LCNF Tier 1 Interim Close-Down Report

1MW Battery, Shetland

SSET1001

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Executive Summary

This report describes the interim findings from the Scottish Hydro Electric Power Distribution (SHEPD) Low Carbon Networks Fund (LCNF) Tier 1 project "1MW Battery, Shetland". It is published in line with the requirement for all LCNF Tier 1 projects to produce a report three years after registration, if the project is still ongoing. The 1MW Battery project is due to conclude at the end of March 2014, after which a final close down report will be provided.

The project commenced in 2010 with the aim of installing a grid scale energy storage device on the SHEPD network in Shetland and integrating this with an active network management system. The success criteria for the project were to: "reduce the peak demand on Lerwick Power Station"; for the battery to "cycle efficiently to meet the needs and profiles of the islands' generation and demand"; and to increase the knowledge and understanding of "battery operation within a network environment".

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

Civil works to build a dedicated battery building commenced in February 2011; in August the battery modules were installed using a bespoke module insertion tool. Two weeks prior to the scheduled energisation of the battery SHEPD was informed of a battery fire at a NAS installation in Japan. A decision was taken to await final written reports, including an independent expert review of the findings, before making a decision about the future of the battery.

Reports received in late 2012 detailed the cause of the fire and the proposed safety modifications. Despite this, SHEPD – and our external consultants EA Technology – concluded that the fundamental safety case had changed and decided that the battery was no longer fit for purpose in this application. An alternative solution was sought which: had an established safety case; was deliverable within an appropriate timescale to allow suitable learning to be obtained; and could be delivered without an increase in cost.

Following approval from the project funders, a valve regulated lead-acid battery was selected as an alternative. The NAS battery was removed in May 2013 and building modifications are currently underway to prepare for the first lead-acid cells due on site in October 2013.

The project has generated significant learning for battery energy storage systems in areas including: procurement, design, construction, installation and safety. While this interim report presents a detailed account of the work carried out to date, SHEPD will revise this once the project is completed. The final report will detail battery commissioning, initial operation and learning relating to these activities. The battery will continue to be trialled and evaluated under the Northern Isles New Energy Solutions (NINES) project.

1 Project Background

As part of Scottish Hydro Electric Power Distribution (SHEPD)'s plans for the Northern Isles it is proposed to install a 1MWe connected battery at the Lerwick Power Station. The battery has won DECC funding towards its' costs.

2 Scope and objectives

Our DECC funding award requires delivery of the 1MWe battery by end March 2011, as a result procurement is well underway, additional functionality of this battery will feature in our Tier 2 bid. This Tier 1 bid secures the initial learning from the installation and operation of the battery and integration with local demand side response to remove station peaks providing additional demand capacity (in a similar way to managing a network load constraint).

Our Tier 2 element subsequently deals with the optimisation of potentially simultaneous modes of operation including:

(a) Renewable generation constraint avoidance;

(b) Power station operation optimisation (to reduce fuel consumption);

(c) Stability control including SVC functions; and

(d) Provision of ancillary services.

This approach maximises the learning and provides the greatest leverage funding from SSE, DECC funding and the LCNF.

3 Success criteria

The battery must be able to reduce the peak demand on the station allowing the connection of new demand (in a similar manner to the management of a network thermal constraint). The battery must also be able to cycle efficiently according to the needs and profiles of the islands' generation and demand. The battery installation will allow SHEPD – and the UK in general – to gain a better understanding of battery operation within a network environment.

4 Details of the work carried out

4.1 DECC Funding

SHEPD applied to the Department of Energy & Climate Change (DECC)'s Smart Grid Demonstration Capital Grant Programme in December 2009 for funding towards the integration and operation of an energy storage device on the distribution network. The application was successful with £1,049,060 awarded in March 2010.

4.2 Procurement

Following the successful funding application SHEPD began to develop the procurement methodology. As this was the first time a grid-scale battery had been procured for the UK market, there was no existing established process to follow therefore SHEPD developed a procurement methodology. SHEPD intended to use the Achilles supplier database[1] to contact and invite parties interested in tendering for the works to register their interest. However Achilles does not have an identifying code for battery or energy storage systems. SHEPD selected two suitable existing codes: 1.8.10 Primary Cells, Batteries & Chargers; and 1.11.4 Generators – Power Station. This was successful and 118 companies were identified, of which 29 registered an interest in tendering for the project.

Next, SHEPD prepared a request for information (RFI) that included screening questions to ensure only suppliers with a product that could meet the project criteria progressed to the tender stage. The questions focused on:

- Safety and environment
- Cost and efficiency
- Compliance with specification
- Programme (and the ability to meet the funding timescales)
- Technical merit

Invitations to tender were sent to 13 suppliers successful at the RFI stage. Of these, two companies chose to submit a joint tender. Two other individual submissions were received. Each submission applied a different battery technology:

[1] The Achilles utility vendor database allows buyers such as SHEPD to quickly identify a list of potential suppliers. Achilles provides a proven pre-qualification system to manage risk in the supply chain. Vendors were further required to complete the 'Achilles verify' process. Achilles conducts a thorough assessment of a vendor's health and safety, quality and environmental capabilities. Buyers include National Grid, Network Rail, EDF Energy and Petrofac and over 6700 suppliers are registered.

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- Sodium Sulphur (NAS)
- Vanadium Redox
- Zinc Bromide

The received tenders were assessed against a tender evaluation matrix produced by SHEPD. This was followed by presentations by each of the prospective suppliers in Perth. The contract was awarded to S&C Electric Europe Ltd (S&C) at the end of September 2010 for the design, supply and installation of a 1MW, 6MWh NAS battery energy storage system (BESS). S&C would purchase the battery from an intermediary Japan Wind Development Co Ltd (JWD) who had procured the NAS battery from manufacturer NGK Insulators Ltd of Japan (NGK). This would mark the first NAS installation in the UK and only the second in Europe.

4.3 NAS battery technology

The fundamental principles of NAS batteries were developed by the Ford Motor Company in 1967. In 1980, NAS was selected as one of four battery technologies for intensive research in Japan[2]. The project sought to develop a BESS with the following characteristics:

- 1MW power output
- 8 hour charge, 8 hour discharge time
- Minimum efficiency of 70%
- 10 years or 2000 cycle service life

NAS achieved some success with the development of a pilot plant in 1990 however durability, economic efficiency and ensuring adequate safety standards required further research[3]. The time and effort required to achieve this – and the advent of new funding programmes for alternative technologies e.g. lithium-ion – resulted in all but one developer to cease developing NAS batteries.

Tokyo Electric Power Co (TEPCO) and NGK continued the NAS battery development and commercialised the product in 2003. By 2010, over 300MW of NAS batteries were installed world wide primarily in Japan and the United States of America at over 215 sites. The largest of these, a 34MW, 220MWh battery connected to a 51MW wind farm in Rokkasho, Aomori prefecture in Japan was commissioned in 2008.[4]

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[2] Battery Energy Storage Systems, May 1991, D.Pavlov, G.Papazov and M.Gerganska

http://unesdoc.unesco.org/images/0009/000916/091670eo.pdf

[3] Inside Cooperative Innovation: Development and Commercialization of Sodium-Sulfur Batteries for Power Storage, April 2013 (updated based on Japanese version 2008), Eishi Fukushima

http://pubs.iir.hit-u.ac.jp/admin/en/pdfs/file/1667

[4] http://www.yokogawa.com/iab/suc/power/iab-suc-jwd-en.htm

Figure 1 - 34MW NAS battery
http://www.ngk.co.jp/english/products/power/nas/installation/

The NAS battery active materials are molten sulphur at the positive electrode and molten sodium at the negative electrode. A solid beta alumina (a sodium ion conductive ceramic) separates both electrodes.

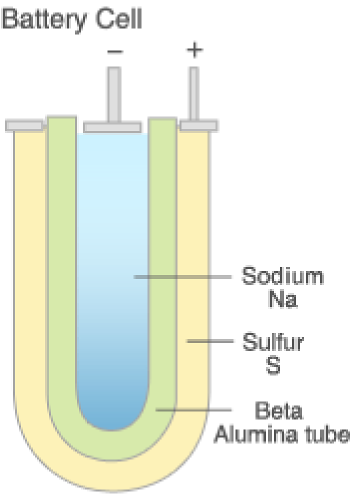

Figure 2 - NAS cell composition
http://www.ngk.co.jp/english/products/power/nas/principle/index.html

Connecting a load to the battery terminals will discharge electrical power through the load. During the discharge cycle sodium ions transfer from sodium at the negative electrode and pass through solid electrolyte to reach sulphur at the positive electrode. As the cycle progresses, sodium polysulfide is formed at the positive electrode while sodium at the negative electrode will decrease.

