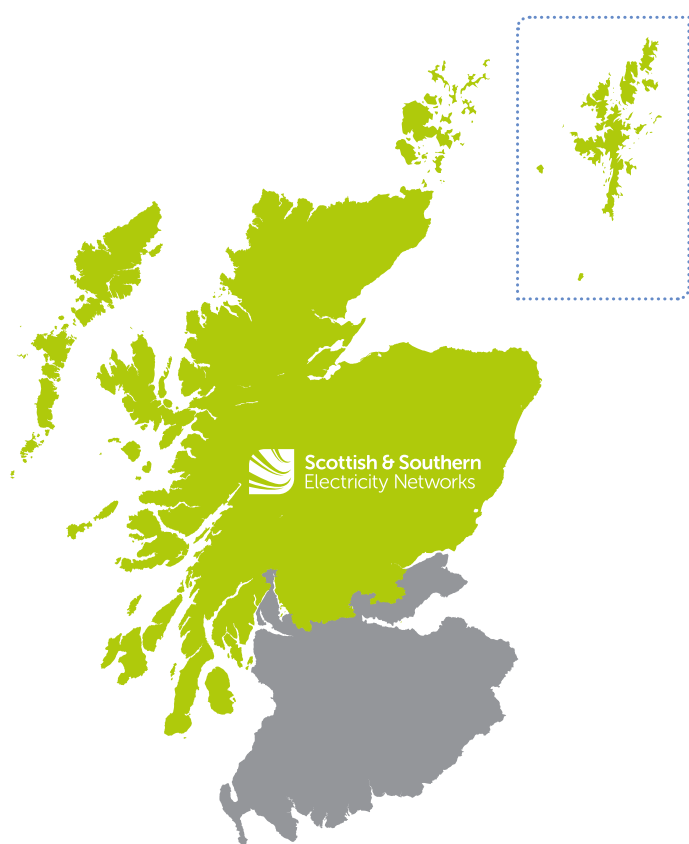


Figure 1.1 The Shetland Isles.

demands could be fulfilled by importing energy generated further afield.

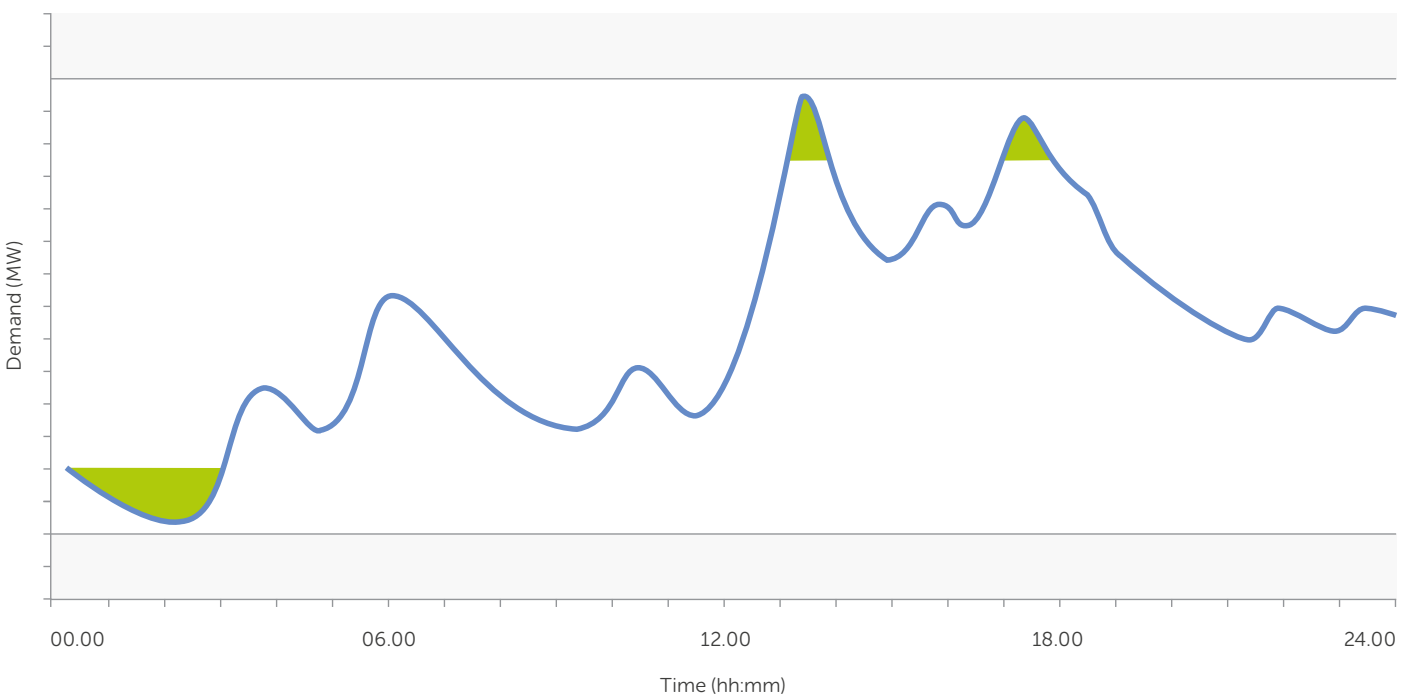
The electrical challenges posed by the existing network and generation mix on Shetland necessitated an innovative approach to both supply and demand management. However, with innovation comes the need to trial solutions before reaching an answer. As a result, SHEPD originally proposed to split the implementation 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 co-ordinated 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 by fossil fuels.
- **Phase 2** (Shetland Repowering) – upgrade 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 was therefore specifically designed and developed to operate in conjunction, and integrate with Lerwick Power Station or its SHEPD specified replacement operated by SHEPD, with SHEPD having a detailed and overarching view of the operation of both NINES and the thermal plant, and the opportunities for savings brought about by NINES in this context.

NINES therefore constituted SHEPD's proposal for Phase 1 of the Integrated Plan and sought to:

- Outline the arrangements and challenges on Shetland;
- Set out the Shetland Repowering considerations;
- Explain Phase 1;
- Set out the costs for Phase 1;
- Identify the project delivery methodology and risks; and
- Outline a mechanism to amend the licence obligation Special Condition CRC 18A to allow Phase 1 to proceed.



**Figure 1.2** In addition to enabling connection of more renewables, NINES sought the ability and control of customer demand to shift peak consumption.



# Executive summary



## 2. Executive summary

### 2.1 Project objectives



Phase 1 of the Integrated Plan was developed with the main aim of informing the optimum repowering solution for Shetland. Whilst its primary objective was to trial 'smarter' initiatives, importantly it also funded elements and infrastructure that expect to endure as part of, or alongside the new energy solution.

The Phase 1 approach was originally explored in a bid, titled 'NINES', under the Low Carbon Networks Fund (LCNF).

When reviewing the original 'NINES' LCNF submission, Ofgem recognised the value of the project in addressing the challenges on Shetland, and noted that, *"aspects of the NINES project solution could potentially provide a lower carbon and lower cost approach to meeting the energy needs of Shetland compared to replacing the ageing Lerwick diesel power station with a similarly sized diesel plant."*

The final Phase 1 approach, whilst technically identical to 'NINES', was somewhat refocused on providing infrastructure and learning specifically for Phase 2 of SHEPD's original Integrated Plan, rather than having a broader UK focus.

There has been significant support, both on Shetland and further afield, for what the original 'NINES' project was intended to achieve. Given that the output of Phase 1 has been very similar to the proposals in 'NINES', we continued to 'brand' the Phase 1 approach as 'NINES' in order to provide continuity for the residents of Shetland.

### 2.2 Review of key objectives

The learning objectives of NINES were a set of hypotheses the project sought to answer outlined within the project determination. Details of the learning outcomes from NINES can be viewed in a series of reports listed in Appendix 4 and a summary of a number of the key findings against the original hypotheses is provided later in this report. The original hypotheses are listed below:

- How can a distribution system be securely operated with a high penetration of renewable generation?
- What is the relationship between intermittent generation and responsive demand, including storage?
- How effective is frequency responsive demand side management in maintaining network stability in an active operational environment and with the interaction of the numerous variables on Shetland's closed electrical system?
- What is the economic impact on industry participants and other stakeholders of the low carbon operation of the network?
- What new commercial arrangements are needed to support a low carbon network?
- What is the impact of the low carbon network on domestic and industrial customers?
- What is the effect on fuel poverty, changes of attitudes, awareness and behaviours amongst consumers and the extent of the financial impact on participants?
- To what extent do the new arrangements stimulate the development of, and connection to the network of more renewable generation and reduce the reliance of the area on fossil fuels?
- What effect does the NINES project and its legacy have on Shetland's economy and on the carbon footprint of the area?

## 2.3 Summary of learning outcomes

The Project integrated a grid-scale battery energy storage system and domestic Demand Side Management (DSM) with an Active Network Management (ANM) system. This enabled the battery and DSM enabled appliances in 234 homes to be scheduled to charge when new non-firm renewable generation would otherwise be constrained. This is the direct enablement of flexible demand management and supports the integration of more local wind generation. The battery can discharge 3MWh during the peak demand which reduces the generation requirement the system operator must provide through conventional generation sources and releases an additional 1MW demand capacity. To date, the battery has completed over 450 operational cycles.

In addition:

- NINES has proven that a distribution system can be operated securely with a high penetration of renewable generation supported by ancillary services from thermal plant. It has also been shown that renewable generators connected via managed connections can experience increased levels of constraint in periods of low demand.
- Frequency responsive DSM has been shown to contribute to stable network operation in conjunction with an ANM system. We have shown that frequency responsive demand can be used to maintain the frequency stability of the system under the calculated limits.

Further learning outcomes are detailed in Section 6.



# 3

## Management of the project



# 3. Management of the project

## 3.1 Project strategy

The creation of an integrated set of modelled outcomes designed to anticipate the impact of NINES was an important element of the project. These series of co-ordinated outcomes 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 were incorporated into the design requirements of the Integrated Plan around the replacement of Lerwick Power Station. Overall, with the successful operation of NINES, we have created the infrastructure and processes to reduce peak demand to a level dependent on the particular assets connected, and their characteristics such as levels of storage or demand reduction. This infrastructure is built in such a way that it is scalable and could readily absorb new flexible assets that may arise under the New Energy Solution for Shetland onto the system for a marginal cost, resulting in a greater return from the sunk costs.

The work in this area covered the following themes:

- Dynamic stability;
- Steady state;
- Unit scheduling;
- Customer demand forecast;
- System development optimisation;
- Strategic risk and operational risk;
- Shetland economic; and
- Commercial.

There are four core elements in delivering the NINES project: an Active Network Management (ANM) System, a 1MW Battery, domestic demand side management (DSM), and renewable generator connections. All of these elements are described in detail in Section 4 of this report.

As well as reducing the peak demand on the islands the NINES project also has wider benefits.

Through the management of the four core elements, NINES has significantly increased the volume of renewable energy that can be connected to the islands' network.

By managing demand and increasing the amount of renewable generation on the islands, the requirement for energy supplied by thermal generation has been reduced.

The principle aim of Phase 1 (NINES) was to inform Phase 2 of the Integrated Plan (as originally envisaged by SHEPD). The learning produced by NINES will de-risk relevant decisions in relation to this next phase and offer valuable insight into the technology and processes required for the creation of Smart Grids for UK DNO's.

## 3.2 Partners

Throughout the project we worked with a number of key partners to develop ideas and understanding in a number of areas. These include but are not limited to:

**Smarter Grid Solutions (SGS)** – Providers of ANM technology, Smarter Grid Solutions is an innovative technology company offering Distributed Energy Resources (DER) integration and control products and services for power utilities and DER operators.

**University of Strathclyde (UoS)** – Research and academic partner providing analysis and development within network modelling.

**Glen Dimplex** – the world's largest manufacturer of electrical heating, developed the heating systems and home communications network utilised within NINES DSM.

**Hjaltland Housing Association (HHA)** – partnered with the NINES project in the installation of the Glen Dimplex Quantum storage devices in 234 of their electrically heated properties.

**Airwave Solutions Ltd.** – provided the wider area communications network (WAN) across Shetland and developed the bespoke software which allowed for the ability to manage heating and hot water energy requirements in the 234 homes.

**S&C Electric Co.** – supplied and maintained the 1MW/3MWh battery and ancillary services, located at Lerwick Power Station, Lerwick, Shetland.



### 3.2.1 Project governance

Governance for the project follows the processes and procedures laid down within the SSE Large Capital Projects Governance Framework Manual. A NINES Project Review Board was established by the Project Director and had a supervisory, assurance, guiding and assessing role for the project. The composition of these boards included key stakeholders from appropriate business areas.

The key objectives of the Project Review Board were:

- To carry out Major Projects Governance Framework Reviews.
- To supervise and guide the Project Team in the implementation of the Project.
- To evaluate and assure progress towards delivery of the proposed/approved business case.
- To support the Project Team in escalated issue resolution.

Members of the Project Review Board were selected from key stakeholders and included staff of sufficient level to ensure appropriate governance was applied. The NINES Project Review Board included the following personnel:

<b>Andrew Roper</b>	–	<b>Director of Engineering and Investment</b>
<b>Valerie Jamieson</b>	–	<b>Head of Procurement and Commercial, Energy Networks and Corporate</b>
<b>Michael Ferguson</b>	–	<b>Head of Networks Regulation (Distribution)</b>
<b>Steve Kennedy</b>	–	<b>Director of Finance</b>
<b>Stewart Reid</b>	–	<b>Head of Asset Management and Innovation / Project Director</b>

### 3.2.2 Project evolution

Inevitably, projects of the size, duration, complexity and scope of NINES encounter changes in circumstances which can impact on the delivery mechanisms and/or outputs of the project. The ability to manage these changes in circumstance represents a test of the resilience and durability of the project.

