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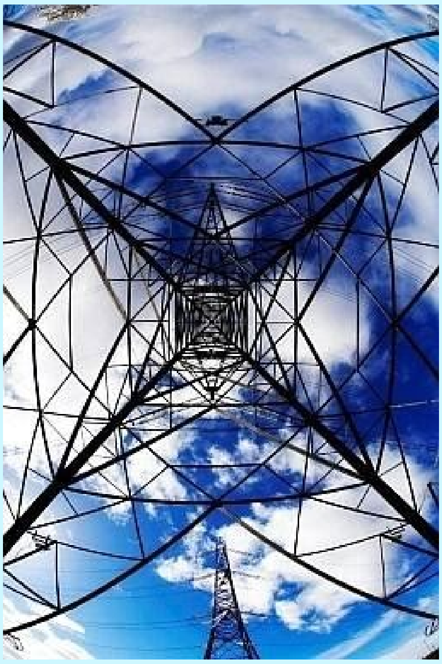

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CONTENTS

1 Introduction

Shetland Islands Council (SIC) has commissioned TNEI to investigate the feasibility of implementing Demand Side Management (DSM) at council sites and domestic properties, and the benefits that this could provide with regard to reduction in the curtailment of the proposed Garth Wind Farm, or of other potential community generation projects. This commission was based on TNEI's proposal No. 9467-01-R0 [1].

The original scope for the investigation comprised two main elements:

- Modelling Workstream – Using network models, together with time-series load and generation data, determine the nature of the generation constraints and the amount of generation constraint that could potentially be alleviated through the use of demand side management techniques.
- Technical Assessment Workstream – Provide an assessment of the DSM techniques used in the NINES study, the technical viability of distributed demand side management, and an understanding of how ANM will work in practice including a review of regulatory and commercial issues.

For the modelling workstream, it was understood that SHEPD would provide network data and other parameters of relevance to the investigation. Unfortunately, following the kick-off meeting SHEDL indicated that they were not able to release this information in the run-up to the forthcoming tender process outlined in their recent consultation document "A New Energy Solution for Shetland" [2]. As a consequence, TNEI and SIC agreed to park the Modelling Workstream, but to continue with the Technical Assessment Workstream.

2 Overview of the electricity system in Shetland

2.1 Generation and demand

There is no connection between the electricity system in Shetland and the grid on the Scottish mainland. All power consumed on the islands must therefore be generated locally, and vice-versa. The islands are served by two main generation plants: Lerwick Power Station (67MW), and the privately-owned generation at Sullom Voe terminal (100MW) which provides up to 15MW into the Shetland grid. There are also several wind turbine generators connected to the system, which contribute a few additional MW of capacity.

Demand on the Shetland system varies between 12MW and 45-50MW (2013-14 data). Most of the demand is concentrated in Lerwick and the surrounding area.

2.2 Network

The backbone of the electricity system on the islands is the 33kV distribution network. The 33kV network extends from Unst to Sumburgh, transmitting power to ten primary substations which in turn feed local 11kV distribution networks.

The overhead line circuits that form the majority of the 33kV network are rated to transmit fairly large volumes of power, relative to demand levels. Three different line specifications are used across the system; their thermal ratings are shown in table 1.

	Line rating (MVA)			
Line spec.	Winter	Spring/ Autumn	Summer	Examples
Light	11.0	10.2	8.8	Sandwick to Sumburgh Firth to Mid Yell
Medium	17.4	16.1	13.9	Scalloway to Sandwick Mid Yell to Gutcher
Heavy	24.1	22.3	19.3	Tumblin to Voe
Ref. SHEPD Long Term Development Statement, table 1				

Table 2-1: 33kV overhead line specifications used in the Shetland system

2.3 Constraints on generator connections in Shetland

On Shetland, the integration of new renewable generation onto the system has given rise to concerns for the system operator, SHEPD. The main issue is not network capacity – even the weakest parts of the 33kV network could accommodate up to 8MW of unconstrained generation without exceeding the thermal capacity of the existing lines. However, the addition of this amount of new generation to the system would have quite a major effect on the operation of the existing generation at LPS.

LPS operates as a 'load-following' generator – it must vary its output to match the residual demand on the Shetland system, in real time [1]. As well as ensuring that the right amount of power is supplied to meet demand on a second-by-second basis, the provision of this function by LPS also ensures that the system frequency and voltage remain stable. Uncontrolled imbalances between generation and demand can lead to frequency deviations and voltage spikes, which can damage electrical appliances and cause safety hazards.

LPS also provides two other vital attributes:

- Security – Generating units at LPS are dispatched in a way that provides a degree of protection against unplanned events, such as failures or trips. This might involve operating three units at part-load, when the demand could be met using just two units at close to full-load. The latter arrangement would be more fuel-efficient, but would not be able to maintain stable operation of the system following a trip of one unit.
- Inertia – All generating units at LPS are synchronous, which means that the speed of the generator is 'locked' to the frequency of the system. When they are running, synchronous generators contribute to the inertia of the system, making it less prone to frequency excursions. Most renewable generators are not synchronous, and do not provide inertia.

Given this background, the addition of new, unconstrained generation to the system gives rise to a number of concerns in relation to the operation and capability of the generation at LPS:

- Residual demand could fall to very low levels a certain times (eg. on a breezy summer night). LPS may be unable to match this demand, due to the minimum load threshold of the dispatched units.
- Power output from wind generation can vary sharply over time, as windspeeds change. This could give rise to high rate of change of residual demand. Generator governors at LPS have limited 'ramp rate', so may be unable to accurately follow the changing demand.
- If the new generation is connected to the main 33kV network via a single circuit, a trip of this circuit would result in the instantaneous loss of several MW of power. This would cause a frequency deviation. With fewer synchronous units coupled to the system, this deviation will tend to be larger than it would otherwise be, and the capacity to rapidly increase generation output to replace the lost power will be lower.

[1] Residual demand is simply the difference between the total demand on the system and the amount of power being supplied by other generators.

2.4 Comparison with Orkney

There are important differences between the two electricity systems serving Orkney and Shetland, and these result in quite different factors being critical in relation to the integration of new sources of generation. Table 2-2 provides a brief summary of these differences.

	Shetland system	**Orkney system**
System is served by conventional generation plant	Yes – Lerwick PS	Yes – Kirkwall PS
System is connected to mainland grid	No	Yes – 2 x 33kV cables
Conventional plant provides 'system balancing' function	Yes	No
Low-capacity cable links between islands	No	Yes
Network limits are the dominant constraint for generator connections	No	Yes
System security and stability issues are the dominant constraint for generator connections	Yes	No

Table 2-2: Differences between electricity systems in Shetland and Orkney

Because the Orkney system is linked to the mainland, it can rely on the mainland grid to maintain a stable frequency regardless of generator trips and other unexpected events. However, there are thermal limits in the various subsea cables links between islands, and across to the mainland.

