Early learning from an electrical storage installation on an 11kV distribution network

October 2012

Contents

1. Executive Summary

In 2007, UK Power Networks procured a 200 kWh Energy Storage System (ESS) for installation at Hemsby, Norfolk as part of the AuraNMS[1] research project, which received support from the Engineering and Physical Sciences Research Council (EPSRC) and the Innovation Funding Incentive (IFI). Having installed the device in April 2011, UK Power Networks has been running a Low Carbon Network Fund First Tier project to gain real, practical experience with the device and its capabilities, and to disseminate the findings to the other DNOs. The project brief can be found on Ofgem's web-site, where it as registered as project UKPNT1001 under the project title 'Demonstrating the benefits of short-term discharge energy storage on an 11kV distribution network'.

The ESS is different from anything previously approved for connection to our distribution networks as it consists of components from a number of suppliers and was fully integrated and tested once assembled on site. Whilst containerised solutions assembled fully in the factory can mitigate these issues, there will be frequent occasions in which the visual impact of a containerised solution is not appropriate, given the surroundings. Furthermore the ESS has computer controlled protection and control systems and has a power electronic power conversion system.

The initial stages of the project have been more challenging than we first anticipated. We encountered a number of technical issues (such as the intermittent tripping of the DC circuit breaker connecting the battery to the voltage source converter) which resulted in the project progressing more slowly than first expected. UK Power Networks now expects the assessment of the benefits for the battery installed at Hemsby to be completed by October 2013.

Although it is too early to draw final conclusions, useful learning has been gained. This report is intended to share this learning and our experience from the installation and early operation of the energy storage device, as well as the findings from simulations and analysis.

The main highlights are as follows:
- The first modes of operation implemented on the device have demonstrated that the energy storage device is performing as expected both in STATCOM[2] (reactive power import/export only) and real power exchange (charge/discharge) modes. Accordingly we were able to reduce voltage fluctuations and manage demand.
- The overall round-trip efficiency of the ESS is quoted by ABB to be more than 90% and we are assessing the overall efficiency of the total installation, which will be impacted by several components: the lithium ion batteries, the power conversion system and the 1 MVA step-up transformer.
- A decision was made to separate the control function from the protection and particularly the back-up protection functionality. Whilst the ESS is capable of performing all three control, protection and backup protection functions, for this first installation, UK Power Networks felt it appropriate to add additional measures, specifically by treating the ESS as a small generator and adding traditional G59 protection. This provided back-up protection for the ESS computer controlled protection system, but represents additional first-of-a-kind costs.

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[1] Autonomous Regional Active Network Management System

[2] A STATCOM is a Static Synchronous Compensator, used as a voltage regulation device on AC networks

- On-going annual operating costs have the potential to be optimised for future installations.
- The project took a decision, for the purposes of transparency and ease of reporting, to meter both import and export rather than treating and settling any round-trip losses as technical losses associated with plant. UK Power Networks had limited interest from energy suppliers, which to an extent was to be understandable for an installation of this size as it was not sufficiently large enough to offer them services, but was large enough to represent an imbalance risk if not forecast with an accurate demand and generation profile. As such, the project has had to proceed on the basis of business and generation tariffs for 'traditional' network users.
- The energy import charges are higher than the revenue that can be generated from exporting a similar amount of energy back onto the network, when considering the specific tariffs being used in this project. We expect this interaction to look substantially different in the case where larger installations are being discussed with a supplier, and in which services are being offered or agreed to help the supplier at the same time as agreeing a settlement mechanism for round-trip losses incurred whilst the device is supporting the distribution network.
- The installation footprint does not necessarily increase significantly for installations with a higher rating and/or energy capacity.
- High depth of discharge will reduce the life of the battery. Other parameters that will have an impact are the number of charge / discharge cycles and, to some extent, calendar ageing.

We welcome enquiries from the other GB Distribution Network Operators who wish to have access to more detail than provided in this summary report.

