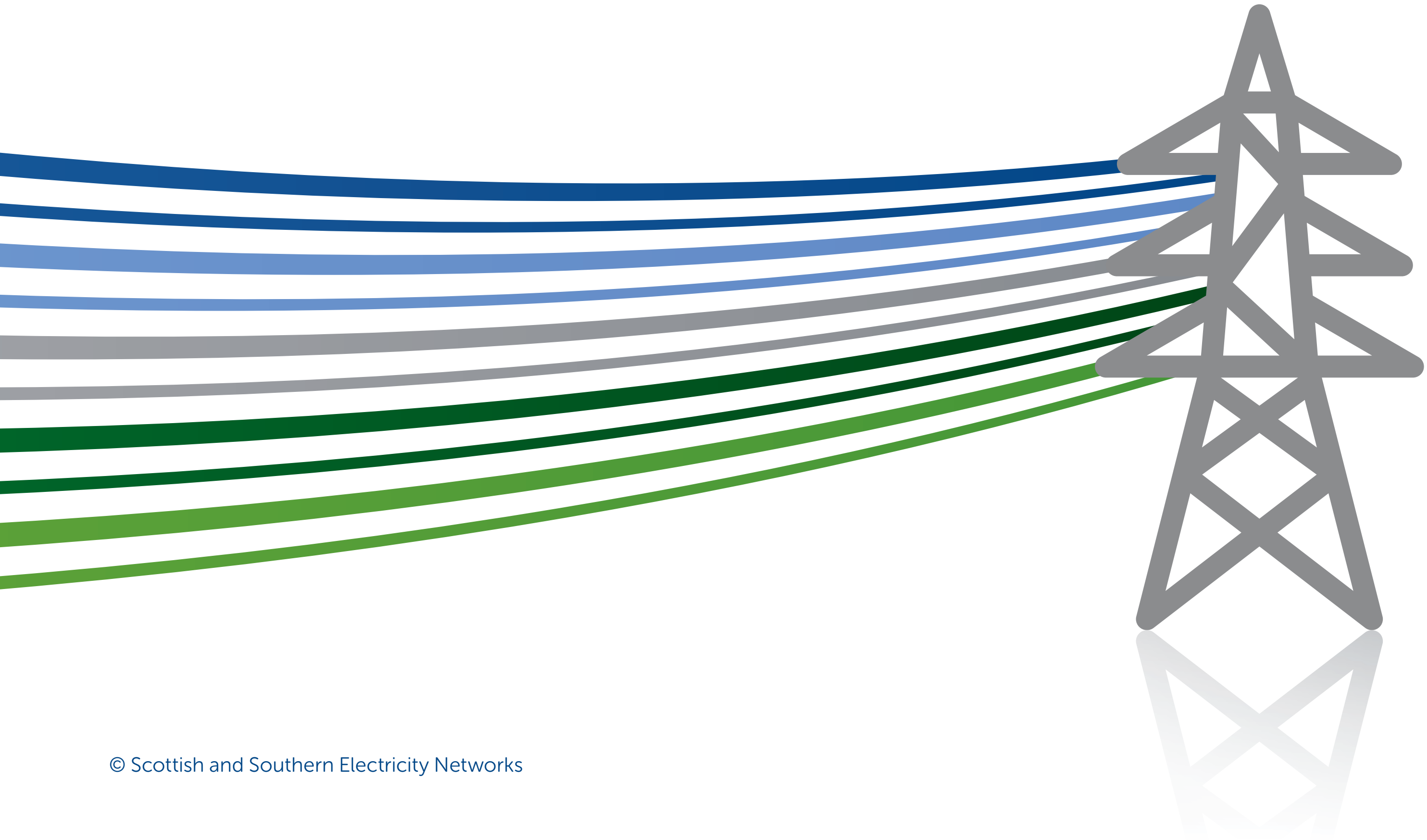
Scottish & Southern
Electricity Networks

University of
Strathclyde
Engineering

NINES

1B DSM Infrastructure Report



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Summary

A Demand Side Management system has been successfully implemented in Shetland within the SSEN NINES project. DSM allows the network operator to balance demand with intermittent generation by controlling the charging of smart domestic space heaters and hot water tanks. The heaters can be switched on and off at varying power levels every 15 minutes, according to a target schedule transmitted from the network control centre; they also estimate their next day's energy requirement and transmit this back to the centre for next day scheduling. This is the first operational smart grid in the UK using this technology.

The devices are installed in 234 socially-owned houses, which together provide 1.6 MW of connected capacity. 199 houses with 1.44 MW are currently on flexible charging; the rest are on fixed schedules, either because customers are unwilling to share data or because they are on tariffs where a fixed time clock will not allow a 24 hour low rate supply.

This report outlines the infrastructure required to make DSM work within NINES as well as the resources required for rollout and operational support. Issues encountered are described, including ensuring effective communications, the performance of the devices, installation aspects. The infrastructure requirements for rollout to another 500 houses in the private market in Shetland are also discussed, including recommendations for functionality enhancements.

Key learning outcomes include the following.

- Future rollouts should target larger, hard-to-insulate houses, which have a higher controllable demand than the typical NINES house for the same DSM enabling infrastructure.

- Persistent communications outages reduced the available controllable power by half. A solution for what is believed to be the root cause of these problems has been developed, but has yet to be deployed and tested.

- Currently the total energy demand is skewed to 10-20% above actual because of two quirks in how individual device status is reported. This requires a correction in the central Element Manager calculation.

- Enhancements required in the device controllers include the ability to store a record of the accumulated daily energy delivery during a power outage and a status flag that shows whether the heating circuit has been switched off.

- The number and length of maintenance visits to houses would be reduced if the in-house devices had over-the-air upgrade capability for firmware, and if the transceiver connection to the heater body were redesigned to allow them to be replaced without dismantling the heaters – transceivers were the components which failed most often.

- Decisions made in NINES to guarantee customer comfort by applying minimum comfort temperatures should be reviewed as they reduced the practical storage capacity of the heaters. Also, normal (occupant-controlled) hot water tanks operate safely without meeting the NINES HSE requirement to cycle through 60 C each day so this practice should also be reviewed.

- Re-programming the LIC to calculate and transmit the energy delivered by devices would give a more accurate central picture of how well the schedule is being followed than the current estimate based on one sample of the power draw every 15 minutes; this would allow the network to fine-tune load shifting during the course of the day.

- The rollout cost was £13,818 per house, around 60% from SSEN for development and support and the rest from HHA for devices and installation. The long term maintenance cost was £739 per house per year, including communications and customer incentives and averaged across HHA and the private sector. A different market model and cheaper communications license will be needed to make DSM rollout financially attractive to a potential DSO.

- Operating in remote locations posed infrastructure challenges:

    - installation by a team of electricians and plumbers took between half and one day if everything went well, but double that time if internal or external communication problems were encountered;

    - deliveries could be delayed, so enough equipment had to be bought and stored so that installation work was not held up;

    - houses could be a long way from the store so plenty of spares had to be taken; and

    - in some locations it was difficult to make a mobile phone call back to the centre.

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Introduction

1. Introduction

1.1 Project Background

In 2010, a license obligation was put in place requiring Scottish and Southern Electricity Networks (SSEN) to present an Integrated Plan to manage supply and demand on Shetland. The Shetland Islands are not connected to the main GB electricity network and, as such, face unique electrical challenges but also a unique opportunity to decarbonise supply. Under the license condition, this Integrated Plan was required to demonstrate that it had identified a solution based on the lowest lifecycle costs, taking into account its environmental obligations.

As part of the Integrated Plan submission, consideration was given to, amongst other things, the upgrading or replacement of Lerwick Power Station, the impact of third party generation requirements, the abundance of renewable energy resources, and the future demand on Shetland. The factors influencing the supply and demand issues on Shetland necessitated an innovative approach to their management. However, with innovation comes the need to trial solutions before reaching an answer. As a result, SSEN originally proposed to split the implementation of the Integrated Plan into two phases:
Phase 1 Shetland Trial (Northern Isles New Energy Solutions, NINES) – implementation of the infrastructure necessary to actively manage demand, generation, reactive compensation and energy storage assets. These elements were coordinated to maximise the amount of energy harvested from renewable generation while maintaining supply quality and security. In doing so, two principal effects are achieved:

- a reduction in maximum demand; and
- a reduction in the electricity units generated by fossil fuels.

Phase 2 (Shetland Repowering) – upgrading or replacement of Lerwick Power Station by SSEN, taking into account the learning acquired during Phase 1 and, where appropriate, extending the Phase 1 technology.

1.2 NINES Elements

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

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

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

1. undertake specific projects that increase understanding of how best to accommodate Shetland's significant wind potential on a small distribution network; and
2. undertake specific projects that increase understanding of how the existing and known future demand on the island can be best managed on a constrained, isolated system.

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

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

2. Domestic demand side management with frequency response
As part of the wider NINES benefits, Hjaltland Housing Association contracted with Glen Dimplex to install advanced

storage heating and water heating in 234 existing homes. These new space and water heaters (the former replaced traditional storage heaters) were provided through HHA and ERDF funding and have been specifically designed to use a flexible electrical charging arrangement, which is based on the predicted demand, weather forecasts, availability of renewables and any network constraints. This initial rollout was intended to help gauge the effectiveness of energy storage and demand side response at the domestic level.

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

3. Renewable generation

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

To address this, NINES has trialled an active network management regime which has offered new renewable connections to developers. Previously developers were required to give their agreement to being constrained when the system cannot accommodate their generation. The measures that have been developed and trialed under NINES reduce this constraint by being able to actively provide demand when there is renewable resource available. Indeed, these arrangements could be necessary even if Shetland is electrically connected to the mainland at some point in the future. If a single mainland link is damaged, this could result in a prolonged outage, which would mean that Shetland would once again be electrically islanded. Therefore the prospect of and ability to constrain will remain for generators on Shetland, albeit on a less frequent basis.

4. Active Network Management (ANM) system

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

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

The following report is one of a number of related reports undertaken by the research team, led by University of Strathclyde and focuses on the infrastructure required to successfully operate Demand Side Management (DSM) within NINES.

The DSM element of NINES uses innovative smart heaters remotely controlled by an ANM System to store energy in homes during periods of excess electricity supply. Prototypes of these smart storage heaters and hot water tanks were developed by Glen Dimplex under the name 'Quantum', and were trialled in 6 houses in Lerwick, Shetland from 2011-2013. Glen Dimplex incorporated lessons learned from the trial into the design of the production versions, which were installed between July 2013 and October 2014 in 234 electrically heated properties owned by HHA.

The University of Strathclyde (UoS) is a partner in NINES and this report is based on work carried out on DSM by the Energy Systems Research Unit (ESRU). It gives an overview of the infrastructure required to make DSM work for the NINES rollout, the resources required for installation and operational support, and some of the issues encountered. General IT infrastructure and operations beyond DSM are not addressed. Other parallel reports by ESRU cover the customer impact of DSM[1], and the impact on the network[2]. Further reports address the operational effectiveness of DSM in frequency response mode[3] and the operational effectiveness of the ANM system[4].

The report makes an input to the following NINES learning objective:

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

NINES UoS Reports	
1A	DSM: Customer Impact
1B	DSM: Infrastructure
1C	DSM: Network Benefits
2A	Battery: Operational Effectiveness
3A	Frequency Response: Customer Impact
3B	Frequency Response: Operational Effectiveness
4A	ANM: Operational Effectiveness
4B	ANM: Functional Design Report
6A	Commercial Arrangements and Economics Report
7A	UoS Knowledge & Learning Report

Table 1 NINES UoS learning reports

2

DSM concept overview

2. DSM concept overview

This section gives an overview of the system. A more detailed description of key elements of the infrastructure can be found in Chapter 3.

2.1 Background

As part of Phase 1 of the Integrated Plan for Shetland, submitted to Ofgem in 2011[5], SSEN were required to provide the infrastructure necessary to actively manage demand, generation, reactive compensation and energy storage assets, including water and space heaters, to store energy in the form of heat. Heater charging is controlled by the DNO using an Active Network management (ANM) system. The ANM system schedules generation from the wind farms, and uses a 1 MW battery as well as DSM to balance peaks and troughs in electricity demand and generation dynamically. This system will allow more intermittent renewable generation to be connected to the network in future. Figure 2.1 shows the main components of NINES.