During the charging cycle, the electric power supplied forms sodium at the negative electrode and sulphur at the positive electrode. As the concentration increases, chemical energy is stored in the battery. The complete cycle is shown in Figure 3.

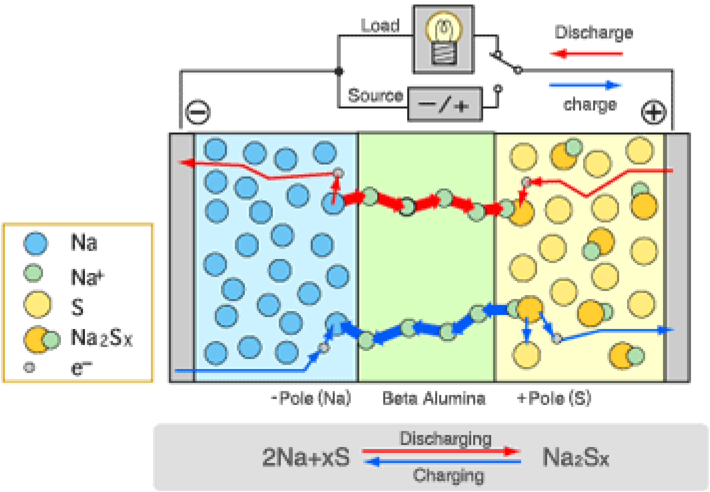

Figure 3 - Charging cycle

http://www.ngk.co.jp/english/products/power/nas/principle/index.html

To maintain the molten active materials the battery has an operational temperature in excess of 300°C. Each cell is hermetically sealed to prevent any escape of material or reaction with air. 384 cells comprise a 50kW module and are contained in a thermal enclosure as shown in Figure 4 to maintain efficiency.

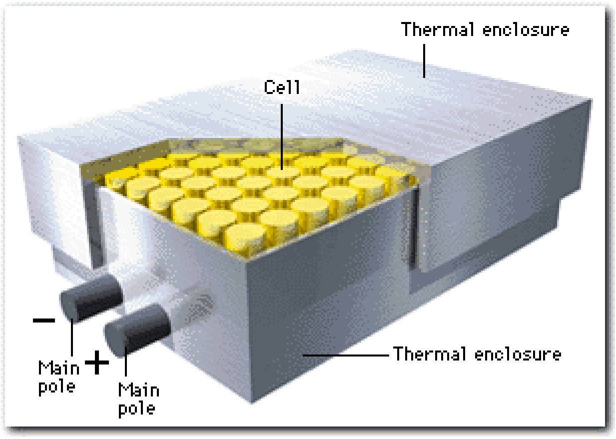

Figure 4 - NAS battery module

http://www.thefraserdomain.typepad.com/energy/2006/01/sodiumsulfur_na.html

20 modules make up the 1MW, 6MWh battery.

4.4 Technical assessment

SHEPD engaged EA Technology (EATL) to assist with the technical assessment for the NAS battery. EATL were tasked with providing support during the commissioning phase and developing a test regime for the battery when it was operational. Prior to this EATL carried out a benchmarking report of the Shetland network. The report considers the benefits the BESS could deliver and pairs these to assessment criteria which the performance of the BESS can be evaluated against. The assessment criteria put forward were: plant margin and fuel efficiency; frequency stability; and voltage control.

4.5 Safety case

EATL were also commissioned to carry out a complete project safety case. The work included:

- A review of relevant codes, standards and legislation
- A review of documentation provided by the supplier
- The preparation of risk assessments
- Seeking specialist input from Ionotec who were involved with the development of NAS batteries in the UK from 1975

4.6 Stakeholder engagement

As with any project, effective identification and engagement with internal and external stakeholders was required to ensure successful project delivery. Key internal stakeholders included Lerwick Power Station operational staff, network operators and planning. External stakeholders included:

- Local Planning Authority – The battery building was consented under permitted development, due to its function and size relative to the existing power station.
- Scottish Environment Protection Agency – The battery was located on the site of the operational power station therefore a modification to the site Integrated Pollution Prevention and Control (IPPC) permit was required.
- Health and Safety Executive – Meetings held in Edinburgh.
- Fire service – Site tour and presentation, no concerns were raised.
- DECC – Contact was primarily through quarterly progress reports.

Our approach to this focussed on initial discussions to state what we were considering and why. This was followed up with further information and a statement of intent before making formal submissions. An ongoing dialogue was then maintained. This approach worked well, with no objections or delays encountered.

4.7 FAT testing

Although the battery technology was well proven, it had not previously been installed in the UK. The nature of the materials within the battery was also new to SHEPD. Therefore SHEPD sent an engineer to participate in the factory acceptance testing (FAT) for both the NGK battery and the S&C power conversion system (PCS). The specific objectives were to:

- Witness quality control
- Accelerate learning in relation to process safety
- Reduce the number of unknowns during the Shetland installation
- Improve the quality of external learning dissemination
- Develop SHEPD's knowledge base in energy storage

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A member of SHEPD's future networks team travelled to Japan in November 2010. The first day provided an opportunity to visit the 34MW battery at Rokkasho.

Figure 5 - 34MW battery, Rokkasho wind farm, Japan

This provided an opportunity to see and understand how a large battery array was run operationally and to engage with staff. The chief engineer for the site accompanied the visit. He explained the wind farm – and batteries – are located in an area with multiple wind farms therefore at times of high wind output, the energy price is low as all the wind farms are outputting power. The main difference of the Rokkasho site is that it is able to store energy when the wind output is high and sell when there is little or no wind and hence, the energy price is very high. Another key benefit is that the wind farm can guarantee its output – i.e. it is not intermittent. This is due to the large size of the battery array and storage capacity.

The batteries were installed purely on an economic basis to be used for energy arbitrage and have been in operation for approximately 5 years without any module failures.

The different energy market conditions of Japan demonstrate how battery storage can become economically viable. This may become more beneficial to the UK grid as the penetration of renewable intermittent generation increases and begins to cause stability and power quality issues.

The second day in Japan provided an opportunity to tour the NGK manufacturing factory in Nagoya. To meet the project time constraints, S&C were able to secure pre-manufactured modules for use in the Shetland project. This meant it was not possible to directly witness the Shetland modules going through the test process. However the visit did provide an opportunity to see the modules destined for Shetland prior to being packed for shipping as well as other battery modules going through the test process.

Almost every component in the battery module was manufactured on site, from the cells to the steel enclosure. The modules were assembled using custom built automated machines particular to each part of the battery assembly process. This required very little human involvement, primarily transferring cells to the next machine, with the entire welding and sealing performed by the appropriate robotic arm. NGK were

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understandably protective of the manufacturing process and as a result would not allow pictures to be taken. However the SHEPD engineer commented that he was very impressed with the automated set-up which would have incurred significant costs to design and implement. The use of an almost completely automated system should also ensure the quality of the product consistent.

The remainder of the visit focussed on technical presentations and discussions covering topics including: transport, installation, commissioning and operation with several of those participating due to be present during the installation in Shetland.

In January 2011, the SHEPD engineer also travelled to S&C's manufacturing factory in Franklin, USA (between Milwaukee and Chicago) to witness the testing for the Shetland PCS. The comprehensive FAT was carried out on the 5th January 2011.

4.8 Use of Enterprise Architecture models for smart grid technology:

This project trialled the use of Enterprise Architecture models to define how the NAS battery system will be operated and maintained in the long term. Use cases, requirements and business process models were created and validated through consultation with project stakeholders. This identified the functionality required in the control system and contributed to the design of the human machine interface (HMI). The methodology also allowed SHEPD to put in place the processes to support the ongoing schedule, updates and alarm response to the system. From this it was possible to estimate the ongoing resource requirements and cross business support for integration of the battery into business as usual practice. Both the process and outputs from this exercise were found to be valuable methods of eliciting and documenting tacit knowledge and promoting communication between project stakeholders from different disciplinary backgrounds. An example of a use case is shown below in Figure 6.