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2. Quotes from UK Power Networks employees

It is essential that all relevant business units are involved in the process of trialling new technologies such as energy storage to make sure that protection and control scenarios are analysed and appropriate settings developed, commissioning procedures are established and followed, operational procedures and training for field staff is in place, and inspection and maintenance responsibilities are established. The following UK Power Networks employees all played an important role in the planning, installation and commissioning of the Hemsby ESS.

“Energy storage systems could make wind power more viable in the future. As well as being variable, wind power output is also unpredictable, which means that balancing the system is going to be more challenging in the future. Devices like this can release energy back into the network almost instantly and will reduce the cost of system balancing”

Dave Openshaw, Head of Future Networks

“Being involved in this R&D project has, and will continue to increase our understanding of the impact electrical energy storage on an 11kV network in a Low Carbon Future.”

Dale Harrison, Distribution Planning Engineer

“Operationally, Hemsby is different from traditional distribution assets and has presented us with many challenges, e.g. operating a complex computer controlled system within our distribution safety rules.”

Paul Swatton, Maintenance Engineer (Hemsby Area)

“This has given UK Power Networks an opportunity to consider the strategic value of storage as an alternative to traditional network reinforcement.”

Stephen Mockford, Head of Engineering Standards

“The multidisciplinary teams from the UK and Sweden have learnt from one another. The safety standards are different and changes in design had to be accommodated.”

Olly Joseph, Project Manager (Delivery Team)

3. Introduction

3.1 Battery characteristics:

UK Power Networks has installed a dynamic energy storage system (ESS) at Hemsby in Norfolk, in collaboration with ABB. The system is based on ABB's SVC Light® product, combined with a Lithium-ion battery storage device and is located in an 11kV distribution network with some penetration of wind power.

	Real power	Real power	Reactive power
Power rating	200kW	600kW	600 kVAr
Duration	1hr	Short duration (15 mins)	Unlimited

3.2 Site selection:

A site was selected such that the maximum range of benefits with the ESS could be considered from a single installation. A rural 11 kV distribution network in North Norfolk with a 2.25 MW wind farm connection was selected.

The storage device is installed at Hemsby at a newly created normal open point between two primary substations, near the remote ends of 11kV feeders from the substations (see Appendix 1). Only one feeder is connected to the ESS at any moment, but it is easy to switch between feeders, allowing for different operational scenarios. Our partners Durham University have modelled the network using network information such as line and transformer data as well as half-hourly operational data comprising feeder current and Distributed Generation output.

A mixture of residential areas, rural areas and seasonally occupied accommodation are supplied by the feeders in this region. The average load on the feeders is 1.15 MW and 1.30 MW with peaks of 2.3 MW and 4.3 MW respectively. The wind farm with 2.25 MW installed capacity is attached midway along the first of these feeders. This installation has ten fixed speed induction generators, so there is significant reactive power demand while generating.

Daily load profiles show that the two feeders have quite different characteristics. On the first, the most significant demand occurs during the night during winter, due to a high number of homes heated by night storage heaters. The second feeder has much less storage heating, and in this case summer loading is higher due to increased holiday demand. These dissimilar characteristics mean that events requiring ESS support (e.g. reverse power flows, voltage deviations, etc.) are likely to occur at different times, increasing the utilisation of the ESS.

3.3 Status:

The installation was commissioned in April 2011. Its purpose is to test the functionality of the energy storage in conjunction with a small wind farm, and trial various applications such as levelling out short time power fluctuations from the wind farm and storing energy during low demand, to be released into the network during high demand. All energy exchanges are measured, settled by energy contracts and not treated as operational losses. This could in turn provide additional capacity in the area.

4 Results from the operation of the energy storage device

4.1 STATCOM Operation (import/export of reactive power only):

The project consortium has agreed a number of trials or tests which build on each other. The first of these, STATCOM operation, was designed to test the performance of the voltage source convertor independently of the batteries.

The aim of these experiments was not to remove all voltage fluctuations, but to reduce the level of fluctuations which would otherwise occur due to uncertain demand and generation. Figure 1 illustrates the relationship between the wind farm output, the reactive power exchanges of the ESS and the modelled voltage at the point of connection with the distribution network.