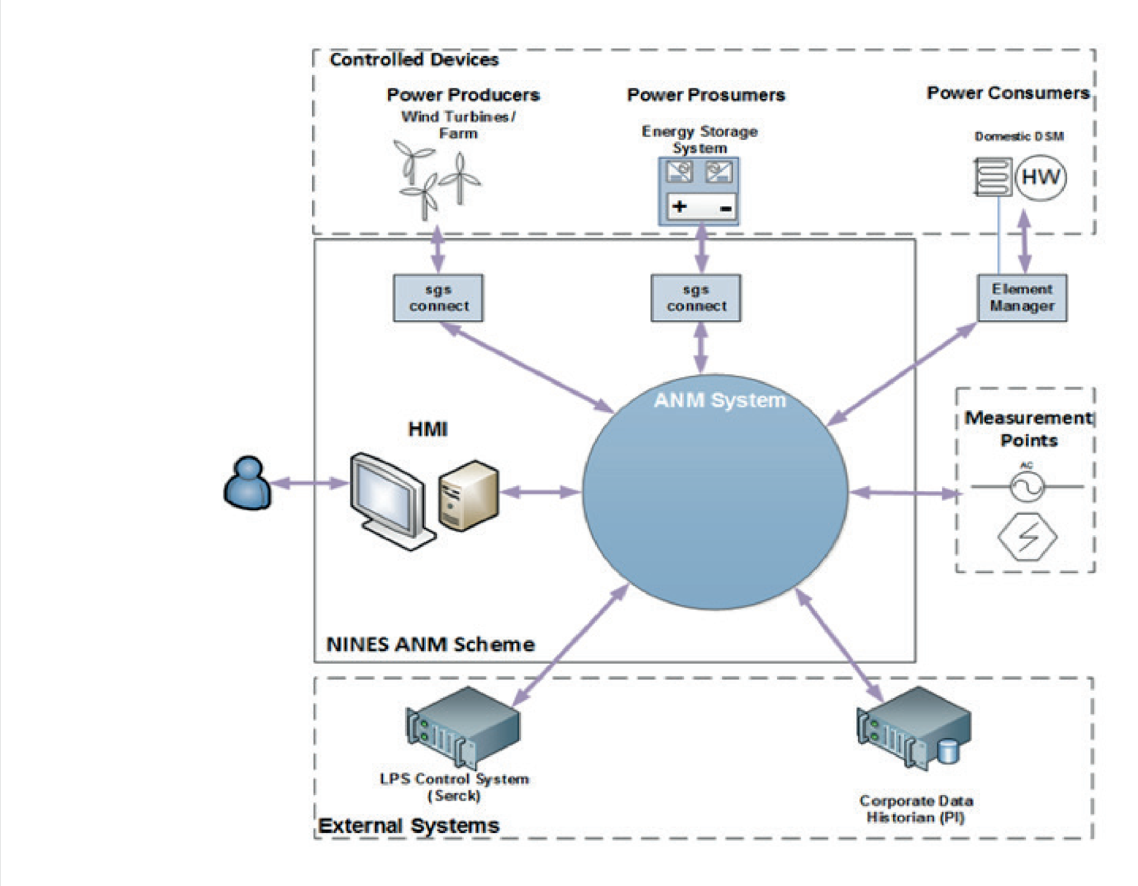


Figure 2.1 NINES ANM with DSM components and communications at top right.

At the end of the prototype trial it was concluded that every DSM house where the heating elements are fully charging allows an additional 2.37 kW of wind generation online as well as contributing to network stability[6].

Originally DSM was intended to operate at an industrial scale as well as domestic, through a 4MW/130 MWh hot water tank to be installed by the district heating provider, Shetland Heat, Energy and Power Ltd. (SHEAP). In early 2015 SHEAP advised SSEN they would no longer be taking part in NINES due to funding and commercial issues.

	2011 proposal to Ofgem	2013 plan	June 2016 live
Houses	750-1000	250	228
Appliances	–	922	708
Flexible power kW/house	15.0	8.2	7.2
Physical storage capacity kWh/house	–	46.8	42.4

Table 1 Evolution of SSEN's domestic DSM scope.

Included in the original NINES submission was the installation of DSM into 750 homes provided by HHA and Shetland Islands Council (SIC). However due to internal financial constraints, SIC announced in October 2012 that they would be withdrawing from the project leaving only the HHA dwellings (Table 2.1). To limit the impact of this change on the project, and provide new learning around domestic DSM, SSEN proposed to recruit private domestic customers to provide DSM and customer engagement events were held in 2014[7].

In April 2014 SSEN's initial Integrated Plan for a replacement power station was rejected by Ofgem in favour of a competitive process to identify a new energy solution for Shetland. This new obligation to invite tenders for network services of the kind offered by DSM caused SSEN to decide that it would be more appropriate to allow the market to take on the development of DSM to a larger scale, so the rollout to the private market is put on hold.

Production versions of the DSM equipment were installed in 234 houses owned by HHA by October 2014: this represents 2% of all homes in Shetland and 9% of social rented dwellings. Most of these houses are newer stock, and smaller properties than the typical Council home, demanding fewer heaters. In addition, only two-thirds of the NINES houses received new hot water tanks: the Quantum tanks were larger than those they replaced and could not be installed in the constrained space available in some of the houses. A variety of issues led to the removal of the DSM equipment from 6 houses, and another 4 were disconnected although the kit is still installed within those homes. In June 2016, 228 DSM enabled homes were operational, with a total demand of 1.6 MW (Table 2.1). SSEN introduced the flexible charging regime in March 2015, making Shetland the first operational smart grid in the UK that incorporates domestic DSM. The system started to operate in its final mode in early February 2016.

2.2 The DSM system

The 'Quantum' heaters at the core of DSM were developed and are marketed by Glen Dimplex[8]. For NINES, Glen Dimplex developed customised device controllers: the devices in Shetland can accept instructions for altering input power every 15 minutes, and relay back status information to the centre. They also contribute to network stability, automatically shutting down charging when the network frequency drops below an acceptable, configurable level and increasing charging when the frequency rises.

The heaters are well insulated, allowing fan-assisted regulation of active output by a user-controlled temperature setpoint (USP) within user-set heating hours. They contain three separate heating coils to allow them to be charged at varying power levels. They also incorporate a maximum temperature cut-off for safety and a minimum temperature switch-on setting to ensure occupant comfort. The hot water tanks also have three heater coils of different sizes to allow variable level charging and were built specifically for NINES. The NINES-specific device controllers in both space and water heaters operate in the same way.

The device controllers employ an automatic charge control algorithm to predict the energy required for the next day (Daily Energy Requirement, DER), based on a number of factors. For space heaters these include the predicted outdoor temperature for the next day, user settings for room temperature, and heating hours. For hot water tanks, the DER is the average of the energy used in the previous three days. Embedded in the control rules is a requirement to prioritise customer comfort over the needs of the network in order to maximise customer satisfaction.

DSM-specific equipment supplied by HHA consists of a transceiver on each heater and hot water tank, which communicates by RF with a Glen Dimplex Home Hub. The Hub in turn is connected serially to a Local Interface Controller (LIC) supplied by SSEN.

Figure 2.2 shows a logical view of DSM communications. The LIC collects status data from the devices and forwards it from the house to a central Element Manager (EM) via a Wide Area Network (WAN) supplied by Airwave Solutions. The EM can poll each LIC at configurable intervals, currently set to 4 times per hour. It aggregates the data into groups for ease of handling, before transmitting it on to the ANM system at Lerwick Power Station. The key data sent are the energy required for the next day (DER) as calculated by the device controllers at midnight GMT, plus the number of devices in communication within the group and their overall rated power and storage capacity.

These data are used by the ANM system to generate 15-minutely target schedules for all controllable generators and storage on the network. The system was designed to be capable of re-computing and re-transmitting schedules every 15 minutes if necessary, although for operational reasons currently this is done just once a day, just after midnight. The target schedule for each group is sent back to the EM together with a forecast for the outdoor temperature for the next day. The EM passes this information to the LICs; it also sends out heater configuration instructions, such as the minimum core temperature or frequency control parameters.

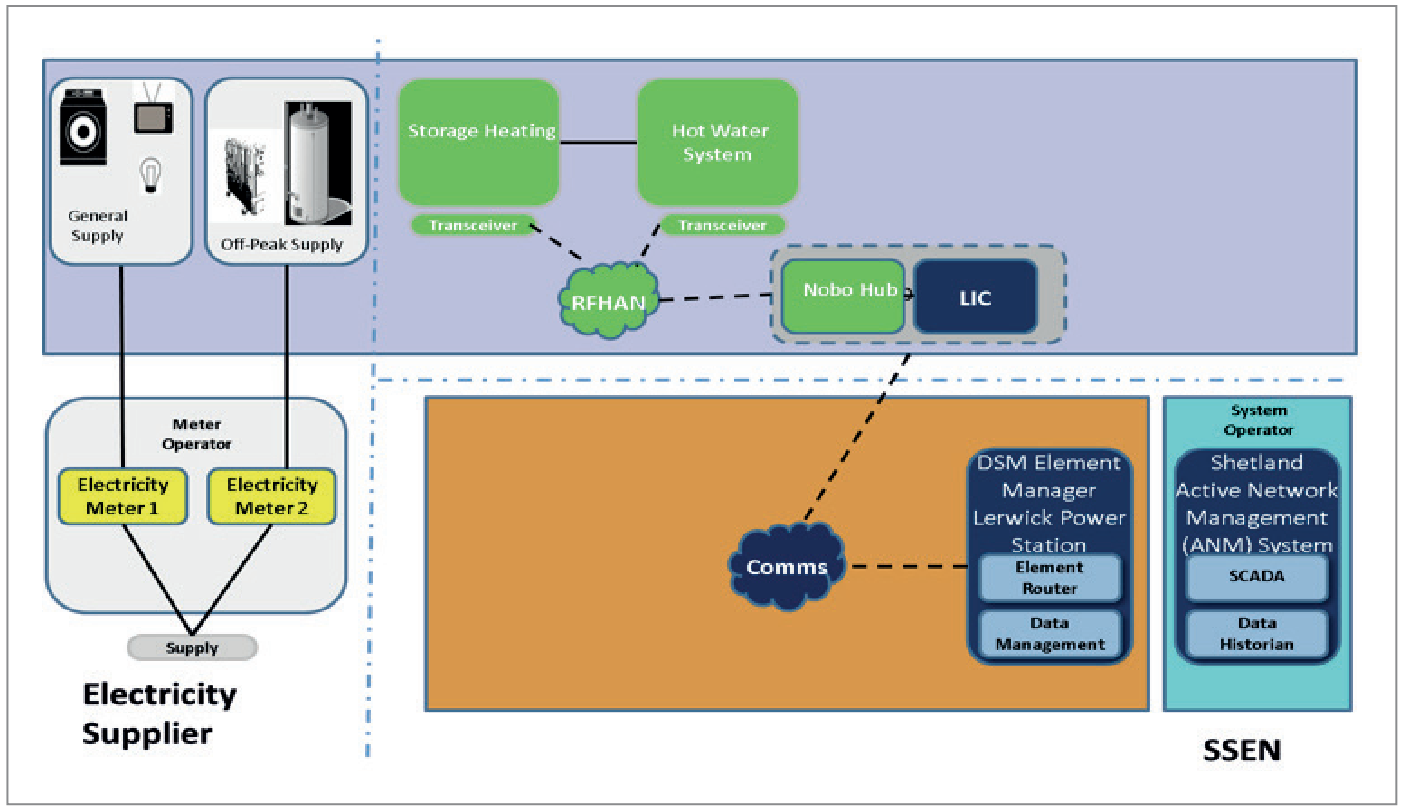


Figure 2.2 Logical view of DSM equipment and communications.

The daily charging schedule for each group consists of a target power profile expressed as a percentage of the total power available at 15 minute intervals. This target power can vary continuously from 0 to 100%. The LIC must translate the continuous profile into a set of instructions that each device is physically capable of following with its individual fixed charging levels at the same time as delivering the DER. Figure 2.3 illustrates how a group schedule works out at an individual device level.

Each device is assigned to one of 18 groups, depending on:

- the type of device (space or water heater) as these have different demand profiles;
- the type of tariff, as customers were not asked to change commercial arrangements with their energy supplier;
- whether the customer's metering arrangement allows DSM to be operated: where a fixed time clock does not allow a 24-hour low-rate supply, DSM is set to allow charging at all times, and the actual charging is controlled by the time clock at full power as before;
- whether occupants are vulnerable: priority service customers and those on prepayment were initially put onto fixed timing DSM where the charging level could be varied but the times were fixed; and
- whether the customers have opted out of allowing their devices to transmit status data, in which case the communications network cannot be used; these homes receive the same fixed-timing target schedule as the equivalent opted-in vulnerable group.

