LCNF Tier 1 Close-Down Report

1MW Battery, Shetland

SSET1001

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Executive Summary

This report presents the findings from the Scottish Hydro Electric Power Distribution (SHEPD) Low Carbon Networks Fund (LCNF) Tier 1 project "1MW Battery, Shetland". 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. After consideration of the residual risk, 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 3MWh valve regulated lead-acid battery was selected as an alternative. In May 2013, the NAS battery was removed and building modifications commenced to prepare for the first lead-acid cells which arrived on site in October 2013. Installation of all 3168 cells was completed in December 2013. Work continued in the first quarter of 2014 to complete the installation of fire suppression and gas detection systems along with some unforeseen revisions to control software. Battery commissioning to allow initial operation of the system was completed in February 2014 with full commissioning and integration into the active network management system completed in June 2014. An optimal battery operating schedule was determined and implemented to prove the battery could provide a reduction in peak demand and cycle efficiently according to the network requirements.

The project has generated significant learning in key areas including: procurement, design, construction, installation, commissioning and safety. Time has been taken to detail knowledge items, necessary for project replication, which may benefit future projects. This experience has fed into the Energy Storage Operators Forum – established by SHEPD during the project – and ensures knowledge transfer to UK Distribution Network Operators. With the Tier 1 objectives complete, the battery energy storage system will continue to be trialled and evaluated under the Northern Isles New Energy Solutions (NINES) project.

The project background, scope and objectives, and success criteria are provided as stated in the project registration document 13th September 2010.

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

[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.

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:

- 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

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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

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]

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.

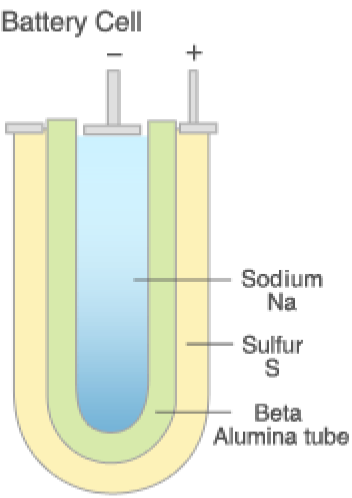


Figure 2 - NAS cell composition
http://www.ngk.co.jp/english/products/power/nas/principle/index.html

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.

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

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.

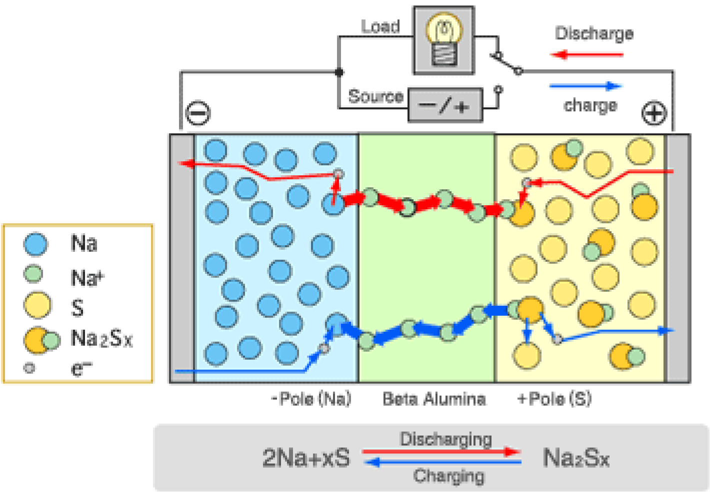


Figure 3 - Charging cycle
http://www.ngk.co.jp/english/products/power/nas/principle/index.html

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.

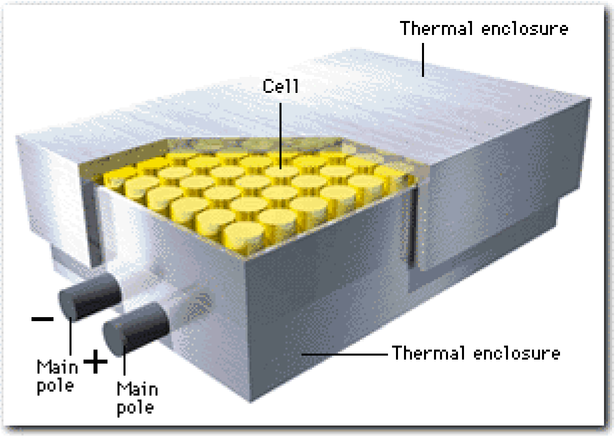


Figure 4 - NAS battery module
http://www.thefraserdomain.typepad.com/energy/2006/01/sodiumsulfur_na.html

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.

The approach to this engagement 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

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 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 product quality is 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.