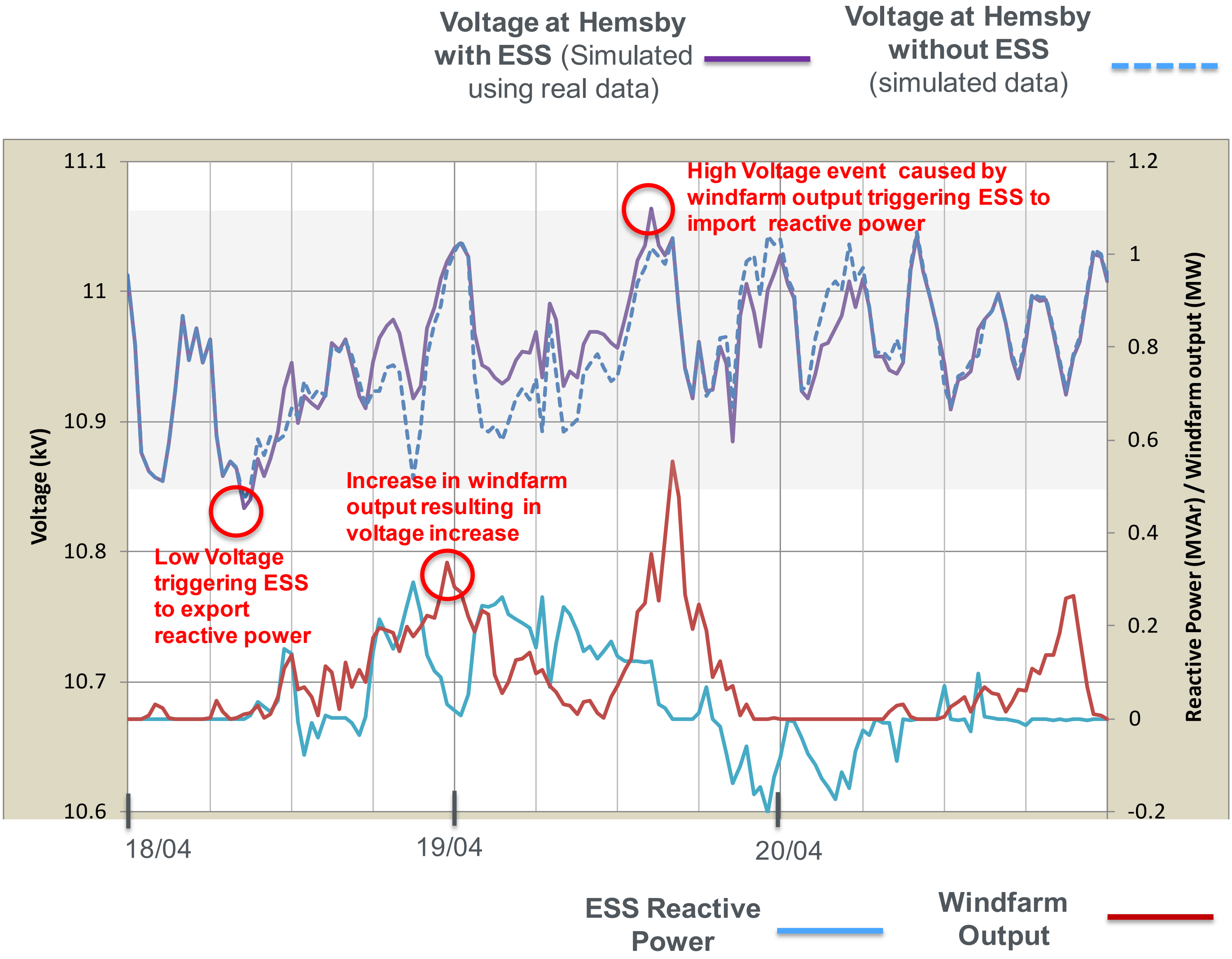

Figure 1: Impact of STATCOM Operation

The ESS reactive power and wind farm output data are currently provided in half hourly readings, and therefore represent an average over each 30 minute period which could include (but not show) short duration fluctuations in consumption/ generation. The voltages are provided from a model of the network, showing what the levels would be with and without the ESS installed. This data is calculated from actual voltage measurements at the Martham primary substation.