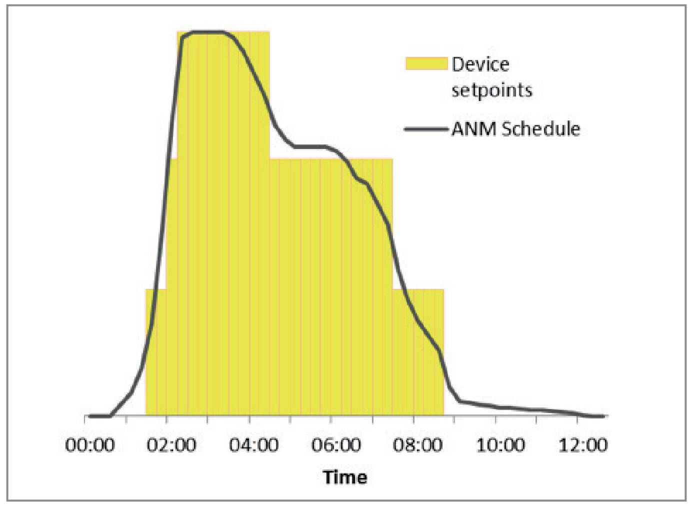


Figure 2.3 ANM generated schedule and its translation to device level.

At the completion of the NINES Project, 199 houses with 1.44 MW of controllable power were in groups with fully flexible charging. 88 of these houses with 0.59 MW are prepayment customers who were transferred to flexible charging at the end of September 2016, after the system had proved that the change to flexible charging would not lead to the customer's credit being used at unexpected times, in order to provide storage for the network. Only 24 houses with 0.17 MW are currently either opted out or have meters and tariffs which do not allow flexible charging.

2.3 Data collection

The system was designed to have no adverse impact on customer comfort or cost while giving the DNO flexibility to run the network in the most effective way. Throughout the project, close contact was maintained with the customers via a dedicated Housing officer at HHA and the NINES Project team within SSEN, who recorded customer queries, practical issues and conducted customer satisfaction surveys. This is discussed in detail in the Customer Impact Report[9].

The performance of all the devices could be monitored centrally from the data from built-in sensors transmitted by the LIC. Device data collected by EM over an 18-week period from 15 February to 19 June 2016 was analysed, as was 12 weeks of Group level data from 29 February to 22 May 2016. In addition, customer comfort was monitored independently in a sample of houses selected to be representative of the whole rollout estate: room temperatures were monitored in 35 houses and hot water consumption in 19, from the time the devices were installed until April 2016. The 8 million lines of data collected, with over 90 million individual data points, were analysed by ESRU, who also carried out modelling studies to supplement the field data. Analysis did not cover the behaviour of devices in frequency response mode as the data collection frequency was too low to: this topic is covered in the Frequency Response Operational Effectiveness Report[10].

3

Infrastructure in detail

3. Infrastructure in detail

This section takes a more detailed look at the physical, logical and human infrastructure required to run the DSM system outlined above.

3.1 Geographical distribution

The majority (79%) of the rollout houses are in the centre and south of Shetland Mainland, with 61% in the main towns of Lerwick and Scalloway (Figure 3.1 and Table 3.1). Because of the concentration in the central towns, most of the houses are served by just two substations. However, given that all the NINES houses were electrically heated to begin with there should not be additional loading on any of the substations.

The West Mainland and the North Islands are the most remote and difficult to access physically from Lerwick Power Station and access to houses in these districts for installation and maintenance can be difficult and time-consuming. In many of these areas the mobile phone signal is weak: the installation engineers had to telephone the NINES Project Team to check that the LIC was communicating with the EM, and the time it took to find a place with a mobile signal also added to the resource impact of servicing these houses.

If the 500 SIC houses had been implemented as originally planned, the proportion in each area would have been similar.

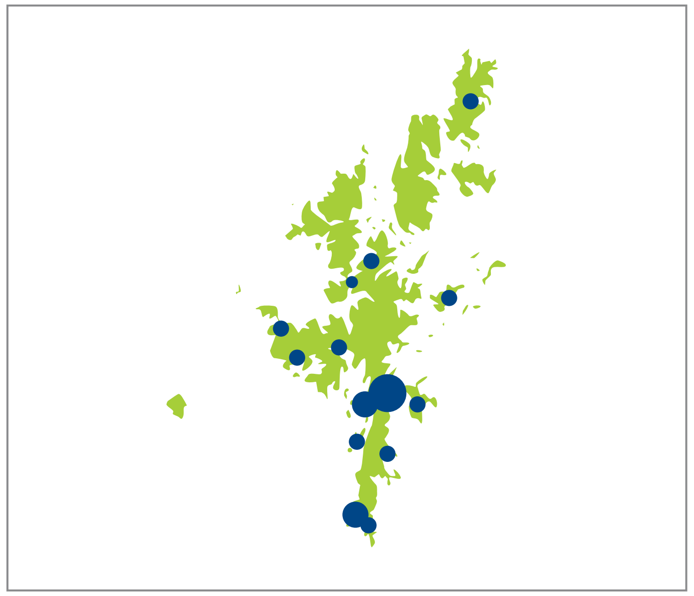


Figure 3.1 Location of DSM houses in Shetland (circle size indicates relative numbers).

Area	Community	Houses
Centre	Bressay, Lerwick, Scalloway,	141
South Mainland	Burra, Cunningsburgh, Scatness, Virkie	34
West Mainland	Bixter, Sandness, Walls	14
North Mainland	Brae, Sullom	11
North Islands	Unst, Whalsay	23

Table 3.1 Geographic distribution of rollout houses.

3.2 System architecture and communications

Figure 2.1 shows how DSM fits logically with the other components of NINES. The EM servers are physically co-located with the ANM and communication between them is via a local area network. Communication between EM and the houses is via a microwave network run by Airwave with 9 base stations. This was chosen because the mobile data service used in the prototype trial had proved to be inconsistent even to the 6 houses within Lerwick. Airwave provides the network for emergency support services communications in Shetland and so their infrastructure was considered to provide a ready-made, cost effective and reliable integrated solution.

Reliable communication with the centre is a prerequisite for operating DSM but this has proved difficult throughout the project. Of the 11 houses which have either been disconnected or had the NINES kit removed, 8 cases were because it proved impossible to establish reliable communications. The nature and extent of the outages is discussed in detail in Section

4.1. The design of the functionality involved three different suppliers: Glen Dimplex for the heaters and Hub; Airwave for the LICs, EM and communications between them; and SGS for the ANM system itself – so assessing the root cause of problems involves coordinating with many actors.

3.3 Equipment installed in houses

The Quantum heaters and hot water tanks are produced by Glen Dimplex[11]. The space heaters are available commercially to work as individual smart heaters, but the control system implemented for NINES was custom-designed to work with remote scheduling.

Four different sizes of space heater were deployed (Table 3.2). All heaters can charge at set levels, 1/3, 2/3 or full power. Storage capacity is equal to 7 hours at full charge. Heat is output by a fan which draws air round the hot core; the fan is actuated when a sensor located under the heater records a room temperature below the user set point during the set heating period. There is also a separate, manual boost circuit which the occupants can use if the heater output is inadequate. In NINES this circuit was also wired to the low-rate meter where the specific tariff allowed, otherwise to the standard rate meter. The production versions of the space heaters have a slightly higher power input and storage capacity than the equivalent prototypes in the 6-house trial.

Just 8 of the installed heaters were faulty. One was overheating, and the heater body had to be replaced but otherwise the faults were mainly in the user interface module. Each time a controller is replaced the device changes identity and the electrician must call up SSEN to register it. The installers reported a design flaw in the way the transceivers have been fitted: if the transceiver has to be replaced, the whole heater must be dismantled to extract it. In 6 of the houses the living room heaters had to be upgraded following revised heating design by Glen Dimplex, and upgrades were offered to 3 more customers who declined.

The Quantum hot water tanks are not available commercially, being custom-designed for the NINES project. As listed in Table 3.3, 3 sizes of tank were deployed, all with the same rated. Each tank has 3 different sized heating coils to enable them to operate at seven discrete power input levels. For safety reasons the maximum allowable water temperature in the tanks is 75 C. A separate 3 kW manual boost element can be operated by the customer to top up tanks.

	QM070	QM100	QM125	QM150
Input / rated power W	1560	2200	2760	3300
Output rating (average) kW	0.7	1.0	1.2	1.5
Rated storage capacity kWh	10.9	15.4	19.3	23.1
SAP Heat retention rating[12]	46%	49%	52%	54%
Number live June 2016	158	248	141	10
NINES kit decommissioned/ disconnected	16	18	9	–
Number faulty	8			

Table 3.2 Number of Quantum space heaters deployed in NINES.

	E125	E175	E210
Input / rated power W	2625	2625	2625
Nominal capacity litres	125	175	210
Rated storage capacity kWh	8.4	12.2	15.0
Number live June 2016	53	47	51
NINES kit decommissioned/ disconnected	1		3
Number faulty	9		

Table 3.3 Number of Quantum hot water tanks in NINES.

	Houses	Transceiver	Home Hub	LIC
Number live June 2016	228	721	228	228
Number decommissioned	6	28	8	8
Number faulty/replaced & spares	–	1	229	10

Table 3.4 Other infrastructure installed in DSM houses.

Faults were encountered with the control boards on 6 tanks, in 3 of these the heaters were not charging at all. In a further 3 cases a faulty cylinder activated the dump valve, dumping hot water and then re-charging multiple times. As with the space heaters, each time a control board is replaced, the appliance has to be re-paired and the electrician must call up SSEN to verify that the device can be seen.

Other infrastructure at each house is shown in Table 3.4. Each device has a transceiver which communicates with the Hub that is connected in series to the LIC. Home Hubs and transceivers were built by Glen Dimplex specifically for NINES. In addition to transmitting data between devices and the EM, the LIC carries out schedule translation, turning the smoothly varying power curve in the target schedule into a series of 96 set points at the fixed levels. The device set-point profile must be as close as possible to the target schedule, be physically possible to follow at each device's specific power levels, and also deliver the required daily energy (DER)[13]. Two of the larger properties with 10 or more heaters required two Hubs each because of the number of devices involved.

If they lose contact with the LIC, the heaters continue to operate in stand-alone mode. The daily energy requirement is calculated in the same way as when connected to DSM, except that instead of receiving a forecast for outside temperature it uses a programmed seasonal band. Charging is at a pre-set level at fixed periods through the day charge levels and timing are set in the firmware during installation to operate at expected low network load times. If the LIC loses contact with EM, it continues to apply the last schedule received as this represents the best fit with balancing supply and demand. If it has not received a schedule it uses a back-up fixed timing schedule which can be re-set over the air when communications are re-established.

The EM's function is to pass data between the LICs and the ANM system, aggregating individual device data on the way up but simply passing on the schedule on the way down the chain. It keeps the historical DSM data in an SQL database. Database mirroring has been set up to support automatic fail-over with an optional witness server also included as part of the resilient design (Figure 3.2).

3.4 Element Manager

The polling interval at which the EM collects data from the LICs and the interval at which it broadcasts data to the LICs can both individually be set at between 5 and 60 minutes. With perfect communications, 600 LICs can theoretically be polled every 5 minutes; however this number goes down non-linearly if communications fail and some LICs have to be interrogated multiple times.

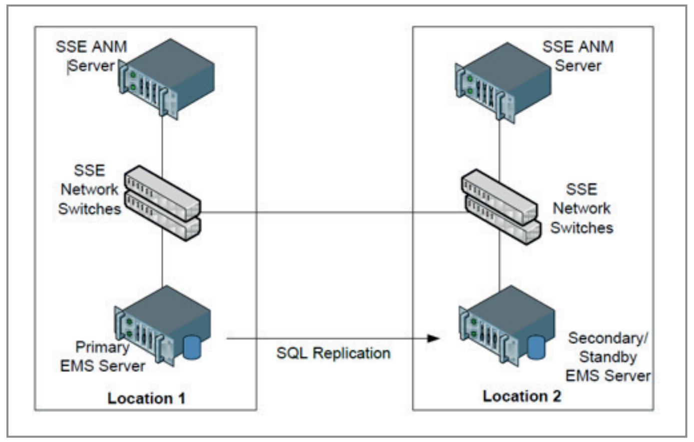


Figure 3.2 Element Manager Physical Architecture[14].

SSEN estimate that with a 10% failure rate 272 LICs can be polled every 5 minutes, and with 20% 176. At present both polling and broadcast interval have been set to 15 minutes. Data collected and aggregated by EM includes the number of devices reporting in each group, whether and at what level they are drawing power instantaneously, the energy stored at that moment as well as the DER. If EM is seeing a LIC but a device is missing – i.e. a device is not seen by the LIC – it is counted as being operational. There is no way to tell if a device has been switched off so the EM makes the following assumptions about unseen devices:

- instantaneous power and energy stored are assumed to be at the last reported value; and
- DER is assumed to be the average reported by other similar devices for calculating Group DER.