Since NINES was originally proposed, several material changes affecting its operation have occurred. These include the loss of several NINES project elements, the rejection of SHEPD's initial Integrated Plan for a replacement power station, and the commencement of a competitive process to identify a new energy solution for Shetland. The impacts of these developments are considered in more detail within this report; however it is essential to note that SHEPD are confident that all objectives of the NINES Project have been successfully produced.

In fact, a key learning outcome is the relative volatility of commercial solutions in comparison to the relative certainty of "asset" based solutions. There is no reason to believe that all projects aiming to contract new flexible services in a confined market place will suffer the same level of attrition; as a result these attrition rates and the overhead costs associated with them need to be built into the risks and contingencies of future projects. It is essential that any proposed solution offers at least a sustained if not an improved experience for our customers, while providing a cost effective and sustainable alternative to the existing option of reinforcement or interconnection. This requirement has defined how SHEPD has responded to changes throughout the projects lifespan. A summary of significant changes are detailed below.

#### Battery technology change

The original NINES project submission included the installation and commissioning of a 1MW, 6MWh Sodium Sulphur NaS battery. Two weeks prior to the scheduled energisation of the battery, at that time the largest battery deployed in Europe, SHEPD was notified of a battery fire at a similar NaS battery installation in Japan. The energisation of the battery was then delayed until a full review of the safety case was concluded; this included an independent review by external technical experts. After consideration of the residual risk, SHEPD concluded that the fundamental safety case had changed and decided that the NaS battery technology originally proposed was no longer fit for purpose in this location.

- **13 March 2013** – SHEPD submitted a Formal Change Request (FCR) to Ofgem in respect of a request to change to the battery technology.
- **17 September 2013** – Following discussions and amendments to the FCR culminating in a revised FCR submission on 05 Sept. 13, Ofgem fully approved the battery technology change from NaS to Lead-Acid.

The replacement of the battery was completed without any increase in cost to customers.



### Changes to DSM scope and introduction of private market model

The scale of the NINES project was larger and more ambitious than any previous similar trials, and a broad range of participants were involved to trial DSM. Included in the original NINES submission was the installation of DSM into 750 homes provided by Hjaltland Housing Association and Shetland Islands Council. However due to internal financial constraints, Shetland Islands Council announced in October 2012 that they would be withdrawing from the project. To limit the impact of this change on the project, and provide new learning around domestic DSM, SHEPD proposed to recruit private domestic customers to provide DSM.

- **8 May 2013** – SHEPD submitted a FCR noting that the Shetland Islands Council (SIC) would no longer take part in or contribute to the project.
- As part of the same change request SHEPD proposed to develop a Private Homes Market Model and also to recruit 500 private customers into the DSM. Although the decision taken by SIC was a loss to the project, SHEPD took the view of using this as an opportunity to expand the offering of DSM beyond the social housing market. In order to achieve a DSM offering which would be suitable to the open market, SHEPD developed a sustainable

Market Model for DSM in Shetland, which could be used to attract different customer types i.e. private home owners and private landlords, working with stakeholders throughout the development of the model to ensure buy in, before going to market.

### Extension to contract

In addition to the introduction of the development of a Private Homes Market Model, a three year extension of the NINES trial with no related extension of allowances was agreed with Ofgem in the decision letter received on 24 May 2013. In the decision letter Ofgem recognised the intention to implement and use the model to sign up to 500 homes with active control of DSM by December 2016.

### Removal of thermal store from project scope

- **4 March 2015** – SHEPD submitted a FCR noting that Shetland Heat, Energy and Power Ltd. (SHEAP) had confirmed that due to funding and commercial issues they would no longer be taking part in the project and the proposed 4MW/130MWh boiler was removed from project scope.

### Reduction in generation capacity

- As part of the same FCR SHEPD submitted a note detailing amongst other points that following the sale of Gremista Windfarm (now known as Luggies Knowe), the connected capacity of this windfarm reducing from 6.9MW to 3MW.

### Cessation to recruitment of private customers

- Again, as part of the same FCR, SHEPD requested that Ofgem review the decision to include the Private Homes Market Model and also to recruit 500 private customers into the DSM within project due in light of regulatory changes and market perception.
- **12 December 2016** - Ofgem confirmed their acceptance/ approval of all three points raised in this FCR.

Material changes to the project have been driven by external factors outside of the control or influence of SHEPD, and these changes have affected the resulting scale of the project as set out in more detail throughout this report. However each change brought learning in relation to the method of recruitment, engagement and contracting of commitments and despite these changes the project has delivered to time and on budget and has met the objectives set out in Ofgem's funding determination letter dated 25 November 2011.

### 3.2.3 Project organisation

Throughout the course of NINES, SHEPD have maintained a consistent structure in the Project organisation which has been an important factor in ensuring successful delivery outcomes.

A representation of this structure is shown opposite:

### 3.2.4 Delivery programme

A high level delivery plan was maintained throughout the course of NINES and progress against the plan was shared with Ofgem as part of the 6 monthly project progress submissions.

A copy of this programme is included in Appendix 5 for information.





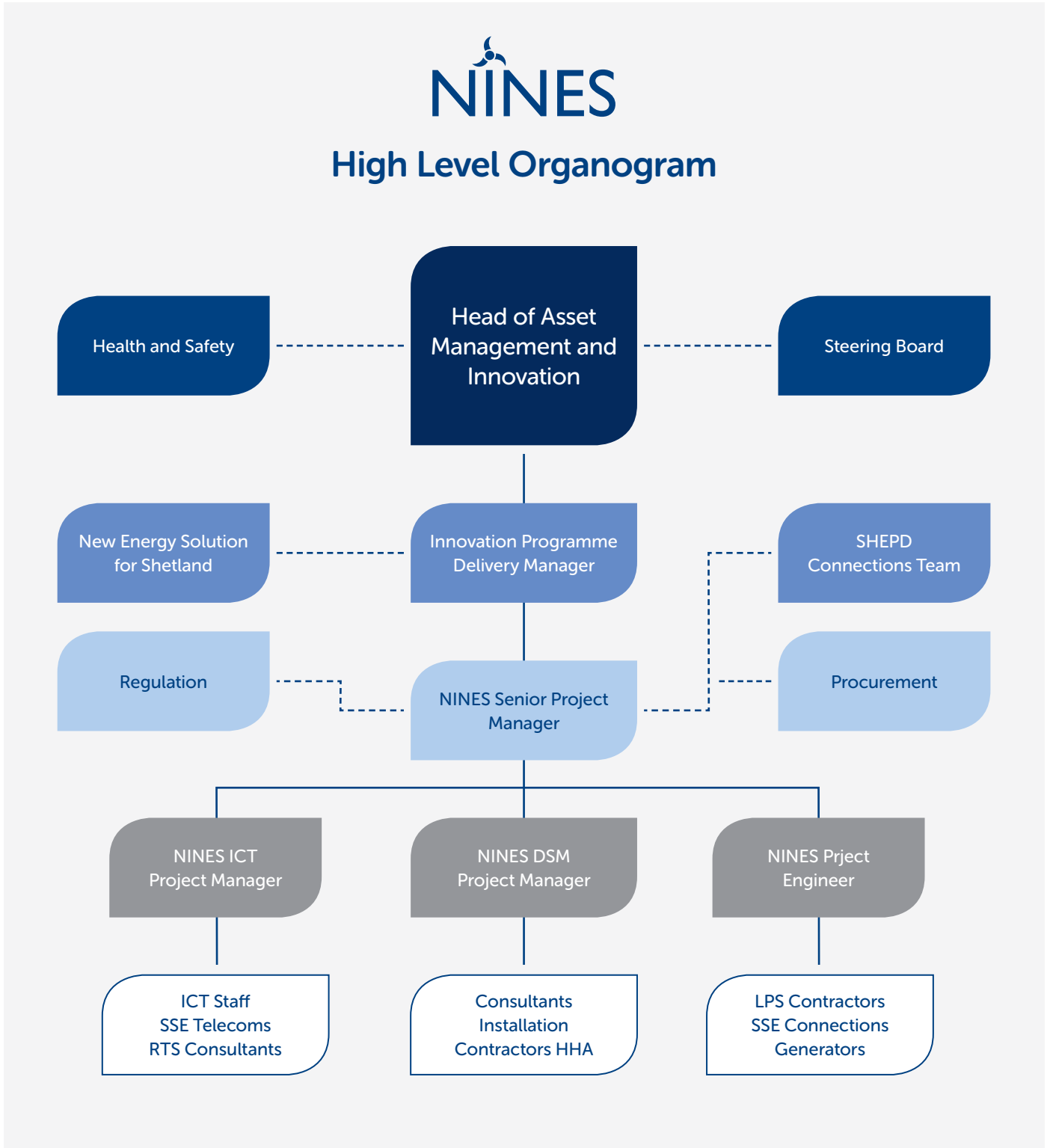


Figure 3.1 NINES high level organogram.

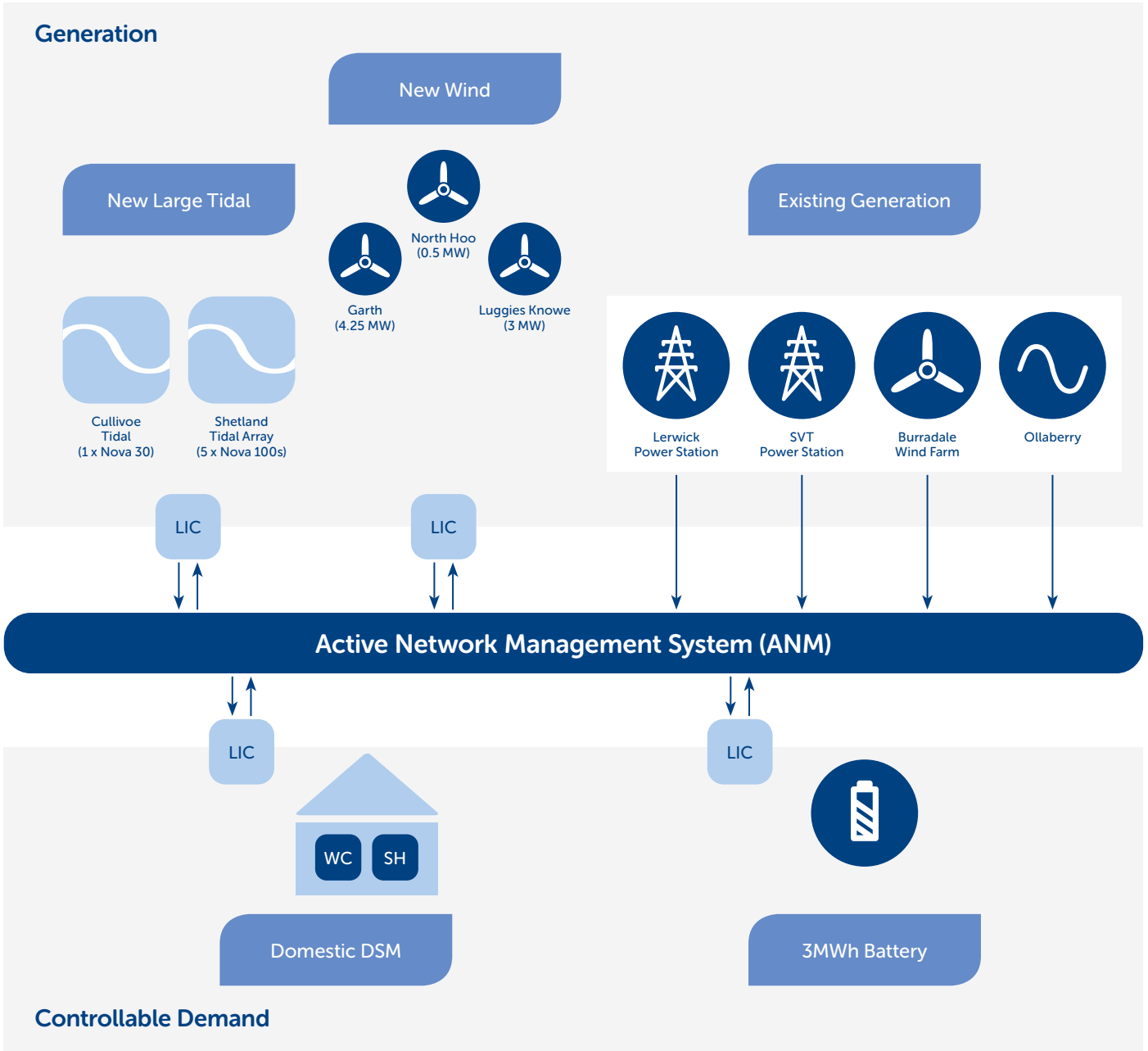


Figure 3.2 Schematic representation of ANM System architecture.

### 3.3 Project Components

This Section provides an overview of the core components which NINES has produced throughout the project, further background and operational detail on each component is available in Section 4.

#### 3.3.1 Active Network Management (ANM) system



SHEPD in conjunction with our project partner SGS, has developed and implemented an advanced Active Network Management system. This ANM system uses real-time data alongside forecast information to use flexible supply and demand at times that suit the Shetland network. The creation of flexible demand has allowed a significant increase in connected renewable generation and has reduced the generated output from Lerwick Power Station (LPS).

A schematic representation of the ANM System architecture is shown in Figure 3.2.

#### 3.3.2 1MW battery system



Figure 3.3 Shetland 1MW battery installation

In February 2014 a 1MW/3MWh lead-acid battery was commissioned onto the Shetland electricity network at 11kV. The two main purposes of the battery were to act as an energy storage system and to facilitate the connection of renewable generation that would otherwise be unable to connect to the island network. The successful operation of the battery is described in more detail in Section 4.2 of this report as is the current status and potential future operation.

#### 3.3.3 Domestic demand side response with frequency response

Following on from an agreement with the Scottish Government in February 2013, Hjaltland Housing Association arranged to install new storage heaters and hot water tanks, along



with communications to provide DSM capability within 234 domestic homes, the installation of these appliances was completed by November 2014.