A number of observations can be made:

- The voltages seen at the ESS, as calculated by the model, will vary as demand and generation conditions change. It is apparent that the voltage is affected by a varying wind farm output, and the ESS is configured to make reactive power exchanges when the voltage at the ESS moves outside of set thresholds or deadband (in this case 10.96kV ± 0.11kV, represented by the shaded area on the diagram).
- On 18 April 2011, a low voltage occurrence (10.83kV) triggers the ESS to export reactive power to support the network voltage.
- Shortly before midnight, an increase in wind farm output results in an increase in voltage. The ESS reacts by reducing the amount of reactive power exported onto the network, to maintain the voltage within the operating parameters.
- On 19 April 2011, there is a peak in the output from the wind farm leads to an increase in network voltage at the ESS. The voltage reaches the upper threshold of the deadband, triggering the ESS to start importing reactive power to reduce voltage.

The parameters for the STATCOM operation were changed on 31 July 2012 in an attempt to make the system compensate for voltage within stricter limits. The deadband settings (under and over-voltage thresholds) were tightened from 10.96kV ± 0.11kV, to ±0.08kV, meaning that lower levels of variation from the desired voltage would prompt a response from the ESS. The impact of this can be seen in Figures 2a and 2b below, which illustrate an increased number of reactive power exchanges after the settings were changed, and the voltage being kept within stricter limits.

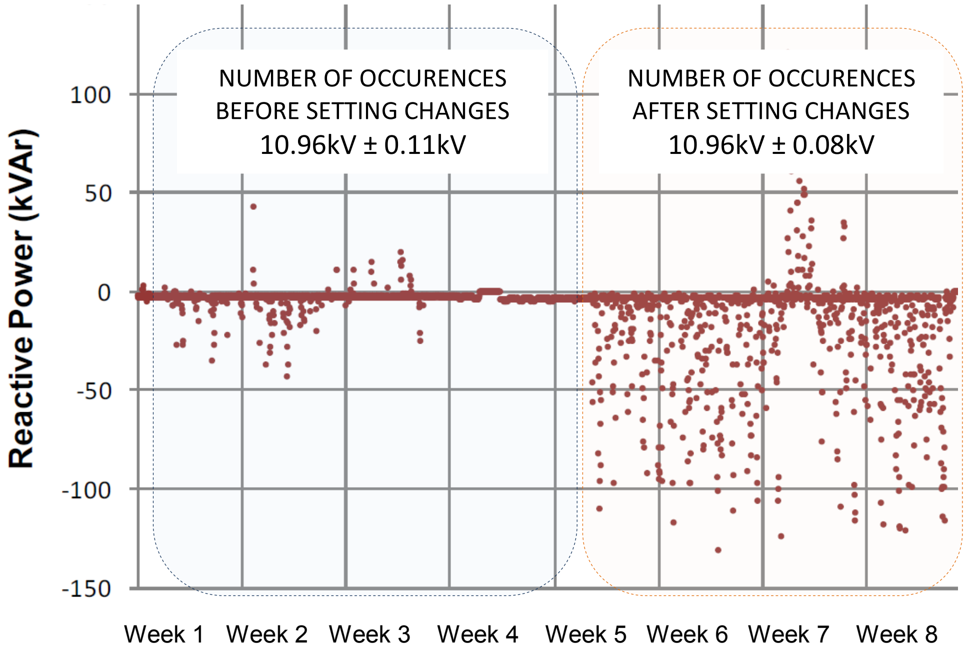

Figure 2a: Impact of changes to STATCOM parameters (occurrences of kVAr exchange)