3 Active network management and DSM

3.1 Existing ANM schemes

3.1.1 Orkney

SHEPD worked together with Smarter Grid Solutions (SGS) to implement an Active Network Management (ANM) scheme covering the Orkney system. The objective of the scheme was to facilitate the connection of further renewable generation capacity on the islands, above and beyond the amount that was already connected to the network with firm (ie. unconstrained) access.

The scheme was trialled in 2006, and the first ANM generators were connected in 2009. Since then, a total of 20 new generators have been added to the system, providing an extra 24MW of generation capacity. Implementation of the ANM scheme cost approximately £500,000; SGS estimates that the scheme has delivered more than £4million of benefits to the local economy, through the revenues associated with the new generators.

The Orkney ANM scheme is also being developed to include a Demand-Side Management element, with a 2MW energy storage device as well as a ‘smart’ charging station for electric vehicles.

3.1.2 Shetland

SHEPD is now working with local stakeholders in Shetland, including SIC, to create a ‘smart grid’ in Shetland. The NINES project involves the use of large- and small-scale thermal energy storage, together with ANM technology based on the Orkney scheme. According to the project website, the idea is that the ANM scheme will control a proposed 6MW wind farm, a 1MW network battery and a 4MW electric boiler linked to the existing district heating system.

3.2 How ANM works on Orkney

The ANM scheme implemented in Orkney considers the system as a number of zones (figure 3-1). Each 'zone boundary' corresponds to a thermal constraint, so power transfers across the boundary must be managed to ensure that the constraint is not violated.

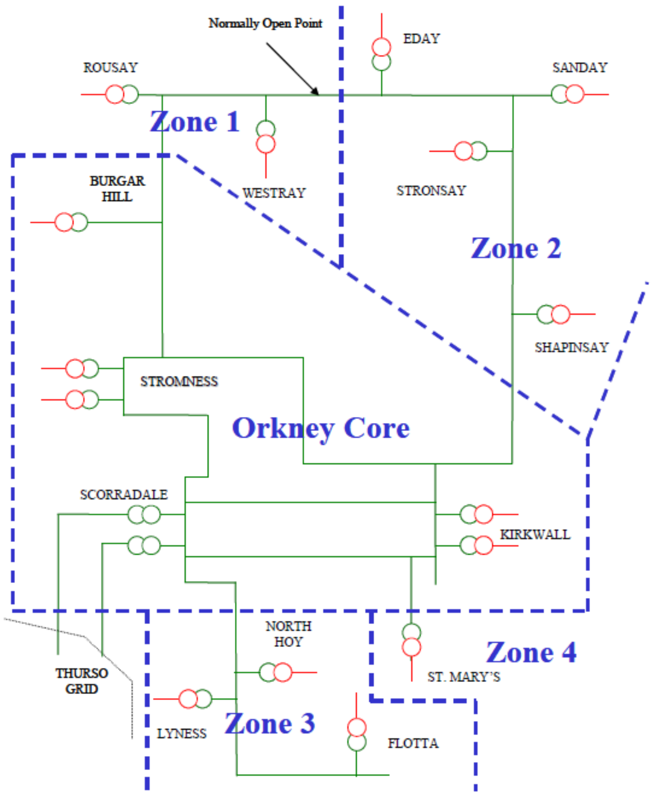

Figure 3-1: ANM zones and boundaries in the Orkney system

This is achieved using real-time monitoring of all demand and generation within the zone. Each constraint has a characteristic set of limits, which define 'safe' and 'unsafe' areas of operation for the zone (figure 3-2). As the values of demand and generation in the zone change, the operating point moves around within the 'safe zone'. If the operating point moves above the trim limit, the ANM scheme signals to the controlled generators, to reduce their power output. As they do so, the operating point moves back into the safe area and operation can continue. If the controlled units fail to reduce their output quickly enough, the operating point might move above the trip limit, approaching the absolute limit. In this case, one or more generators will be tripped off the system to prevent violation of the network constraint.

Conversely, with DSM (ie. controllable demand), the ANM scheme can try to move the operating point back into the safe area by signalling to the controlled loads to either reduce or increase the amount of power they take from the network. If this change in demand can be achieved at little real cost (eg. if the energy can be stored for later use), then this DSM action should be prioritised over trimming generator output. Reducing output from generators results in the loss of available energy, so is more 'costly'.

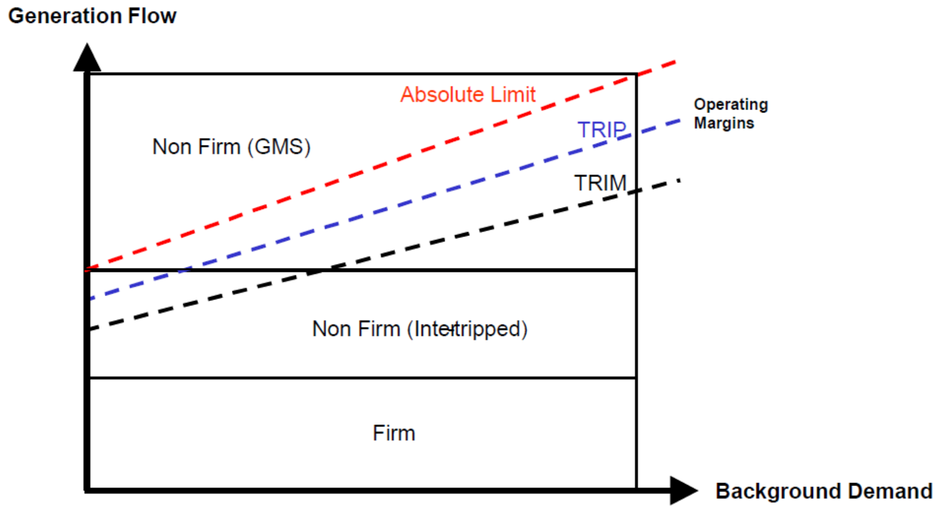

Figure 3-2: Representation of a constraint at a zone boundary

The ANM scheme is implemented as a distributed control system, comprising a central hub together with a number of local controllers located at generation sites and at key locations across the distribution network (figure 3-3). Communication between the hub and the local controllers is via BT 'private wire' connections.