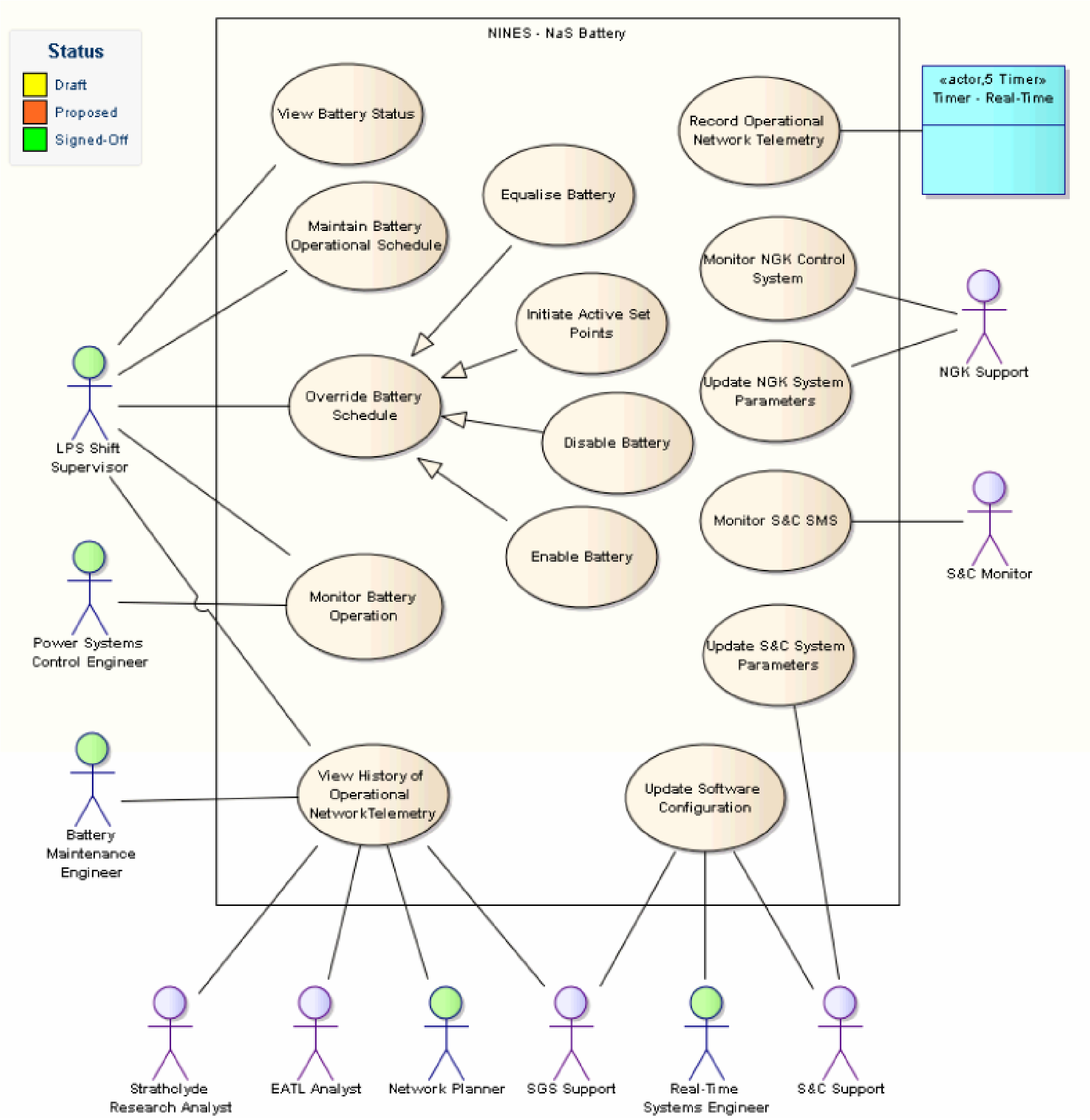


Figure 6 - NAS battery level 0 use case, an example of Enterprise Architecture documentation

4.9 Civil works

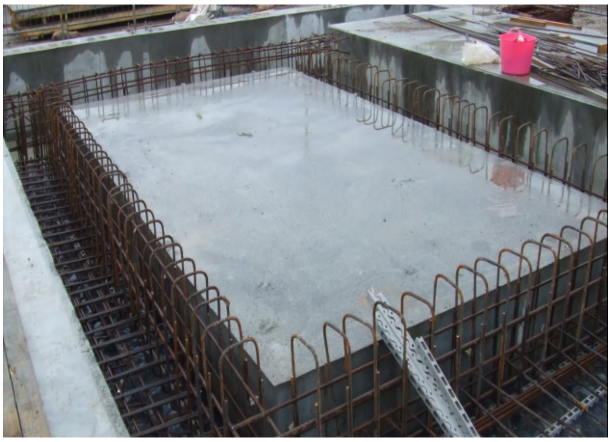
Plans for the battery building were specified by MacGregor McMahon to applicable British Standards. A building plan visualisation in relation to Lerwick Power Station (LPS) is shown in Figure 7 with a close up shown in Figure 8.

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 system 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 loader crane, 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.

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 loader crane 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

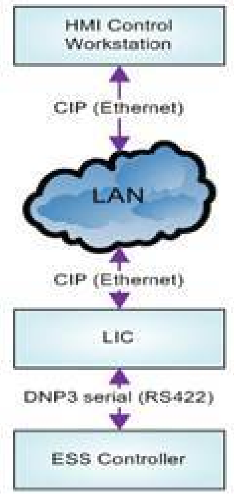
Following the completion of remaining cable works, the battery was ready for commissioning.