If on the other hand a LIC is not visible at all to EM, or it does not declare a group ID, then its devices are assumed to be operating in stand-alone mode and not counted. Devices in opted-out groups are not visible but for ANM scheduling purposes they are treated like the devices in the equivalent opted-in group.

Data passed by EM to ANM comprises the number of devices in the group, the number providing feedback, the rated power of the group and its energy storage capacity, the instantaneous power draw as a percentage of the rated power, the actual energy storage as a percentage of capacity, and the energy required the next day[15].

3.5 Services

DSM is a service and needs people to install, operate and maintain it. For NINES, SSEN reported needing the following people and skills:

Operational support

- A tenant support officer at HHA was in place through the rollout, whose role was to assist in signing up tenants, explain what they should see during installation, carry out surveys, and handle customer queries. This post was full time for the first year and then half time thereafter, and was funded by SSEN.

- 3 customer service staff at SSEN assisted with hosting customer engagement events, managing customer agreements, liaising with installation planning, responding to customer or HHA queries, providing support to contractors during installation, following up problems and issues reported, and arranging decommissioning of homes.

- Customer information, problems registered and contact records were recorded on Excel spreadsheets. It was time-consuming to ensure that multiple copies of the data were up to date and consistent data was available to the relevant project members while meeting data protection requirements. A standard Customer Relationship Management system would have allowed the Customer Service team to operate more productively.

Installation:

- A representative from the local meter operator (SSE Metering) visited each house before installation, to ensure that a 24 hour low rate supply would be available and make any necessary metering adjustments.

- A team of two electricians visited each house to remove old appliances, install and test the heaters, Hub and LIC kit, and to demonstrate the controls to the tenants. This took at least half a day if no rewiring of heaters was required, or a full day if rewiring was needed. Where there was a hot water tank, a plumber was also needed for the day. Installation was paid for by the owner of the properties (HHA), as were disposal costs for old heaters.

- When the home kit had been tested the electricians telephoned SSEN, who pinged each individual device to ensure that it could be seen. This process should take 20 minutes but in fact could take up to half a day if new aerials were needed to extend the wireless range and the Hub and LIC moved if necessary. In some of the more remote locations where mobile signals were poor just making the phone call to SSEN could be a challenge.

- The remote location and long lead times for equipment meant that a large storage area was needed for equipment over the rollout year in order not to hold up installation work. This comprised equipment owned both by SSE and HHA.

- The full installation to all 234 homes took from July 2013 to October 2014, 413 contract days excluding weekends, summer, Christmas and Easter holiday periods.

- A follow-up visit was made to all houses by an electrician to reprogramme the heater firmware. In a subsequent set of visits between November 2015 and April 2016 the Home Hubs were replaced, and the LIC firmware was upgraded. The installation contractor estimated that at most 3-4 properties could be visited in one day.

- Issues noted during installation:

    - the user interface on the heaters turned out to be easily damaged, and the LICs sometimes did not perform at installation so a level of spares had to be carried; and

    - several revisits were required to properties mainly because Hubs did not have the capability of taking over-the-air updates.

Other services:

Following on from an agreement with the Scottish Government in February 2013, HHA arranged to install new storage heaters and hot water tanks along with communications to provide DSM capability within 234 domestic homes; the installation of these appliances was completed by November 2014. Throughout the installation programme Glen Dimplex provided remote technical support to HHA during the installation. Airwave Solution Ltd. provided the WAN across Shetland and developed the bespoke hardware and software (LICs and the EM) based on functional requirements defined by SSEN and the ANM developer Smarter Grid Solutions Ltd., which allowed for the ability to manage heating and hot water energy requirements in the 234 homes.

Both Airwave and SGS had Service Level Agreements with SSEN for support of the system in operation. Other IT support was provided by SSE's IT division.

3.6 Data Protection and Customer Communications

A risk assessment was carried out for the 6 house trial and summarised in an informal document[16]. The three top risks concerned loss or exposure of personal and system data by SSEN and their partners. A data protection strategy approved by Ofgem was developed for the HHA rollout[17] and the Open Market[18]. The key elements of the strategy are:

- explaining to customers what data will be collected and how it will be used;

- limiting access to customer personal data such as addresses to specific NINES project staff in SSEN and to specific vetted partner staff;

- limiting access to metered consumption data to specific NINES project staff in SSEN;

- obtaining customers' consent to the use of device data, and not collecting this if they have not actively consented to do so;

- encrypting electronic data and transmitting this via a secure protocol over a private network; and

- storing data only in systems that have been certified for this purpose.

The risk to corporate reputation if customers have their heating or hot water supply disrupted is mitigated by the design of the heater control systems which prioritise customer comfort and amenity over network needs.

4

Performance issues

4. Performance issues

Scottish & Southern Electricity Networks

NINES is a complex project comprising several new technologies, each of which must work individually and in cooperation. Inevitably, the interaction of these technologies within the overall context of the project can lead to performance issues when viewed from an individual appliance perspective. The ability to identify and manage these issues represents a test of the resilience and durability of the project as a whole and offers valuable learning opportunities.

4.1 Communications

The DSM system functions because the network is able to control devices remotely and depends on continuous good quality data about device status being available. Communications have been the biggest challenge throughout the project, both in terms of the availability of data and the frequency with which it can be updated.

4.1.1 Communications outages

In the period of data analysis, only around 50% of the total data expected was in fact collected by EM. Over any period of time, some heaters are not seen at all, others appear and then disappear. This has a significant impact on the quality of the schedules produced by ANM and on the reliability of the demand; these impacts are discussed in the Network Benefit Report[19].

Figure 4.1 shows the state of device communications each day over 18 weeks for all houses in groups that have opted in.

- Only about half the devices on any one day were visible for more than 90% of the time. These were not always the same devices from one day to the next, as those with generally good communications sometimes had bad periods, while others made an appearance for a few days only. This is most clearly illustrated in Appendix I, which shows a visual representation of the state of communications each day and by device.
- Over a third of devices in any one day are never seen. Again, it is not necessarily the same devices from one day to the next – every device in the 'no data in day' category in Figure 4.1 does appear at some point during the 18 weeks.
- 20 devices never appeared at all, in houses where other devices were visible. Most are storage heaters in halls or dining rooms where it is plausible that they have been switched off, but one is a water tank and two are living room heaters where it is more likely that they are on but operating in stand-alone mode.
- In the week of 7-13 April 2016 the EM developed a fault where it was exceeding the maximum allowed polling time, and cutting off before it had interrogated all the LICs. This meant that over half of the LICs were not visible to ANM that week. SSEN report that the fault was fixed and has not been seen since. However, Figure 4.1 shows that some systematic loss of data seems to have occurred again on 6 May.

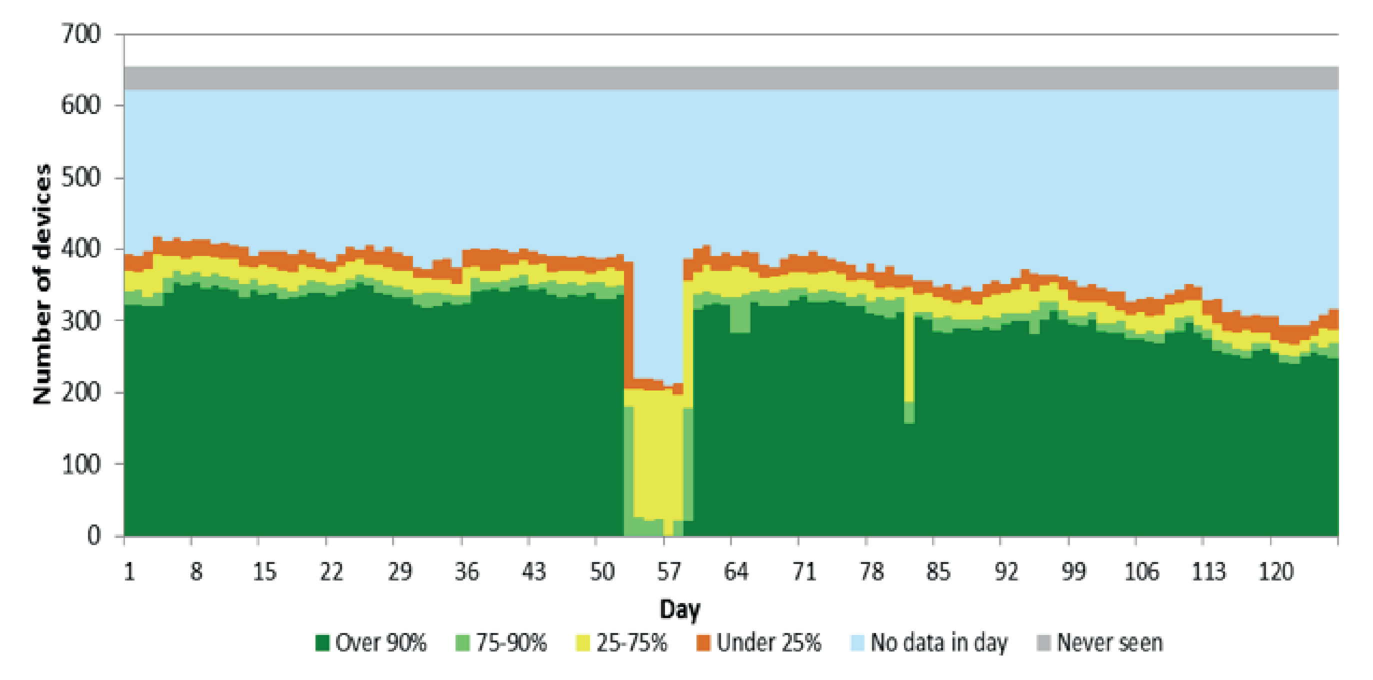


Figure 4.1 Visibility of devices reporting each day over 18 weeks.

It is not possible to tell whether a device has been switched off or is just out of communication as an early design decision was taken not to include reporting of on/off status from the LIC. The increasing number of devices disappearing from view in May and June are likely to be because heaters are being switched off for the summer. However, all the devices had periods of missing data; the best return was from two devices that returned data on more than 90% of polling periods in 120 out of the 126 days (House 161). Many devices appeared occasionally on odd days only. Appendix I shows a visual representation of day-by-day visibility for each device, with each block on the horizontal axis representing a day and the vertical axis showing the devices arranged by house number.

Figure 4.2 summarises how many devices gave good data on how many days over the 18 weeks. 90% data return means that no more than 9 polling periods were missed for a device in any day.

In many cases the problem seems to be within the house, where one heater is showing good data and another is patchy (examples: H025, H028, H037, H054). Houses that appear to suffer particularly from this are the larger two-storey semi-detached in Unst, and the detached bungalows in Sandblister.

However, in other cases, where all heaters in a house appear and disappear together, the problem would appear to be with the LIC to EM communication (examples: H015, H055, H069, H086).

Within the houses, the heaters communicate with the Home Hub by a radio frequency (RF) Home Area Network. This network is affected by the layout of the house and the location of the Hub relative to heaters. The RF networks of neighbouring houses can also interfere with each other. A number of upgrades were made over the course of the project; including re-positioning the Hub within the house, supplying larger aerials and changing the firmware, but problems persisted even after all the Hubs were replaced over the winter of 2015/16.

In a number of HHA properties issues were encountered with the RF network causing Residual Current Devices (RCDs) to operate.

Independent testing carried out by EA Technologies established that although the LICs were designed and manufactured in compliance with Ofgem standards, electromagnetic interference, generated from the Airwave LIC installed within the homes can cause nuisance tripping of the RCD in circumstances where the RCDs had been manufactured by Memera (MEM) pre-1999 and when the LIC were installed in close proximity to the RCD.

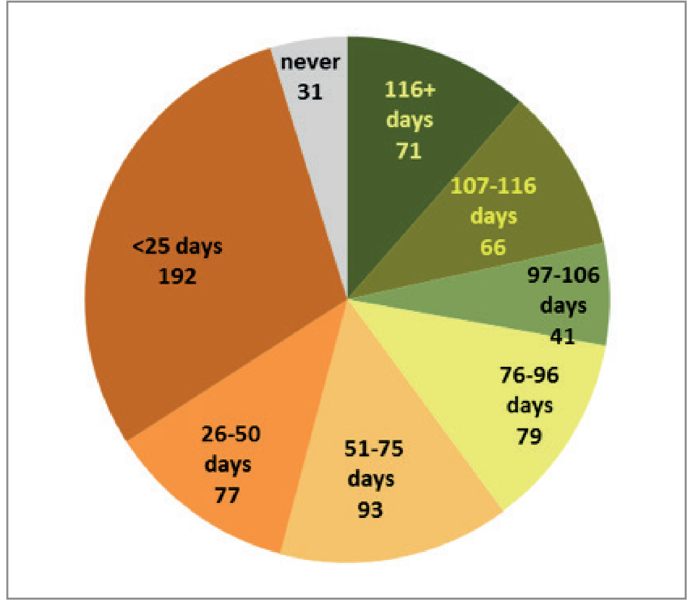


Figure 4.2 Number of devices returning >90% data each day (126 days' data).