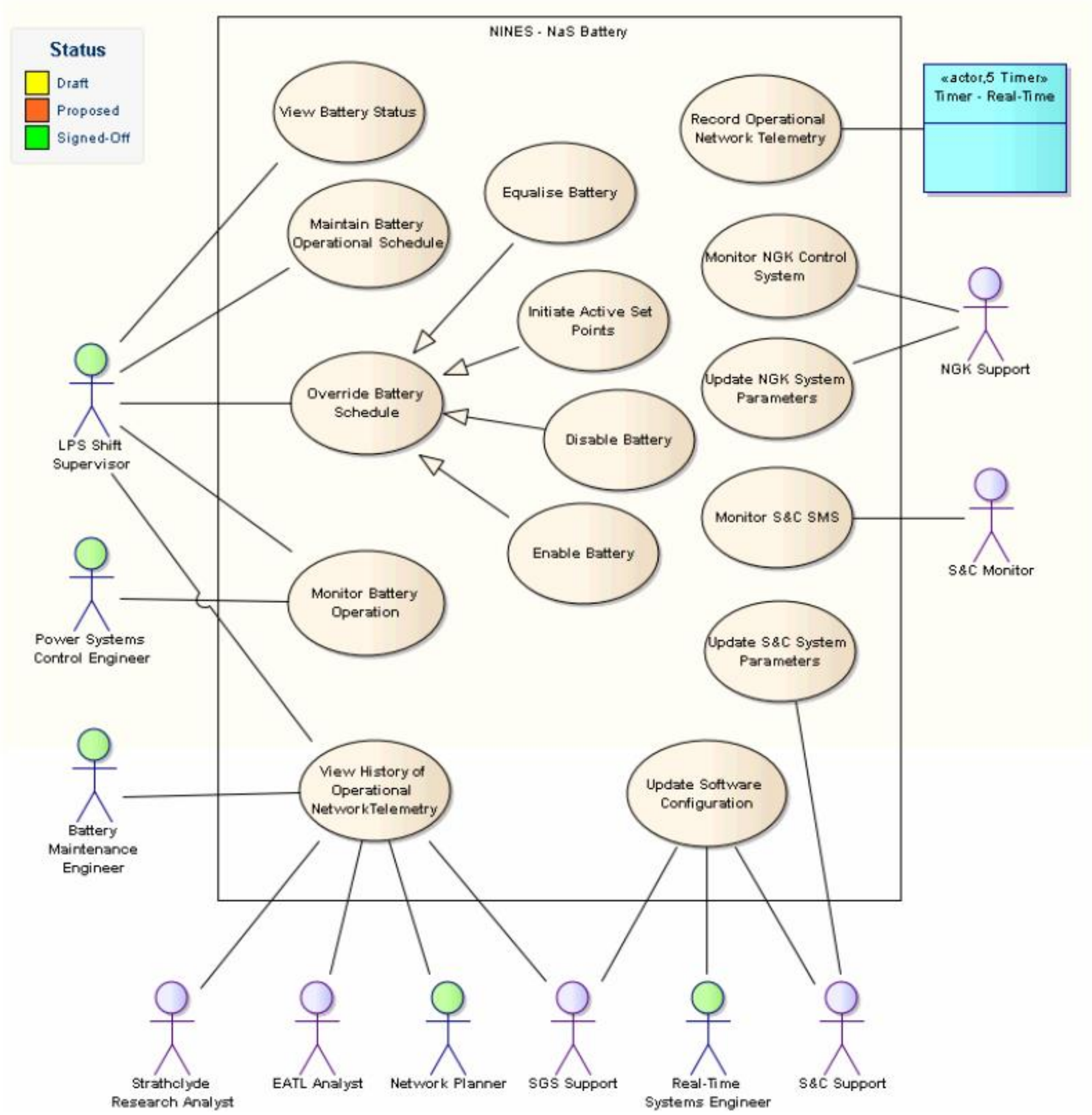


Figure 6 - NAS battery level 0 use case, an example of Enterprise Architecture documentation

4.9 Civil works

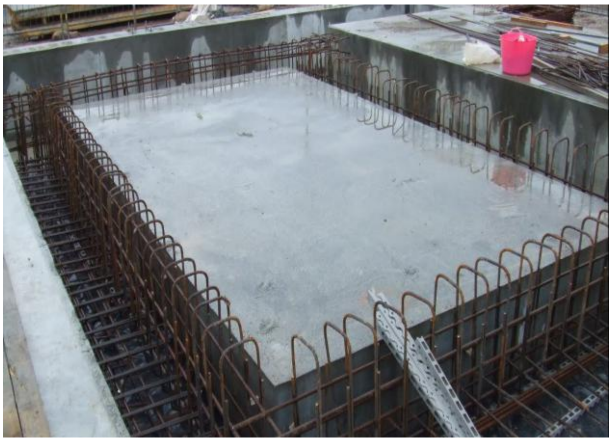
Plans for the battery building were specified by MacGregor McMahon to applicable British Standards. A building plan visualisation in relation to Lerwick Power Station (LPS) is shown in Figure 7 with a close up shown in Figure 8.

Figure 7 - Battery building visualisation in relation to LPS

Figure 8 - Battery building visualisation, North West view

Contracts for the building construction were awarded to Powerteam and Corrie Construction with work commencing on site on the 1st February 2011. Figure 9 shows the development of the site:

February – CDM site initiated, site excavation, first concrete poured



March – Concrete and rebar laid, foundations complete

April – External building frame erected

May – Building fully clad, internal works begin

Figure 9 - Battery building site development

4.10 NAS battery installation

The battery modules and power conversion arrived in Shetland in early March 2011 as shown in Figure 10.

Figure 10 - Battery modules and PCS in storage on Shetland

The Great East Japan Earthquake and tsunami in March 2011 resulted in a delay to the manufacture of the steel battery enclosure. This did not affect the programme significantly and the enclosure arrived on site in July 2011. Figure 11 shows the installed enclosure frame:

Figure 11 - Installed battery enclosure frame

SHEPD, S&C and local company Ocean Kinetics were joined by engineers from NGK and JWD to assist with the battery module installation. A bespoke tool was provided by NGK to meet the 5mm tolerance specified. This specialist equipment had not been previously deployed in the UK. To establish its suitability for the task and the operators' competence to use it, SHEPD tasked Arch Henderson to carry out an assessment and confirm compliance with BS EN 1090-2:2008 Execution of Steel Structures. Copies of the operators' competence were received from the NGK factory in Japan and UK authorised contractors certified the assembly of the equipment.

Figure 12 shows the battery being lifted out of its transportation frame by HIAB, ready to be placed on the battery insertion tool.

Figure 12- Battery module being removed from transportation frame

Once a battery module has been safely placed on the insertion tool and aligned correctly, nitrogen gas is used to raise a series of ball bearings. This greatly reduces the friction and the 3.4 tonne battery module can be inserted into the frame with ease as shown in Figure 13.

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Figure 13 - Battery module insertion

The additional lateral ball bearings can be seen in Figure 14.

Figure 14 - Ball bearings reduce friction

Once a module has been successfully installed, the insertion tool is run along a track. This provides a quick method of repositioning the insertion tool to install a further module at the same height. This can be seen in Figure 15.

Figure 15 - Track allows quick repositioning of insertion tool

Next, the insertion tool is removed by HIAB and replaced with the first layer of the insertion tool's frame. The insertion tool is then returned on top of the frame and modules in the second row can be installed. This process was repeated until the modules in the top row had been successfully installed as shown in Figure 16. The Shetland installation had a total of five rows.

Figure 16 - Battery insertion tool at full height

In less than three days, all 20 modules had been installed. The battery configuration as installed is shown in Figure 17 with the enclosure doors open.

Figure 17 - NAS battery system installed at Lerwick Power Station

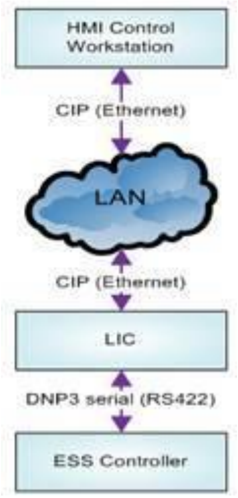
Following the completion of remaining cable works, the battery was ready for commissioning.

4.11 Control systems

SHEPD worked with Smarter Grid Solutions (SGS) to: specify, design, deliver, integrate, test and support the control system for the BESS. The purpose of this work was to streamline the future integration of the BESS into the active network management (ANM) system to be developed under the NINES project.

The initial analysis methodology considered the existing Shetland network, the battery operating parameters (including the algorithm for determining a partial of full battery cycle) and the S&C PCS control system. Once the technical analysis was complete, this progressed to a requirements specification and subsequently a functional design specification.