A summary of the performance of DSM, the impact on customers and an outline of our next steps in relation to DSM is provided in Section 4.3 of this report.

### 3.3.4 Renewable generation via managed connections



The nature of connecting renewable generation to an island network such as on Shetland means the whole network can be susceptible to voltage and stability issues. By the application of the above noted components SHEPD has managed to treble the amount of connected renewable generating capacity on the Shetland network from 3.86MW of connected renewable generation pre-NINES to a total of 12.405MW post NINES. Section 3.4 of this report provides a breakdown of the size and type of renewable generation that NINES has allowed to connect, and outlines future intentions with regard to how these generators will be managed in the future.

### 3.4 Safety management plan

A Safety Management Plan was created as part of the project governance requirements. This plan described how safety, health and environmental risks were managed throughout all stages of the project. This includes compliance with all statutory and legislative requirements.

The Safety Management Plan defined the SHE philosophy and formed the basis for management and assessment of the effectiveness of risk control measures.

The project was managed by an internal team headed up by the Innovation Delivery Manager with a direct team of Project Managers, Engineers and Analysts, supported by other SHEPD departments including IT, REAL TIME SYSTEMS and Power

Station staff. The team was further supported by external consultants and contractors such as SSE Telecoms.

The organisation of the project was such that Health and Safety on the project as a whole is everyone's responsibility. All project personnel worked to instil a strong health and safety culture amongst the SHEPD team and amongst partners, contractors and suppliers.

Contractors appointed to the project were assessed on their approach to Health and Safety as part of their overall tender submission and sample Health and Safety documentation was required within the tender return.

### 3.5 Management of risk

A risk management plan for the project was developed to provide a system for management of the risks from the initial stages of the project through to closedown. The risk management plan was maintained throughout the course of NINES and was shared with Ofgem as part of the 6 monthly project progress submissions.

Key risks were highlighted to members of the Project Board as appropriate to ensure adequate mitigation was applied.



# Summary of project outputs



## 4. Summary of project outputs

### 4.1 Active Network Management (ANM) status



#### 4.1.1 Current status

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 expected outputs which were developed to monitor and understand how new storage assets behave. When the new energy solution is identified, SHEPD will aim to ensure the ANM system continues to provide this core functionality and adaptive support for the enduring solution.

By creating flexible demand on the islands we have made progress in exploiting and maximising Shetland's renewable generation potential on an islanded basis, and in reducing the generated output from replacement thermal generation as can be seen in the table opposite.

Initial studies based on the project's original scope suggested that it could be possible to reduce the peak demand by up to 11MW, facilitated through the NINES project elements. This was primarily based upon the application of the ANM system working alongside a number of different technologies including:

- The 1MW battery at Lerwick Power Station (1MW of storage);
- The storage and water heaters in 1850 homes (which may have offered the potential to flex up to 9MW of existing demand); and

- SHEAP's thermal store and associated extension (funded by SHEAP and ERDF) to the current district heating scheme (which may have offered up to 4MW of flexible demand) and 0.9MW of demand reduction.

A key driver for the trial was to develop an understanding how some of these technologies work and interact in a real-life environment. The original trial elements noted above offered SHEPD up to a theoretical maximum of 11MW storage/flexible demand. However, the domestic demand side response currently extends to 234 homes, and the thermal store along with the requirement to introduce 500 private homes as part of the DSM have both been removed from scope and were therefore not available to contribute to the project.

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 25MW of generation is under real-time ANM control. Figure 3.2 shows the logical architecture of the NINES ANM system and the links to external devices under ANM control.

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. NINES demonstrated the actual maximum load reduction achievable with the revised project components, and the extent to which this is actually available in practice. The following table sets out the benefits attributable to NINES in this context.



Demand Reduction (MW)	Mid-case presented in Integrated Plan submission (to December 2016)	Position at Project End Date
Battery (MW)	1	1
SHEAP (MW)	0.9	0
HHA (MW)	1.05	1.05
Private (MW)	1.11	0
Total (MW)	4.06	2.05

Renewables	Mid-case presented in Integrated Plan submission (to December 2016)	Position at Project End Date
Energy removed (GWh/annum)	30.3	25.6
Renewables connected (MW)	12	8.545

Importantly, the above initiatives as part of NINES target just 234 homes on the islands. There is therefore scope to use the learning from this phase to provide wider benefits on the island. Having used NINES to provide and verify the infrastructure and the impact of the ANM solution, the incremental cost of widening the scope of the trial is likely to be lower than developing an entirely new solution, whether this is achieved by SHEPD or by other third parties through solutions which are offered through future competitive tenders.

### 4.1.2 Development

ANM was successfully demonstrated by SHEPD 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 28MW 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.

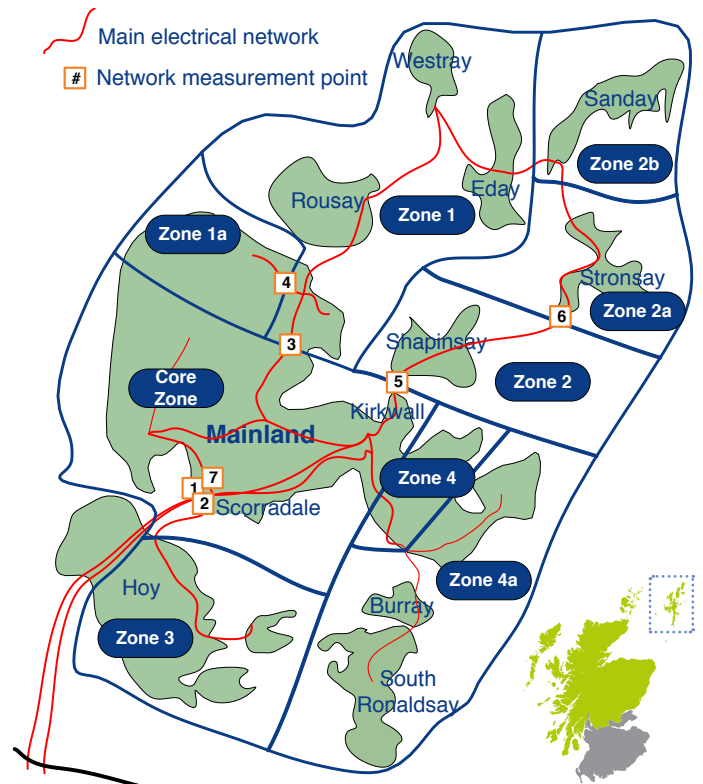


Figure 3.4 Representation of the Orkney ANM

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 SHEPD Network Management Centre in Perth. SHEPD 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.

### Controlled Devices

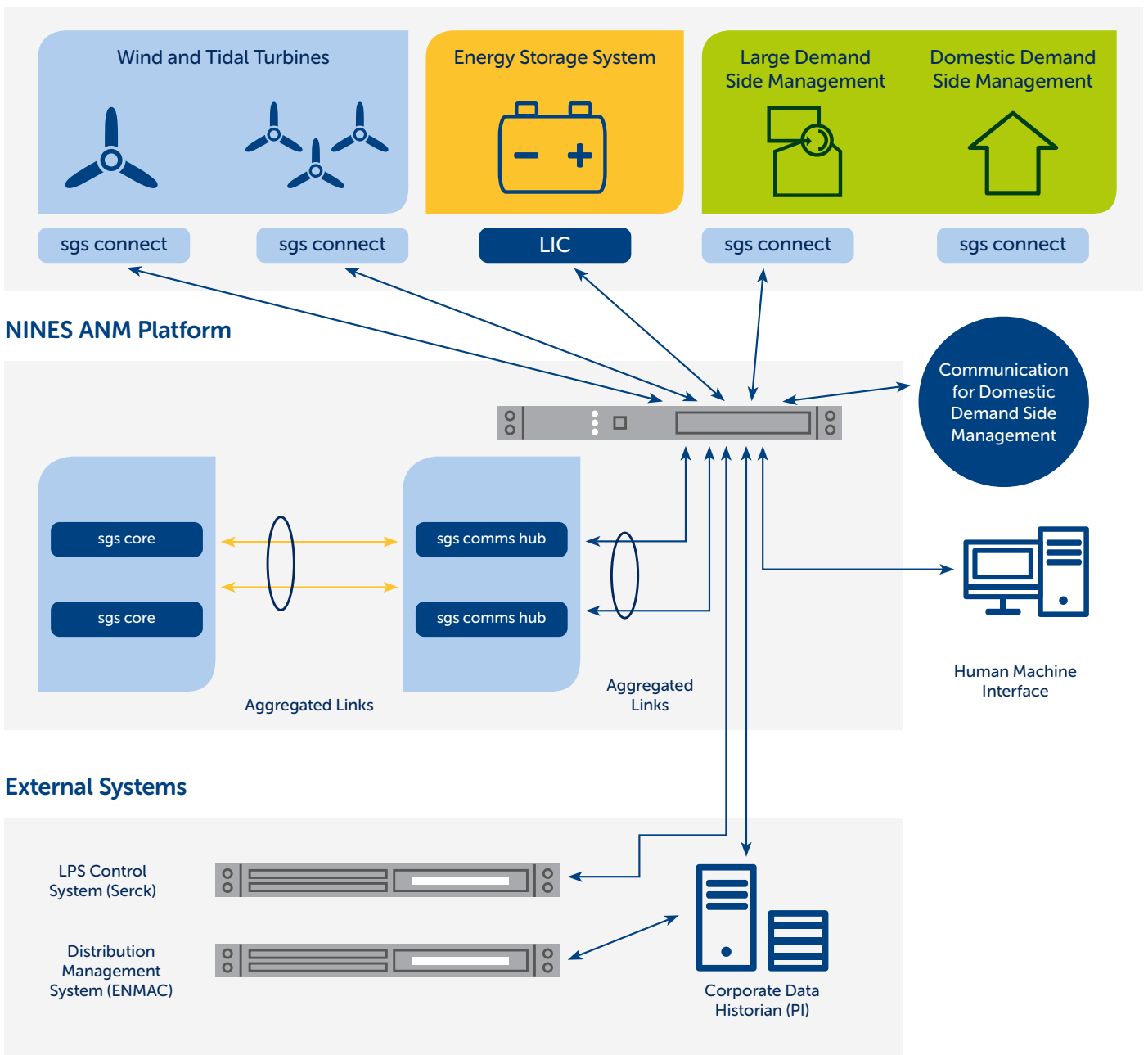


Figure 3.5 NINES ANM System Logical Overview.



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
  - 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 SHEPD 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 status to modify system operation.

The ANM functional requirements are presented across three areas:

1. **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.

2. **Device Scheduling:** Where forecasts are used to derive and issue schedules to appropriate devices to meet the objective of smoothing the demand curve.
3. **Configuration and Interface:** The requirements associated with ANM user interactions, the capability to issue manual control commands, and interfaces with other SHEPD systems.

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.

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, DSM 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.

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.

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The ANM system requires 24 hour forecasts of power in each 15-minute block for all generation including existing and ANM-controlled, and all energy demand outside of ANM control.

The weather forecast is updated hourly and contains hourly values for the first 24 hours, and 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 converts this to expected wind power production in 15-minute intervals.

The ANM derives a 24-hour schedule of set-points for ANM controlled devices at least once a day. 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, DSM 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.

The DSM 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.

The user interface must provide the capability for SHEPD engineers to observe, intervene and re-configure elements of the ANM system, schedule and actions. This includes operator visibility of forecasts with the capability to update forecasts manually, allowing user experience to inform the forecasting process.

The ANM Operations Team, consisting of SHEPD engineers, can 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. 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.

The constraint management element of ANM was required to control managed devices as a real-time response to prevailing network conditions.

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 SHEPD 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: system frequency maintained within +/- 2% of nominal (+/- 1Hz). The instantaneous loss of all renewable export will require sufficient primary frequency response pick-up from the online synchronous generators. 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 14.3MW limit of instantaneous renewable generation that could be accommodated onto the Shetland system without breaching frequency limits following an outage.

- Network Operation Constraint: total exports from renewable generation and SVT must not displace LPS export below meeting 40% of system demand.

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.

- Spinning Reserve Constraint: sufficient spinning reserve must be 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 any instantaneous drops in energy generation from renewable generation must be picked up by the SVT generators. There is a limit of 23MW export from the SVT site, therefore displacement of renewable generation export from SVT following outage must not exceed 23MW. This specifies a limit on instantaneous renewable generation export such that it, in combination with the instantaneous export from SVT, must not exceed 23MW.

- **SVT Offline Constraint:** when SVT is not exporting to the Shetland system, all ANM-controlled generators are to be curtailed to a 0MW (zero export) set-point.

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.

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 (DSM):** approx. 4.2MWh. New electrical space and water heaters in domestic homes releasing controllable electrical demand and providing sub-second frequency response. In addition to alleviating generator curtailment, this DSM 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:** 135MWh. 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 DSM, 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 DSM must be managed within bounds that ensure customer's heating needs are met and not adversely affected.

- **Battery: 6MWh.** 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, it was not proposed that the battery 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 generators, multiple constraint autonomous control, in a manner that mirrors the ANM system demonstrated as part of the Orkney Smart Grid Project.

### 4.1.3 Optimisation

The NINES project has provided a significant amount of learning to those that operate the Shetland electrical system on a daily basis. SHEPD, with support from the developers of the ANM system SGS, worked to develop a list of feature enhancements for the NINES system in order to provide further benefit from its ongoing operation beyond the end of the NINES project and into the business as usual life of the system.