It has also been confirmed that the affected RCDs were the subject of a design change around 1999/2000 to improve EMC (electromagnetic compliance) immunity. This followed updates to applicable standards but both the old versions and newer versions of this type of RCD met applicable standards at time of manufacture and installation. No other type of RCD was identified as being affected by this problem. This issue was compounded due to the electromagnetic interference being of sufficient magnitude to affect an area covered by a radiated field of approximately 1.5 m around the LIC. Additional checks therefore took place in surrounding owned properties to ensure there was no impact to neighbouring customers by causing their circuits to trip. Mitigations were considered, including fitting an extension antennae (>1.5 m away from the RCD), moving the LIC (>1.5 m away from the RCD) or replacing the affected RCD with a more modern equivalent. More modern equivalents of the affected RCD are not commonly available but could be remanufactured at a cost of approximately £180 per device. Replacement of the affected customer consumer unit would be significantly more expensive and more intrusive for affected customers. Replacement of the affected device also does not guarantee that an adjacent property will not be affected. Taking these factors into consideration, we chose the fitment of external antennae as the best and most cost effective pragmatic approach.

Of the 11 houses which have either been disconnected or had the NINES kit removed, 8 cases were due to poor communications. Four were homes on the most northerly island where the EM could not see the LICs even after repeated attempts. In 4 of the remaining operational houses none of the devices has been visible in 18 weeks of EM data; in three of these the LIC and devices were registered at installation but not seen since, while in the fourth the LIC has never been visible.

The impact of these problems on the amount of flexible power available is high. At best only around 60% of the connected flexible power was available on any day, falling to 45% in the summer (Figure 4.3). This fall in the number of high-data space heaters over April and May is because heaters are switched off during the summer; and space heaters that were not seen at all may have been turned off permanently – as happened in the prototype trial where 1 out of the 13 space heaters was never actually turned on. However, it is less likely that hot water tanks were either permanently off or else being regularly switched off and on.

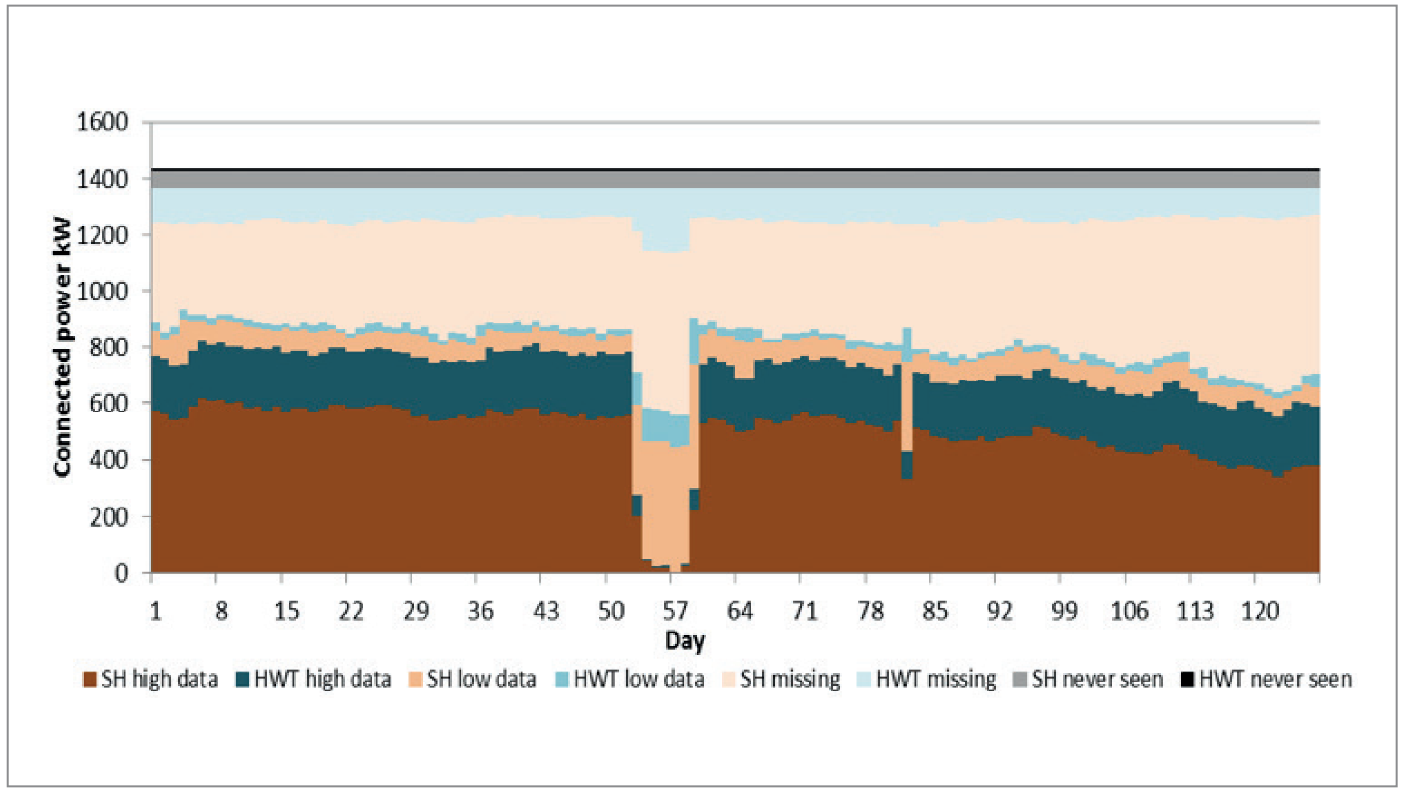


Figure 4.3 Daily available flexible power over 18 weeks.

SSEN's investigations concluded that the root cause data outages lay with the RF network within the houses. Most (although not all) LICs responded when 'pinged' directly, showing that the WAN is working. Within the houses, the interference from neighbouring RF networks could corrupt the pairing of a device with its Home Hub. Glen Dimplex subsequently upgraded the code for the Hub to controller interface but this has not been rolled out yet.

However, it is possible that there are some functionality problems with the LICs themselves. According to the specification, if they do not have recent data for a device they ought to send the last known data through, with the device communications status flag set to zero[20]. In practice however not a single data line recorded by EM shows zero comms status, but devices appear and then disappear from period to period.

4.1.2 Polling period and devolution of control to LICs

The 15-minute polling period followed by the EM is longer than the 5 minutes initially specified and much longer than the 1 minute implemented in the prototype houses. In the original version of the LIC/EM system, the EM had the primary control function, calculating the discrete device set-points and assessing whether the correct amount of energy had been delivered to each house. The heating circuits can switch on or off at 1-minute intervals, and in the prototype trials they were observed to be doing just that[21], so energy consumption can be monitored accurately only if EM collects data once every minute.

However, given the experience of poor communications in the prototype trial and the large number of devices in the rollout, 1 minute polling was considered unnecessarily demanding, and lower control accuracy was accepted in return for increased scale. The LIC polls the heaters separately and should hold a set of data for each device at all times[22]. At this stage the EM was still expected to carry out the detailed scheduling of the devices and it was therefore specified that the envisaged 750 LICs, with up to 10 devices each, should be polled at 5 minute intervals[23]. In practice however if a LIC is not visible the EM has to try multiple times to communicate up to a timeout of 1 second; even 5 minutes proved to be too short a time to collect data from all 234 homes. As the rollout progressed the shortest practicable interval turned out to be 12 minutes.

In the current Version 2 of the system, the control function has been devolved to the LIC and the EM is now merely a messaging and data storage system, so external communication every 15 minutes does not compromise functionality for the customer. However, the network operator has little insight into how well energy is being delivered against schedule, as the data now being sent to ANM about energy consumption and storage capacity represents less than 7% of the time the devices are operating. The only point when the ANM system has an accurate picture of how much energy is still required is at midnight when new DER targets are received; as the day progresses a central estimate of how much energy has already been delivered during the day becomes progressively less reliable. This will restrict the ability of the ANM to fine-tune load shifting if in future the network decides to re-schedule more than once a day. This could however be resolved if the LIC were programmed to calculate and transmit energy delivered as well as instantaneous power. This should be straightforward to implement: the basic functionality to integrate under a load curve already exists because that is also used for schedule translation.

4.1.3 Impact of Communications System on RCDs

The impact of the Airwave communications and affected RCDs is discussed in section 3.2.1. The learning associated with this could not realistically be predicted and although some evidence around the effects of electromagnetic interference on RCDs is available, very little applies directly to the UK market.

Although all devices appear to be fully compliant with standards and specifications applicable at the time of manufacture and installation, we appear to have uncovered a potential issue which impacts devices built to previous standards when operating in close proximity to current communication devices. The Airwave system incorporated into the Local Interface Controller is compliant with Ofcom licensing and relevant standards. The model of RCD, common to all the faults, was designed and tested to BS EN 50082-1:1992, which required immunity to an electric field strength of 3 V/m but made no immunity requirement for conducted interference at 412 MHz. The later model of the RCD, which has not resulted in reported faults, was released circa 2000. The 2000 era RCD was designed and tested to BS EN 61008-1:1995, which cites BS EN 61453:1996, requiring immunity to an electric field strength of 10 V/m but not requiring immunity for conducted interference at 412 MHz. It should also be noted that when tested at Airwave the unshielded RCD tripped due to interference from a mobile phone. This could have implications for the smart metering roll out where communication mediums are very similar to that used by Airwave solutions or GPRS mobile telephone technology. Further detailed studies will need to be carried out to ascertain the extent of this issue but initial learning to date has been shared with Ofgem and DECC. In general the findings are as follows.

- Airwave Solutions operate in the 412MHz/ 5W band.
- One type of RCD manufactured pre 1999/2000 is susceptible to nuisance trip when sited less than 1.5 m from the LIC.
- Modern versions of the same RCD manufactured post 2000 are not affected.
- Certain other manufacturers RCDs manufactured pre 2000 appear to be unaffected.
- No conclusion on how many other type of RCDs manufactured pre 2000 may be affected.
- The pre 2000 RCD also tripped when in very close proximity a cellular mobile telephone (less than 50 mm between RCD to mobile telephone).
- Smart Meters will be mounted in close proximity to consumer units containing a multitude of types of RCDs.
- Communications for smart metering will utilise either cellular technology or 400MHz/ 2W band.

4.2 Heater functionality

4.2.1 Spurious reported demand

Devices that are switched off can appear to be on in EM and report non-existent demand. During the winter, 10-15% of the reported energy required for next day was spurious; in the summer the proportion was even higher (Figure 4.4).

On the space heaters the heating circuits are wired separately from the controllers. As there is no on/ off status report, if the occupant switches the heating circuit off without also switching off the controller, then the latter continues to operate as normal. It calculates and transmits DER, and sets the heating circuit to switch on according to the target schedule provided. As however the heater fails to reach the room temperature set by the occupant, it calculates even higher energy demand for the next day. These heaters can be recognised by the fact that they report that they are drawing power almost all the time but the core temperature is flat at 50 C (the lowest temperature that the core sensor can measure). Although only 6-12 devices are in this condition on any one day, their collective demand is so high that they distort the overall demand noticeably.

4.2.2 Storage capacity

The real storage capacity in both space and water heaters is always significantly less than that reported by the device.
The space heaters are programmed to maintain a minimum core temperature of 50 C in order to maintain a minimum heat reserve at all times: charging starts automatically when the temperature falls to this level. At 50 C the heater reports itself to be around 10% full. The core sensor cannot measure below this in any case and cannot show a value below 50 C. Charging cuts off when the core sensor measures 210 C, 105% of nominal maximum[24]. So the real controllable storage capacity is only around 95% of nominal, 6.5 hours at full rated power rather than 7. The LIC however reports the 7 hour capacity (Table 4.1).