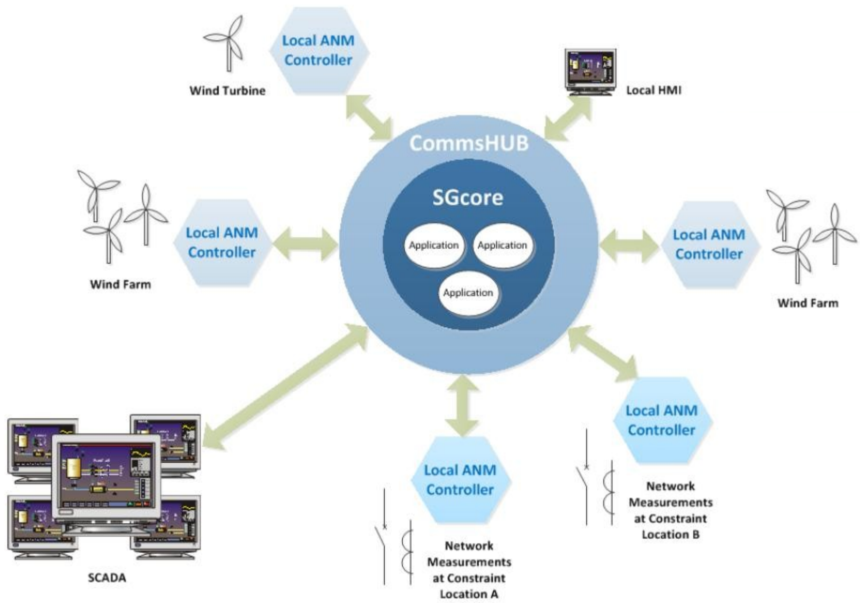

Figure 3-3: ANM system components

3.3 Relevance of Orkney DSM techniques to the Shetland system

Although the underlying reasons for the constraints in Shetland are quite different to those in Orkney, the ANM approach implemented in Orkney can be adapted to represent certain aspects of the Shetland case. In particular, the minimum load threshold for the generation at LPS can be treated as a thermal constraint. The threshold imposes a minimum value on the power transfer from LPS to the rest of the system; looking at it the other way, it imposes a maximum value (which is negative) on the power transfer from the system to LPS. Seen this way, the minimum load requirement looks quite similar to a thermal network constraint. Controllable generators and loads could both be used to ensure that this particular limit is respected.

However, the minimum load threshold is only part of the story in Shetland. As discussed earlier (section 2.3), there are other concerns regarding the effects of adding new generation to the Shetland system:

- Higher rates of change in the residual load, requiring more responsive governor systems; and
- The possibility of an instantaneous loss of power infeed, due to a trip or fault, and the resulting frequency deviation.

Both of these concerns focus on the ability of the system to respond to changes that take place over very short timescales. The Orkney ANM approach does not offer a solution, as it is designed to deal with relatively slow changes in the operating state of the system. In order for an ANM scheme to address these issues, it would have to provide fast-acting control of some generators and/or loads, to increase the transient stability of the system. Possible solutions might include:

- Use an energy storage device to 'smooth out' the output profile of intermittent generators (eg. wind farms), in order to eliminate very high rates of change of generation.
- Use DSM with built-in frequency sensing, to provide a fast reduction in load if there is a sudden drop in system frequency.
- Use a rotating synchronous condenser to provide additional inertia on the system, as well as improved control of voltage and/or reactive power.

3.4 Concluding comments

In this study, Shetland Islands Council has tasked TNEI with investigating the potential for utilising DSM at council-run sites, and considering the potential benefits that this would provide with regard to integration of new generation on the islands – including the proposed generation at Garth wind farm. Sections 4 and 5 of this report focus specifically on these questions.

4 Assessment of scope for DSM in Shetland

4.1 Comparison of Domestic versus Focused DSM

TNEI consider that, when implementing the demand management scheme, Shetland Islands Council is likely to benefit from economies of scale by utilising the largest available sites. This is because the cost of demand side management is largely independent of the size of the demand. From previous project experience, TNEI are aware that implementing a network control system can cost around £1000 per year per control location. This figure covers the cost of providing all required communications infrastructure, control systems, and licensing of required software. Therefore, a DSM portfolio comprising a small number of high-demand sites will be more cost-effective than a portfolio consisting of numerous domestic properties.

It is likely that Shetland Islands Council's larger sites could have thermal storage with demand of as much as 50 kW. In comparison, the NINES project assumed that domestic thermal storage would be sized at around 8 kW. Assuming a fixed cost of £1000 per annum, then with focused demand side management the control aspects alone would cost around £20 per kW, whereas with domestic DSM they would cost around £125 per kW. Clearly, these exploratory cost estimates would seem to favour focused demand side management rather than domestic.

The caveat on these conclusions is that domestic demand side management could be more attractive if smart meters are already installed. Domestic smart meters would aggregate many domestic loads with control at a single central point. Therefore, this would reduce the number of control locations required.

To support these conclusions, TNEI have sought the views of several demand aggregation service providers. Some responses are included below:

- It will not be economically feasible to bridge a connection for a large number of domestic loads unless there is a central data collection point at which all these sites can be aggregated;
- "The economics simply do not stack up" for aggregating small loads if there is a requirement to install the control systems;
- The greater the capacity of the demand per site, the lower the installation costs per MW;
- The minimum single point interface is 600 kW.

It should be noted that these responses were gathered in the context of demand side aggregation for selling into the balancing and settlement market. Obviously, this application will not be suitable for Shetland Islands Council, and so the economic case would need to be fully explored. However, the broad conclusion which can be drawn, both from TNEI's research and the stakeholder engagement is that fewer loads with larger capacities will be more cost effective than more loads with smaller capacities.

4.2 Analysis of heat demand at SIC sites

Shetland Islands Council provided information about the consumption of heating oil at many of their sites, including care homes and schools. Figure 4-1 plots the maximum monthly oil usage at each site against the minimum monthly usage. The chart shows that there is some degree of correlation between maximum and minimum monthly usage, with maximum monthly usage typically between two and three times greater than minimum.

The group of “other sites” includes Gremista Workshop, Sellaness Ferry Store, Sellaness Garage and the Town Hall.