The main outcomes of this work will be in the following areas:

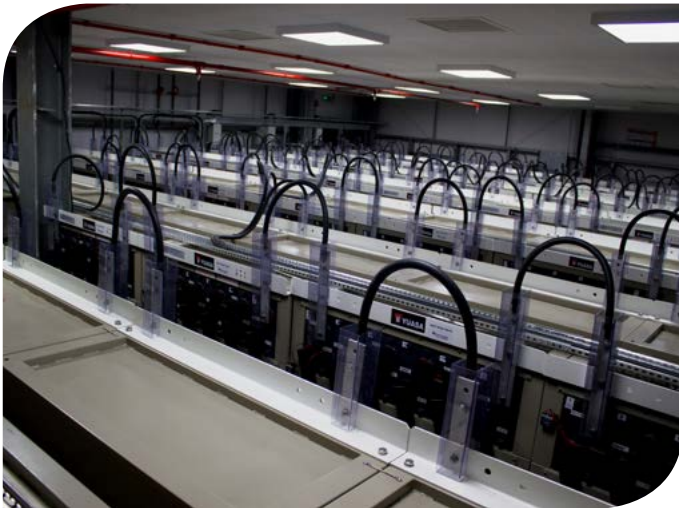
- Receive data input of previous days demand from the system operator for use in the day ahead scheduling application;
- Update ANM User Interface;
- Add the energy storage system as a real-time controllable device.; and
- Improve the performance of day ahead scheduling.

It is anticipated that the upgrade to the existing ANM system will be completed in 2017. Following the introduction of these enhancements, the NINES ANM will operate in a more effective way providing even more benefit to the connected assets than have already been provided via the NINES Project and will allow the NINES ANM to more easily meet the potential requirements following the completion of the current Shetland competitive process.

#### 4.1.4 Future intentions

Following the completion of the current Shetland competitive process, SHEPD will assess the extent to which the ANM system is able to continue to provide this core functionality for the enduring solution. It is however anticipated that the NINES ANM will be an important tool in the management of a number of the assets.

### 4.2 1MW battery



#### 4.2.1 Current status

A 1MW/3MWh lead-acid battery was installed and commissioned at Lerwick Power Station in February 2014. The battery system is in part made up of 3,168 individual energy storage cells. The battery sought to help to optimise and stabilise the operation of the existing island network by helping to reduce demand peaks. It also helped to facilitate the connection of 8.545MW of new renewable generation.

The capital cost of the battery was part funded by DECC via a Smart Grid Demonstration Capital Grant for £1.1m and £1m from Ofgem's Low Carbon Network Fund Tier 1. The remainder was funded through NINES. The learning informed the battery's role in the repowering solution Phase 2 of the Integrated Plan, and is informing its role in the context of the new energy solution.

On 16 January 2017 an incident occurred whereby 2 cells were found to have failed. Investigations into the cause of this incident were carried out by SHEPD, S&C Electric, the contractor chosen by SHEPD to supply and install the battery

and ancillary systems, and Yuasa, a contractor to S&C who manufactured the battery cells. These investigations resulted in the identification of an additional 370 cells in various level of deteriorating charging capacity.

Following the conclusion of these investigations and at the recommendation of S&C Electric the battery was removed from service.

It should be noted that the identification, investigation and subsequent removal of these cells was carried out in a safe manner with no injury and/or impact to the environment.

#### 4.2.2 Development

Following initial tendering and specification exercises with supplier S&C, installation of the original NaS battery was completed in September 2011. However, just prior to the commissioning and energisation of this battery SHEPD were informed of a fire in a similar installation in Japan and a decision was taken to remove and replace the NaS battery. The removal was completed in May 2013.

Following this decision SHEPD continued to work with S&C Electric to identify a suitable replacement battery. Proposals were presented to Ofgem for a replacement option in the form of change requests which were subsequently agreed by Ofgem on 17th September 2013. The replacement 1MW/3MWh lead-acid battery was completed to plan and initially commissioned during February 2014. SHEPD submitted a Tier 1 Close-Down Report to Ofgem at the end of June 2014 (1), this presented the key learning outcomes from the battery element of the project to that date in areas including: procurement, design, construction, installation, commissioning, initial operation and safety.

December 2014 saw the publication of 'A Good Practice Guide on Electrical Energy Storage', a reference guide consolidating the learning from the 12.6MW / 20.6MWh of electrical energy storage deployed by the UK Distribution Network Operators (DNOs).

The '1MW Battery, Shetland' project enabled SHEPD to submit two case studies – 'sodium sulphur' and 'lead-acid' – for inclusion, the latter of which was also selected for reference in the separate executive summary document.

In February 2015, an important project milestone was reached with a further upgrade to the ANM which in turn allowed the scheduling of the battery to become fully automated. A continuous period of operation allowed SHEPD to analyse the effectiveness of the rules around which the

automated scheduling operates and SHEPD worked closely with SGS to identify and deliver improvements and refinements to these rules which succeeded in the auto scheduling of the battery via the ANM system.

### 4.2.3 Future intentions

Currently SHEPD are working along with S&C Electric on a paper which sets out a number of options with regard to managing the battery moving forward. These options include permanently removing the battery from operation on the Shetland network, replacing the 1MW/3MWh battery with an alternative technology on a like for like basis, re-visiting the power and energy requirements on the Shetland network, and replacing the battery with an alternative technology and an optimised power and energy capability.

It is anticipated that SHEPD will not be in a position to recommend a preferred strategy until the second quarter of 2017. SHEPD will ensure that Ofgem are aware of progress and outcomes on this issue, and that potential impacts on the New Energy Solution are taken into account.



## 4.3 Domestic demand side management with frequency response

### 4.3.1 Current status

Following a review of potential flexible demand apparent within the Shetland housing stock, which reviewed appliance use vs consumption carried out by SHEPD as part of the Tier 1 SSET1003 Trial Evaluation of DSM project. Space and water heating appliances were proven to be the appliances which offered the greatest potential affect on demand 'shifting' while still providing customers with the expected levels of comfort and control.

SHEPD engaged and worked with Glen Dimplex to produce a range of smart electric space and water heating appliances which were communications enabled for installation within the NINES project. SHEPD worked with Hjalmland Housing Association and Glen Dimplex to install these 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 Hjalmland and financed in part by 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.

The programme for the initial installation within the 234 HHA properties was completed in November 2014. SHEPD had originally planned to partner with Shetland Island Council (SIC) to increase the number of homes with heating and hot water systems connected and controlled via NINES. Following the loss of SIC, we planned to recruit a further 500 private homes, bringing the total number of homes under the project to 734; however this part of the project was halted in March 2015 pending clarity on the outcome of the competitive process and the new energy solution. This clarity was achieved when Ofgem agreed to our request on 12 December 2016 to remove the acquisition of private homes from scope, however any extension of this solution that forms part of the new energy solution will be informed by the learning from NINES.

These energy storage appliances can receive remote signals every 15 minutes, through the DSM communication infrastructure, and they allowed a more flexible approach to charging. Figure 4.6 illustrates the infrastructure system of DSM. This infrastructure includes a transceiver that is installed within each device and communicates with Dimplex home hub. The control in the house is made by the home hub, which is then connected to a local interface controller (LIC). The LIC exchanges data between households and Element

Manager (EM), with EM being responsible for aggregating and communicating data to the ANM control system at the Lerwick control centre. ANM system at the Lerwick centre, operated by SHEPD, controls a signal sent between ANM and LIC. More detailed information on DSM infrastructure can be found in DSM Infrastructure Report produced by UoS NINES WP 1.

The remote signals that the DSM appliances receive instruct them when to operate, while also enabling them to send feedback information regarding their statuses, e.g. if they are charging, are on stand-by, switched off, etc. This communication and control allows the DSM homes to provide capability for demand side management. In addition, the heating devices are frequency responsive, so that they can stop charging if the system frequency drops, or start charging if system frequency rises above the specified limits. Thus, the frequency responsive heaters can help system operator maintain the balance between the demand and supply and therefore, maintain system frequency and security.

In addition to following signals sent by Shetland power system operator through the ANM system, the appliances are also enabled to consider the comfort level of occupiers in the

households. These DSM-capable devices are configured to be automatically switched off when room temperature is high and switched on when the room temperature reaches the minimum level, with the high and low temperature levels both set by the users. Based on the energy use during the previous day, and in order to ensure the different comfort level required by each participating DSM household, an algorithm embedded within the heating devices calculates the Daily Energy Requirements (DER) for each device for the next day.

At midnight, EM gathers the DER calculation results from each household. It then aggregates DER data according to scheduling groups, and sends the result to ANM which uses these for the next day scheduling. Once the schedule is determined, ANM sends the results to EM, which then sends instructions to each DSM device. Therefore, the schedule of the heating appliances in each household (i.e. set points of the space heaters and water tanks) will follow the instructions of ANM DSM schedule.

The new heating system is designed to be more efficient, while also allowing the customer full control of both temperature and operating time and allowing for charging at times that best suit

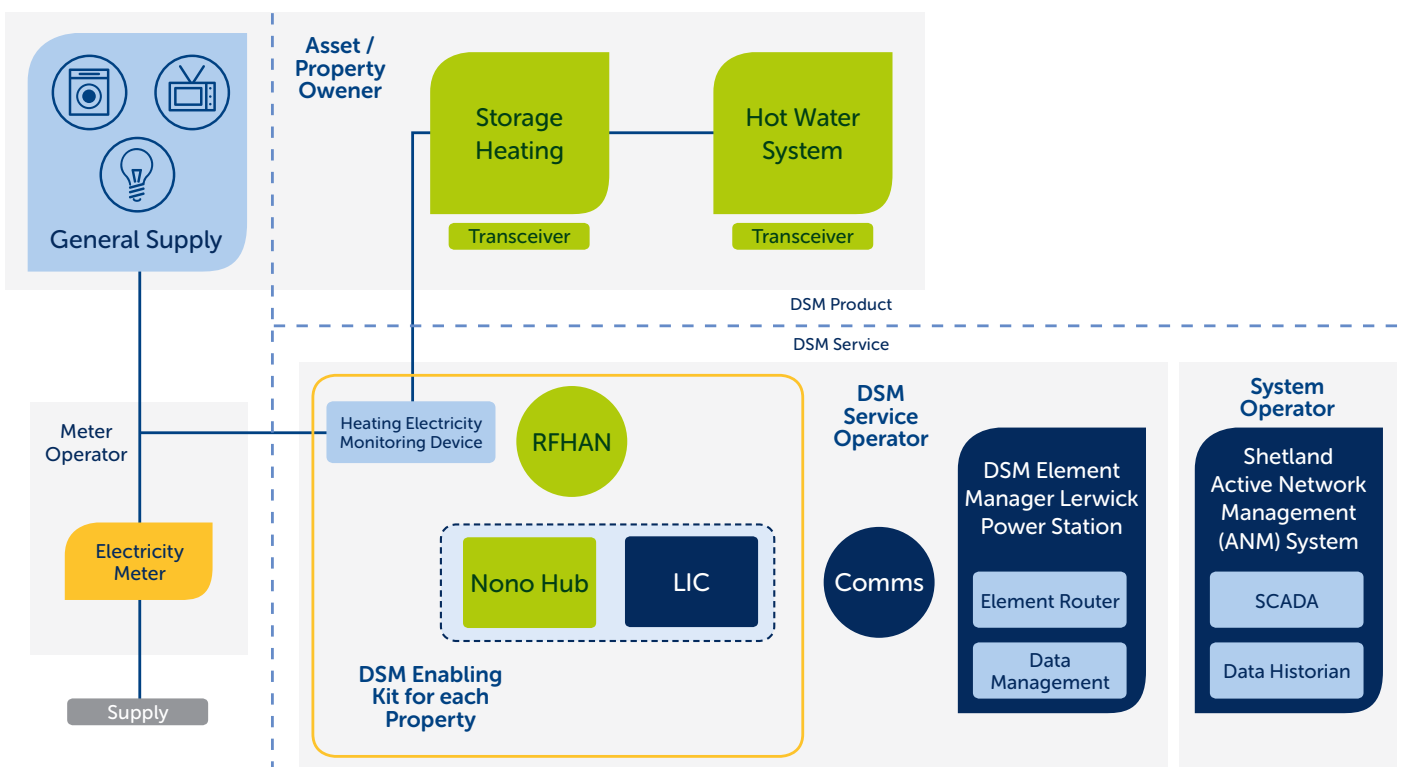


Figure 4.6 DSM Infrastructure.

the network. Currently we have up to 1.4MW of connected load which will automatically respond to a frequency event on the network should the need arise.

Previous progress reports highlighted our success in increasing the amount of connected load being flexibly charged via the ANM. Although the project is formally closed we continue to flexibly charge the space and water heating in 234 homes across Shetland. The charging requirements remain under the full automated control of the ANM, which means that up to 1.246MW of domestic demand continues to be flexibly charged.

As of 24 March 2017, 85% of customers in the 234 properties originally signed up for NINES have been retained. Detailed breakdown of customer movements is shown in the table below:

DDSM Sign up	DDSM Sign up	Percentage %
Consented	199	85%
Declined	7	3.01%
Pending	17	7.28%
Removed	11	4.71%
	<b>234</b>	<b>100%</b>

As explained in a number of previous progress reports, the overall number of consented properties continues to be impacted by a relatively high turnover in occupancy within the social housing properties which creates a number of administrative challenges. As of 24 March 2017, however, only 7 customers have declined to take part in the project; a number of these are for personal reasons not directly related to DSM. It should be noted that customers continued to sign up to NINES without any financial incentive to do so as payments are no longer made following changes in tenancy. This suggests that customers are motivated to join NINES for reasons other than financial benefit and we consider this to be a key learning point from the project.

Throughout the project we have continually tried to engage with the new tenants who have moved into these properties, although in some cases we have been unable to receive a response from all of the customers concerned. Customers with NINES equipment installed in their properties who have chosen not to consent to take part in DSM still provide network benefits as they are available to be flexibly charged within their existing tariff period ("fixed" rather than "dynamic" DSM), and frequency responsive devices have been installed within the properties which can provide network stability benefits in the event of frequency events occurring.