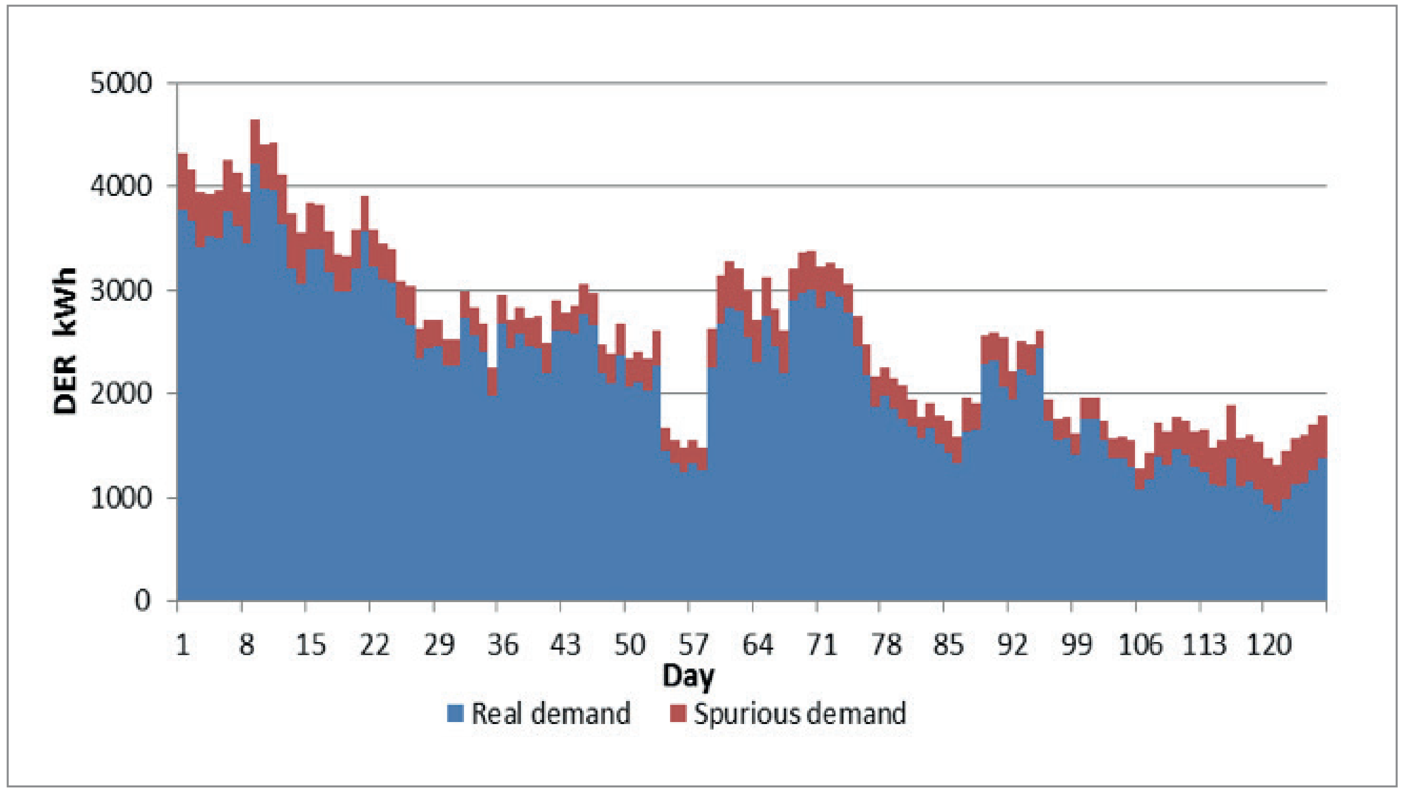


Figure 4.4 Real and spurious demand reported to EM each day.

	QM070	QM100	QM125	QM150
Input / rated power W	1560	2220	2760	3300
Rated storage capacity kWh	10.9	15.4	19.3	23.1
Real storage capacity, min 50^{0}C kWh	10.4	14.6	18.3	21.9
Uncontrolled output 50% full kWh/day	4.2	5.7	6.8	8.9
Uncontrolled output 25% full kWh/day	2.3	3.1	3.3	4.1

Table 4.1 Available storage capacities and uncontrolled output of space heaters.

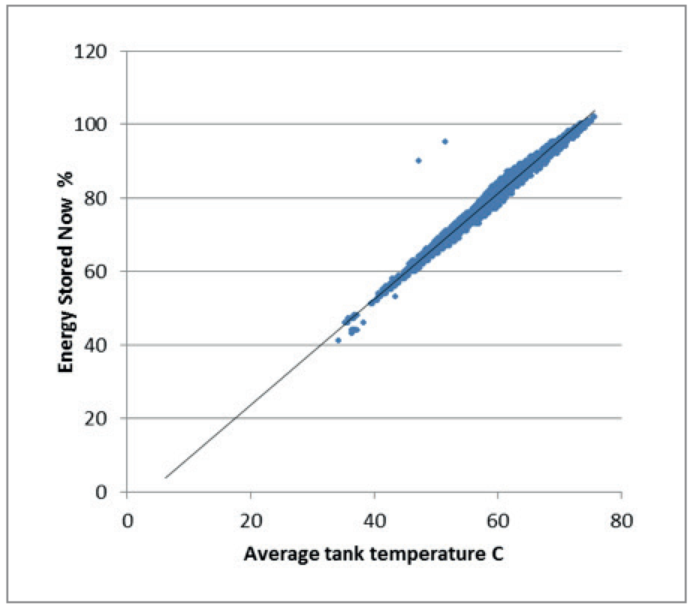


Figure 4.5 Reported energy stored in a water tank as a function of water temperature.

In the hot water tanks the maximum allowable water temperature is 75 C and the physical minimum is the temperature of the incoming mains water, generally around 10 C. The nominal storage capacity is however reported relative to a water temperature of 0 C (Figure 4.5), so overstates the physical capacity available by around 20%.

The storage capacity available in practice in NINES is further limited by the minimum heat reserve setting, where if the temperature at the third sensor falls below 40 C the tank starts charging automatically. This means that the average tank temperature is never allowed to fall below 25 C: the devices are therefore configured to have a practical controllable capacity only around two-thirds of nominal (Table 4.2).

4.2.3 Uncontrolled output and standing losses

The space heaters are much better insulated than those they replaced. In laboratory tests carried out by Glen Dimplex, each of the three smaller heaters retained at least 50% charge after 24 hours of uncontrolled discharge from full. Extrapolation indicates that without the fan it would take around 24

	E125	E175	E210
Input / rated power W	2625	2625	2625
Rated storage capacity kWh	8.4	12.2	15.0
Maximum real storage capacity kWh	6.7	9.8	12.0
Practical capacity with 40^{0}C minimum kWh	5.6	8.2	10.0
Standing loses at 40^{0}C kWh/day	0.9	1.1	1.3
Standing loses at 75^{0}C kWh/day	1.3	1.5	1.9

Table 4.2 Available storage capacities and losses in hot water tanks.

hours more for the core to discharge itself to the minimum temperature. Data from the Q150 heater was not available, but there is no reason to believe that it would be any different.

However, although the level of uncontrolled output is less than in older models, it is still high. Figure 4.6 shows how the uncontrolled output of three of the heaters varies with core sensor temperature in laboratory tests. The core temperature measures the level of fill: when they are reporting themselves one quarter full, the heaters emit 2-4 kWh per day, and when they are half full this rises to 4- 9 kWh per day.

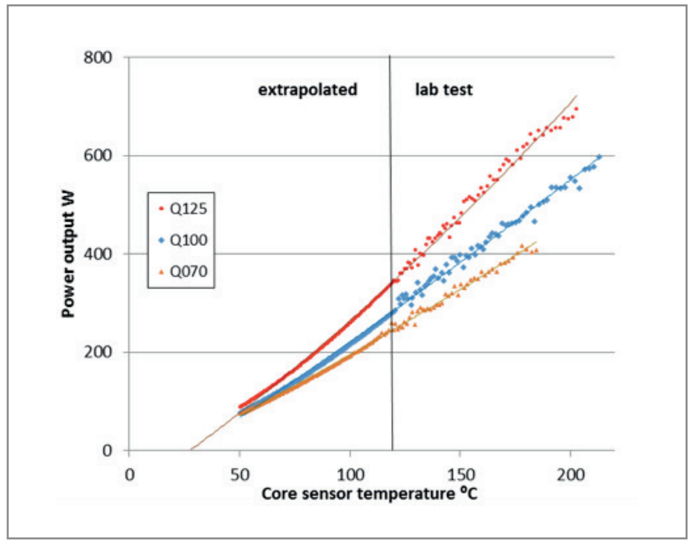


Figure 4.6 Uncontrolled output and measured core temperature in space heaters.

As laboratory test data was not available for the Q150, its uncontrolled output was estimated by extrapolation – see Table 4.1.

In the hot water tanks standing losses are similar to other comparable commercially available tanks, between 1-2 kWh/ day depending on tank size and water temperature (Table 4.2). Given the requirement to maintain a minimum tank temperature, and the requirement to cycle the tank up to 60 C once each day, they will operating at a higher temperature on average than a normal, user-controlled tank so lost heat will be greater. This is discussed further in the Customer Impact Report[25].

4.2.4 Zero rated power reported

The space heaters can have periods when they report perfectly plausible data except that they show a zero rated power and maximum storage capacity. 29 out of 373 space heaters with more than 10% valid data exhibited this behaviour for at least one week, and 6 showed zero rated power for the whole period. This underrates the total capacity by a maximum of 59 kW, around 10% of the total power available for the devices seen. It also affects scheduling because when the EM calculates the Group DER it uses the average of DER/ Rated Power for the devices not seen. If half the devices are not seen then the total DER is over-estimated by up to 5%.

4.2.5 Hot water tanks HSE cycling

The tank control systems have been designed to cycle the water temperature to 60 C at least once per day in order to prevent the risk of bacterial infections. This was a difficult piece of functionality to implement at the same time as neither over-charging nor under-delivering on the day's energy, and took multiple iterations[26].

However, even after the most recent upgrade not all tanks meet this requirement. In the 18 week recording period, 121 hot water tanks returned almost complete data on more than 2 days. Of these, 91 failed to reach 60 C and 13 of these failed to reach 57 C on 2 or more occasions. Figure 4.7 shows the time profile of average tank temperature for two of the latter. In reality, occupant-controlled water tanks operate safely without meeting this requirement. Also, by raising the average water temperature above what is needed it results in wasted heat though higher standing losses. The need for HSE cycling should be reviewed before future rollouts.

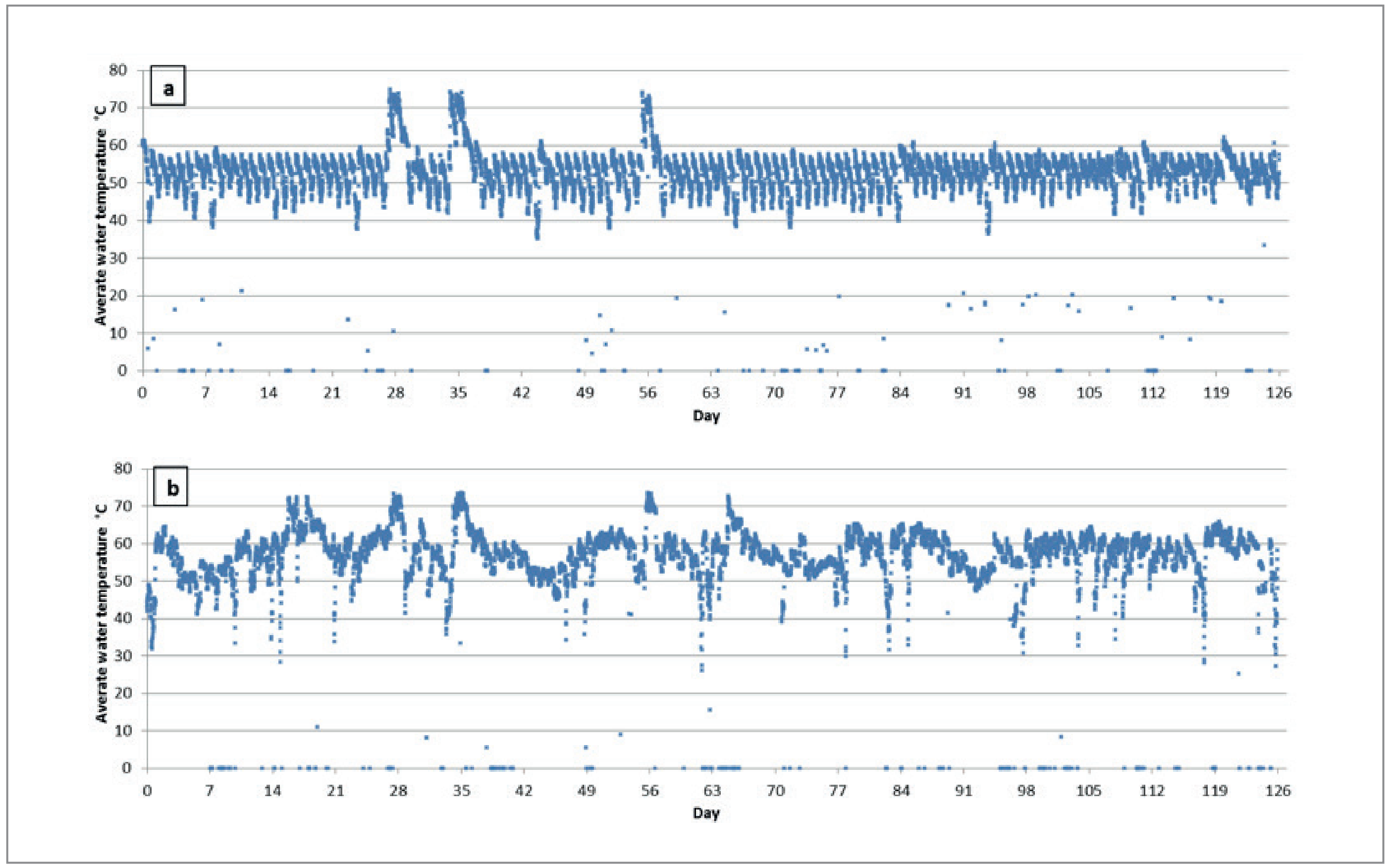


Figure 4.7 Examples of hot water tanks which regularly fail to cycle through 60 C each day. a) H0139, b) H0130.