SGS delivered a local interface controller (LIC) to provide control and monitoring of the BESS. A remote HMI installed at Lerwick Power Station control room would provide operators with access. The high level system architecture is shown in Figure 18, the LIC in Figure 19 and an HMI screenshot in Figure 20.



HMI – Human Machine Interface

CIP (Ethernet) – Common Industrial Protocol

LAN – Local Area Network

LIC – Local Interface Controller

DNP3 – Distributed Network Protocol

ESS – Energy Storage System

Figure 18- High level system architecture

Figure 19 - Local interface controller

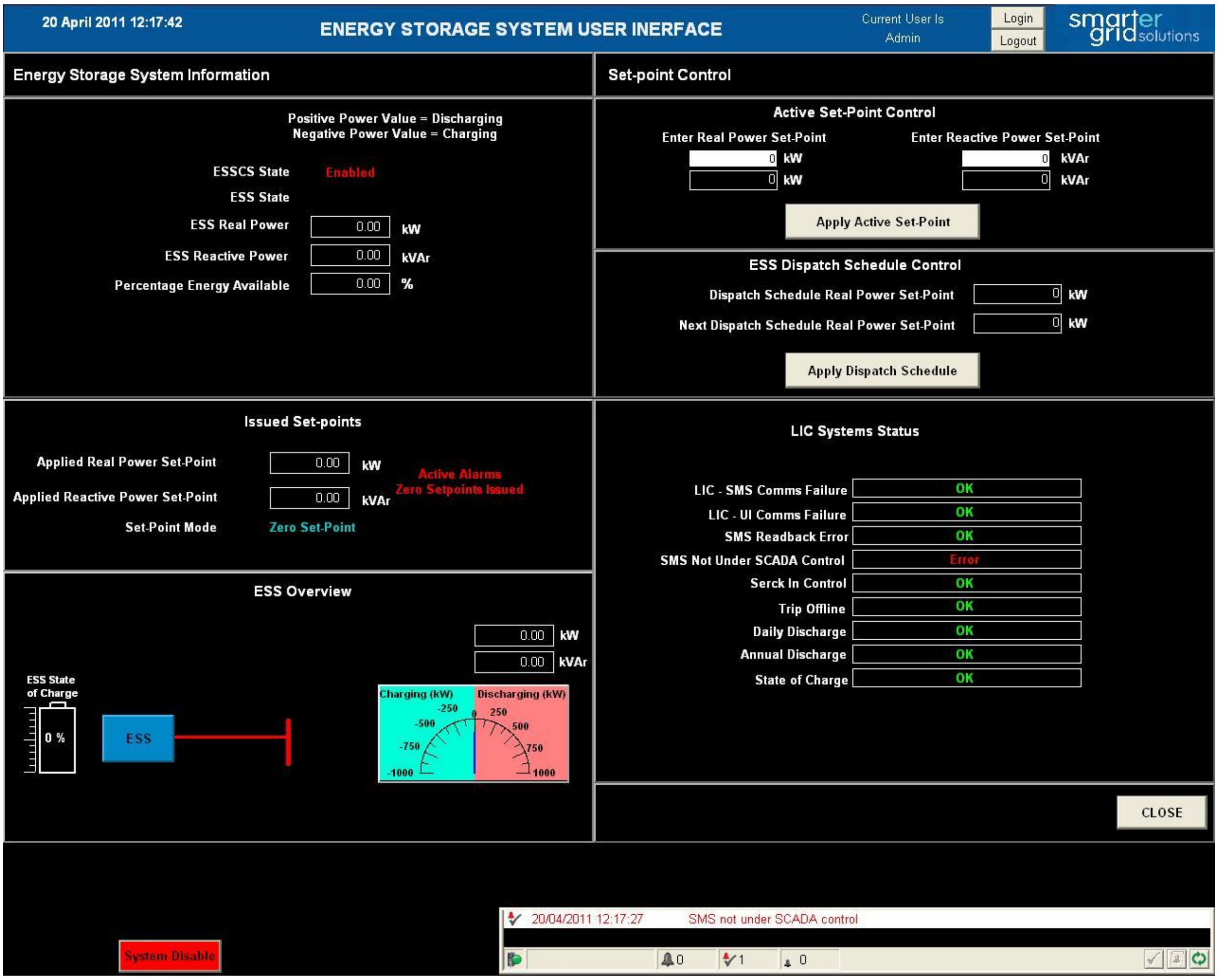


Figure 20 - HMI screenshot for monitoring and control of the BESS

4.12 Battery commissioning

On the 30th September 2011, just two weeks before the scheduled energisation date of the battery, SHEPD were notified of a fire at a NAS battery installation in Japan. NGK recommended that all NAS battery installations worldwide shut down until the root cause of the fire had been established.

Following a series of investigations, testing was instigated by NGK to be carried out by the Japanese Fire Authority and the Hazardous Material Safety Technology Association. This work took place throughout 2012.

There were considerable delays in receiving results from the tests and SHEPD were not satisfied with the verbal updates provided. SHEPD made the decision to await full and final written reports, including an independent expert review of the findings, before making a decision about the future of the battery. The fire and potential implications for the NAS battery installation necessitated significant modifications to the planned approach. Additional tasks included a review of the findings from the Japanese fire investigation and a re-assessment of the safety case using the new information from this exercise. These activities are described in the following section.

4.13 Response to NAS battery fire in Japan

4.13.1 Review of investigation findings

The final report received from NGK suggested the possible cause of the fire was due to the expulsion of electrolyte from a single cell caused by a short circuit. This triggered a cascading failure of multiple cells. The report proposed the following remedial actions:

- Fuses will be added between battery cells in modular batteries to prevent a short circuit current from causing a fire.
- Insulation boards will be placed between blocks in battery modules to prevent leaking molten materials from causing a short circuit.
- Anti-fire boards will be placed between battery modules above and below to prevent fire from spreading to other battery modules.

These are shown in Figure 21.

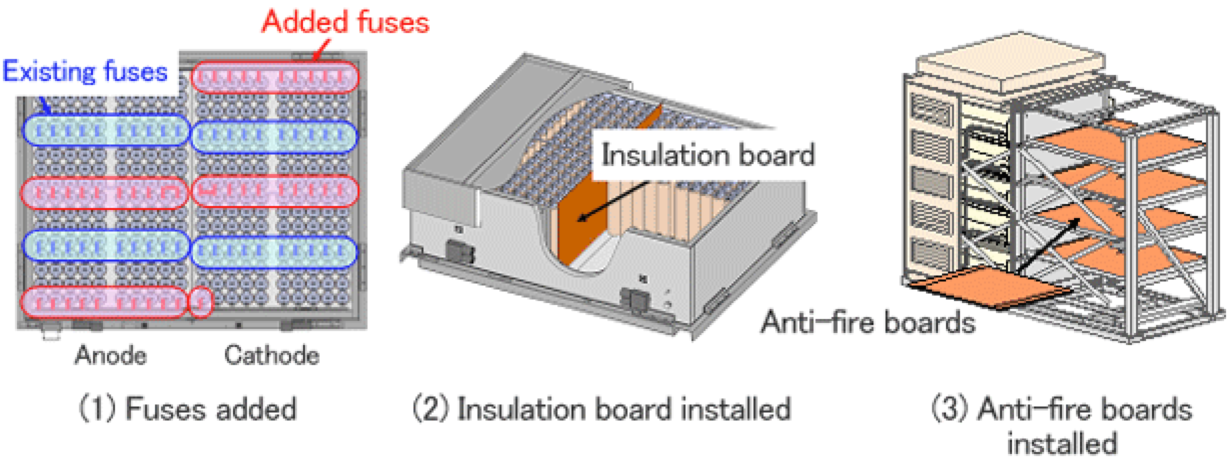


Figure 21 - NGK remedial measures to enhance safety
http://www.ngk.co.jp/english/news/2012/0607.html

The remedial measures did not however address the root cause of the fire – the failure of a cell and the expulsion of its contents. Implicit in the report was that even with the remedial work in place, the risk of fire could not be eliminated entirely.

Input was sought from external experts; together SHEPD and EATL agreed that the outcomes from the report fundamentally changed the safety case. The original safety case was built on the understanding that a fire could not occur in the Shetland battery, this position having been established after an independent expert review of test data provided by the manufacturer. Reviewing the original safety case from the position that such a fire could in fact occur, further reports and testing were requested to identify the impact of a fire and any subsequent release of gas. These reports failed to satisfy SHEPD's concerns.