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

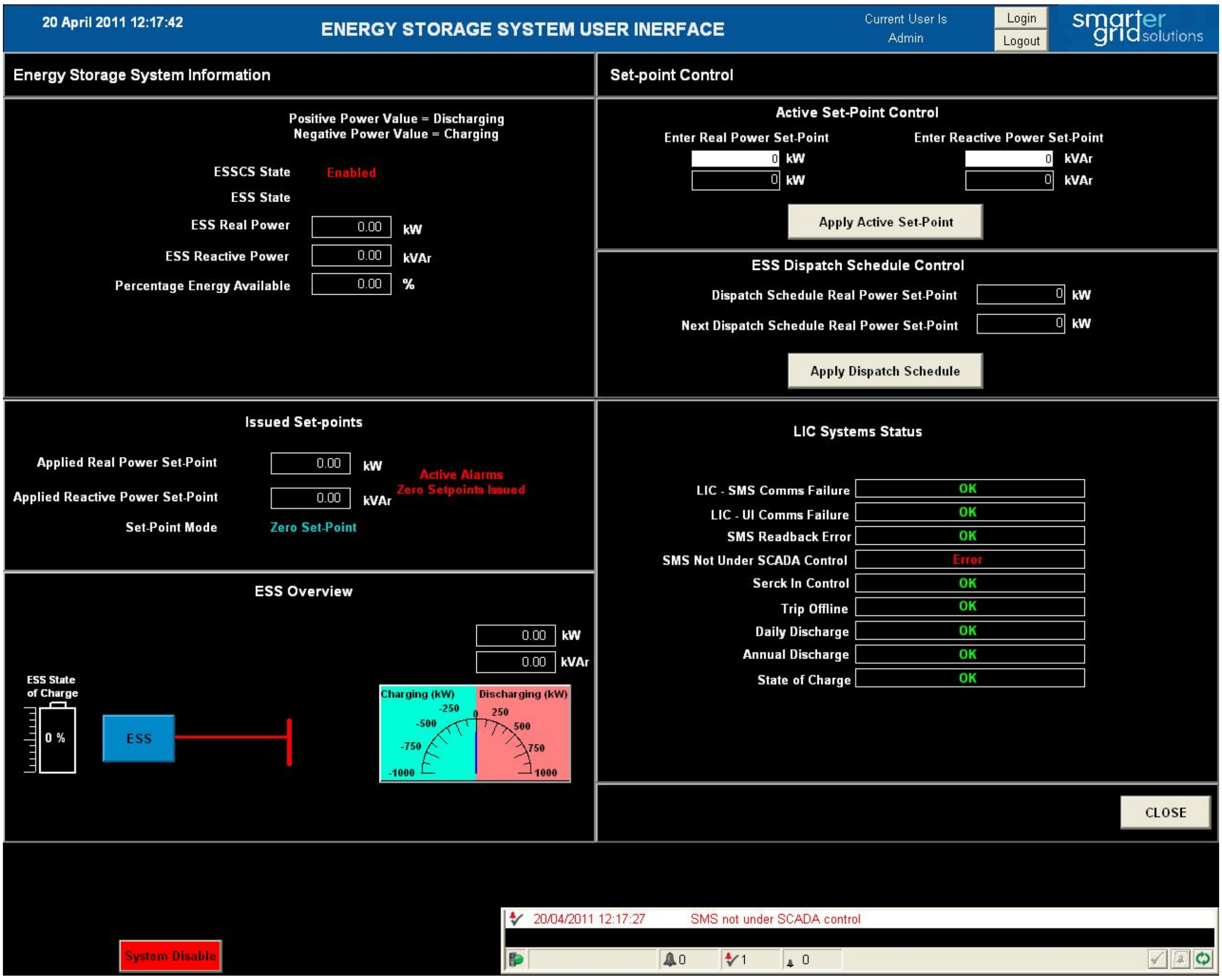


Figure 20 - HMI screenshot for monitoring and control of the BESS

4.12 NAS 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 insufficient information in 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.

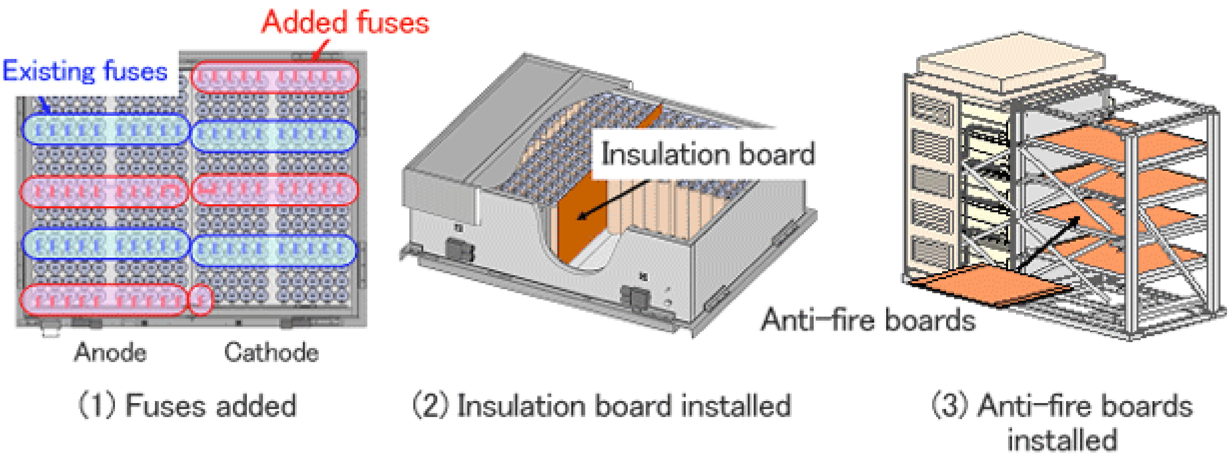


Figure 21 - NGK remedial measures to enhance safety
http://www.ngk.co.jp/english/news/2012/0607.html

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 could therefore necessitate the evacuation of Lerwick Power Station, a local district heating system and other residences. This would require SHEPD to switch 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 consequences 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. Contrasting these non-network connected standby applications, the '1MW Battery, Shetland' installation applied a novel application to the technology.

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 5.6.

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 arrived on schedule 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] The manufacturing plant in Wales produces a smaller cell than what was required for the Shetland project.