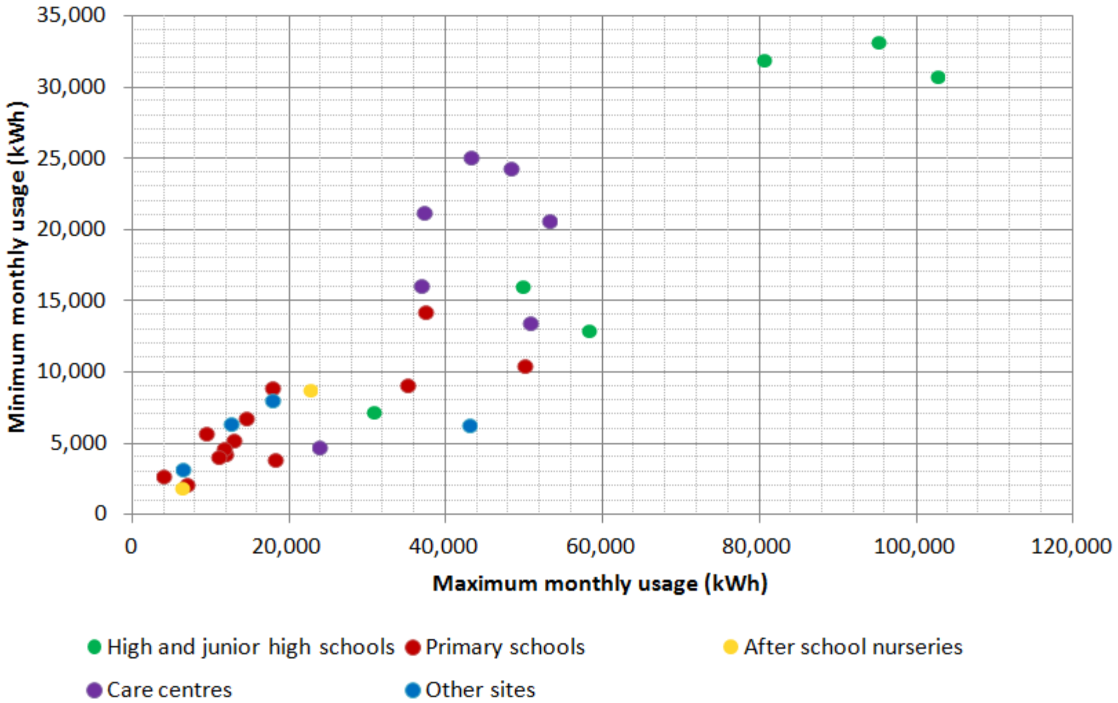

Figure 4-1: Oil Usage at Shetland Islands Council Sites by Type

It appears that consumption is generally lower at primary schools, nurseries and other sites, and tends to be higher at high and junior high schools and care centres. However, within each group of sites, there is a wide variation in the levels of demand and there is a great deal of overlap between the different groups. Therefore, it makes more sense to consider sites by their usage, rather than by the nature of the site[2]. In these terms, sites could be broadly categorised as follows:

1. Small sites with maximum monthly demand up to 25,000kWh (15 sites);

[2] The daily pattern of heat demand may make certain types of sites more favourable than others. For example, heat demand at care homes will tend to show less a less pronounced daily cycle than that at schools, with more significant demand during the night. This would suggest that care homes could be better sites for DSM installations aimed at utilising excess wind energy during night-time periods of low network demand.

2. Medium sites, with maximum monthly demand between 25,000kWh and 60,000kWh (13 sites);
3. Large sites, with maximum monthly demand greater than 60,000kWh (3 sites).

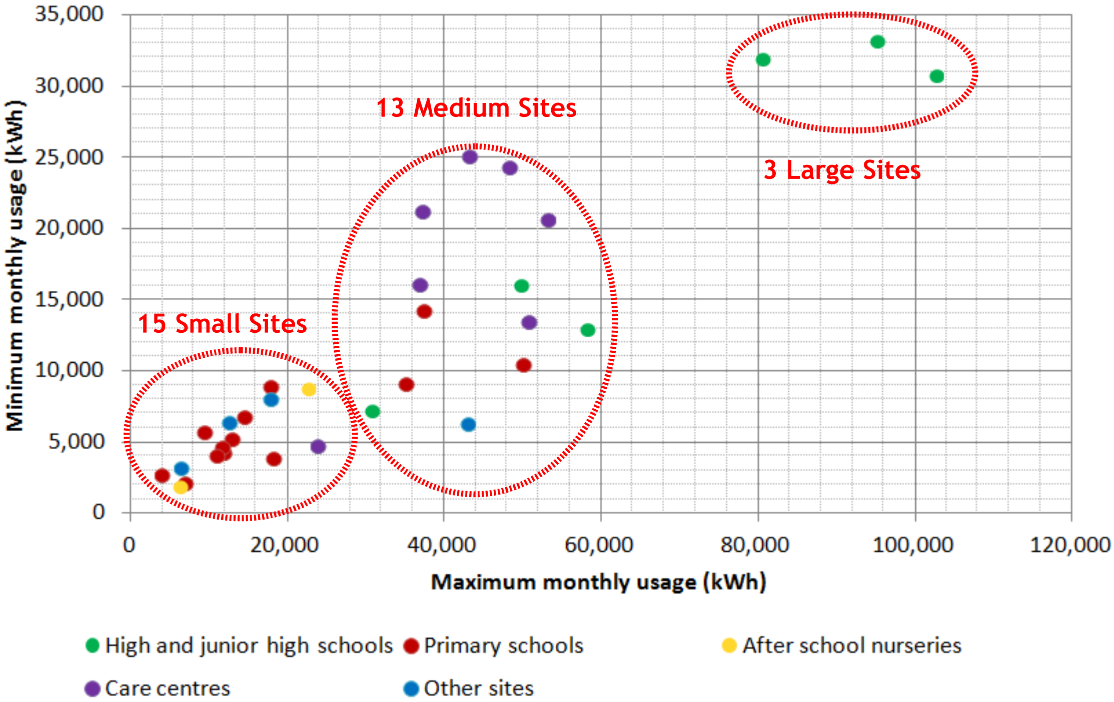

Figure 4-2: Oil Usage at Shetland Islands Council Sites by Size

As discussed Section 4.1, it is likely that the greatest benefit of the demand side management scheme would be realised by utilising the sites with the largest demand for heat. Therefore, the 13 medium and 3 large sites are likely to be the most appropriate for demand side management.

5 Thermal Storage Facility

A conceptual design for a thermal storage facility is proposed here, informed by the discussion of heat demand levels in Section 4.2. The proposed facility is sized to suit the medium sites. As energy usage at the three large sites is roughly double that at the medium sites, the energy requirements at the large sites could be met using two similar thermal stores.

5.1 Conceptual design

The overall function of the thermal store is to act as a buffer between the available heat sources at the site, and the time-varying heat loads (figure 5-1). The facility to store heat means that the sources do not have to match the loads on a minute-by-minute basis. Heat loads can be sustained, for a limited period, without any energy input from the sources. Conversely, energy can be accepted from sources at times when the heat load is very low; this energy is stored for later use.