The reports conclude that if a fire were to occur, it would burn for a significant period of time and would involve evacuating Lerwick Power Station and potentially switching off the electricity supply to the whole of Shetland for a number of days. Whilst the likelihood of a fire occurring is extremely low, the associated consequence would be catastrophic.

For these reasons and without a suitable resolution to allow a fire to be extinguished in an acceptable timescale, SHEPD concluded that the NAS battery was no longer fit for purpose.

4.13.2 Change in battery technology

Once approval from the project funders had been sought, SHEPD and S&C began to seek an alternative battery technology. Criteria set for the replacement battery were:

- Established safety case
- Fit within the existing battery building footprint
- Deliverable within a reasonable timescale to allow suitable learning to be obtained
- Deliverable with no additional cost to customers

Alternative solutions were limited, with the required timescales being the most restrictive factor. Lead-acid emerged as the sole alternative technology with two manufacturers able to meet the delivery schedule. The first of these utilised valve-regulated lead-acid (VRLA) and became the preferred supplier. This is because the second option utilised a more traditional flooded cell design. The former could be racked four cells high whereas the latter was limited to a single level. This would have required significant modifications to the battery building and therefore resulted in a greater overall cost.

4.13.3 NAS battery removal

S&C, along with Ocean Kinetics, Power Systems UK and an engineer from NGK returned to site in May 2013 to commence the removal of the NAS battery system. The working party's previous experience of installing the modules was beneficial; all modules were quickly and safely removed and packaged securely for transport back to Japan for sale to another customer. The bespoke installation tool was utilised for the removal of the modules increasing UK operators experience in using this equipment.

4.13.4 VRLA selection

VRLA batteries manufactured by GS Yuasa of Japan were put forward as a replacement to the NAS battery. GS Yuasa formed in 2004 following the merger of two of Japan's most established lead acid manufacturers, each with almost 100 years experience with the technology. The Shetland project was to benefit from the company's UK technical contacts and Yuasa have a manufacturing plant in Wales[5]. In the UK, Yuasa sell 1.2 million cells per annum, equivalent to over 1GW of energy storage.

Yuasa provided high level details of six recent UK installations; primarily used in data centres as an uninterruptible power supply (UPS). In addition, SSE Telecoms own and operate a similar small asset at the Fareham data centre in Hampshire. What sets the Shetland installation apart is the novel application.

4.13.5 Request for information

SHEPD sent out a request for information (RFI) to fulfil the requirements of a technical assessment and basis for the safety case. S&C maintained a good dialogue with Yuasa during this period and subcontracted Thamesgate for their prior experience in installing battery rooms in data centres. Outcomes from the lead-acid safety case are presented in Section 6.5.

4.13.6 Cell order

S&C secured manufacturing slots at Yuasa's factory in Japan despite competition from other large orders. The first cells are on schedule to arrive in October 2013 with the remainder following shortly after in November 2013.

4.13.7 Building modifications

Lead-acid batteries have a much lower energy density than NAS. S&C and their designers assessed the maximum number of lead-acid cells that could be installed in the existing battery building without significant structural modification. To this end, the lead-acid battery footprint would increase by almost a factor of 3 but only have half the energy storage capacity. This is summarised in Table 1. The increase in footprint is shown in Figure 22.

Table 1 – Battery comparison summary

Battery Technology	Weight (tonnes)	Power (MW)	Energy Storage (MWh)
NAS	~70	1	6
Lead-acid	~200	1	3

[5] Unfortunately the output from the Wales factory was contracted until 2014.

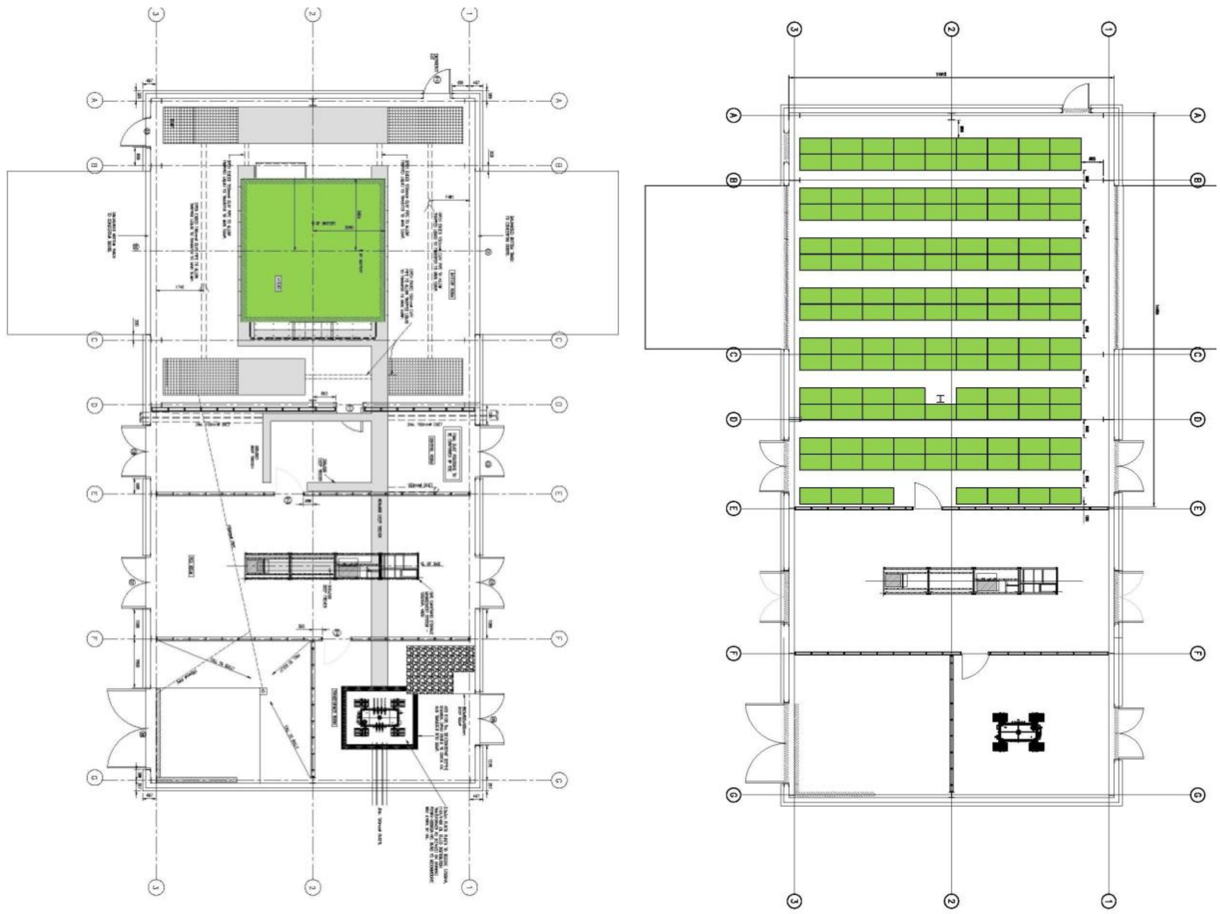


Figure 22 - Battery footprint comparison

To accommodate this increase in footprint, some minor building modifications will be required. This includes the removal of a partition wall and moving the existing control equipment to increase the size of the battery room.

Of greater interest is the change in operating temperature between the two batteries. The lead-acid battery has an optimum[6] operating temperature of 20°C compared to the NAS battery at 350°C. As such, the building was previously designed to dissipate heat. To combat this and improve the thermodynamic characteristics of the battery room, the large roller doors will be removed and clad. A floating ceiling will also be introduced and modifications to the HVAC systems are underway. This will increase the insulation in the room, require less energy to maintain the optimum temperature and ensure the efficiency of the battery is not significantly reduced.

[6] This temperature will ensure battery life and performance are maintained.

5 The outcomes of the project

5.1 Grid scale battery procurement strategy developed

Use of Achilles register to invite tenders

The use of the Achilles supplier database was demonstrated through this project and has subsequently been used in further tenders for energy storage systems by SHEPD and other DNOs. The outcome, a list of potential suppliers identified from the search codes is detailed in Table 8. The inaugural DNO Energy Storage Operator's Forum (ESOF) meeting discussed battery procurement and the Achilles searches DNOs undertook. SHEPD have also successfully used Achilles in their Orkney Storage Park project[7].