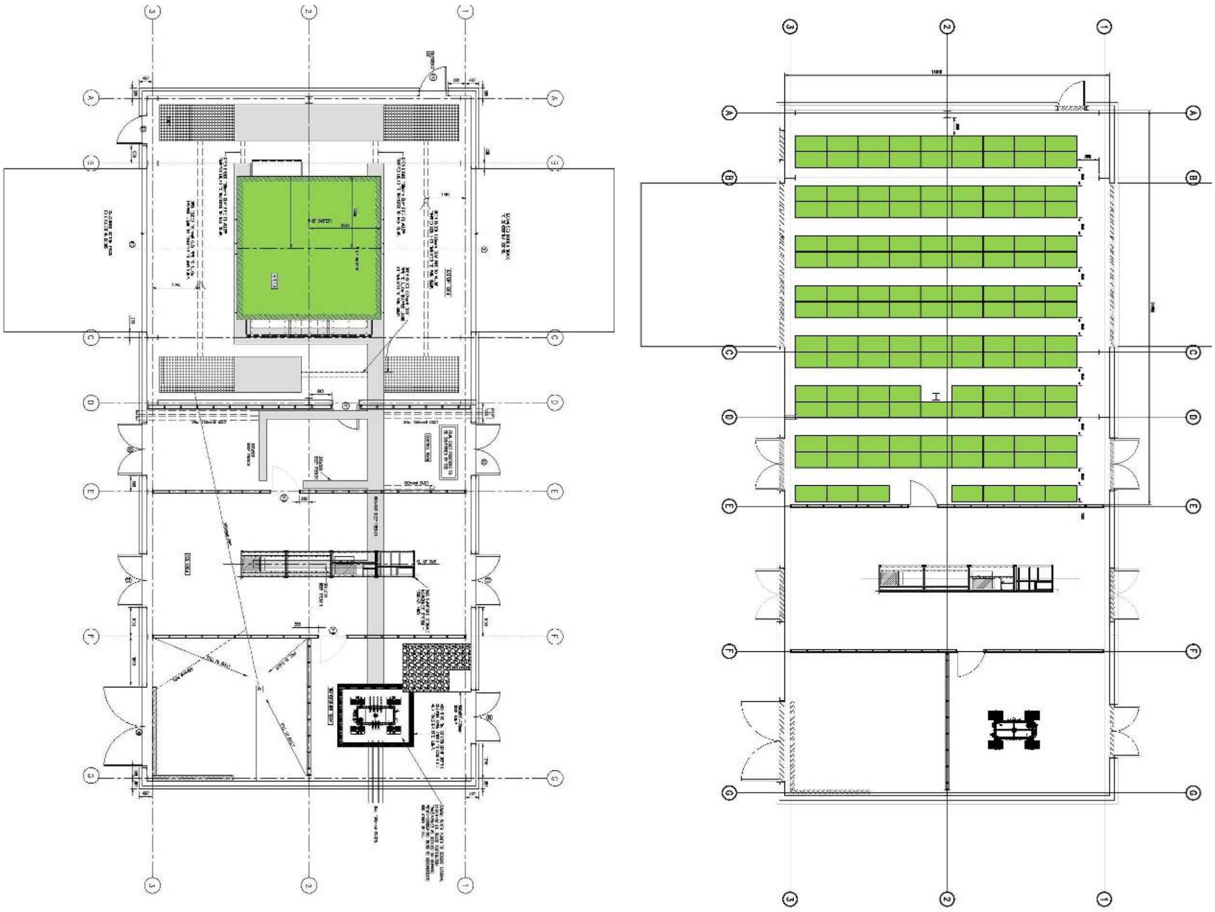


Figure 22 - Battery footprint comparison

To accommodate this increase in footprint, some minor building modifications were required. This included 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. The building was previously designed to dissipate heat. To combat this, and improve the thermodynamic characteristics of the battery room, a floating ceiling was introduced and the large roller doors were removed and clad. Modifications were also made to the HVAC system. The combined effect of these changes increases the insulation in the room, requires less energy to maintain the optimum temperature and ensures the efficiency of the battery is not significantly reduced.

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

4.13.8 VRLA battery installation

Yuasa and Thamesgate were responsible for the VRLA battery installation under supervision of S&C and SHEPD. Rows of six cells had been pre-assembled when they arrived in the UK to minimise the packing materials brought on site and to speed up the installation. Where space allowed, the rows were lifted into position with mechanical assistance otherwise a trolley jack was used. Installation work is shown in Figure 23.

Figure 23 - VRLA battery installation

A completed rack of cells is shown in Figure 24.

Figure 24 - VRLA battery rack

Eleven racks are connected in series to make up a battery string. Each string is protected with a 250A isolator as shown in Figure 25.

Figure 25 - 250A string isolator

There are twelve strings in total, split into two groups of six. Each group has its own battery cabinet containing six 200A 3-pole MCCB's providing a further point of isolation for each string. The battery cabinet also contains a single 1440A rated 4-pole MCCB (poles linked in parallel) complete with 48V DC shunt trip if isolation of the entire half of the battery is required. Twelve 95mm cables run from the battery cabinet to supply the six strings. Four 150mm cables run from the battery cabinet to the power conversion system. The battery cabinet is shown in Figure 26.

Figure 26 - Battery cabinet

Two photos of the complete installation are shown in Figure 27 and Figure 28.

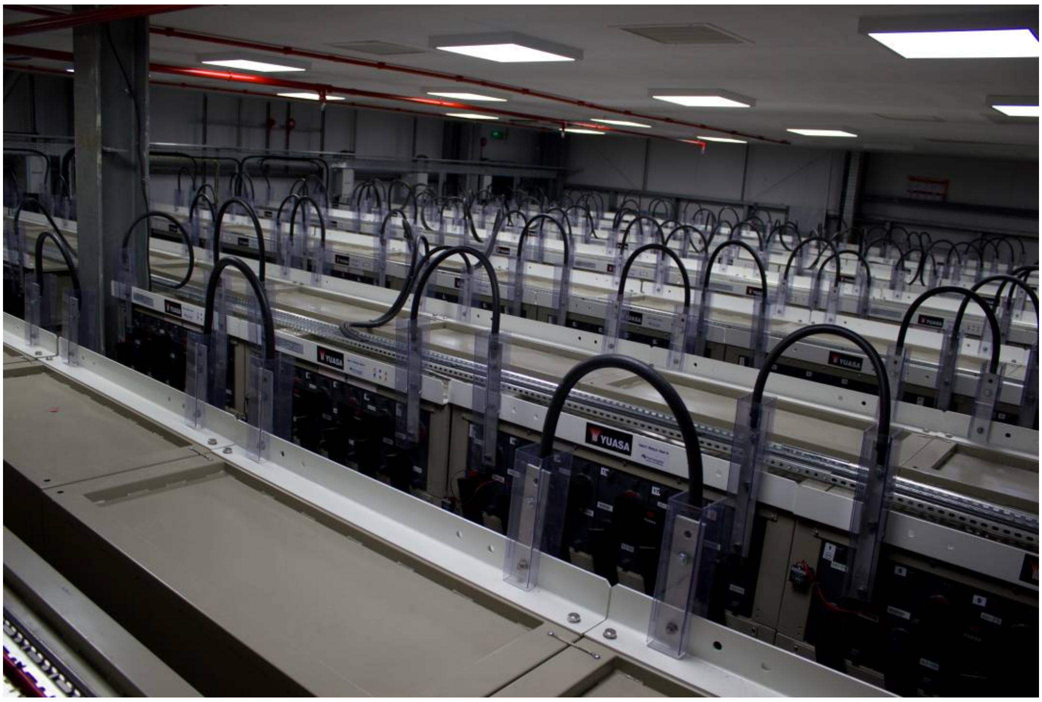


Figure 27 - Installed battery (i)

Figure 28 - Installed battery (ii)

Figure 29 illustrates the string layout.