Figure 4.7 Locations of DSM households.

### 4.3.2 Future intentions

The heating and hot water appliances have now been operating in the tenants' homes over an extended period of time and our intentions with regard to the future operation of demand side management on Shetland are set out below.

This initial roll out was intended to help to gauge how effective storage and demand side response is at the domestic level. If these elements were successful, it was anticipated that this approach could be voluntarily extended (if customers chose to take it up) to additional homes with the theoretical potential to be rolled out to all electrically heated houses in Shetland, using the core ANM scheme which is already in place to service the original homes. It should however be noted that due to the impending removal of the wide area network (WAN) which is the communications network external to the homes, a replacement communications infrastructure would have to be installed.

There is some evidence that DSM space heating did not result in systematically higher consumption or costs, although direct meter readings were not available. Room temperatures were unchanged; the new space heaters are better insulated than those they replaced, and modelling studies show that, other things being equal, the new heaters should use 10-18% less energy to maintain the same room temperature. DSM may have slightly increased energy consumption in the form of hot water: higher availability may have translated into higher use, and discretionary customer comfort and hygiene settings meant that tanks operated at higher average temperatures than with normal customer control.

Schedule timing in itself had no impact on cost or consumption, no difference was observed in the performance of devices on flexible scheduling and those on fixed timing. The Quantum devices were designed to meet customer requirements in both stand-alone mode and with remote control. However, two design flaws can lead to increased energy use under specific circumstances and these should be addressed ahead of future rollouts.

The NINES DSM technology is best suited to large, poorly insulated houses which need a lot of energy to maintain comfortable temperatures. The technology is inherently a poor fit in modern, well insulated houses which require little heating, less than the uncontrolled output of storage heaters. Even if heater insulation were to improve radically, the contribution of such houses to controllable power and storage would be very small relative to the overhead.

Following completion of NINES and subsequent discussions with Ofgem, it is our intention to remove DSM capability from the heating and hot water appliances in the remaining DSM homes. This intention has been reached taking the following factors in to account:

- Retaining a relatively small number of customers and therefore a reduced capability does not provide material demand shifting or demand reducing capability;
- The existing provider of DSM communications infrastructure has confirmed that they will not provide licenses and support for the current communications network beyond project completion;
- The formal appointment of SHEPD to the role of DSO will present the potential for a conflict of interest and a barrier to the DSM market on Shetland. SHEPD could potentially carry out future tenders (such as CMZ or similar) on Shetland for services, which could provide a route for these parties to become involved; and
- Fundamentally SHEPD consider that Aggregators should fulfil the customer management role going forward.

### 4.3.3 Customer interaction and management

For as long as SHEPD continues to operate demand side management on Shetland we remain fully committed to providing the support and services required. Should any instance of unexpected appliance behaviour be reported by customers either in terms of appliance performance or level of energy consumption, we will continue to work with

Glen Dimplex and HHA to establish an understanding of the root cause(s) of this behaviour and resolve any adverse customer impact.

## 4.4 Renewable generation via managed connections

### 4.4.1 Connection summary



The following table summarises the current status of NINES renewable generation connections. As can be seen, all of the generators forming the "NINES Queue" have now been connected. The chart below shows that in all cases the dates the generators finally connected were significantly later than the original connection offer date and whilst this has impacted on the overall amount of renewable generation over the project timeframe, these delays in connection were in all cases outside the control and management of SHEPD.

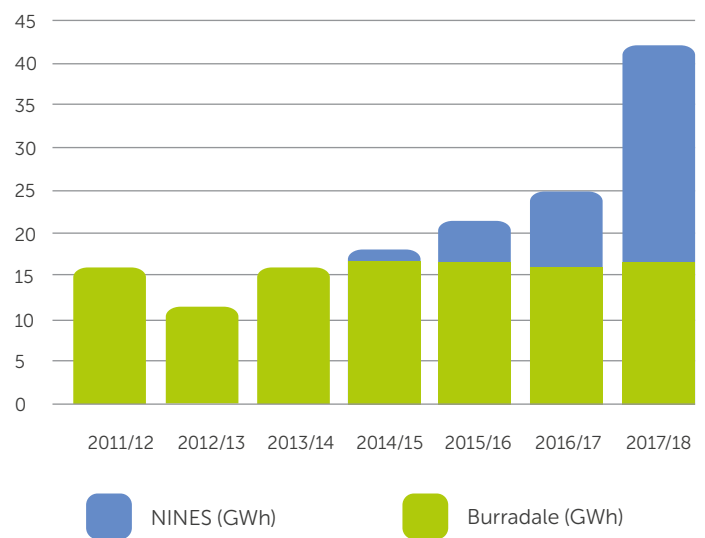


	Capacity	Status	Original Connection Offer Date	Connection Date
Cullivoe Tidal, Yell	45KW	Accepted as 1st Small renewable	December 2013	April 2014
Garth Windfarm, Yell	4.5KW	Accepted as 1st Large renewable	May 2015	March 2017
Luggies Knowe, Lerwick	3MW	Accepted as 2nd Large renewable	May 2015	December 2015
Shetland Tidal, Yell	500KW	Accepted as 3rd Large renewable	October 2014	100kW connected December 2015, with a further 200kW in June 2016. The remaining 200kW to be connected at an unspecified date
North Hoo Field Windfarm, Lerwick	500KW	Accepted as 4th Large renewable	February 2014 (Accepted on a Non Contestable works only)	November 2014

#### 4.4.2 Current Status

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. Before the advent of NINES, allowing more renewable generation which is unavoidably intermittent would have caused voltage and stability constraints however NINES has allowed the deployment of a mix of wind and tidal generators that range in scale from 45kW up to 4.5MW to be connected to the network. To address this, NINES trialled an ANM system which has offered renewable developers connections and scheduled access for export. 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 have managed this constraint by being able to manage demand when there is renewable resource available.

The success of this approach can clearly be seen on the chart below and this also shows the expected output from NINES connected renewable for 2017/18 following the connection of all renewable generators to the NINES Queue.



As of 24 March 2017, the amount of renewable energy brought on to the Shetland Network is 14.9GWh and it is anticipated that this number will rise significantly through 2017/18 following the connection of Garth windfarm (4.5MW).

The requirement to continue to manage the NINES connected generators 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 and the prospect of constraint would remain for generators on Shetland, albeit on a less frequent basis.

### 4.4.3 Future intentions

Generators connected via the NINES ANM will continue to generate on to the Shetland network on a managed basis. Following the conclusion of the competitive process to establish an enduring solution for Shetland, it is possible that additional renewable generation may be introduced to the network. This is likely to be limited given the existing level of constraint on intermittent generation on Shetland.

However, it is thought unlikely that any additional generation will have a direct effect on the generators in the "NINES queue" as additional generators will effectively be behind the NINES generators in an extended queue. The first non-firm generator to connect has generating priority over all later connecting generators at all times, SHEPD have applied this process, known as 'Last In First Out' (LIFO) as the BAU approach across its ANM installations.

As noted above, the ANM is currently configured to allow intermittent export only when the Sullom Voe Terminal generators are online. SHEPD will need to determine whether the competitive process has delivered services which replicate the effects of SVT, and what steps require to be taken if this is not the case (e.g. whether any additional services require to be procured).

The use of ANM will 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 and the prospect of constraint would remain for generators on Shetland, albeit on a less frequent basis.

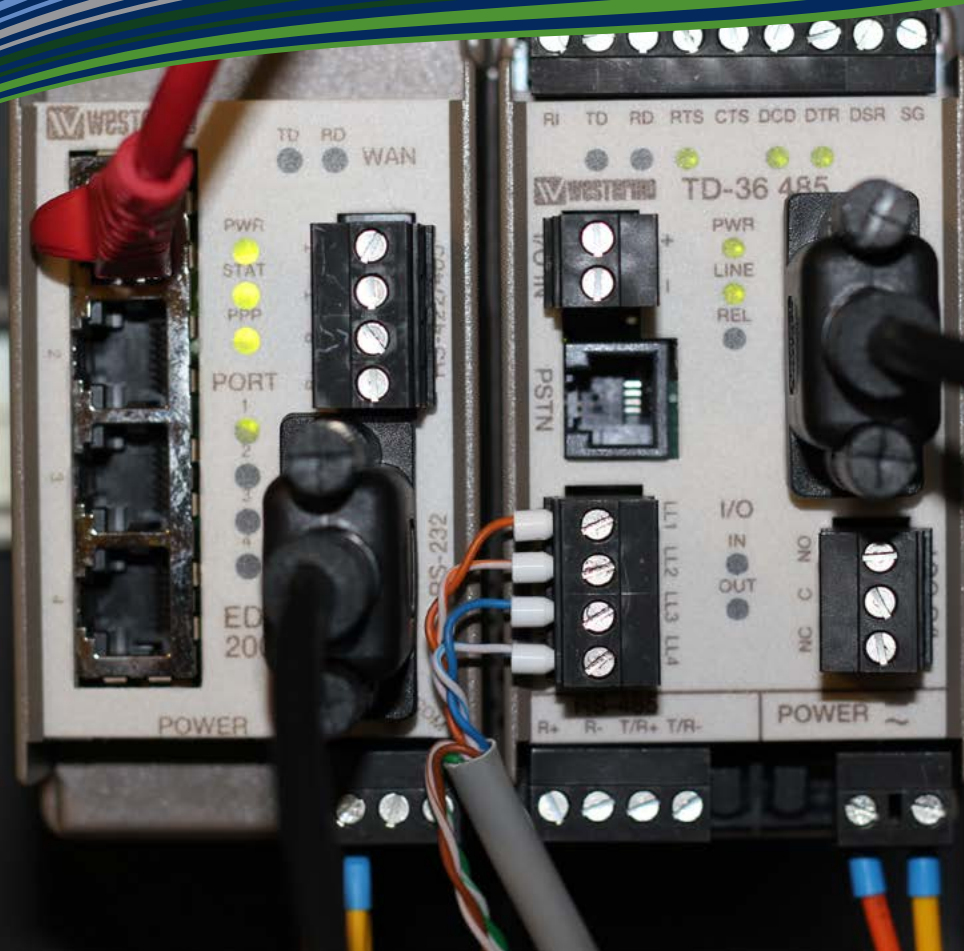
### 4.4.4 Customer interaction and management

As the project has now formally closed, customer engagement and ANM system operation is being managed by the SHEPD Active Solutions Team (AST). The AST has been formed as part of SHEPD's Asset Management and Innovation department to operate and maintain project assets such as ANM schemes under BAU operation alongside non-project applications of these systems.

The ways that NINES generators can contact SHEPD have not changed with existing contact telephone numbers and email addresses remaining in place. It is expected that generators will not be detrimentally impacted by this change.



# Summary of financial outcomes



## 5. Summary of financial outcomes

On 25 November 2011, Ofgem provided a funding determination letter confirming their approval the SHEPD's proposals, subject to the conditions in the Schedule to this Determination and their agreement to fund the project to the value of £15.33m. Forecasts of the NINES project finances have

been provided in each of the 6 monthly progress reports and a final financial breakdown of the project in detailed in Appendix 1. The table below summarises the details in Appendix 1 and provides information on total spend across main budget heads.

	Existing Project Forecast	Full Project Forecast	% Forecast Spend Against Allowance
Labour	£6,831,000	£6,813,000	100%
Equipment	£2,757,000	£2,580,000	94%
Contractors	£4,116,000	£4,419,000	107%
IT	£1,411,000	£1,306,000	93%
Travel & Expenses	£117,000	£136,000	116%
Decommissioning	£100,000	£0	0%
<b>Overall spend</b>	<b>£15,332,000</b>	<b>£15,254,000</b>	<b>99%</b>

As can be seen, despite the number of significant changes to the project over its duration, SHEPD has managed to maintain overall spend matching the requirements set out in the determination.

In addition to this, the NINES Project has attracted a total of £3.26m of external funding and a breakdown of this is shown below.

Partner / Collaborator	Involvement in Project	Funding Received
Department of Energy and Climate Change	Smart Grid Demonstration Capital Grant Programme	£1,049,600
Glen Dimplex	Development of new generation of responsive storage heaters	£150,000
Hjatland Housing Association	Housing Association. HHA will install replacement heating and hot water systems in 230 homes across the Shetland Islands	£1,060,000
LCNF Tier 1	Battery	£1,000,000
<b>TOTAL</b>		<b>£3,259,600</b>

It is important to note that without the NINES Project, these levels of external funding could not have been accessed.

# Learning and dissemination



# 6. Learning and dissemination

## 6.1 Principles and governance

Learning and dissemination has always been considered a key requirement of the NINES project. The initial project learning and conclusions to date were presented in the December 2014 report and in July 2015 SHEPD worked with UoS with the intention of producing a number of reports and outcomes around key questions. 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 main achievements directly related to the NINES components is as follows:

- 8.545MW of renewable generation connected on to the Shetland Network;
- 14.9GWh of renewable energy generated on to the network via the NINES ANM (9.32GWh in 2016/17)\*;
- 1.92GWh of energy imported by the battery to March 2017; and
- 1.45GWh of energy exported by the battery to March 2017.

\* The amount of renewable energy generated annually on to the network is expected to rise considerably following the connection of Garth Windfarm (4.5MW connected March 2017)

We are confident that learning from this project will materially inform and address the following areas:

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

Through application of ANM, flexible connections, the 1MW battery and DSM, NINES has proven that a distribution system can be operated securely with a high penetration of renewable generation. NINES has proven that by controlling these solutions centrally, increased levels of renewables can be connected while maintaining system reliability and safety.

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

The relationship can be defined in three core attributes:

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

The ANM platform provides a link between the intermittent generation and responsive demand. Operational experience has provided guidance as to how the ideal scenarios for maximising renewable generation and reducing demand peaks can be found. The project has proven that through active management the relationship between intermittent generation and demand can have a positive impact, and if supported with widespread DSM and storage elements can help to address network issues such as voltage stability and frequency fluctuations.