Screening and evaluation criteria established

The project developed and issued several documents during the procurement process. These are detailed in Table 8. At each stage screening and evaluation criteria were utilised to ensure the successful procurement of the battery. The most notable of these was the requirement for manufacturers to underwrite the battery efficiency within the warranty. This often resulted in a deviation from the headline figure and thus provided a more conservative – and possibly more accurate – estimate of the battery efficiency.

Changes in how batteries are procured

The procurement of the NAS battery utilised learning from earlier projects, specifically from the IFI project to install a flow battery at Nairn primary substation. We included clauses to mitigate against the failure of containment or delays in resolving faults which would prevent us from operating the system. This project significantly changed the way in which batteries are procured in two key ways. The first of these relates to the point at which the system is considered to be complete. It is normal practice when procuring network equipment to make a large proportion of the payment when the equipment is complete at the factory, or physically installed on site. The energisation or operation of the equipment may follow on some time later (for instance the end of the outage), which is out with the control of the supplier and therefore withholding payment would be unreasonable. However, in this project the delay was encountered at the point after battery installation, but prior to energisation. It is now established practice to have increased penalties for delay to system energisation and to retain additional payment until this milestone is completed. The second point relates to the debate regarding who should own energy storage systems, in relation to the balance of risk and reward to distribution customers. This is an area SHPED are actively exploring in the Orkney Energy Storage Park and UKPN are through the LCNF Tier 2 Smarter Network Storage project. There is no definite conclusion to this yet, but this project highlighted a number of the key concerns relating to ownership of this type of technology.

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[7] This project also used the search code 1.10.1 Electricity.

For more information on this project see: http://www.ssepd.co.uk/HaveYourSay/Innovation/Portfolio/OrkneyPhase1/

5.2 Reference installation of a NAS battery

SHEPD have carried out a reference installation for a first of a kind (FOAK) deployment of a NAS battery in the UK. This involved identifying and resolving numerous design, construction and operational issues as set out in Section 4. Documents detailing the transportation, storage, installation and operation of NAS batteries are detailed in Table 8.

5.3 NAS safety case

The work carried out on the NAS safety case identified the relevant codes, standards and legislation for the NAS battery. This was later used as a benchmark for assessing the VRLA technology. The review of supplier documentation highlighted key information related to the safety case and appropriate questions were raised and resolved with the supplier. Details of both these items are listed in Table 8.

The outcome from the review of the Japanese fire investigation concluded that the NAS battery is currently not fit for purpose in the location specified but may well be suited to applications in a different setting. The main reason for this is the lack of a fire extinguishing, or suppression, system. Without a credible system a fire could create a situation that would require the evacuation of the power station for a considerable period of time[8] until the fire self extinguished. This is unacceptable within a power station environment such as Lerwick. However this would not preclude sighting similar batteries in other locations and the manufacturer has resumed production of the batteries with the additional safety modifications described in 4.13.1. The battery manufacturer may also look at developing a fire suppression system which could be used in future although the timescales for this are not known at the present time.

5.4 NAS battery specification

The specification of the NAS battery is shown in Table 2. This details the make up of the battery, its characteristics, primary materials and warranty.

[8] This would be measured in days, not hours.

Table 2 - NAS battery specification

NAS Battery Specification	
Battery manufacturer	NGK Insulators Ltd.
Manufacturing location	Nagoya, Japan
Battery type	Sodium Sulphur (NAS)
Power	1MW
Energy storage	6.32MWh
Module weight	3400Kg
Total no. of cells	7040
No. of modules	20
No. of cells per module	352
BESS nominal voltage	640V
Voltage range	470V to 745V
Current range	-900/+1400A
Primary materials	Sodium polysulphides, sulphur, sodium
Warranty	15 Years / 4500 cycles

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5.5 Lead-acid battery specification

The specification and configuration of the lead-acid battery is shown in Table 3. This details the make up of the battery, its characteristics, proposed configuration, primary materials and warranty. The final report will include the battery operational efficiency.

Table 3 – Lead-acid battery specification

Lead-Acid Battery Specification	
Battery manufacturer	GS Yuasa International Ltd.
Model	SLE 1000
Manufacturing location	Kyoto, Japan
Battery type	Valve Regulated Lead-Acid (VRLA)
Power	1MW
Energy storage	3MWh
Cell size	1000Ah
Cell Weight	64Kg
Total no. of cells	3168
No. of cells per module	6
No. of modules per string	44
No. of strings	12
BESS nominal voltage	528V
Voltage range	475V to 645V
Current range	Maximum +/-2500A for whole system
Primary materials	Lead, lead dioxide, dilute sulphuric acid
Warranty	5 Years / 1500 cycles

5.6 Lead-acid safety case

Assessment against relevant legislation

First the battery was assessed against the relevant legislation. Of most importance, the battery is compliant with ‘JIS C 8704 Stationary Lead-Acid Batteries’, the Japanese equivalent to IEC 60896-21 and IEC 60896-22, Stationary Lead-Acid Batteries – Valve Regulated Types. This sets out a comprehensive method of test and requirements for VRLA batteries. The results have been shared with SHEPD.

Consideration was also given to whether the battery was subject to lower-tier Control of Major Accident Hazards (COMAH) regulations. Discussions between SHEPD, the Health and Safety Executive (HSE) and Scottish Environment Protection Agency (SEPA) took place in August 2013 and were very informative. The HSE concluded that the Shetland lead-acid batteries are defined as ‘articles’ under the Registration, Evaluation, Authorisation and restriction of Chemicals (REACH) regulations and Classification, Labelling and Packaging (CLP) regulations and therefore do not meet the definition of ‘dangerous substances’ in COMAH.

Assessment against fire and hydrogen gassing

Second, Buro Happold were instructed to carry out a quantified fire engineering assessment for the lead-acid battery. The results were favourable:

- The assessment of available data has been noted as challenging due to little fire load testing being available. This reflect the extremely low likelihood of a fully developed fire occurring.
- The results indicate that it is not considered credible that a fire in the battery storage building could develop large enough to cause fire spread to adjacent buildings or fuel storage.
- The main components, lead, lead oxide and dilute sulphuric acid do not contribute to the fire load. Instead this is the case material ABS rated at UL94:HB and constitutes up to 10% of the battery weight.
- There are a number of additional safety factors concurrent throughout the report.

Next, consideration was given to hydrogen gassing. Discussions with Yuasa indicate that under normal operating conditions hydrogen gassing would be close to zero – a 99% reduction compared to traditional flooded lead-acid cells. Details of the fire engineering assessment, safety data sheet and considerations to hydrogen gassing and ventilation are outlined in Table 8.

Despite these positive outcomes, S&C have opined to install a very early smoke detection apparatus (VESDA) with a hydrogen gas detection system. This will be connected to an inert gas fire suppression system and forced ventilation to respond to a fire or build up of hydrogen respectively.

5.7 Technology Readiness Level (TRL)

The NAS TRL was not increased due to not reaching the operational stage. The project is applying a novel – GB – application to the mature lead-acid battery technology. It is expected that the lead-acid BESS TRL will be 8 or 9 on completion of the project.

6 Performance compared to original project aims, objectives and success criteria

The difficulties reaching the operational stage of the project have prevented many of the objectives and success criteria from being met at this stage. This section will be revised in the final close down report once learning from operational experience has been established.

Table 4 – Extent to which objectives have been met

Objective	Met?	Commentary
Delivery of the 1Mwe battery by the end of March 2011	✓	The NAS battery and PCS were delivered to Shetland on schedule.
Secure initial learning from the installation of the battery	✓	The project has exceeded the aims of this objective. The project's experience of two battery technologies has generated significant learning in a number of areas including the: procurement process; design of the battery building; installation and removal of the NAS battery; and well documented safety cases for NAS and lead-acid batteries.
Secure initial learning from the operation of the battery	✗	The project has not yet reached the operational stage to allow this objective to be evaluated. By the end of March 2014, we will have had nearly four months of total operation, using the phase 1 and phase 2 VRLA systems. The nature of the VRLA system and the agreed warranty conditions will allow us to complete initial analysis in this timescale.