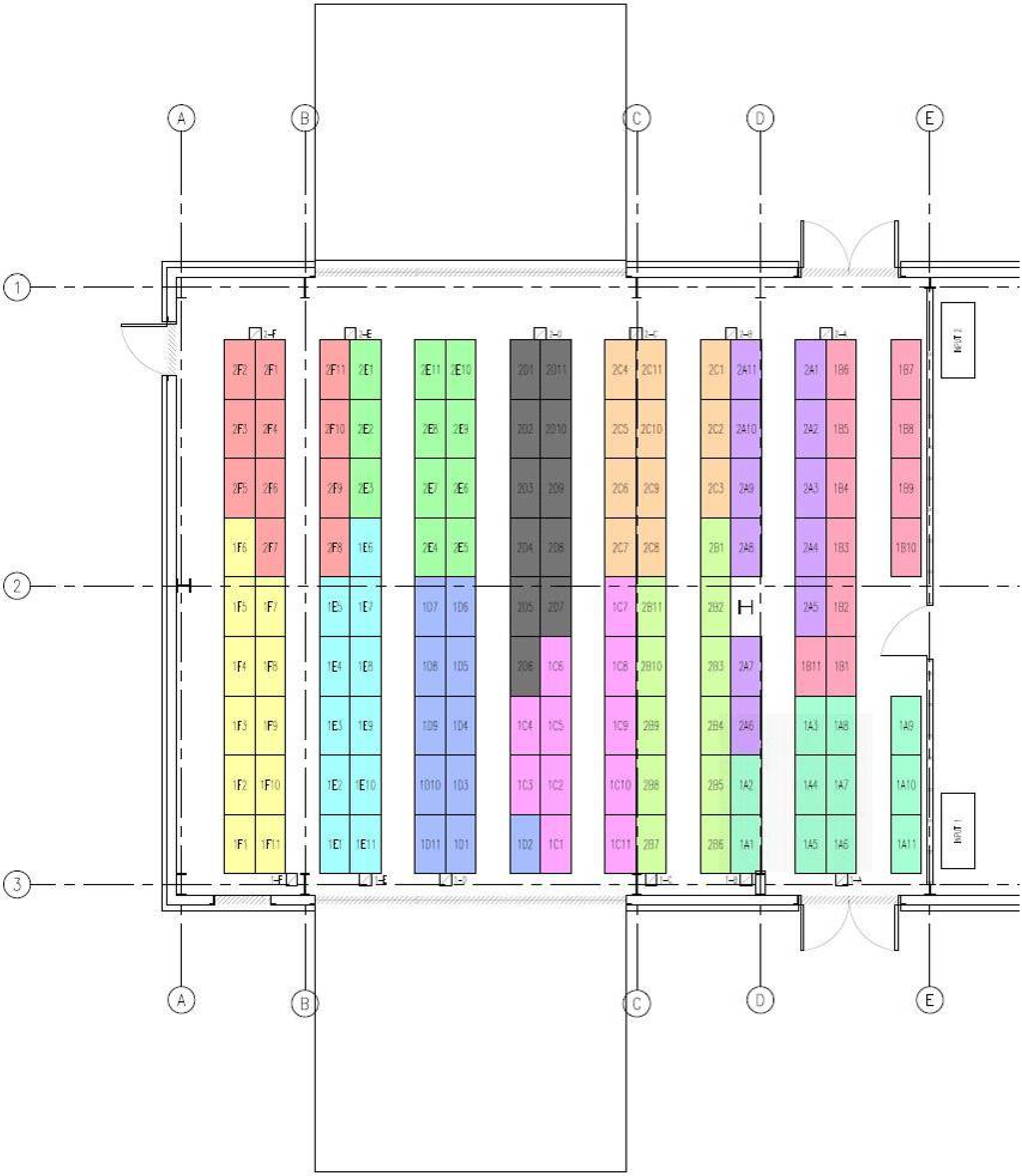


Figure 29 - String layout

4.13.9 Safety systems

Following the installation of the battery cells, works continued to fit a fire suppression and hydrogen detection system. Thamesgate procured and installed a Very Early Smoke Detection Apparatus (VESDA) Laserplus double knock system with hydrogen gas detection as shown in Figure 30.

Figure 30 - VESDA and hydrogen detection

The hydrogen detection units shown in the top right of Figure 30 are configured to respond to a concentration of hydrogen. The lower explosive limit (LEL) of hydrogen is 4%. At 1%, or 25% of the LEL, the hydrogen detection system triggers a relay which activates the forced ventilation in the building. At 2%, or 50% of the LEL, the hydrogen detection system triggers a second relay which trips the power supply to the battery.

The VESDA is connected to a ProInert IG-55 inert gas fire suppression system. The double knock aspect of the VESDA ensures the system doesn't fire unintentionally. The gas bottles are situated in a storage room as shown in Figure 31.

Figure 31 - Inert gas for fire suppression

4.13.10 Battery monitoring system (BMS)

A battery monitoring system (BMS) was provided by Yuasa in conjunction with REAP systems. The BMS provides data to the power control system (SMS) to ensure the battery cells are charged within the manufacturer's specification. A secondary purpose allows for data logging for the lifetime of the battery that can be used to optimise performance and provide troubleshooting support if required. The BMS has two displays for presenting data on the two halves of the battery. It can also be set to a graphical display which details the state of charge of each of the strings. For reference one of these displays is shown in Figure 32 detailing a fully charged battery sitting idle.

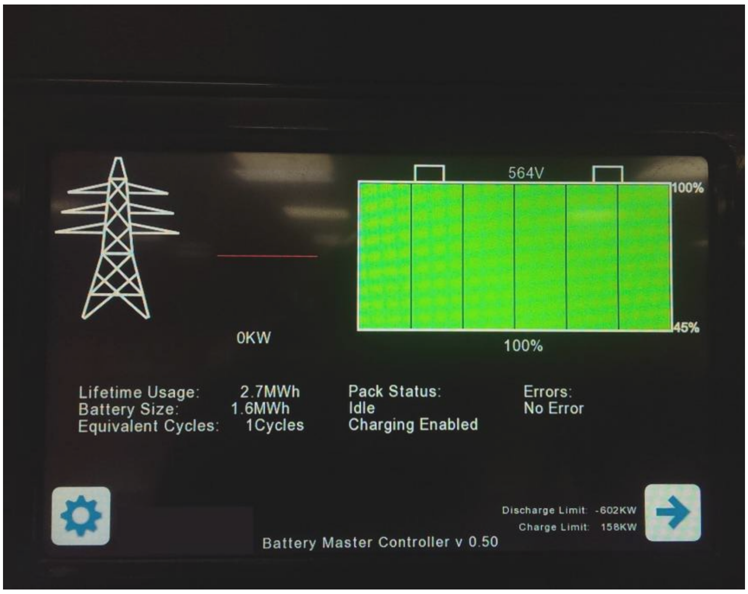


Figure 32 - BMS display

4.14 BESS commissioning

Commissioning of the battery energy storage system was an involved process, a brief summary is provided here. It was necessary to fully retest the power conversion system and aspects of this required specialist input from S&C's US personnel. Examples of issues encountered include: software and component upgrades; replacement of the UPS; and reforming capacitors. In parallel the VRLA cells were inspected and tested by the battery manufacturer. Testing of the emergency stop circuits, fire alarms and CCTV were all completed before on-load testing of the battery could commence. At this stage protection could be tested to confirm it operated as expected.

The next step of commissioning was the communications architecture. This included: the BMS to power conversion system (SMS); the SMS to the local interface controller (LIC); and the remote terminal units into the power station's SERCK supervisory control and data acquisition (SCADA) system. A software upgrade was required for the BMS to allow communication with both halves of the battery. A loss of communications was experienced between the SMS and LIC. This was resolved by installing shielded fibre optic cable between the two devices. A number of data points required remapping and some scaling corrections in the SERCK SCADA system.