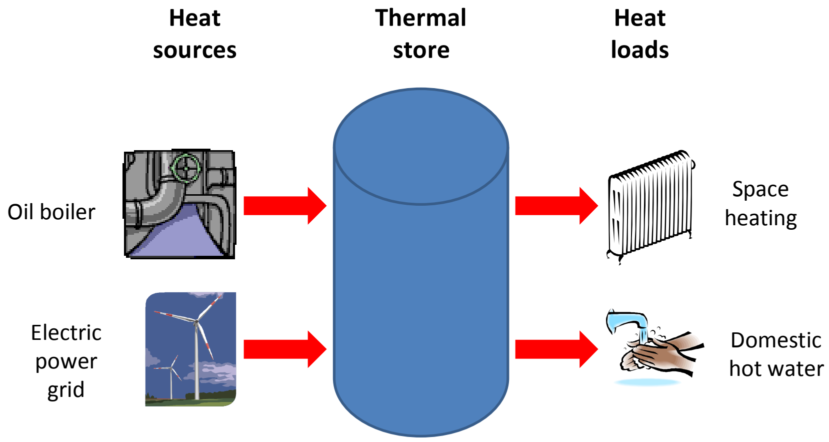

Figure 5-1: Thermal store function

5.1.1 Overview of the facility

The proposed thermal store will comprise a large, insulated hot water storage tank (figure 5-2). The tank will contain two heat exchanger coils – a lower coil for space heating loads and an upper coil for domestic hot water. It will also have a number of connections and other features, including:

- Upper coil inlet and outlet
- Lower coil inlet and outlet
- Upper and lower tank connections

- Sleeves for electric immersion heaters
- Three sleeves for temperature sensors
- Drain and vent connections

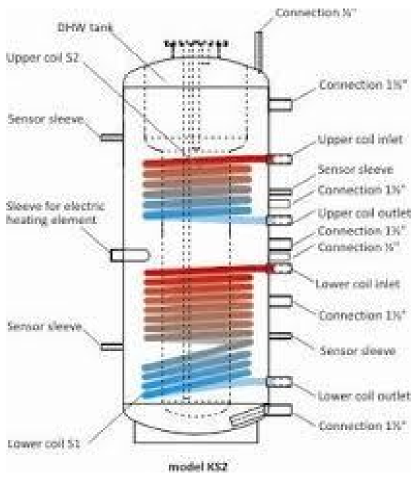

Figure 5-2: Thermal store with heat exchange coils

The thermal store will be integrated into the existing heating and hot water systems at the site (figure 5-3). The mass of water in the tank will become part of the boiler circuit, via the upper and lower tank connections. The upper coil will provide the domestic hot water supply, via a thermostatic mixing valve. The lower coil will become part of the heating circuit, with the output temperature again being controlled by a thermostatic mixing valve.

The immersion heater, or heaters, will be wired into the mains supply at the site. Each heater will be controlled by a local ANM controller, via a suitably rated contactor. Due to the high power rating of the heaters, it may be necessary to replace some of the existing electrical infrastructure at the site, and to review the capacity of the incoming network connection.

By supplying heat to the thermal store, the sources tend to raise the temperature of the mass of water held in the tank. This increase in temperature corresponds to an increase in stored energy. Conversely, the heat loads tend to lower the temperature of the water, reducing stored energy. The temperature range of the store is limited, for practical reasons. The tank-top temperature is limited to 95degC, and has a minimum value of 60degC in order to provide adequate heat output.

NB. From a functional viewpoint, the thermal store could be either vented or un-vented. However, an un-vented system is likely to offer more flexibility with regard to the elevation of the store in relation to the boiler and other system components.

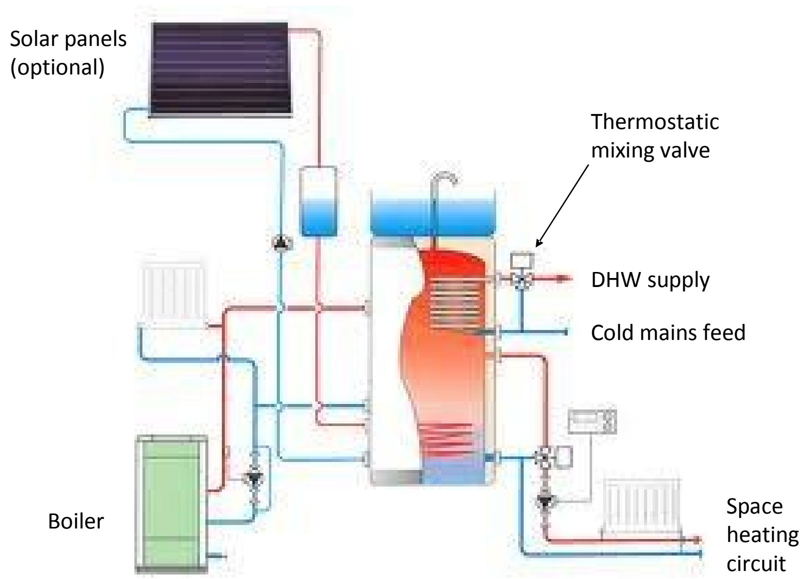

Figure 5-3: Integration of thermal store with existing heating and hot water system

5.1.2 Site heating requirements

For the generic thermal storage facility, the following assumptions are made about the nature of the heat demand at the site:

- Maximum monthly demand is 60,000 kWh;
- Maximum daily demand is 2,500 kWh, and maximum sustained demand is 200 kW, i.e. peak demand for heat on the coldest day will be approximately twice the average demand over 24 hours.

From these assumptions, it follows that the heat output elements must allow for a maximum output (from the thermal store to the load) of 200 kW.

- The upper coil must be rated for 50kW, with a cold feed at 10degC
- The lower coil must be rated for 150kW, with return at 30degC

5.1.3 Rating of heat sources

The existing oil boiler will continue to be the main source of heat in the system, particularly during colder periods. The immersion heaters are used primarily to provide a ‘controllable load’ facility to the electricity system; they are not rated to supply the peak heat demand at the site (up to 200kW on the coldest day).

However, if enough wind energy is available, the electric heaters might provide the majority of the heat requirement during the summer months.

The 'optimal' rating of the immersion heaters is a trade-off between function and practicality. More powerful heaters provide a larger load for the purpose of network management, but there may be limitations on the amount of load current that can be supplied. These limits are imposed due to the rating of the existing electrical infrastructure at the site or of the incoming supply. Table 5-1 provides some indicative power outputs for heaters, subject to different load current limits.