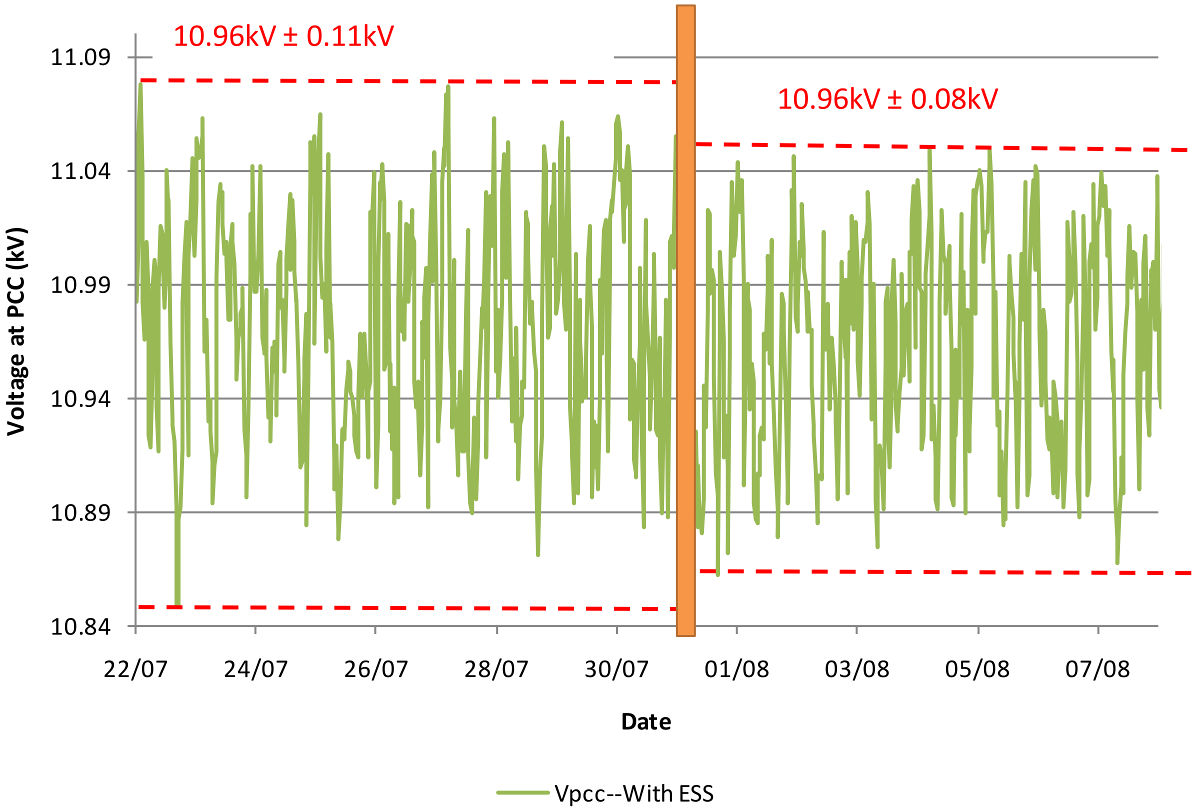

Figure 2b: Impact of changes to STATCOM parameters (voltage being kept within stricter limits)

4.2 Real power exchanges (charge / discharge):

Since May 2012, exchanges of real power have begun. Whilst charging and discharging the battery, the demand at the local primary substation (Martham) was closely monitored in order to assess the impact on the network.

Details of the first tests carried out are as follows; the impact is shown in Figure 3. The dotted line shows what the feeder demand would have been without the ESS intervention (simulated data).

- **Step 1**: 100kW export of real power (discharge) for a 30-minute period. This resulted in a drop in network loading, but fluctuations due to changing wind farm output and local demand were still observed.
- **Step 2**: Stop export of real power for 30 minutes.
- **Step 3**: 75kW import of real power (charge) for a 60-minute period. This resulted in a slight increase in network loading.
- **Step 4**: 100kW export of real power (discharge) for a 30-minute period. A sharp decrease in network loading can be observed.
- **Step 5**: 75kW export of real power (discharge) for a 60-minute period.