Also of note was the commissioning of the fire suppression and hydrogen detection systems. The hydrogen detection system was tested using a bottle of sample air that contained the appropriate concentration of hydrogen. This was injected into the system while a laptop provided visual confirmation that the hydrogen level increased as expected. Upon reaching 25% of the LEL, the relay operated as expected and triggered the forced ventilation. Upon reaching 50% of the LEL, the second relay operated as expected and tripped the power. This was confirmed by S&C engineers at the SMS.

4.15 Initial BESS operation

Following the initial charge discharge cycles carried out during commissioning, the attention turned to the objective of reducing peak demand. As the battery is scheduled in 15 minute blocks, SHEPD engineers determined the highest 12 points on the Shetland demand curve over 15 minute intervals. This provided an optimum 3MWh discharge schedule for reducing the peak demand.

For charging, the initial schedule was set with a large enough 'window' to cover the three tiered charging process and any equalisation charge required.

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 10. 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 10. 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 Innovation Funding Incentive (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 SHEPD 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/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 10.

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 10.

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	7680
No. of modules	20
No. of cells per module	384
BESS nominal voltage	640V
Voltage range	470V to 745V
Current range	-900/+1400A
Primary materials	Sodium polysulphides, sulphur, sodium
Warranty	15 Years / 4500 cycles

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, configuration, primary materials, operational efficiency and warranty.

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 / Energy Storage	1MW / 3MWh
Cell size	1000Ah
Cell Weight	64Kg
Total no. of cells	3168
No. of cells per rack / No. of racks per string	24 / 11
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
Efficiency[9]	75%
Warranty	5 Years / 1500 cycles

[9] Data for the determination of battery efficiency is measured at the 11kV circuit breaker and therefore includes all losses experienced in the battery cycle. This includes battery, power conversion system, transformer and cable losses. Data measured by the battery monitoring system determined the battery efficiency in isolation to be 85.5%.

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 was noted as challenging due to little fire load testing being available. It was stated this reflects 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 it is the case material, ABS rated at UL94:HB which 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. A greater volume of hydrogen was expected during the initial equalisation charges. Despite these positive outcomes, and as a result of the novel operating regime, S&C opted to install a very early smoke detection apparatus (VESDA) with a hydrogen gas detection system. This is connected to an inert gas fire suppression system and forced ventilation to respond to a fire or build up of hydrogen respectively. Details of the fire engineering assessment, safety data sheet and specifications for auxiliary equipment are outlined in Table 10.

5.7 Technology Readiness Level (TRL)

The NAS TRL did not increase due to not reaching the operational stage. The project has applied a novel – GB – application to the mature lead-acid battery technology. LCNF governance treats the TRL of the total project, or combination of technologies being trialled, rather than the TRL of an individual component. Assessment against the TRL levels[10] would indicate the TRL of the lead-acid BESS to be between 8 and 9.

5.8 Reduction in peak demand

Section 4.15 describes how an initial optimum schedule for the BESS was calculated.
The resultant schedule is summarised in Table 4.

Table 4 – Battery schedule

Start Time	End Time	Function
0730	0830	Discharge
1230	1330	Discharge
1630	1730	Discharge
2300	0700	Charge

Figure 33 graphically displays the actual battery cycle run and how this affected the demand curve the Shetland network operators had to manage. In the battery cycle graph three 1MWh discharges are carried out to coincide with the network's peak demand. The Shetland demand graph clearly shows the impact the battery has. With respect to battery charging, the battery cycle graph shows the three tiered charging cycle. The battery initially charges at 1MW. Upon reaching 80% state of charge the charging rate reduces to 0.66MW; and at 90% state of charge the charging rate reduces again to 0.33MW. The Shetland demand graph illustrates how charging the battery at this time raises the trough in demand.

[10] http://webarchive.nationalarchives.gov.uk/+/http://www.berr.gov.uk/files/file47575.pdf