Integration with local demand response	✗	As set out in Section 4.9, the project successfully provided the means to integrate a BESS with local demand response. However as the NAS battery was not successfully commissioned, this objective is not yet complete. Demand response is however already underway in the wider NINES project, which the Shetland battery will integrate with. It will therefore be possible to exceed the initial objective by March 2014, due to the significantly larger demand response that will be available.
Reduce station peak demand to provide additional demand capacity (similar to managing a network load constraint)	✗	The project has not yet reached the operational stage to allow this objective to be evaluated. Analysis work which has been carried out by the University of Strathclyde under the NINES project has however provided further evidence to inform this mode of operation. It will therefore be possible to fully achieve this objective by March 2014.

Table 5 – Extent to which success criteria have been met

Success Criteria	Met?	Commentary
The battery must be able to reduce the peak demand on the station allowing the connection of new demand.	✗	The project has not yet reached the operational stage to allow this success criterion to be evaluated.
The battery must be able to cycle efficiently according to the needs and profiles of the islands' generation and demand.	✗	The project has not yet reached the operational stage to allow this success criterion to be evaluated.
The battery installation will allow SHEPD – and the UK in general – to gain a better understanding of battery operation within a network environment.	✗	The battery project has secured substantial learning to further the understanding of battery operation within a network environment. However, until a suitable period of operational run time has been achieved, this success criterion cannot be classed as met.

7 Required modifications to the planned approach during the course of the project

A significant modification to the planned approach was the change in technology from NAS to VRLA following the fire at a NAS installation in Japan and subsequent investigation described in Sections 4.12 and 4.13. The modification required an extension to the project end date, from March 2012 to March 2014.

8 Significant variance in expected costs and benefits

8.1 Costs

Table 6 shows the expected overall cost of this Tier 1 project to the end March 2014. As detailed in the registration form, the overall project draws on a number of funding sources, this section relates solely to the Tier 1 component. Spend to date has been £910k with an expected final spend of £960k. Changes in the cost of individual components are detailed below:

Table 6 – Tier 1 Project Budget

Item	Forecast (£k)	Expected Final (£k)	Variance (£k)	Variance (%)
Battery system	300	300	0	0
Civil and building works	115	138	23	20
Auxiliary systems	10	32	22	220
Network connection	100	75	-25	-25
Battery control system	125	118	-7	-5.6
Communications systems	40	37	-3	-7.5
External assessment	90	60	-30	-33.3
SHEPD labour	220	200	-20	-9
Total	1000	960	-40	-4

Battery building

Due to the coastal location of the battery site, SHEPD always intended to have the enclosed battery inside a dedicated building. We did however opt to have the additional protection of salt filters on the battery enclosure air intakes. This addition required a change to the shape of the battery – (2x2x5) arrangement of modules instead of (4x1x5). The change meant that access from two sides had to be provided as opposed to just one. Together with the need to use the specialist module insertion tool described in Section 4.8, this increased the size of the battery room inside the building. The requirements for access around the PCS were also greater than initially estimated, further altering the original shape. As a result of these required changes, civil work costs increased by 20%.Further modifications to the battery building are required to accommodate the VRLA BESS. These costs shall be absorbed by the supplier.

Ventilation system

Both the NAS battery and PCS have forced air cooling. SHEPD knew that this would therefore require sufficient air flow into the building to service these cooling systems. Our initial design maximised natural ventilation, but the suppliers' final heat profiles showed this would be insufficient. We therefore replaced this with a forced air cooling system (note this is only forced, not chilled, air). The additional cost of the forced air cooling system increased the auxiliary system costs by 220% (16% on civil costs by comparison).

Network connection

SHEPD were able to utilise a spare 11kV breaker on the existing Gremista switchboard, with minor works to change the protection system and add a power quality recorder. This reduced network connection costs by 25%.

External assessment

As detailed elsewhere in this report, external assessment and validation formed an important part of building the safety case for the battery technologies and the work to ensure valid learning will be captured in the operational phase. From the time of initial budget this work has been further refined and in particular learning from the operational phase of the VRLA system is anticipated to utilise internal rather than external resource, this reduced the expected cost by 33.3%.

8.2 Benefits

The project benefits can be split into two distinct areas, those which formed the core purpose of the project (planned benefits) and those which arose during the course of project delivery (additional benefits).

8.2.1 Planned benefits

Transferable learning on battery installation and commissioning

As detailed previously in Section 4, this project has generated a substantial quantity of widely applicable learning on the procurement, design, installation and commissioning of grid scale battery systems.

Reduction of winter demand peaks

While this benefit has not yet been achieved, work carried out in parallel on the NINES project by the University of Strathclyde analysed the potential for the battery to achieve this. The analysis was of the peak demand period which occurs at lunchtime. Figure 22 below shows the comparative maximum demand over a typical 7 day period and indicates the duration of lunchtime peak between the 28th January 2010 and 3rd February 2010. It can be seen that this peak is of short duration such that the 1MW / 3MWh battery can be scheduled to discharge and easily – and consistently – reduce the peak by 1MW. We aim to validate this through operational experience in the next phase of the project.

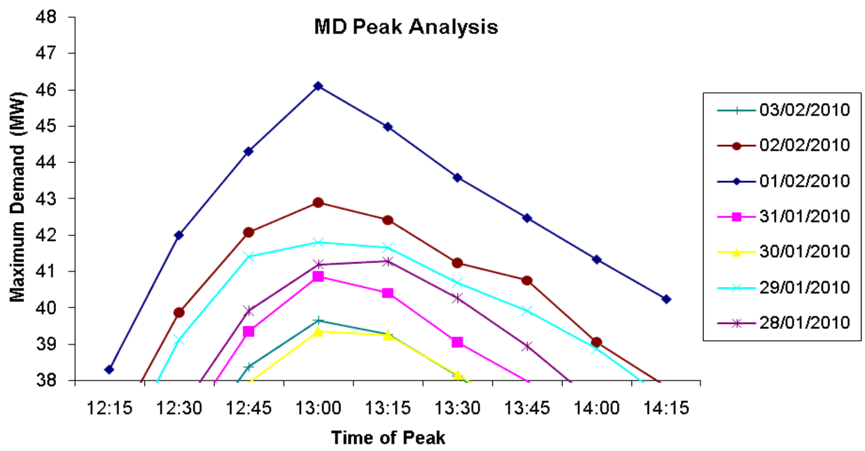

Figure 23 - Winter demand peak analysis

Connection of additional renewable generation

As above, this benefit has not yet been achieved. However, the modelling work by University of Strathclyde concluded that to charge the battery from otherwise constrained renewable generation, the limiting factor on the Shetland network is the stability limit. There are two components to this, the frequency limit which for a 1MW battery would be reached at 0.44MW and the dispatch rule which would be reached at 0.8MW. This assumes that the battery can not provide any frequency response functionality and is therefore a conservative estimate. In the operational phase of the project – under NINES – we will investigate the extent to which these limits can be increased.

Understanding of battery operation, applicable to all DNOs

As we have yet to reach the operational phase of the project, this section will be presented in the final close down report.

8.2.2 Additional Benefits:

Establishment of ESOF

The scale of this project was significantly larger than any previous trial of battery systems, which resulted in significant work on the technical assessment and safety case, detailed previously in Sections 4.4 and 4.5. To complete this we worked with EATL, who brought significant experience and expertise to the project. It did however also highlight the extent to which there should be collaboration between DNOs and the need for an accessible forum to discuss, question and transfer learning between projects. To this end, in early 2012, SHEPD and EATL jointly instigated the Energy Storage Operators Forum (ESOF). This forum is now well established, with the 5th meeting scheduled for late September and also taking the lead on energy storage dissemination at this years LCNF conference in Brighton.

Two battery technologies

Although disappointing that we were unable to proceed with the NAS technology, it has meant that we have gained learning on two different battery technologies, without any additional cost.

9 Lessons learnt for future projects

A number of learning outcomes have been presented throughout the body of the report. The '1MW Battery, Shetland' project was the first to be registered by SHEPD therefore aspects of this have both directly and indirectly influenced all of SSE's LCNF projects including the LV batteries at Chalvey and the Orkney Storage Project. This includes everything from simple aspects such as a better understanding of the project registration pro-forma and governance, to building on pre-existing documents for tenders or contracts. Further to this, lessons were learned within the project that have been beneficial. The change in technology required aspects of the project to be repeated. Examples include: the safety case and technical assessment; building works; and the battery installation. SHEPD went into this with a better understanding of the requirements and this prior experience shoudl continue to contribute to the successful delivery of the project.

GB DNOs working on similar projects are encouraged to review the tables in Section 11 for resources that may assist their future projects.