### How effective is frequency responsive demand side management in maintaining network stability in an active operational environment and with the interaction of the numerous variables on Shetland's closed electrical system?

Frequency responsive DSM has been shown to enable stable network operation in conjunction with an ANM system. We have shown that frequency responsive demand can be used to maintain the frequency stability of the system under the calculated limits.

Using Frequency responsive DSM, more renewable generation can be allowed on to the network than DSM without frequency response (DSM only when used to increase the demand). The amount of additional wind that could be connected by using FR-DSM is around six times greater than that with DSM only. For example, 1.639MW of frequency responsive DSM allows 1.36MW of additional wind to be connected, compared to 0.212MW when using DSM alone.

### What is the economic impact on industry participants and other stakeholders of the low carbon operation of the network?

- The use of domestic demand to provide fast frequency response if practical and effective.
- NINES project spending in the Shetland Islands supported 17 person-years of employment on Shetland, over £1 million of output and £507,000 of local Gross Value Added;
- Lower domestic electricity consumption increased household income for the 223 households by the equivalent of a total of £7,950 for each year of operation;
- The annual economic impact of this additional income on the Shetland economy is equivalent to £10,000 of output and additional employment of 0.2 persons per year;

### What new commercial arrangements are needed to support a low carbon network?

The use of Flexible solutions is subject to a large number of new risks associated with the interactions between the different economic and social drivers of public authorities and businesses. This results in a need for significant over-provision of flexibility in any given geographical area to achieve the optimal benefit.

To support a move to a low carbon network, areas which require further development include tariff structures, changes to the regulatory framework, development of ancillary market services and a market for domestic services.

The formal appointment of SHEPD to the role of DSO will present the potential for a conflict of interest and a barrier to the DSM market on Shetland however this could provide the opportunity to develop new commercial arrangements which allow aggregators to engage with domestic customers. SHEPD could potentially carry out future tenders (such as CMZ or similar) on Shetland for services, which could provide a route for these parties to become involved.

### What is the impact of the low carbon network on domestic and industrial customers?

NINES demonstrated that it was possible to fully integrate a number of domestic properties with an ANM system capable of autonomously scheduling demand either at times where intermittent renewable generation would otherwise be constrained, or when demand was low. This has not only served to reduce peak demand on Shetland but has allowed a higher utilisation of renewable energy. Domestic properties have the potential to provide a useful source of demand side response for DNOs. There is significant roll out potential in the UK with over 2.2 million homes currently using electrical heating systems. This could provide significant benefits in balancing the GB network in future.

The use of ANM on Shetland has enabled the connection of 8.545MW additional renewable generation which provides a reduction in CO<sub>2</sub> emissions (through reduction in fossil fuel generated energy).

### What is the effect on fuel poverty, changes of attitudes, awareness and behaviours amongst consumers and the extent of the financial impact on participants.

- The project deliberately set out to not influence customer behaviour.
- Domestic customers continued to sign up to NINES following changes in tenancy when no financial incentive was provided. This suggests that customers were motivated to join NINES for reasons other than financial benefit.
- Recruitment of demand flexibility via a Housing Association was found to be relatively straightforward and cost effective. Learning from other trials such as New Thames Valley Vision Project have found that recruitment of private individuals has a higher effort per sign-up and a slow rate of recruitment, which adds considerable time and cost to the process.

- Analysis and experience during NINES shows that there is no significant difference between customers using prepayment metering arrangements and customers on standard credit metering arrangements. This indicates demand flexibility for fuel poor customers can still be leveraged without negatively impacting this potentially vulnerable set of customers.

Fuel poverty levels on Shetland have reduced in the latest data, with 52% of households living in fuel poverty (down from 53%) (Scottish Government, 2017). Lower domestic electricity consumption increased household income for the 223 households by the equivalent of a total of £7,950 for each year of operation; NINES has contributed towards this overall reduction through installation of more efficient heating appliances.

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

- Without a form of 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 deployment of ANM through NINES has more than trebled the volume of renewable generation on Shetland, taking the contracted renewable capacity to 12.5MW.
- As of 24 March 2017, the amount of renewable energy brought on to the Shetland Network is 14.9GWh and it is anticipated that this number will rise significantly through 2017/18 following the connection of Garth windfarm (4.5MW).

The ANM platform provides the capability to control generation in its current form. The system rules can be altered should future commercial arrangements change. Generation or storage capability can be added or removed from the system, ensuring flexibility for the future network.

#### What effect does the NINES project and it's legacy have on Shetland's economy and on the carbon footprint of the area?

University of Strathclyde have produced a report showing NINES project spending in the Shetland Islands supported 17 person-years of employment on Shetland, over £1 million of output and £507,000 of local Gross Value Added;

They have highlighted that lower domestic electricity consumption increased household income for the 223 households by the equivalent of a total of £7,950 for each year of operation and that the annual economic impact of this additional income on the Shetland economy is equivalent to £10,000 of output and additional employment of 0.2 persons per year;

NINES has more than trebled the volume of renewable generation on Shetland, taking the contracted renewable capacity to 12.5MW.

As of 24 March 2017, the amount of renewable energy brought on to the Shetland Network is 14.9GWh. It is predicted that this value will rise to 25.6GWh in 2017/18 following the connection of Garth Windfarm (4.5MW) which is the final renewable generator to connect to NINES. It is estimated that as a result of this, NINES connected wind will reduce fossil fuel generation and provided a reduction in CO2 emissions from fossil fuels of 11.8%.

The ability to provide credible answers to these questions is the key indicator of the success of the NINES project overall. In addition to the Learning outcomes listed below in Appendix 3 of this report we have provided information on a suite of learning reports that will provide insight into the methodology by which SHEPD along with University of Strathclyde set about answering the questions as well as highlighting a large number of findings and conclusions.



## 6.2 Additional learning

Due to the collaborative nature of this project and the number of elements considered, it is not surprising that a number of areas of unanticipated learning have emerged. Details of these additional learning points are as follows:

### 6.2.1 Active Network Management

The trial of the ANM solution on the Shetland Isles has presented a great deal of learning for all project partners. One of the most significant learnings from the operation of the ANM system is that decisions made during the design of the trial to simplify the way the ANM platform operates, resulted in a lack of operability and control by the operators during more complex network operational situations.

The system was successful in controlling demand and generation, but there needed to be changes in the way in which the limits of the system were applied. The constraint rules were based on theoretical network studies and assumptions made in the early stages of the project (e.g. that LPS would supply a maximum of 40% of the demand) – in real-time operation this assumption was no longer valid due to the changes in operating regime at LPS and therefore, the constraint rules were no longer appropriate for the network.

Other changes such as a reduction in the size of the battery, and reduction in the number of DSM homes resulted in less capability for the system to use responsive demand to support renewable generation and help minimise the peaks/troughs of the demand. The capacity of flexible demand decreased, however there were no changes made to expectations or to operational regimes.

As a result of the project, the ANM platform successfully communicates with all elements of NINES and demonstrates the ability to be flexible for future changes to the network.

The project has identified the further ways in which the performance of the ANM platform can be improved in order to maximise available renewable resources, and help to reduce demand peaks and troughs. The final round of upgrades and re-configurations to the ANM platform, determined through the learning as part of this trial, due to take place in 2017 will ensure that the system is ready for changes which may arise in the future of the Shetland Islands electricity network.

The ANM mainly schedules the flexible groups to charge between midnight and 5 am; on average, 75% of the day's demand is scheduled in that period. With only limited wind generation connected, overnight charging works best on most

days to level demand on the power station. However, this uses up the controllable storage very quickly, and by the second half of the day each unit of controllable power has very small controllable storage.

### 6.2.2 Demand side management

- The speed of recruitment of DSM in a domestic and commercial market place is extremely slow in comparison to conventional reinforcement and asset related smart solutions. For these solutions to be readily adopted by DSOs in a changing demand situation the flexibility must where possible to pre-existing.
- Recruitment of demand flexibility is relatively straight forward and cost effective in relation to Housing associations and councils as opposed to private individuals where the effort per "sale" and the slow rate of recruitment make the process non-viable for all but the slowest network demand changes.
- The underlying fixed costs (in particular communications) make small scale demand side management (Small pockets of demand in a high number of locations) uneconomic.
- The limited DSM installed in 234 houses has delivered limited benefits to the network so far, but has resulted in much useful learning.
- The expected benefit from frequency response has not materialised because the main problem is with under-frequency events, where the DSM devices need to be charging and switch off to contribute to network stability. Charging takes place over around 8 hours at most each day; and so far the Lerwick Power Station has not relied on it operationally.
- With 30% of devices regularly out of communication and unavailable the theoretical wind generation that could be supported reduces from 385 to 230 MWh.
- Flexible charging uses a greater range of the physical storage capacity than fixed timing schedules. For space heaters the overall flexible range is between 20-60% of capacity in winter, falling to 20-40% in summer. For hot water tanks on flexible charging the range is 60-85%. The different control algorithms used by the two devices bias the space heaters to be working just above the minimum, and the hot water tanks to just under the maximum capacity.

- DSM has had very little impact on control room operations; however, it has made a fundamental change in the network's relationship with customers as the DSM service is the provision of heat and hot water rather than electricity. This has meant having to manage day to day relationships with many small customers to solve behavioural as well as technical problems. It also requires keeping track of a mass of detailed data.
- The maximum net value of each house to the DSM supply chain is slightly less than £200 per year, plus the value to the network operator of 1-5 kW of flexible load and up to 8.2 kW of frequency responsive load. The net cost of each house to the supply chain is £330-£380 per year in communications and support services. All other costs and benefits are transfers within the supply chain. This model is not financially viable as it stands even with no customer loyalty or levelisation payments. Becoming viable requires an order of magnitude reduction in the communications costs, and/ or additional subsidy payments.

### 6.2.3 Renewable generators

The management of the timetable for connection to the network by renewable generators was entirely in the hands of the developers and the project had no influence over site progress. In all cases the impact of this was that renewable generators were connected to the NINES queue significantly later than the original intended connection date and this has materially impacted the amount of renewable generation on to the Shetland network over the project timeframe. It should be noted however that all of the generators have now connected via NINES and it can be expected that levels of generation moving forward will significantly increase to expected levels.

This is a success story for NINES. However at times some of the generators remain materially constrained in part as a consequence of lower levels of storage than was originally envisaged being available. SHEPD will require to consider how to manage these aspects in it's work on the New Energy Solution for Shetland.

### 6.2.4 Battery

Technology choice has been a key consideration throughout the course of the project.

The original choice of a 1MW/6MWh NaS battery was innovative and bold however, for reasons outlined in this report and with the full agreement with Ofgem, it was decided to change technology to a 1MW/3MWh LEAD-ACID. Due to levels of

deteriorating performance the future of this battery system remains in doubt and it is expected that discussion around remediation will be on-going beyond the NINES project timescale.

### 6.2.5 Operational impact

Often the practical implementation of a design can highlight unforeseen issues, and NINES was not immune to these factors:

- The DSM communication network was subject to software upgrades over the course of the project. Upgrades to the wide area network (WAN) were largely managed "over the air" resulting in minimal impact to customers as they would have been unaware that an upgrade was happening, however the Home Area Network which was developed by Glen Dimplex did not have the facility to upgrade software "over the air". The impact of this was that where HAN upgrades were required each customer was visited in person by a Glen Dimplex authorised technician and the upgrade how performed the upgrade manually. Fortunately, instances of this nature only occurred once during the project and visits were managed and co-ordinated between SHEPD, HHA and Glen Dimplex to minimise the impact to customers.

The key learning from this outcome is to ensure that in future should remote monitoring and/or control equipment be located in customers' homes, this equipment should be specified with the ability of receive updates remotely.

- The nature of flexibility does not need to be constrained by Smart meters in particular in relation to Fast Frequency response, this is not a capability of smart meters however the project has shown that the integration of logic into appliances can provide this service.
- The withdrawal of Shetland Islands' Council (SIC) from participation in DSM and the withdrawal of SHEAP from the intention to extend their existing district heating network and to introduce a 4MW thermal storage facility under NINES control.

The removal of SIC and SHEAP from the project resulted in a substantial reduction in heat and hot water storage capability. Significant efforts were made by SHEPD to address the impact of this however overall the project lost a substantial amount of storage capacity.

A key learning point from these experiences is that when engaging with third parties to provide energy storage facilities,

it is better to ensure that there is an over subscription from third parties at an early stage so that any changes of a similar nature can be accommodated without significant impact to the intended levels of storage.

### 6.3 Stakeholder engagement

Throughout the duration of the project SHEPD has endeavoured to ensure that all key relevant stakeholders were identified according to the requirements of the time and appropriate dissemination materials and information produced and an events list to highlight the level of stakeholder engagement has been provided in Appendix 2 of this report.

### 6.4 Learning capture and dissemination outputs

SHEPD has worked with the University of Strathclyde to develop a reporting structure that allows SHEPD to provide answers to the questions identified in Section 6.1.

With this in mind we have developed a suite of reports as shown in Appendix 4. Over the length of the project a number of papers and presentations have been produced and taken place to showcase the project to the wider community, highlighting learning to date and future proposals.

In addition, to mark the end of this project SSEN has arranged for a two day event to take place at The IET Building in London on 28th and 29th March 2017. This event will consist of a series of presentations and workshops covering the following topics:

- The commercial relationships and infrastructure required to deliver DSM on Shetland;
- The impact of Frequency Responsive equipment on the Shetland network;
- DSM - the impact of demand side management on customers;
- Operational effectiveness of an Active Network Management (ANM) system;
- How to build an ANM;
- The impact of Battery Energy Storage Systems on the Shetland network; and
- Generators' commercial arrangements and infrastructure.