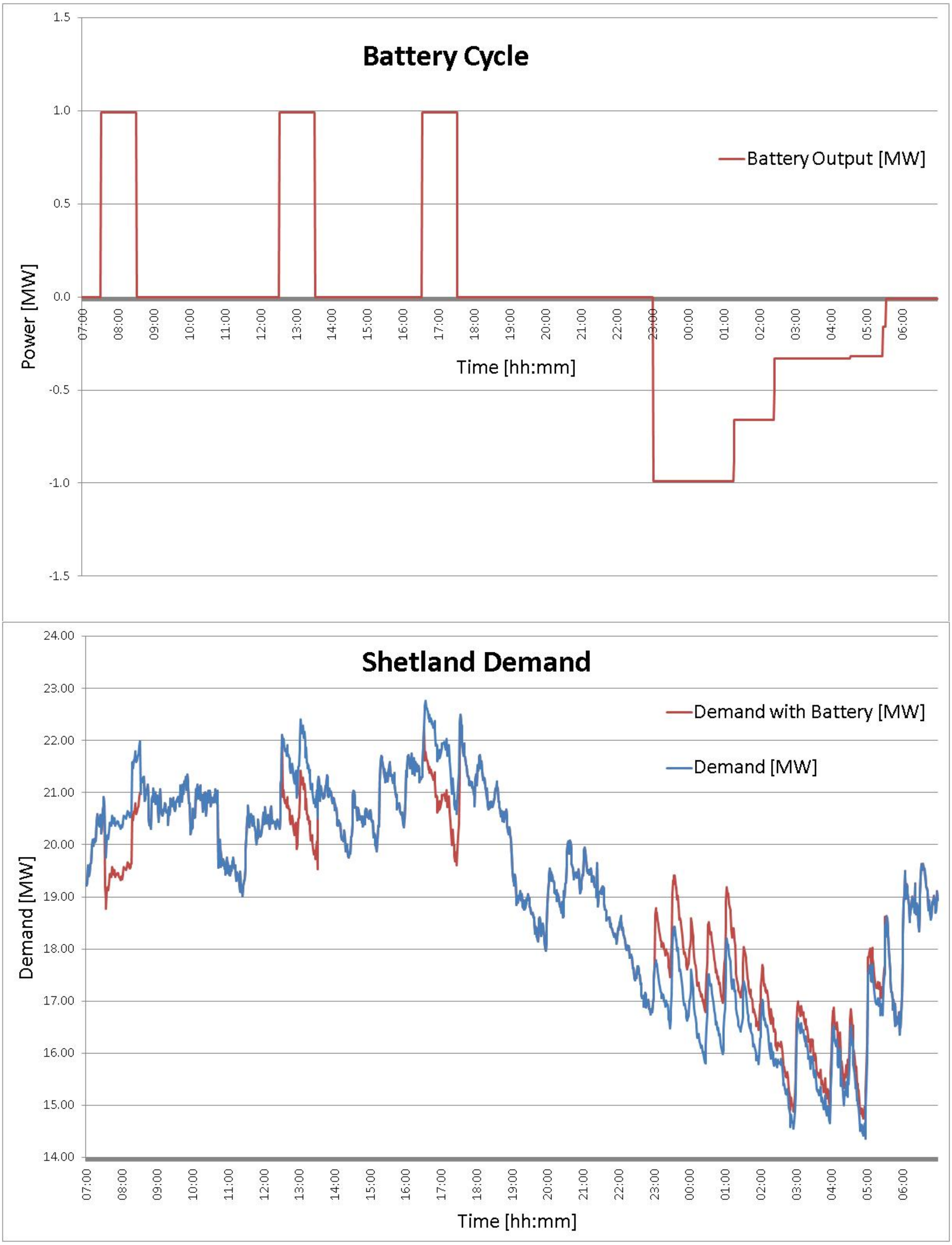

Figure 33 - Battery providing a reduction in peak demand

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

The performance compared to the original project objectives and success criteria have been assessed in Table 5 and Table 6.

Table 5 – Extent to which objectives have been met

Objective	Met?	Commentary
Delivery of the 1MWe battery by the end of March 2011	P	The NAS battery and PCS were delivered to Shetland on schedule.
Secure initial learning from the installation of the battery	P	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	P	The commissioning stage allowed stakeholders to effectively run a series of small charge and discharge cycles to build confidence in the BESS. The first full 3MWh discharge allowed the battery manufacturer to estimate the round trip efficiency for the battery. Further battery cycles have allowed SHEPD engineers to calculate the network efficiency of the BESS.
Integration with local demand response	P	The integration with local demand response required integrating the battery control solution with the active network management system of the NINES project. Prior work carried out by SHEPD and SGS to deliver, integrate, test and support a LIC and remote interface – the initial BESS control system – streamlined the completion of this objective. As additional hardware for the NINES project was established (as assets of the active network management system were installed) the battery control solution remained largely untouched, only requiring new/upgraded software, or further configuration. The exploitation of this outcome will be a key element of the 'operate and evaluate' phase of the NINES project.

Reduce station peak demand to provide additional demand capacity (similar to managing a network load constraint)	P	Evidence of the battery providing a reduction in station peak demand is shown in Section 5.8.

Table 6 – 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.	P	The project has successfully demonstrated a 1MW reduction in the summer peak demand (Section 5.8). Further analysis indicates that the battery shall be capable of reducing the winter peak demand (Section 8.2.1).
The battery must be able to cycle efficiently according to the needs and profiles of the islands' generation and demand.	P	The battery can be scheduled in 15 minute blocks. Discharge offers the greatest flexibility whereas maximum charging rates are dictated by the battery state of charge. Analysis of whether the charging scheduled can be optimised further will be determined as operational experience increases.
The battery installation will allow SHEPD – and the UK in general – to gain a better understanding of battery operation within a network environment.	P	The '1MW Battery, Shetland' project has secured substantial learning to further the understanding of battery operation within a network environment. The establishment of ESOF (Section 8.2.2) confirms this, having brought UK DNOs closer together to work collaboratively to share knowledge of their energy storage projects. However for the '1MW Battery, Shetland' project this is only the start of the story as much of the operational learning will be carried out under the ongoing NINES project. This includes studies into possible engine optimisation, frequency response capability and autonomous scheduling via an active network management system to maximise renewable generation output.

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 and significantly enhanced the learning outcomes.

8 Significant variance in expected costs and benefits

8.1 Costs

Table 7 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 7 – 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 were required to accommodate the VRLA BESS. These costs have been absorbed by the supplier.

Ventilation system

Both the NAS battery and PCS required air cooling. SHEPD knew that this would 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. 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. In addition to this and the knowledge products detailed in Table 10 the project team have hosted a number of visits and presented to a wide range of industry stakeholders.

Reduction of winter peak demand

While the battery has not yet been operated during the winter months, work carried out in parallel on the NINES project by the University of Strathclyde analysed the potential for the battery to achieve a reduction in the winter peak demand. The analysis focussed on the period of peak demand which often occurs at lunchtime. Figure 34 below shows the comparative maximum demand over a seven day period and indicates the duration of the 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 consistently reduce the peak by 1MW.

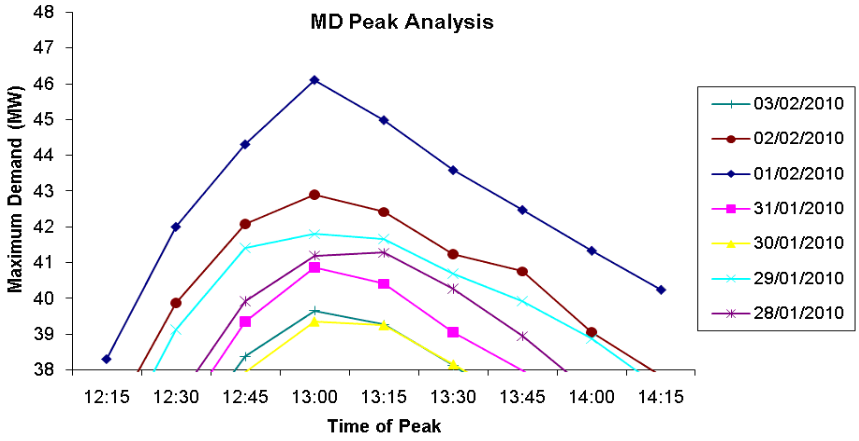

Figure 34 - Winter demand peak analysis

Connection of additional renewable generation

The installation of the battery has facilitated capacity for additional renewable generation. Several renewable energy projects are currently being developed in Shetland that will receive a managed connection under the NINES project. The first of these, a 45kW tidal generator began exporting power at the end of May 2014. Modelling work by the University of Strathclyde investigated the limiting factors to the connection of additional renewable generation on the Shetland network and concluded that to charge the battery from otherwise constrained renewable generation, the stability limit is key. 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. During the operational phase of the project – under NINES – SHEPD will investigate the extent to which these limits can be increased.