10 Planned implementation

Converting innovative new technologies and solutions to business as usual (BAU) is a fundamental goal for SHEPD's Future Networks team. Learning from the operation of this project – and other projects in the SSE R&D portfolio – will inform SHEPD on the use of batteries in terms of BAU. The primary use of the Shetland battery is to reduce the peak demand. When charging, the battery will also be capable of providing extra demand during the minimum network load. Under NINES, the battery will be assessed in its ability to optimise the running of engine sets and remove renewable constraints. The battery forms a key element of the recently submitted integrated plan for Shetland where it could contribute to the overall new station from early 2017. However commercial considerations will play a large part in determining the optimum mix of varying technologies within a future BAU solution.

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11 Project replication and intellectual property

A further principle aim of SHEPD's Future Networks team is the learning, knowledge capture and subsequent dissemination of key project information and resources that could benefit future projects. GB DNOs working on similar projects are encouraged to contact our team through futurenetworks@sse.com to discuss learning relating to the materials contained in Table 7 or 8. Table 7 details the primary components used in the project. Items in grey were used only for the NAS battery solution and are no longer required, Table 8 details relevant knowledge products.

Table 7 – Components required for project replication

Component	Products used in project or commercially available equivalents
Battery	1MW, 6MWh Sodium Sulphur (NAS) battery manufactured by NGK Insulators Ltd
Battery	1MW, 3MWh VRLA battery manufactured by GS Yuasa
Power Conversion System	1MW, 1.25MVA PureWave Storage Management System (SMS) manufactured by S&C Electric
Transformer	1250KVA, 11KV/480V oil filled transformer manufactured by Power & Distribution Transformers Ltd
Local Interface Controller	Allen Bradley CompactLogix Programmable Logic Controller
Remote Terminal Units	Talus C10e and Talus T100 manufactured by Schneider Electric UK
Desktop Client	PC running Windows XP
Software	Microsoft SQL 2008, Rockwell FactoryTalk View Site Edition, Rockwell Factory Talk Transaction Manager, Rockwell RSLinx Classic, RSLogix5000
Gas detection (NAS)	Draeger Regard 3900 control system with 6 X Polytron transmitters for H2S and SO2 gas detection
Fire and gas detection (lead-acid)	Very Early Smoke Detection Apparatus (VESDA) Laserplus (VLP002) double knock system with hydrogen gas detection
Fire suppression	Prolnert IG-55 inert gas fire suppression system
Air conditioning	8 x Toshiba RAV-SM804CT ceiling suspended air conditioners connected to 8 x Toshiba RAV-SM803AT-E heat pump condensers

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Table 8 – Knowledge products required for project replication

Knowledge item	Application	IP ownership
Results of Achilles searches	Search codes used to identify potential suppliers and results	SHEPD
Invitation letter IB-AWM-170301	Advance invitation letter sent to prospective suppliers detailing general requirements	SHEPD
Invitation to tender	Includes: instructions for tender applications, a draft contract, a tender pro forma, pre construction information and appendices	SHEPD
Tender evaluation matrix	Provides evaluating criteria, description and associated weighting to assess the tenders received	SHEPD
SSE Storage Management System (SMS) specification rev.1	Specification for the power conversion system	S&C Electric Company
SSE Storage Management System FAT report	Report detailing factory acceptance testing for the power conversion system	S&C Electric Company
SSE Storage Management System O+M manual rev.2	Operating and maintenance manual for the power conversion system	S&C Electric Company
Battery inspection test certificate	Warehouse inspection and battery module FAT certificate	Japan Wind Development Co Ltd and NGK Insulators Ltd
Battery control cabinet test certificate	Test certificate for NAS battery control cabinet	NGK Insulators Ltd
NAS battery storage manual for 1MW battery system MAND-P358-ST-01	Storage instructions for the NAS battery	NGK Insulators Ltd
NAS battery transportation manual for 1MW battery system MAND-P358-TR-01	Transportation instructions for the NAS battery	NGK Insulators Ltd
NAS battery installation manual for 1MW battery system MAND-P358-IN-01	Installation instructions for the NAS battery	NGK Insulators Ltd

NAS battery instruction manual for 1MW battery system, SSE, Shetland MAND-NP-201017	Details safety and operating precautions, configuration and specifications for the NAS battery	NGK Insulators Ltd
Site acceptance test procedure and reporting form for 1MW battery system, SSE, Shetland NAS-111154	Details the site acceptance testing for the NAS battery	NGK Insulators Ltd
Technical analysis proposal Energy Storage System trial on Shetland SGS-200035-04A	Technical analysis of the ESS trial	Smarter Grid Solutions Ltd
Technical analysis methodology Energy Storage System trial on Shetland SGS-200035-05B	Technical analysis of the ESS trial	Smarter Grid Solutions Ltd
Production of design specifications Energy Storage System trial on Shetland SGS-200035-06A	Outlines the objectives of each specification document	Smarter Grid Solutions Ltd
Technical analysis report Energy Storage System trial on Shetland SGS-200035-07A	Technical analysis of the ESS trial	Smarter Grid Solutions Ltd
Requirements specification Energy Storage System trial on Shetland SGS-200035-08B	Defines the functionally required by the BESS control system	Smarter Grid Solutions Ltd
Functional design specification Energy Storage System trial on Shetland SGS-200035-09A	Primary design document for the BESS control system	Smarter Grid Solutions Ltd
User interface guide Energy Storage System trial on Shetland SGS-200035-10A	Introductory guide to the user interface for the BESS	Smarter Grid Solutions Ltd

Test specification Energy Storage System trial on Shetland SGS-200035-11B	Details the factory acceptance testing and site acceptance testing for the battery control system	Smarter Grid Solutions Ltd
Shetland battery project Battery and process safety review Review of codes, standards and legislation Project No. 78830 Report No. 6504	Review of relevant codes, standards and legislation	EA Technology
Shetland battery project Battery and process safety review Review of documentation and operating manual Project No. 78830 Report No. 6509	Review of documentation provided by supplier S&C Electric in relation to the BESS	EA Technology
Shetland battery project – Technical assessment benchmark report Report No. 78840/1	Analysis benchmarks to assess the network performance of the BESS	EA Technology
Fire engineering Lerwick battery installation NAS fire safety assessment 030430 Rev.2	Quantified assessment of potential fire safety implications in the event of a fire in the NAS BESS. Assesses the risk of fire spread from the BESS to adjacent buildings including a 3-D radiation model. Also considers SO2 dispersion	Buro Happold
Fire engineering Lerwick battery installation NAS fire safety assessment 030430 Rev.3	Quantified assessment of potential fire safety implications in the event of a fire in the lead-acid BESS. Assesses the risk of fire spread from the BESS to adjacent buildings including a 3-D radiation model	Buro Happold
Information request	Request for information issued to S&C Electric to assess technical design, safety case and O+M requirements for lead-acid solution	SHEPD
SSE Storage Management System (SMS) specification rev.2	Specification for the power conversion system amended for the change in technology to lead-acid	S&C Electric Company

Yuasa technical training seminar	Training programme covering: basic chemistry of VRLA batteries; charge and discharge characteristics; factors affecting battery life; and installation recommendations	Yuasa Battery Europe Ltd
SDS VRLA batteries rev.4	Safety data sheet for Yuasa's Valve Regulated Lead-Acid batteries	Yuasa Battery Europe Ltd
Installation guide ver.3	High level installation guide for Yuasa VRLA batteries	Yuasa Battery Europe Ltd
Gas production in Yuasa VRLA batteries QAT02-D	Provides details of hydrogen gassing expected during normal operation and example calculations	Yuasa Battery Europe Ltd
Ventilation QAT02-M	Equation Yuasa use to determine ventilation requirements	Yuasa Battery Europe Ltd
Safety requirements for secondary batteries and battery installations Part 1: General safety information BS EN 50272-1:2010 Part 2: Stationary batteries BS EN 50272-2:2001	Covers safety aspects associated with: electricity; electrolyte inflammable gas mixtures; storage; and transportation. Details requirements on safety aspects associated with the erection, use, inspection, maintenance and disposal of lead-acid batteries	BSI
Stationary lead-acid batteries Part 21: Valve regulated types – Methods of test BS EN 60896-21:2004 Part 22: Valve regulated types – Requirements BS EN 60896-22:2004	Provides the method of testing and requirements that will result in the battery meeting the needs of a particular operating condition or industry application. Includes templates for the: reporting format, battery user statement of requirements and battery manufacturer (or vendor) statement of test results	BSI

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