4.3 Operational issues

4.3.1 Susceptibility to power outages

The heaters appear particularly susceptible to even momentary interruptions to power supply. If there is a power outage, the controller resets the amount charged so far that day against DER to zero, so that much more energy is drawn than needed. SSEN report that this appears to be a particular problem in the exposed South end of Mainland where 37 outages occurred between January 2014 and June 2016 and customers questioned the reason for high consumption. This is discussed further in the Customer Impact Report[27].

4.3.2 Hub and LIC updating

The Glen Dimplex controllers and Home Hub were designed in 2010 and cannot be updated remotely as would be routine today. Any changes to the firmware required a home visit. This was time-consuming and inconvenient for the customers. Also, during the Hub replacement programme, 25 of the LICs had to be replaced and updated offsite as they could not be updated remotely. Any future rollouts should incorporate over-the-air update capability.

4.4 Commissioning problems

A number of problems were encountered during the first 18 months of operation[27], but were subsequently fixed.
The most serious issue was that the Home Hub could swap the identities of two or more devices within a house (the 'swaperoo' phenomenon). Because the RF networks from neighbouring houses could interfere with each other, the swaps could occur even with other houses, so the LIC target schedules for delivering DER were incorrect. This problem has not recurred

since the Home Hubs were replaced in February 2016. Other problems encountered and resolved during commissioning were as follows.

- Temperature feeds not updating in the controllers and so DER calculated incorrectly; resolved in a firmware upgrade.
- At the changeover from GMT to Summer Time, the clock switched from 02:00 back to 01:00 continuously, never arriving at customer-set time for heating; resolved in a firmware upgrade.
- Some heaters were not wired securely to the supply so although they were communicating normal performance the heating elements were not on consistently. This was only uncovered after customers had repeatedly complained about being cold. Future rollouts should implement robust quality assurance processes during installation.

5

Costs

5. Costs

The rollout project lasted 3.5 years, starting the year after the prototype trial ended and finishing two years after all the installations were complete. SSEN and HHA reported spending £3.23 million in all, including development, procurement and installation of the devices by HHA, IT support and operational support by HHA and the Customer Service Unit.

5.1 Project costs

A cost breakdown is given in Table 5.1, based on the data provided by SSEN and HHA. 39% of the total was incurred at the houses: comprising heaters, installation, commissioning, fixing problems in the field, equipment removal in decommissioned houses, replaced kit and spares. Most of these were paid for by the owner of the properties, HHA. Of the rest, 49% was incurred in developing and testing the shared infrastructure, and 12% for operational support. SSEN's share of the costs was £8,379 per house live in June 2016. Customer incentives averaged out at £101 per house: each customer that opted in was paid £100, and those with independent monitoring received an additional payment of £50 each.

5.2 Ongoing operational support

After the project is formally finished, excluding any variable payments made to customers, SSEN estimate that it will cost around £490,000 per year to keep it going at the current scope:

- £286,000 for communications network (£1,222 per year per house);
- £150,000 per year for the 3-person Customer Service Unit;
- £30,000 per year for maintenance visits by contractors, assuming 20% of houses visited; and
- £25,000 per year for IT support.

	Total	Cost per house	Notes
Direct costs at houses			
In house devices	£471,726	£2,016	Paid by HHA, installed in 234 homes
In house installation	£628,274	£2.685	Paid by HHA, installed in 234 homes
LICs & communications setup	£149,360	£638	Installed in 234 homes
Incentive payments	£23,650	£101	Average over 234 homes
	£1,273,010	**£5,440**	
Direct costs – shared infrastructure			
EM development & Airwave comms	£600,000	£2,564	Average across 234 homes
Communications license and support	£858,000	£3,667	£286k for 3 years
Database development	£25,000	£107	Average across 234 homes
Servers & related infrstructure	£50,000	£214	Average across 234 homes
IT network	£50,000	£214	Average across 234 homes
	£1,583,000	**£6,766**	
Operational support			
Tenant liaison	£45,000	£192	
Customer Service unit	£245,000	£1,047	Up to 3 FTE over 3.5 years
IT support – in house & third party	£87,500	£374	
	£377,500	**£1,613**	
Grand total	**£3,233,510**	**£13,818**	**Ave. cost per house for 234 homes**

Table 5.1 Costs of NINES DSM rollout and support through project phase.

6

Future rollouts

6. Future rollouts

6.1 Future rollout strategy

The HHA houses are some of the smaller, newer, and better insulated properties on Shetland and provide limited controllable capacity and storage. Larger, less insulated houses would provide higher capacity for the same infrastructure and communications overhead. Modelling studies show that a private market strategy that targets such houses should give a higher benefit to both occupants and the network as discussed in in the Customer Impact Report[28]. Two types of houses are particularly suited to DSM and both are well represented in both Shetland and in the rest of Scotland:

- those built before 1945, with solid or hard to insulate cavity walls, large rooms, and high ceilings - estimated 1200 private dwellings in Shetland; and
- 1945-93 built, typically timber frame, block & render cladding, and no or moderate retrofit wall insulation - estimated 3100 private dwellings in Shetland.

From the customers' perspective, these houses need more heat overall so off-peak tariffs will have a proportionately large impact, and the uncontrolled output from the heaters makes a valuable contribution to keeping overnight temperatures from falling too far. For the DSM Service Operator, each house will provide larger controllable capacity and is more likely to make full use of that capacity.

6.2 Infrastructure needed

SSEN's Open Market Model[29] does not envisage that hot water tanks will be installed in private houses, because these cost more than standard tanks and have long lead times as they are built to order. The HHA rollout required an average of 2.5 space heaters per house. If the future rollout strategy focuses on larger, older and less well insulated properties they will require more and bigger space heaters.

DSM enabling kit for each private home will comprise a clamp-on device to measure heating electricity consumption as well as the LIC and the Home Hub. Currently an annual visit to each home will be required to check that the clamp-on heating electricity meter is working correctly.

To gain maximum benefit from DSM, around 15.8 MW of controllable capacity will be required, with around 2500 houses and 8000 controllable space heaters; this is discussed in detail in the Network Benefit Report[30]. According to specification the EM should be capable of collecting data every 5 minutes from 750 houses with 10 devices each. Airwave has estimated that 4880 LICs could be handled by their network of 9 base stations at 15 minutes if 10% of LICs are unresponsive. So both the EM and the network infrastructure should be capable of supporting an optimal rollout: this assumes that the imminent Glen Dimplex Hub upgrade solves the polling congestion problems and that the network does not wish to schedule more than once per day. However, if the polling period is reduced to 5 minutes then the EM will require to be expanded and additional network base stations installed.

In the opinion of the DSM Project Manager, an expansion to another 500 houses in the private market could be supported with the current level of customer and IT support. However this excludes any additional development costs required to solve any EM-LIC functionality issues.

If the rollout is predominantly to houses that currently use electrical heating then there should be no impact on the substations. This is likely to be the case: Lerwick Power Station reports at least 17 MW of identifiable off-peak electrical heating demand in Shetland, and SSEN's analysis of the number and location of electricity meters indicates that around 3,000 houses currently have a two-tariff supply and are therefore good rollout candidates. If however substantial numbers of previously oil-heated private homes switch to storage heating and increase the overall load level, substation constraints may come into play.

6.3 Estimated capital and operating costs

In 2013 SSEN estimated that it would cost them £2,020 per house on average to roll out to 500 private homes over 3 years. After the rollout was completed, the cost of maintaining the system would be £645 per year averaged across the HHA and private sector houses, comprising: £300 per house per year for communications; £245 per year in incentive and levelisation payments to private sector houses plus customer churn; and annual DSO operating costs amounting to £100 per operational house. When compared to the £85 that the DNO makes on average each year per house, the cost of DSM in this fashion is financially unsustainable.

The purchase and installation of the heaters will be paid by the home-owner. If the rollout strategy focuses on larger, older and less well insulated properties that require more and bigger heaters, then the direct cost of heaters to each homeowner will be higher than seen by HHA. Table 6.1 gives a comparative estimate based on 4 heaters per house with an equal mix of all four sizes. New customers who are switching from direct heating may be able to install fewer heaters, but those who are replacing oil or LPG fired central heating systems with storage heaters may also need to buy new panel heaters for other rooms in the house.

	HHA Rollout	Private market
Average space heaters/house no	2.5	3.9
Average power/device kW	2.18	2.46
Average cost of space heaters/house	£2,016	£3,145
Installation costs per house	£2,685	£3,000
Total cost to homeowner	**£4,701**	**£6,145**

Table 6.1 Comparison of homeowner paid kit and costs in rollout and private market.

Additional capital costs will be needed to upgrade the existing Hubs to fix the RF communications problems; a previous sequence of home visits for upgrade was estimated to cost around £80,000. Other work that may incur costs that cannot at this stage be estimated includes further changes to LIC-EM functionality and the purchase of a CRM system.
SSEN believe that no additional operating expenditure would be required to service 500 more houses.

7

Learning outcomes

7. Learning outcomes

This review of the infrastructure required for operating Demand Side Management in social housing in Shetland contributes to the NINES learning objective:

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

- Each house in the rollout needed the same DSM enabling infrastructure of a Home Hub, a LIC, and a license for WAN communications irrespective of how many heaters were installed (except for two very large ones which required double). However, the NINES rollout was predominantly to small, relatively new and well insulated homes with an average of only 5.4 kW space heating per house. If future rollouts target larger, hard to insulate houses, which make up half of the Shetland housing stock, then the controllable capacity available for the same overhead could be doubled. In addition, such houses will have a longer heating season and are less likely to be turned off in summer.

- The available controllable power was reduced by about half due to significant data outages which persisted even after several system upgrades: only about half the devices could be seen consistently, and a third of devices were never seen. The RF communications within a house appear to be the root cause of the problem, and Glen Dimplex have developed a solution that is believed will work. This solution needs to be rolled out and tested in the NINES houses well ahead of any further rollouts.

- The DER reported by EM for a group was 10-20% above actual, due to two quirks in the way heaters report status. Both problems should be corrected by changing the calculation method in the EM. The rated power of each device could be checked against a fixed lookup table, and corrections made for zero entries. Switched off devices can be identified by looking for those where the core temperature is flat at 50 C all day and their DER discarded. This would improve schedule following in both current and future rollouts.

- Device controllers are affected by momentary power outages: they keep DER in memory but not the record of how much has already been stored against that DER, so they over-charge and customers see high consumption. This should be corrected in the firmware before future rollouts.

- Other functionality in the heaters that would help with future rollouts include the following.

    - A status flag in the device data that shows whether the heating circuit in a device has been switched off, if necessary by sacrificing some other data. This would remove non-operational devices from EM’s calculation and give a more accurate group DER.

    - Over- the-air upgrade capability for device controllers and Home Hubs so that future firmware upgrades do not require a site visit.

    - Redesigning the transceiver connection to the heater body to allow them to be replaced without dismantling the heaters.

- The decision to apply minimum comfort temperatures reduced the practical storage capacity of space heaters to 95% of nominal, and that of hot water tanks to two-thirds. The need for these comfort settings should be reviewed for future rollouts.

- Hot water tanks do not consistently meet the requirement to cycle through 60 C each day to prevent bacterial infection. However, occupant-controlled water tanks operate perfectly safely without meeting this requirement, and raising the average water temperature above what the customer needs wastes heat through higher standing losses. The need for HSE cycling should be reviewed before future rollouts.