A project closedown event was held over the 28th and 29th March 2017 at the IET Building, Savoy Place, London. In total over 200 people registered for the event with 203 people attending across the two days. Amongst others, attendees included 10 DNO representatives (excluding SSEN), four government representatives and 11 academics. The level of interest in this event provides an indication of the importance of the project to the UK and international energy networks community.

It is expected that over the course of 2017 other events including All-Energy and LCNF will take place to ensure that all key stakeholders have a chance to be aware of the NINES outcomes.

In terms of academic influence, Appendix 3 provides details of a number of academic and research papers relevant to the project that have been produced to date. In addition to this we can confirm that two academic papers on NINES have been submitted and are being considered for inclusion in the CIRED 2017 conference in 12 – 15 June 2017. Details of these papers have been included in Appendix 3 of this report.

### 6.5 NINES website

The NINES website (<http://www.NINESsmartgrid.co.uk>) has been live since December 2013, since inception it has been enhanced and upgraded at several occasions including addition of learning points and progress.

Over the time the site has been live, we have had;

- 17,823 visits to the site;
- 14,819 users visiting the site; and
- Visitors from 138 different countries throughout the world.

The overall number of visits to the NINES website indicates there is a strong demand for information on the project and fact that just over 3,000 of these are return visits shows there is enduring interest in the learning provided by NINES. One of the most popular areas of our site is the library where users can browse the publications of the learning generated on our project.

The NINES information and website content will remain available to users through an internet presence beyond the close of the project. All NINES customers, stakeholders and interested parties will have the ability to download materials, review the project and contact us as required. We can also confirm that all of the learning reports listed in Appendix 4 will be made available via the website.

7

# NINES legacy



# 7. NINES legacy

## 7.1 Influence of NINES on New Energy Solution for Shetland

The Integrated Plan for Shetland was submitted to Ofgem on 31 July 2013. Following the submission of the Integrated Plan, Ofgem requested further information including a proposed Incentive Mechanism (IM) and Relevant Adjustment (RA) as required by CRC18A.11. SHEPD submitted this to Ofgem on 23 December 2013.

This IM was subsequently rejected by Ofgem in a determination issued on 22 April 2014. This determination required SHEPD to carry out various actions including the appointment of an independent auditor to oversee an open and public consultation and competitive tender process. Any proposed solution within the competitive process will have considered, and will integrate with any enduring elements of NINES. The bidders have been required to take the learning, progress and where applicable the outcome of NINES into account when developing their bids.

The tenders are currently under evaluation. Decisions on the outcome of this process are on schedule to take place in the Autumn of 2017.

Work is underway to determine how the enduring component parts of NINES project should be treated in the context of the new energy solution. This is being undertaken with Ofgem, and will reflect feedback provided by bidders and existing NINES stakeholders as the competitive process develops. SHEPD's current proposals are that the ANM system, the NINES generator queue and the battery are retained on an enduring basis, and that the ANM system is used to connect in and dispatch any future intermittent and storage services, and to offer "DSO" functionality.

## 7.2 Influence of NINES on innovation projects

The NINES Project is one of a whole portfolio of innovation projects SHEPD are managing under LCNF, NIA, NIC, and other funding mechanisms. These can be broadly grouped into four key areas of development which are; *Safety, Health and Environment, Reliability and Availability, Connections and Capacity, Customer and Social Obligations*, and the ultimate aim of all of these projects is to save the customer money.

The chart below shows the evolution of NINES as a project and also shows how NINES has already provided knowledge, learning and insight across a whole range of areas.

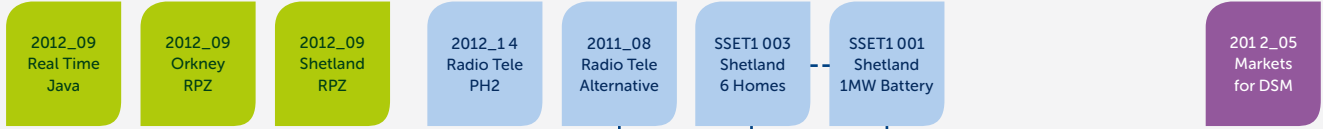
Early learning outputs from the NINES battery informed a number of other DNOs' energy storage projects including UKPN's Smarter Network Storage, and Northern Powergrid's Customer Led Network Revolution.

In particular, the learning around energy storage developed through this project led directly to the establishment of the Energy Storage Operators' Forum (ESOF). This is a forum whose membership comprises all of the GB DNOs and the Transmission System Operator. ESOF facilitates open and honest sharing of information and experience (including any failures or challenges encountered) between members on the practical aspects of Electrical Energy Storage systems through the whole project lifecycle. The learning from the two batteries deployed in Shetland contributed two case studies to the ESOF Good Practice Guide on Electrical Energy Storage.

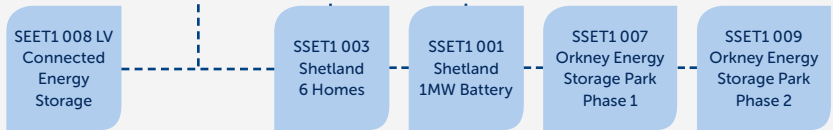
"SSEN played a significant role in ESOF and shared the learning from their portfolio of Tier 1 EES projects (Chalvey, Orkney and Shetland), both with other DNOs, the TSO and the wider industry via the GPG. As one of the first DNOs to install EES using Tier 1 and IFI funding this enabled SSEN to assist others as the volume of DNO storage projects increased. SSEN hosted technical visits to their Chalvey and Shetland installations through the ESOF meetings, and these were attended by representatives from all the DNOs, and TSO and the ENA. To date the Good Practice Guide has been downloaded over a thousand times and continues to act as a resource for the energy storage industry"

EA Technology

## IFI Projects



## Tier 1 Projects



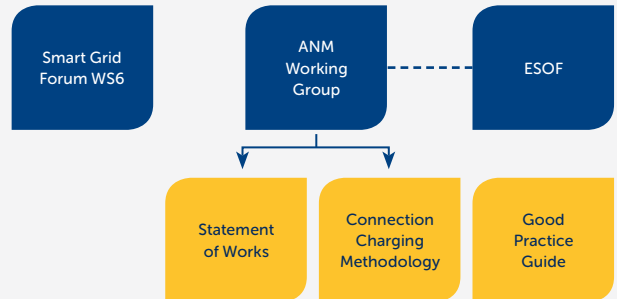
## Knowledge Transfer Projects



## Knowledge Transfer Enabling BAU Conversion



## Knowledge Dissemination



# Glossary



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## 8. Glossary

<b>ANM</b>	Active Network Management	<b>LPS</b>	Lerwick Power Station
<b>AST</b>	Active Solutions Team	<b>NaS battery</b>	Sodium-sulphur battery
<b>BAU</b>	Business as Usual	<b>NIA</b>	Network Innovation Allowance
<b>DDSM</b>	Domestic Demand Side Management	<b>NIC</b>	Network Innovation Competition
<b>DER</b>	Daily Energy Requirements	<b>NINES</b>	Northern Isles New Energy Solution
<b>DMS</b>	Distribution Management System	<b>PAYG</b>	Pay-as-you-go
<b>DNO</b>	Distribution Network Operator	<b>RA</b>	Relevant Adjustment
<b>DSM</b>	Demand Side Management	<b>RPZ</b>	Registered Power Zone
<b>DSO</b>	Distribution System Operator	<b>RTS</b>	Real Time Systems
<b>EM</b>	Element Manager	<b>SCADA</b>	Supervisory Control and Data Acquisition
<b>ENA</b>	Energy Networks Association	<b>SGS</b>	Smarter Grid Solutions
<b>ERDF</b>	European Regional Development Fund	<b>SHE</b>	Safety Health and Environment
<b>ESOF</b>	Energy Storage Operators' Forum	<b>SHEAP</b>	Shetland Heat, Energy and Power Ltd.
<b>FCR</b>	Formal Change Request	<b>SHEPD</b>	Scottish Hydro Power Electric Distribution
<b>HHA</b>	Hjaltland Housing Association	<b>SIC</b>	Shetland Islands Council
<b>IET</b>	Institute of Engineering and Technology	<b>SSEN</b>	Scottish and Southern Electricity Networks
<b>IM</b>	Incentive Mechanism	<b>SVT</b>	Sullom Voe Terminal
<b>LCNF</b>	Low Carbon Networks Fund	<b>UoS</b>	University of Strathclyde
<b>LIC</b>	Local Interface Controller	<b>WAN</b>	Wide Area Network
<b>LIFO</b>	Last-in-first-out	<b>WP</b>	Work Package



# Appendices



# Appendix 1

## Financial breakdown

	Revised Project Forecast	Original Project Forecast	% Spend v. Project Forecast	Justification of Variance (in excess of 10% of budget)
Labour	6831	6831	100%	
Project Management / System Studies and Design	3023	2857	106%	
ICT and System Integration	1690	1627	104%	
Automatic Network Management Scheme	421	399	106%	
SHEAP Thermal Store and District Heating Extension	66	400	17%	Thermal store was removed from scope however preparatory works had already proceeded.
Domestic Storage - ph1 - 750 homes	715	678	105%	
Non Domestic Storage	50	60	83%	Non-domestic storage was removed from scope however preparatory works had already proceeded.
Modelling - Learning and Dissemination	655	632	104%	
NAS Battery	193	178	108%	
Equipment	2580	2757	94%	
ICT and System Integration	281	257	109%	
SHEAP Thermal Store and District Heating Extension	96	100	96%	
Domestic Storage - ph1 - 750 homes	696	729	95%	
Non Domestic Storage	0	75	0%	Non-domestic storage was removed from scope however preparatory works had already proceeded.
Modelling - Learning and Dissemination	32	241	13%	Non-domestic storage was removed from scope however preparatory works had already proceeded.
NAS Battery	1475	1355	109%	
Contractors	4419	4116	107%	
Automatic Network Management Scheme	2627	2462	107%	
Domestic Storage - ph1 - 750 homes	210	175	120%	Additional costs are associated with the management of a 3 year no-cost extension to the original contract.

	Revised Project Forecast	Original Project Forecast	% Spend v. Project Forecast	Justification of Variance (in excess of 10% of budget)
Modelling - Learning and Dissemination	966	911	106%	
NAS Battery	616	568	108%	
IT	1306	1411	93%	
ICT and System Integration	1274	1171	109%	
SHEAP Thermal Store and District Heating Extension	0	100	0%	Non-domestic storage was removed from scope however preparatory works had already proceeded.
Modelling - Learning and Dissemination	10	120	8%	Underspend is a result of removal of acquisition of private homes and non-domestic storage from scope.
NAS Battery	22	20	110%	
Travel & Expenses	136	117	116%	
Project Management / System Studies and Design	136	117	116%	Additional travel costs are associated with the management of a 3 year no-cost extension to the original contract.
Decommissioning	0	100	0%	
NAS Battery	0	100	0%	We await the outcome of decisions on future battery requirements.
<b>TOTAL</b>	<b>15254</b>	<b>15332</b>	<b>99%</b>	

## Appendix 2

### Events list

Event	Date	Content / Key Message
OR54 Annual Conference	September 2012	Managing Projects In An Uncertain World: Engaging Stakeholders, And Building A Systemic View Of Risk – <b>presentation by Fran Ackermann, Susan Howick, John Quigley, Lesley Walls and Tom Houghton.</b>
BRE Low Carbon Built Environment Seminar: The Future is Electric Heating, but is it Sustainable?	September 2012	Case Study: Home space and water heating aspects of the SSE Shetland NINES project – <b>Katalin Svehla</b>
ENA LCNF Conference 2012	October 2012	Interim outcomes and learning from six modelling focusing on the unit scheduling and dynamic models – <b>presentation by Graham Ault.</b>
IEEE ISGT, Berlin	October 2012	Introduction to the interdependent system models in providing inputs to the active network management (ANM) design and configuration. Early results from model development and testing are presented with specific focus on the stability limits for the connection of additional renewable generation – <b>Michael Dolan &amp; Simon Gill.</b>
Community Energy Scotland conference	November 2012	Community impacts and benefits of the NINES approach - the potential – <b>presentation by Stewart Reid.</b>
2012 ANZAM Conference, Perth Australia	December 2012	Presented paper - "Managing projects in an uncertain and volatile world: engaging stakeholders, and building a systemic view of risk" – <b>Fran Ackermann.</b>
Risk Consortium (ManSci) event	February 2013	Presented overall view of NINES project – <b>Tom Houghton.</b>
European Wind Energy Association Conference 2013, Vienna	February 2013	"Operating a Wind Farm in the Future Smart Grid".
Scottish Renewables, Edinburgh	18–19 March 2013	Panel discussion on energy storage at Grid Conference session – <b>Stewart Reid.</b>
All Energy, Aberdeen	22–23 March 2013	Dedicated NINES session comprising several presentations – <b>Stewart Reid.</b>
Renewable Energy World Europe Conference, Vienna	4–6 June 2013	Controllable domestic energy storage.

Event	Date	Content / Key Message
CIREN 2013, Stockholm	10–13 June 2013	Building a framework for integrated risk management of complex projects: The case of a major distribution network investment – <b>Tom Houghton</b> .  Modelling and Delivery of an Active Network Management Scheme for NINES – <b>Simon Gill</b> .
EURO 2013 (European Conference on Operational Research), Rome	1–4 July 2013	Managing complex projects for industry: developing a new approach to risk management.
BS2013 (13th International Conference of the International Building Performance Simulation Association)	August 2013	Electricity storage within the domestic sector as a means to enable renewable energy integration within existing electricity networks – <b>J Clarke et al</b>
Regional Science Association international British and Irish Section Conference	August 2013	Impacts of NINES project on Local economy and electricity demand growth forecasting.
ESREL 2013 Annual Conference	29 September–2 October 2013	Modelling systemic risks to inform a repowering decision.
Scottish Energy Systems Group (SESG) Seminars	October 2013	Presentations on DSM context, methods and outcomes
Community Energy Scotland conference	October 2013	Community impacts and benefits of the NINES approach – lessons learned.
IEEE Innovative Smart Grid Technologies conference Panel Session	October 2013	Panel session on low carbon smart grids with 5-6 contributions from other similar initiatives including 2-3 on Shetland.
12th Wind Integration Workshop	22–24 October 2013	Market systems for managing curtailment of wind generators.
LCNF Conference 2013	November 2013	Final outcomes and learning from modelling activities.
SHEPD Future Networks conference (interim stage) – Scottish focus	1-day workshop	Integrated plan draft contents and outcomes of winter 2012/13 NINES trial results (DSM, ANM, etc.).
SHEPD Future Networks conference completion stage) – UK focus	1-day workshop	Wider implications of NINES trials on Shetland for: generation active management, domestic DSM, commercial demand, energy storage, ANM.