	Rated circuit current, per phase		
	16A	25A	40A
	Maximum heater output		
Single phase supply, 230V	3kW	5kW	8kW
Three phase supply, 400V	9kW	15kW	24kW

Table 5-1: Indicative power output of immersion heaters

It is possible to install two or three immersion heaters in one thermal store, to provide higher levels of heat input. Although each heater can be fed via its own circuit, the incoming supply to the site must be rated to carry the total current consumed by the heaters. The incoming supply will probably be rated for 40A, 63A or possibly 100A per phase.

In practice, then, the rating of the on-site electrical system is likely to limit the total immersion heater power to 50kW or less. This amount of power – or something close – can be delivered from a 100A three-phase supply, using either two 40A heaters or three 16A units. At some sites, however, it may not be possible to get anywhere near the 50kW level, due to the limitations of the electrical supply.

It is interesting to consider the immersion heater power required to meet the minimum daily heat demand at the sites in question. For the medium sites, the minimum monthly heat demand ranges from 6,000kWh to 25,000kWh (figure 4-1). This equates to an average daily demand of between 200kWh and 830kWh. If this demand is met entirely from overnight use of the immersion heaters, the required input power would range from 25kW to 100kW (assuming the heaters are switched on for 8 hours overnight). Sites with the lowest levels of minimum demand could therefore find that they cannot utilise all of the stored energy over the daily load cycle; this should also be considered in the selection of immersion heaters.

- The thermal store should have three immersion heater sleeves. If some sleeves are not used, they can be blanked off.
- The thermal store should be sized for a maximum immersion heater input of 50kW.
- Selection of immersion heaters for a particular installation should take account of the limitations of the existing electrical infrastructure at the site, and also of the minimum daily heat demand.

5.1.4 ANM/DSM requirements

To contribute to the ANM scheme, the thermal storage facility at each site must provide two functions:

1. It must be able to decrease electrical demand (by switching off heating elements) to reduce peaks in system demand, even at times when heat demand at the site is high;
2. It must be able to increase electrical demand (by switching on heating elements) to allow continued operation of wind generation through periods of low demand, even at times when heat demand at the site is low.

The thermal storage facility must be able to sustain both of these functions for relatively long periods. Typically, an electrical demand peak can last for approximately 2-3 hours and periods of low demand (eg overnight) can last for approximately 6-8 hours.

5.1.5 Thermal capacity of the store

With the oil boiler providing the primary source of heat input to the store, the ‘decrease demand’ function can be achieved with little impact on the operation of the thermal store. The boiler will simply supply more heat to the thermal store, to make up for the heat that had previously been provided by the immersion heater. This can be achieved without a significant run-down in the heat stored in the tank.

The thermal capacity of the heat store is driven primarily by the ‘increase demand’ function. If the store is asked to increase electrical demand on a warm summer night, the energy that is ‘spilled’ into the store from the electrical system has to be held there until it can be used the following day. The oil boiler is no help in this scenario – it should be on standby.

Assuming the grid energy is spilled for a duration of 8 hours, with no significant heat load on the store during this period, it follows that the store needs to provide a thermal capacity (ie. range from minimum charge to maximum charge) of roughly 400kWh (ie. 50kW x 8hours). Given the temperature limits indicated earlier, this equates to a volumetric capacity of $10m^3$ (ie. 10 tonnes weight of water).

- The capacity of the thermal store should be approx. 10,000 litres
- The store should operate close to low charge during summer, to maximise available capacity for storage of spilled energy during the overnight period

5.1.6 Dimensions and budgetary costs

TNEI contacted two suppliers of thermal stores to obtain indicative dimensions and costs for a store of this capacity:

- McDonald Engineers (Glenrothes, Fife)
- Evinox Ltd (Epsom, Surrey)

We have received a quotation from McDonald Engineers (appendix B); to date, Evinox have not responded to our request. Table 4-2 provides a summary of the information provided in the quotation from McDonald Engineers.

Dimensions	2.0m diameter x 3.4m high (excluding insulation)
Weight	750 kg
Cost each (1 off)	£9,500 ex VAT (see notes)
Cost each (10 off)	£8,400 ex VAT (see notes)
Note 1: Quoted costs include transport to mainland UK Note 2: Costs are for a bare steel shell, without internal heat exchange coils	

Table 4-2 Dimensions and costs for 10,000 litre thermal store

In a subsequent conversation, McDonald Engineers indicated that we should allow an additional £1,000 per unit for the addition of a 200kW heat exchange coil[3].

5.2 Capex and opex budgets for thermal storage facility

5.2.1 Capital budget

TNEI has developed an indicative capex budget for a single thermal store installation, including integration into the existing electrical, heating and hot water systems at the site (appendix A). The total budget is almost £40,000, however this does include two provisional sums amounting to £10,000, for works that may or may not be required at a particular site. For a well-chosen site, then, the total budget could be as low as £30,000. Conversely, these provisional sums may not be sufficient to cover the necessary expenditures at a difficult site.

Some further economies are possible if SIC were to proceed with installation of thermal stores at a number of sites. The unit cost of the thermal store itself is £1,000 less, if an order is placed for 10 units rather than for a single unit. Moreover, the £5,000 provision for detailed design and specification of the thermal store would be shared across multiple installations, rather than being borne 100% by a single site. Taken together, these factors could reduce the cost per installation by £5-6,000.

5.2.2 Operating costs

The main ongoing costs associated with the operation of the thermal store and DSM system will be:

- Electricity costs, associated with the operation of the electric immersion heaters during times of low system demand and high windspeeds

[3] As indicted in section 5.1.2, the store will require a 50kW top coil and a 150kW bottom coil, so the actual cost for the two coils may be somewhat higher than the figure for a single 200kW coil.

- ANM controller costs, covering the provision of the local ANM controller and ongoing charges for use of communications facilities
- Maintenance costs for the thermal store and associated equipment

The electricity costs can be estimated very roughly. Assuming the key periods of low demand occur during ‘summer nights’ (ie. 8h per night, 180 nights per year), and that wind output is high during 50% of this time, we find that the immersion heaters will be switched on for up to 720 hours per year. Given a maximum rating of 50kW and a unit price of 10p/kWh, this translates to an annual cost of £3,600.

As mentioned earlier in this report (section 4.1), the annual cost for implementing the control infrastructure associated with an active network management system is roughly £1,000 per control location. This covers the cost of communications links as well as the local controller itself.

The thermal store itself has no moving parts, and requires very little maintenance. Although some associated components do have moving parts (eg. contactors, mixing valves), they tend to be extremely reliable. An annual maintenance budget of £1,000 is adequate to cover a routine annual inspection, with a contingency for breakdowns and replacement of worn parts.