Understanding of battery operation, applicable to all DNOs

Since the initiation of this project, many of the other UK DNOs have commenced energy storage projects which cover a number of technologies and operational objectives. This is a good thing as there is no substitute for the experience that operating an asset can provide. Dissemination of this operational experience shall be important and SHEPD are in a strong position to do this. Table 10 details the knowledge items developed through the project that may be useful for project replication. Other initiatives are under way to share this information and much more learning will be achieved as the battery is evaluated under the NINES project as mentioned previously.

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 SHEPD worked with EATL, who brought additional experience and expertise to the project. It did however 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 - the group was responsible for presenting a breakout session on energy storage dissemination at the 2013 LCNF conference in Brighton[11]. The seventh meeting of the group was held in Shetland in June 2014. This included a technical tour of the 1MW VRLA BESS and control systems at Lerwick Power Station.

Two battery technologies

Although disappointing that it was not possible to proceed with the NAS technology, it has resulted in SHEPD learning about two different battery technologies, without any additional cost.

9 Lessons learnt for future projects

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[12] and the Orkney Storage Project[13]. 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 contributed to the successful delivery of the project.

A number of learning outcomes have been presented throughout the body of the report. The key learning outcomes are summarised in Table 8. GB DNOs working on similar projects are encouraged to review the tables in Section 11 for resources that may assist their future projects.

[11] http://www.smarternetworks.org/Files/Low_Carbon_Network_(LCN)_Fund_131203110442.pdf

[12] http://www.ssepd.co.uk/Innovation/Portfolio/LV_Batteries/

[13] http://www.ssepd.co.uk/Innovation/Portfolio/OrkneyPhase1/

Table 8 – Summary of key learning outcomes

Phase of project	Key learning outcomes
Procurement	Development of a grid scale battery procurement strategy including: § The use of Achilles register to invite tenders and determination of suitable search codes § Establishment of screening and evaluation criteria § Changes in how batteries are procured
Design	For both NAS and VRLA battery technologies: § Safety cases detailing relevant codes, standards and legislation § Fire assessment § Battery specifications BESS control system
Installation	Reference installations of NAS and VRLA BESS detailing: § Transportation, storage, installation and operational procedures § Identification and resolution of design, construction and operational challenges.
Commissioning	Commissioning of a grid scale BESS including safety systems Integration with an active network management system
Initial operation	Initial assessment of round trip efficiency Determination of optimal schedules Reduction in peak demand and increased capacity for renewable generation

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 provide 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. Battery storage could contribute to the overall new integrated plan solution for Shetland. However commercial considerations will play a large part in determining the optimum mix of varying technologies within a future BAU solution.

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 9 or 10. Table 9 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 10 details relevant knowledge products.

Table 9 – 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 – Prior to integration with ANM	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	1 x Hitachi RAS-16FSXN outdoor unit, 4 x Hitachi RCI-3.0FSN3Ei cassette units, 2 x Hitachi KPI-802X3E ventilation heat recovery units

Table 10 – 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 Shetland Islands PureWave SMS O&M Manual	Operations 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	Proposal to undertake analysis of generation and load profiles to determine the impact the BESS may have on the operation of LPS and the Shetland demand profile	Smarter Grid Solutions Ltd
Technical analysis methodology Energy Storage System trial on Shetland SGS-200035-05B	Sets out the information sought and assumptions made before outlining five scenarios and four operating modes for analysis	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	Details the analysis methodology and presents the results and conclusions of the technical analysis	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-200035-09B	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
Local interface controller specification: Battery NINES Project SGS-200183-04B	Replaces document 200035-09B. Describes the functionality and implementation of the battery local interface controller	Smarter Grid Solutions Ltd
CDM file	Documents passed to SHEPD upon close down of the CDM site. Contains relevant COSHH assessments, MSDS and RAMS	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
Lerwick BESS specification	Details the Yuasa VRLA battery specification	Yuasa Battery Europe Ltd
String connection sketch	Drawing outlining how eleven racks of VRLA cells are connected to form a single string	Yuasa Battery Europe Ltd
Installation guide ver.3	High level installation guide for Yuasa VRLA batteries	Yuasa Battery Europe Ltd
Instruction manual VRLA battery for cycle use SLE-500, SLE-1000	Contains: safety precautions; details for transportation, installation and initial cycle use; information on operation, maintenance and inspection; and end of life disposal	Yuasa Battery Europe Ltd

SLE faulty cell replacement guide V1	Details the cell replacement process	Yuasa Battery Europe Ltd
Rack Drawing YS-SLE001-01	Engineering drawing of a battery single rack detailing dimensions	Yuasa Battery Europe Ltd
Safety statement for the operation of Yuasa SLE batteries	Safety statement covering the main topics from the safety data sheet	Yuasa Battery Europe Ltd
SLE battery datasheet	Manufacturer data for the Yuasa VRLA SLE series of cells	Yuasa Battery Europe Ltd
MSDS VRLA batteries rev.4	Safety data sheet for Yuasa's Valve Regulated Lead-Acid 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
Battery monitoring system (BMS) functional specification	Details the purpose, requirements, operating specification and limitations for the BMS	Yuasa Battery Europe Ltd
BMS schematic	Drawing detailing the BMS connections	Yuasa Battery Europe Ltd
Fire suppression	Documentation for the fire suppression system. Includes: test certificates for fire suppression equipment; introductory user guide to the fire detection and alarm components; specifications, configuration options and warranty information; Information sheet on the gas extinguishing components of the fire suppression system; Calculations by Fire Suppression Ltd for the battery room at Lerwick Power Station; and drawings.	Thamesgate Interiors Ltd

Air conditioning	Schedule of air conditioning equipment and maintenance log. Manufacturer documentation from Hitachi Europe Ltd for air conditioning controller, source for alarm codes and installation manual. Test certificates completed by Climate Control (South East) Ltd and calculations from testing by Thamesgate. Additional details for ventilation and drawing detailing the air conditioning and ventilation layout.	Thamesgate Interiors Ltd
Casoline MF – concealed grid MF suspended ceiling system	Scope of works, manufacturers literature and RAMS for floating ceiling installation	Thamesgate Interiors Ltd
Electrical information	Provides a scope of works for installation of mechanical power supplies and small power and lighting. Documentation includes: electrical installation certificates for lighting and power; lighting calculations for battery room; manufacturers literature for LED panels; a small power and lighting drawing; and a mechanical power and control wiring drawing	Thamesgate Interiors Ltd
Battery build	Documentation detailing scope of works for battery installation, switchgear, isolators and cabling. Also includes: specifications for MCCBs; cable calculation and specifications; and a battery build drawing detailing string layout.	Thamesgate Interiors 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