Event	Date	Content / Key Message
Webinar series	On-line	Various topics.
Shetland stakeholders event	1-day workshop	Update on NINES developments.
Training for SSE staff, Joe Clarke	9–13 September 2013	1-week module delivered as part of Power Plant Engineering course, included outline of NINES DDSM and findings (pros and cons) to date.
Energy Institute Annual Lecture, Glasgow, Joe Clarke	21 November 2013	External lecture.  NINES discussed under the heading of future energy options with smart grid.
13 <sup>th</sup> International Building Performance Simulation Conference, Chambery, France  Joe Clarke, Jon Hand, Jae-min Kim, Aizaz Samuel and Katalin Svehla	25–28 August 2013	Conference paper delivered.  Electricity storage within the domestic sector as a means to enable renewable energy integration within existing electricity networks.
Back to the Future: a new life for storage heating? Katalin Svehla ESRU, with HHA, Dimplex, SSE	Half-day seminar, Tuesday 4th March, 2014	Target audience: Local council and housing association people; Scottish Government; Building services engineers; Scottish DNO and Ofgem.
'Mainstreaming Innovation' webinar  'A bright future for storage heating'  1-hour webinar hosted by UoS, Sponsored by Scottish Government  (Ref: <a href="http://www.mainstreaminginnovation.org/content/webinars/213/">http://www.mainstreaminginnovation.org/content/webinars/213/</a> )	21 March 2014	This seminar discussed how a new generation of storage heaters with better insulation and improved output control perform, both in stand-alone mode and when their charging is controlled by a smart grid. It included present outcomes from field trials of the technology in the Shetland NINES project as well as modelling studies.
Energy Storage Operators Forum (ESOF)	Shetland, 17 June 2014	NINES Project and Technical Visit:
2 <sup>nd</sup> Conference on Building Simulation and Optimization, Joe Clarke, Simon Gill, Jon Hand, Jaemin Kim, Ivana Kockar, Aizaz Samuel and Katalin Svehla	London, 23–24 June 2014	Conference paper accepted.  The use of simulation to optimise scheduling of domestic electric storage heating within smart grids.
European Lead Battery Conference	Edinburgh August 2014	Shetland battery.
LCNI Conference	Aberdeen, 20–22 October 2014	Energy storage and demand side management.
Ofgem WS6 Workshop	London, 13 October 2014	Energy storage and demand side management.

Event	Date	Content / Key Message
Shetland Consultation Events	Shetland / Glasgow November 2014	Public Consultations on potential new energy solutions for Shetland.
Utility Week Conference	Birmingham, 22 April 2015	Making DSM Happen – Working in New Ways.
All-Energy Conference	Glasgow, 6 May 2015	Shetland An Energy Island – Demand Side Management of Customers.
Ofgem Workshop	London, 6 October 2015	NINES – Working Heating Harder.
IET - Distributed Generation 2015	Glasgow, 12 November 2015	NINES – A Case Study.
LCNI Conference	Liverpool, 25 October 2015	The Impact of Frequency Responsive DSM Equipment.
LCNI Conference	Liverpool, 25 October 2015	Engagement in Innovation.
LCNI Conference	Liverpool, 26 October 2015	NINES – Managing Change.
New Energy Solution for Shetland Presentation to Bidders	Glasgow, 19 April 2016	Attendance at event.
SHREC Conference	Inverness, 21 April 2016	Update on Project Progress to date.
All-Energy Conference	Glasgow, 5 May 2016	The Potential of Frequency Responsive DSM Equipment.
LCNI Conference	Manchester, 12 October 2016	NINES – Energy Storage and Network Management.
2050 Scotland's Youth Climate Group workshop	Glasgow, 26 November 2016	NINES – Solutions for a Low Carbon Future.
Industrial and academic delegation from Korea	East Kilbride, 22 February 2017	NINES – The Story So Far.
NINES / NTVV Closedown Event	London, 28 / 29 March 2017	NINES Learning Outcomes.

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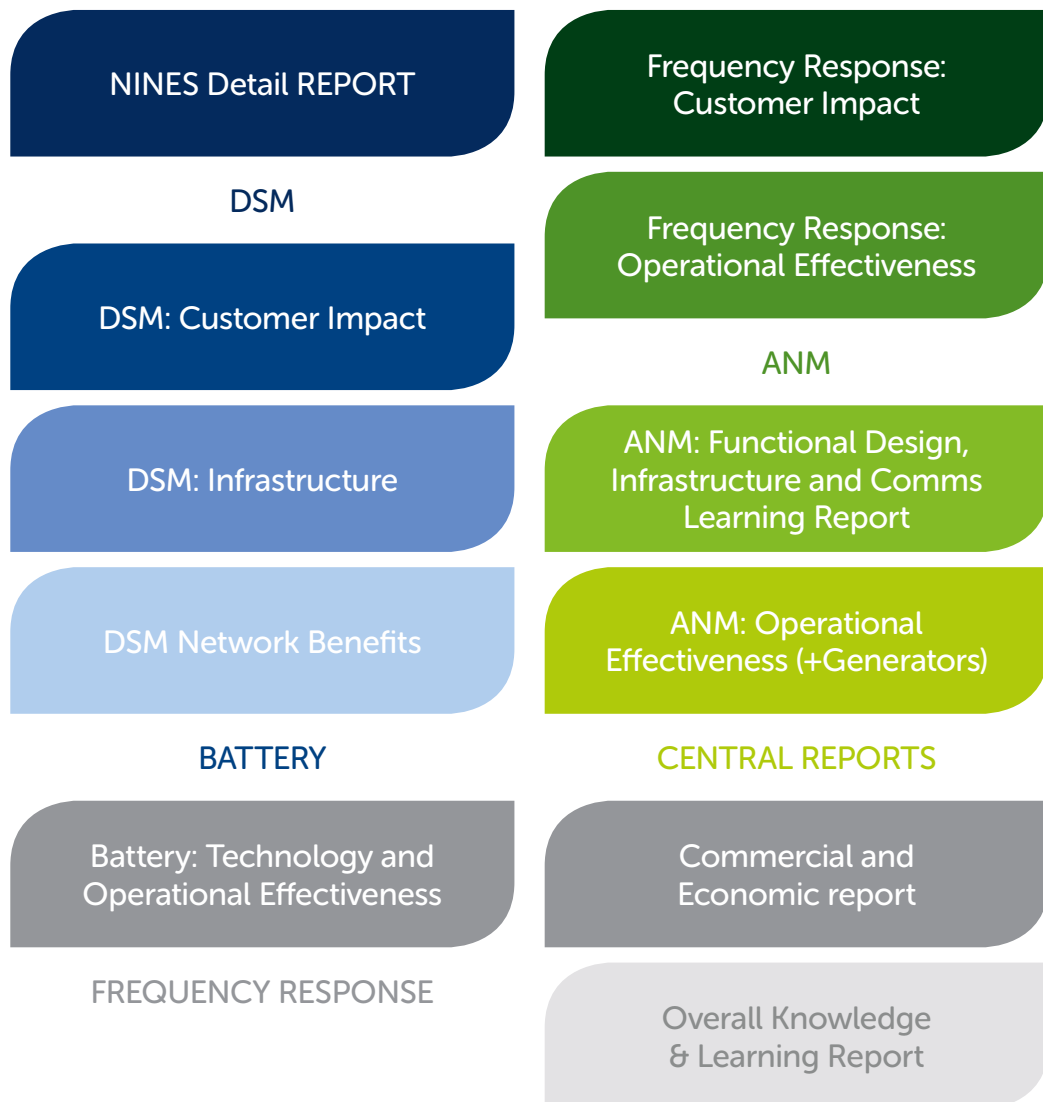
# Appendix 3

## Publications and papers

- *Dolan, Ault, Frame, Gill, Kockar, Anaya-Lara, Galloway, Mathieson, Reid, Clifton, O'Neill, Foote, Svalovs*, 'Northern Isles New Energy Solutions: Active Network Management Stability Limits', IEEE Innovative Smart Grid Technology Conference, (Berlin, October 2012).
- *Ackermann F, Howick S, Walls L, Quigley J and Houghton T* "Managing projects in an uncertain and volatile world: engaging stakeholders, and building a systemic view of risk" ANZAM (Perth, Australia 2012)
- *Ackermann F, Howick S, Walls L, Quigley J and Houghton T* "Managing projects in an uncertain world: engaging stakeholders, and building a systemic view of risk" OR54 (Edinburgh, UK 2012)
- *Dolan, M. J., Gill, S., Ault, G. W., Barnacle, M., Foote, C., Bell, G.*: "Modelling and Delivery of an Active Network Management Scheme for the Northern Isles New Energy Solutions", CIREN – (Stockholm, June 2013)
- *Houghton T, Ackermann F, Howick S, Quigley J and Walls L* "Building a framework for integrated risk management of complex projects: The case of a major distribution network investment", CIREN (Stockholm, Sweden 2013)
- *Walls L, Quigley J, Houghton T, Howick S and Ackermann F* "Modelling Systemic Risks to Inform a Repowering Decision" ESREL (Amsterdam, Netherlands 2013)
- *Ackermann F, Howick S, Walls L, Quigley J and Houghton T* "Managing Complex Projects for Industry: developing a new approach to risk management" EURO 2013 (Rome, Italy 2013)
- *Clarke, J; Hand, J; Kim, J; Samuel, A; Svehla, K*: "Modelling electricity storage within the domestic sector as a means of enabling renewable energy integration within existing electrical networks". Building Simulation 2013, (Chambery, France, 26-28 August 2013)
- *G.S. Hawker, L. Kane, K.R.W. Bell*, "Wind Power Plant Behaviour in a Pay-as-bid Curtailment Market", 12th International Workshop on Large-Scale Integration of Wind Power into Power Systems as well as on Transmission Networks for Offshore Wind Power Plants, (London, October 2013)
- *Graham Ault, Joe Clarke, Simon Gill, Jon Hand, Jaemin Kim, Ivana Kockar, Aizaz Samuel and Katalin Svehla*, "THE USE OF SIMULATION TO OPTIMISE SCHEDULING OF DOMESTIC ELECTRIC STORAGE HEATING WITHIN SMART GRIDS" Building Simulation and Optimization Conference BSO14, (London, June 2014)
- *Simon Gill*, "Maximising the benefit of distributed wind generation through intertemporal Active Network Management", Ph.D. Thesis (University of Strathclyde, Glasgow, March 2014)
- *Mohamed Edrah*, "The impact of domestic frequency responsive demand on the Shetland Islands", CIREN (University of Strathclyde, Glasgow, January 2017)
- *Han Xu*, "Utilisation of energy storage to improve distributed generation connections and network operation on the Shetland Islands", CIREN (University of Strathclyde, Glasgow, January 2017)



# Appendix 4 Knowledge and learning outcomes reports



# Appendix 5

## Delivery programme

Task name	Start	Finish
<b>WP 1 Ofgem Consultation</b>	<b>31 January 2011</b>	<b>31 March 2017</b>
<b>WP 9 Electrical Baseline Modelling</b>	<b>28 July 2010</b>	<b>20 June 2014</b>
SSE Steady State Modelling	14 March 2011	26 December 2011
UofS Modelling, learning and dissemination	28 July 2010	20 June 2014
<b>WP 2 Integrated Operations / Comms</b>	<b>3 January 2011</b>	<b>4 July 2014</b>
Comms Tender / Procurement	21 November 2011	1 October 2012
Integration testing	6 May 2013	3 October 2013
<b>WP 4 ANM Inegration</b>	<b>13 June 2011</b>	<b>24 May 2013</b>
ANM Hardware configuration and deployment	14 March 2011	27 April 2012
<b>WP 11 – 1MW Battery</b>	<b>7 Ferbruary 2011</b>	<b>2 May 2013</b>
Replacement Battery Pre Works	15 April 2013	7 May 2013
PH1 replacement 1MW – 0.5MWh	28 October 2013	26 November 2013
PH2 replacement 1MW – 3MWh	11 December 2013	1 July 2014
<b>WP 7 Domestic Storage Heating</b>	<b>1 November 2012</b>	<b>1 August 2014</b>
Hjaltland legal / commercial agreement	1 November 2012	7 June 2013
DDSM Roll Out – Pre config works	22 April 2013	28 June 2013
Customer Engagement	6 March 2013	31 July 2014
HHA Works	1 November 2012	1 August 2014
DDSM Public Roll out	27 May 2013	30 December 2013
<b>WP5/6 Thermal Store / Gremista Windfarm</b>	<b>1 August 2011</b>	<b>7 December 2015</b>
Commercial Principles – Rules of Access	15 September 2011	1 January 2014
WP5 Gremista Windfarm	1 August 2011	7 December 2015
<b>WP 10 Renewable Connections</b>	<b>15 September 2011</b>	<b>2 May 2013</b>
Commercial Principles – Rules of Access	15 September 2011	20 January 2012
Connections Dates	17 April 2014	7 March 2017
Phase 2 Sheland Repowering Integrated Plan	1 May 2013	23 December 2013





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