Total operating costs are therefore likely to be £5 – 6,000, per installation. The majority of these costs are for electricity; sites where the installed immersion heaters produce less than 50kW will have correspondingly lower operating costs.

5.2.3 Potential benefits with regard to Garth wind farm

Garth Wind Farm has a proposed capacity of 4.5MW. Shetland has very high wind speeds, and net capacity factors for the wind farm could be as high as 50%. Shetland Islands Council have advised that up to 30% of the wind farm’s output could be constrained. The effect of this level of constraint for a range of capacity factors, in terms of lost exports, is shown in Table 4-3. Given export revenues of £90/MWh, the cost of this lost electricity can be approximated.

Net Capacity Factor	**Available Output**	**Curtailed Output (30%)**	**Cost of Lost Output**
35%	13.8 GWh	4.14 GWh	£373k per annum
40%	15.8 GWh	4.73 GWh	£426k per annum
45%	17.7 GWh	5.32 GWh	£479k per annum
50%	19.7GW h	5.91 GWh	£532k per annum

Table 4-3: Cost of curtailment at Garth wind farm

The implementation of DSM at SIC sites will not eliminate curtailment of the wind farm altogether; however, it would have the effect of increasing demand during the summer period, and thereby reducing the amount of curtailment. A portfolio of ten DSM installations could provide a total DSM capacity of up to 500kW; this is less than 5% of the existing minimum system demand. The resulting reduction in curtailment is extremely uncertain, but it is unlikely that this relatively small increase in demand will have a large effect. A 10% reduction in curtailment – say from 30% to 27% of available output – would be a plausible 'order or magnitude' estimate.

The 30% curtailment figure is, in any case, based on the operational constraints of the current electricity infrastructure in Shetland. With the approaching closure of Lerwick Power Station and re-engineering of the system (see section 6), the existing operational constraints will fall away and be replaced with a new set of operational issues, limits and possibilities. In this new environment, the benefits of DSM to the wider network may well be recognised explicitly, through ancillary service contracts and payments.

5.2.4 Levelised cost of DSM at SIC sites

A rough estimate of the 'levelised cost' of providing the proposed DSM facilities can be made, using a simple payback approach. Assuming the capital cost of the schemes have to be recovered after ten years, the total annual cost can be obtained by adding 10% of the capex budget to the annual opex. This gives a total annual cost of £9-10,000, for a single site. For a site with installed immersion heater capacity close to the 50kW target, this equates to an annual unit cost of £200/kW.

NB. This calculation has not accounted for any benefit relating to curtailment levels at Garth wind farm.

6 Regulatory and commercial issues

6.1 Regulatory context

6.1.1 Electricity in Shetland - who does what

In Shetland – as elsewhere in the UK – the electricity supply system is split into a number of different functions in order to facilitate competition and customer choice. The three main functions are generation, distribution and supply.

There are two main generation facilities in Shetland: Lerwick Power Station (LPS), and the 100MW power station at the Sullom Voe terminal. Between them, these two facilities currently provide over 90% of the electricity supplied to retail customers on the islands, with the remainder being provided by local wind generators. LPS is owned by SSE's Generation business, and is operated by Scottish Hydro-Electric Power Distribution (SHEPD). The Sullom Voe facility is owned by a consortium, and the power station is currently (since May 2014) operated by Cofely Ltd.

With regard to distribution, Shetland forms part of a Licence area that covers the northern part of mainland Scotland, plus the northern and western isles. The Distribution Licence for this area is held by Scottish Hydro-Electric Power Distribution (SHEPD). As the Distribution Licensee, SHEPD is responsible for maintenance and development of the distribution network on the islands, and for providing suitable connection to the network for existing and new customers.

The role of an electricity supplier involves buying power from generators and selling it on to the supplier's retail customers. As well as paying generators for the power they buy, suppliers also pay charges to the distribution licensee to cover the cost of providing the network connecting generators to customers (Use of System charges). Although customers in Shetland are free to choose other suppliers, most are supplied by SSE Energy Supply Ltd., which trades under the name Scottish Hydro Electric.

6.1.2 Special issues affecting Shetland

The electricity supply system in Shetland is an isolated island system – there is no connection between the system on the islands and the power grid on the mainland. This fact creates special regulatory issues that affect Shetland alone, and which do not arise in other island communities such as Orkney and the Western Isles, which are connected to the mainland grid.

The key issue concerns the cost of generation in Shetland. Suppliers operating in Shetland do not have access to the generation market operating on the mainland; the power that their customers use has to be procured from generation facilities located in Shetland. The owners of these facilities claim – with some justification – that their operating costs are considerably higher, per unit of power generated, than the corresponding costs for a large power station on the mainland. Because of these high costs, the prices charged for generation on Shetland are three or four times higher than the average market price for generation in mainland GB.

Despite the high cost of generation in Shetland, the tariffs paid by retail customers on the islands are no higher than those paid by similar customers elsewhere in the SHEPD licence area. This is due to the Common Tariff Obligation, which was introduced by section 3(2)(a) of the Electricity Act 1989 and subsequently enacted by secondary legislation and Licence conditions. Under these conditions, SHEPD recovers the additional costs of procuring generation in Shetland, through an uplift in the Use of System charges paid by suppliers across the whole SHEPD licence area. This uplift amounts to an additional annual cost of £19 per customer across the north of Scotland, and in 2013/14 resulted in an annual cross-subsidy to Shetland of £26.6 million. This uplift arrangement will fall away at the end of March 2015; Ofgem is currently consulting on revised arrangements to replace it [3].

There is another important debate regarding the electricity supply system in Shetland. Lerwick Power Station, which provides roughly 50% of the electricity supplied on Shetland, will have to be shut down within a few years due to its age and poor emissions performance. The debate concerns what should be done to replace LPS given its vital role in system balancing and frequency control, as well as in simply generating power. This question has to be seen in the broader context of the subsidy provided to Shetland under the current uplift arrangements, and the massive potential for renewable generation on the islands.

In 2013, SSE published proposals to build a new 120MW gas turbine power station at Rova Head near Lerwick. The projected cost of the project was £150 million. However, SSE failed to convince Ofgem that this proposal provided the most cost-effective solution to the closure of LPS, and in April 2014 Ofgem asked SSE to undertake a public consultation looking at alternative solutions. SSE has since published a consultation document [2], and plans to conduct an open tender process during the course of 2015. At the end of 2015, SSE will put forward its recommended solution for Ofgem to consider, and hopes to be in a position to award contracts in 2016.