- The EM currently collects data from the LICs every 15 minutes, which is too long an interval to make an accurate estimate of how much of the day’s DER has been delivered and how much flexible headroom remains as the day progresses. This is not a problem while scheduling is done only once a day at midnight when new DER targets are received but will restrict the future ability of the ANM to re-schedule during the day. Re-programming the LIC to calculate and transmit energy delivered as well as instantaneous power would allow the network to fine-tune load shifting.

- The overall cost of the rollout, including development costs, central infrastructure, decommissioned houses, replacements, upgrades and spares was £13,818 per house, over half of which was paid by SSEN and the rest by HHA for devices and installation. The long term maintenance cost was estimated at £739 per house per year including communications and customer incentives, averaged across HHA and the private market. Potential DSOs will need a different market model and significantly cheaper communications licenses to make DSM rollout financially attractive.

- A Customer Service team of 3 plus IT support were needed to support the rollout. SSEN believe that this will also be enough to support rolling out to another 500 houses in the private market. However, it is recommended that a Customer Relationship Management system would be required in order to allow the team to communicate efficiently both in terms of cost management and customer management.

- Installation of the equipment by a local team of electricians and plumbers took between half and one day if everything went well. However, it could take double that time if the Hubs had to be repositioned before they could see the devices, or bigger aerials had to be installed before the EM was able to communicate with the LIC. This work was funded by HHA, and in future rollouts will be paid for by the customer, so before a new contract is signed it will be essential to test whether the site has robust internal and external communications.

- The planning of future rollouts in Shetland needs to take into account the infrastructure challenges of operating in remote locations. Deliveries can be delayed, so enough equipment needs to be bought and stored so that installation work is not held up. Houses can be a long way from the store so enough spares need to be taken to each, especially of the device User Interfaces which are easily damaged. In some locations it can be difficult just to make a mobile phone call back to the centre to coordinate testing if the EM can see the LIC.

Appendix 1

Visual representation of device communications

Appendix 1 – Visual representation of device communications

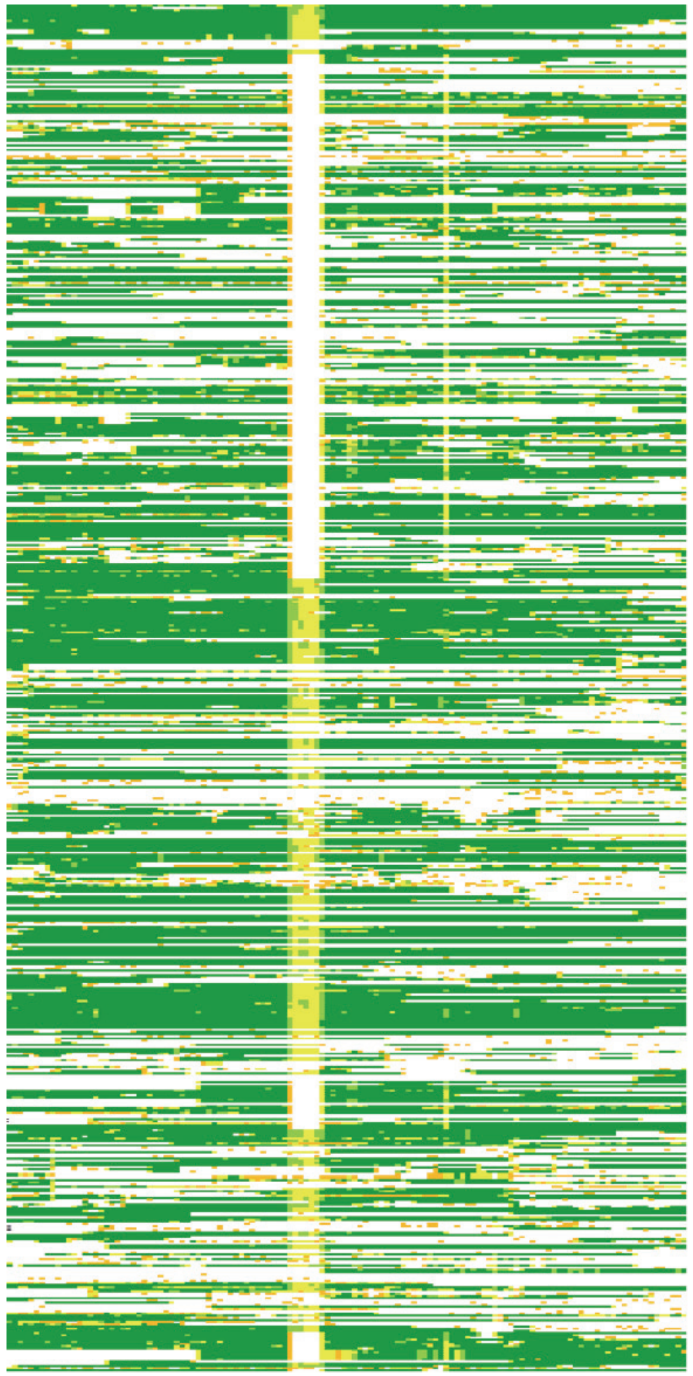
The figure opposite shows day-by-day visibility for each of the 708 devices over 18 weeks. Each square on the horizontal axis is one day. The devices are arranged by house number on the vertical axis, but because of the small scale it has not been possible to identify individual devices.

The colour coding shows how many occasions each day the device was in communication with the Element Manager:

- Dark green – 90% or more of the time
- Pale green – 75-90%
- Yellow – 25-75%
- Orange – less than 25%
- White – no communication at all that day

Even though it is hard to distinguish any individual device at this scale, the overall picture gives a good impression of the nature and extent of data outages. Very few devices had continuously good communication throughout, and some had uniformly poor communications. In many cases periods of good data are followed by occasional outages, and then good data resumes – these are dark green horizontal bands punctuated by paler colours. In others, periods of little or no communication are punctuated by periodic bursts of data – these are white bands with the occasional coloured block. Where the white band is unbroken the device is most probably switched off.

In the week 7 to 13 April 2016, a fault in the Element Manager meant that the time taken to poll all LICs exceeded the maximum allowed, and some LICs were not polled at all. Most of the houses between H0004 and H0125 were adversely impacted by this. A second, smaller glitch appears to have occurred on 6 May.



Footnotes

1:	1A NINES DSM Customer Impact Report (2017) University of Strathclyde/ ESRU.	8
2:	1C NINES DSM Network Benefit Report (2017) University of Strathclyde/ ESRU.	8
3:	3B NINES Frequency Response Operational Effectiveness Report (2017) University of Strathclyde/ IEEE.	8
4:	4B NINES ANM Operational Effectiveness Report (2017), SGS Ltd.	8
5:	Proposals for the development of the Integrated Plan for Shetland (2011) Ofgem Online, www.ofgem.gov.uk/Networks/ElecDist/Policy/Documents1/Phase%201%20Consultation %20Aug%202011.pdf (accessed 12/02/12).	10
6:	NINES Learning and Dissemination Report (November 2013) University of Strathclyde.	11
7:	NINES DSM Market Model (October 2013) SSEN.	11
8:	Technical Specification for Glen Dimplex Appliances - NINES Installation. (April 2013) GD-Quantum-TS-001, Glen Dimplex Heating.	11
9:	1A NINES DSM Customer Impact Report (2017) University of Strathclyde/ ESRU.	13
10:	3B NINES Frequency Response Operational Effectiveness Report (2016) University of Strathclyde/ IEEE.	13
11:	Technical Specification for Glen Dimplex Appliances - NINES Installation (April 2013) GD-Quantum-TS-001, Glen Dimplex Heating.	16
12:	Building energy performance assessment support website, http://www.ncm-pcdb.org.uk/sap/pcdbsearch.jsp?type=391&pid=44, accessed 10 October 2016.	16
13:	Design Specification for the LIC Component Required for SSE NINES, Issue 1.5, 29 April 2016, Airwave Solutions.	17
14:	Design Requirement Specification Element Manager Component, v 2.1.2, 11 May 2016, Airwave Solutions.	17
15:	NINES Project - ANM to DDSM Element Manager interface requirements, SGS Ltd, 12 May 2015.	18
16:	NINES Shetland 6 Homes Risk Review. SSEPD, undated.	19
17:	NINES – Northern Isles New Energy Solutions Data Protection Strategy, SSPED, 22 October 2013	19
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19:	1C NINES DSM Network Benefit Report. (2017) University of Strathclyde / ESRU	21
20:	Design Specification for the LIC Component Required for SSE NINES, Issue 1.5, 29 April 2016, Airwave Solutions.	24
21:	DDSM Trial House Monitoring: Performance of Quantum Devices (2013) University of Strathclyde/ ESRU.	24
22:	Design Specification for the LIC Component Required for SSE NINES, Issue 1.5, 29 April 2016, Airwave Solutions.	24
23:	Design Requirement Specification Element Manager Component v2.1.2 . (2016) Airwave Solutions, 11 May	25
24:	This is the maximum temperature measured by the sensor, not the actual temperature of the core. A sensed temperature of 190 C is equivalent to a real core temperature of 620 C. However, when the heater is charging it can take up to 2 hours for the core temperature to equalise, so the sensed temperature continues to rise to almost 210 C.	26
25:	1A NINES DSM Customer Impact Report (2017) University of Strathclyde/ ESRU.	28
26:	DDSM Observations & Interpretation of Data v0.2 (2016) SSEN.	28
27:	1A NINES DSM Customer Impact Report (2017) University of Strathclyde/ ESRU.	29
28:	1A NINES DSM Customer Impact Report (2017) University of Strathclyde/ ESRU.	35
29:	NINES DSM Market Model (October 2013) SSEN.	35
30:	1C NINES DSM Network Benefit Report (2017) University of Strathclyde/ ESRU.	35

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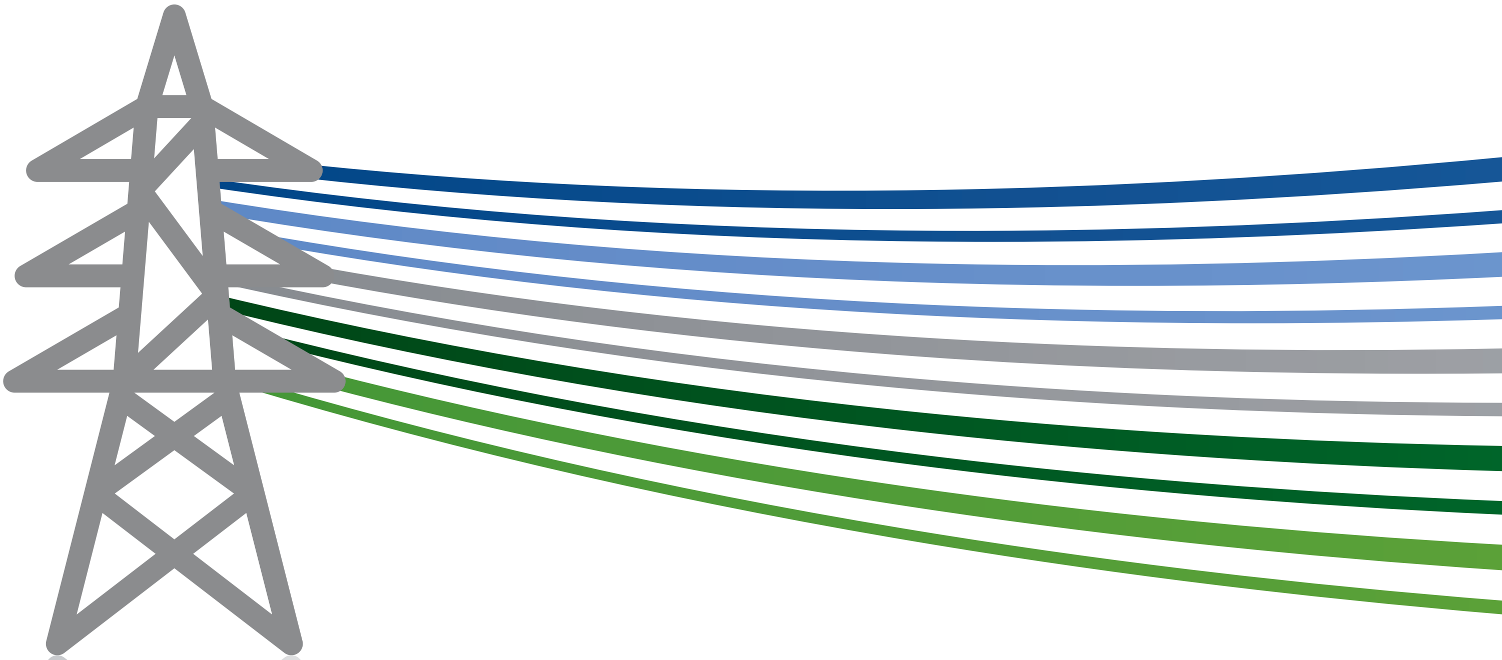

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