6.2 Commercial opportunities for SIC

SSE's forthcoming tender process will seek proposals for "a new energy solution for Shetland". Given Ofgem's rejection of the Rova Head proposal, on grounds of cost, there is now an opportunity for interested parties to put forward alternative solutions. Solutions that avoid the conventional 'power station' model are likely to be of interest, particularly if they harness the islands' plentiful wind energy resource. However, the key challenge is how to provide a stable and secure electricity supply system, to serve the needs of homes and businesses on the islands, without resorting to the use of conventional generation plant.

This tender process represents a commercial opportunity for SIC. Certain organisations will be planning to submit proposals to SSE, based on Active Network

Management approaches; these proposals will be more credible and attractive if they are linked to existing projects which can provide power and system balancing functions within an ANM architecture. SIC is involved in two such projects: Garth wind farm, and a portfolio of possible DSM facilities at council-run sites.

Given this alignment between the interests of SIC and those of possible bidders into the SSE tender process, the key task for SIC is to make contact with these bidders and discuss how the SIC projects can contribute to their proposed solutions. The key questions to be addressed in these discussions will include the following:

- What are the technical capabilities that could be provided by SIC, that would be of greatest value to the solution you are planning to offer?
- Are you planning to offer financial payments to generators and DSM sites that provide these capabilities?
- How would payments be quantified, and what contractual arrangements would this involve?
- What can SIC do to assist you with the preparation of your bid?

SIC should therefore aim to find out who is planning to bid in the SSE tender process, as a first step. The next step will be to identify bidders whose interests are most closely aligned to those of SIC – in terms of being interested in ANM-based solutions. These bidders can then be contacted for the purpose of initiating the kind of discussions outlined above.

7 Conclusions

The key conclusions from this investigation can be summarised as follows:

1. Because the electricity system in Shetland is an isolated island system, with no connection to the mainland grid, the underlying reasons for constraint/curtailment of new wind generators are different to those in Orkney. As a result, the ANM approach implemented in Orkney is likely to provide only a partial solution to the issues faced in Shetland.
2. Focused DSM, utilising the heat demand at larger council-run sites, is likely to be more cost-effective than domestic DSM.
3. Implementation of DSM at SIC sites can be achieved using proven thermal store technology. The existing oil boilers would continue to provide most of the heat demand at the sites. Electric immersion heaters would probably be dispatched during periods of low system demand (ie. summer nights).
4. For a ‘medium’ site, the indicative capex budget for a DSM installation is around £40,000; this gives an approximate levelised annual cost of £200/kW.
5. A portfolio of ten DSM installations could provide a total DSM capacity of up to 500kW; this is less than 5% of the existing minimum system demand. The resulting reduction in curtailment is therefore extremely uncertain.
6. Benefits of DSM with regard to curtailment of Garth wind farm have not been quantified in this study. Given the forthcoming closure of Lerwick power station, the nature of the operational limitations on the system are likely to change in any case, so the merits of carrying out this assessment are debatable.
7. The current SSE consultation and subsequent tender process [3] provide an opportunity for SIC to understand the needs of ANM solution providers, and to get a feel for the commercial aspects of DSM in a future ANM-based system.

8 References

[1] "Demand Side Management Investigation", proposal No. 9467-01-R0, TNEI, June 2014

[2] "A New Energy Solution for Shetland", SSE-PD, October 2014. Available at https://www.ssepd.co.uk/ShetlandEnergy/

[3] "Consultation on Scottish Hydro-Electric Power Distribution Shetland energy cost recovery arrangements", Ofgem, October 2014. Available at https://www.ofgem.gov.uk/ofgem-publications

Appendix A – Capex budget for thermal store installation

Design and project management			
	Detailed design and specification of thermal store	5,000	
	Site-specific installation design	2,000	
	Procurement and contract administration	5,000	
	Sub-total	**12,000**	
Supply of thermal store and associated equipment			
	Thermal store (bare shell)	9,500	
	200kW internal heat exchange coil	1,000	
	Immersion heaters	500	
	Heavy current contactors	100	
	Control system, sensors etc	300	
	Misc. pipework, valves, supports, cables etc.	300	
	Thermal jacket	100	
	Sub-total	**11,800**	
Transport and on-site works			
	Additional shipping cost to Shetland	500	
	Modifications to boiler building	5,000	provisional sum - site dependent
	Upgrade to grid connection and/or on-site electrics	5,000	provisional sum - site dependent
	Installation and erection of thermal store	500	
	Plumbing and wiring works, including controls	3,000	
	Commissioning and testing of system	1,000	
	Sub-total	**15,000**	
Total capital budget		**38,800**	

Appendix B – Summary of oil consumption data for SIC sites

Site	Annual usage (kWh)	Max. Monthly usage (kWh)	Min. Monthly usage (kWh)
Brae High School	769,392	95,176	33,176
Aith Junior High School	361,211	58,249	12,926
Baltasound Junior High School	340,913	49,764	15,994
Sandwick Junior High School	791,742	102,622	30,746
Scalloway Junior High School	633,635	80,468	31,881
Whalsay Junior High School	206,594	30,642	7,240
Burravoe Primary School	41,131	3,873	2,766
Dunrossness Primary School	335,425	49,903	10,556
Hamnavoe Primary School	86,862	11,687	4,326
Happyhansel Primary School	120,402	17,945	3,958
Lunnastig Primary School	101,936	12,726	5,249
Mossbank Primary School	314,430	37,142	14,300
Nesting Primary School	46,006	6,770	2,188
Ollaberry Primary School	83,321	9,283	5,793
Skeld Primary School	130,189	14,251	6,805
Tingwall Primary School	100,663	11,579	4,730
Urafirth Primary School	78,552	10,748	4,140
Whalsay Primary School	255,717	34,893	9,179
Whiteness Primary School	163,687	17,764	8,984
ASN Gressy Loan	153,661	22,650	8,818
Sandwick ASN	48,866	6,206	1,919
Fernlea Care Centre	311,624	36,735	16,131
Isleshavn Care Centre	196,571	23,847	4,771
Nordalea Care Centre	372,019	50,723	13,572
North Haven Care Centre	416,127	43,114	25,172
Overtonlea Care Centre	407,373	48,180	24,421
Viewforth Care Centre	411,491	53,076	20,698
Wastview Care Centre	349,354	37,186	21,249
Gremista Workshop	225,104	42,905	6,334
Sellaness Ferry Store	107,840	12,586	6,398
Sellaness Garage	54,169	6,473	3,262
Town Hall	159,495	17,849	8,075

Appendix C – Quotation for supply of thermal store

See following sheet