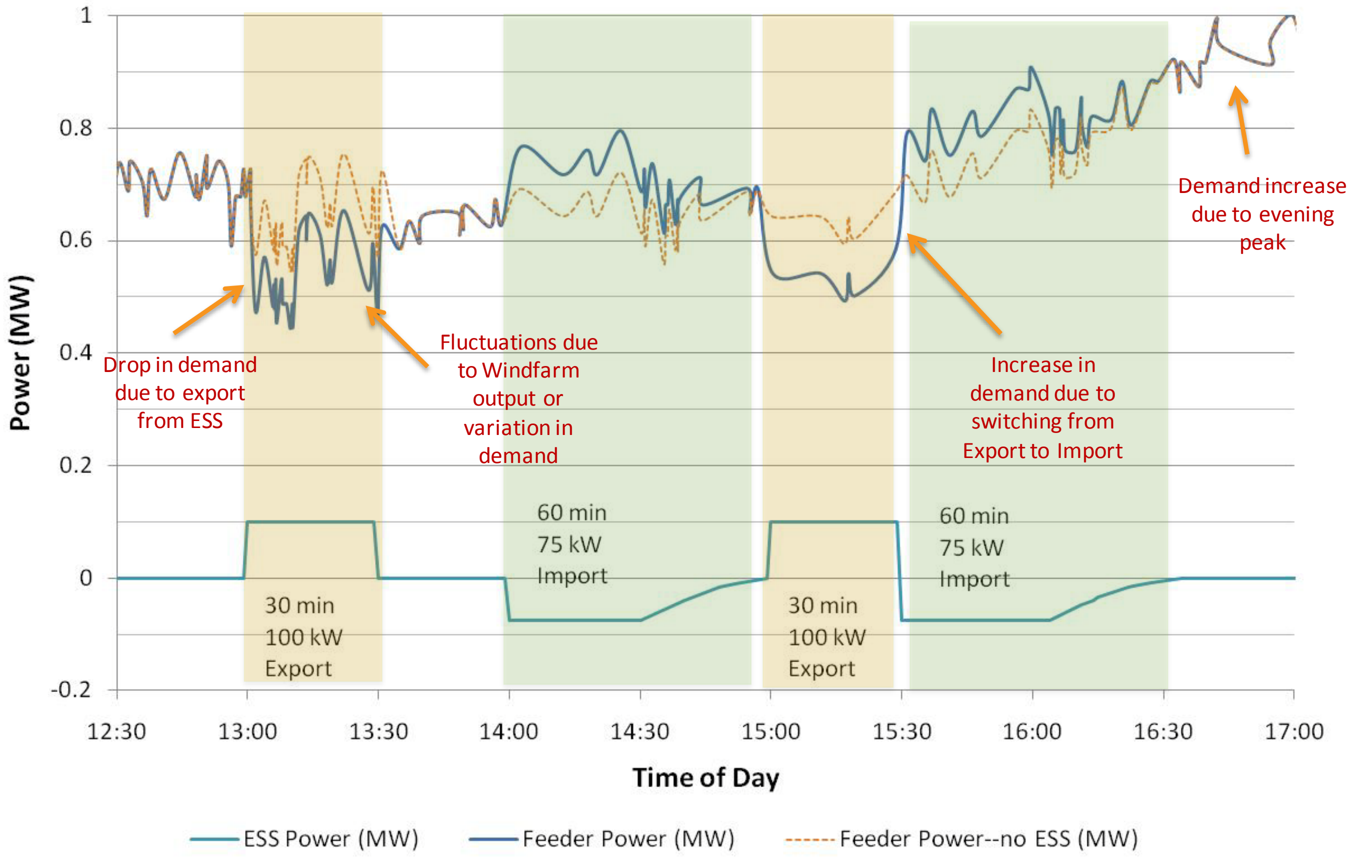

Figure 3: Impact of real power exchanges

4.3 Conclusions from STATCOM operation and initial real power exchanges:

Analysis of the STATCOM operation and first real power exchange schemes have demonstrated that the storage device is able, as expected to:

- Reduce demand by exporting real power.
- Reduce voltage fluctuations by either exporting reactive power to increase the voltage, or importing reactive power from the network to lower the voltage.

The impact of being able to reduce fluctuations and manage demand is that it provides the possibility to accommodate additional demand or generation on the existing feeders, within the thermal limits of the plant and circuit, without breaching voltage limits or needing to curtail generation.

4.4 Energy storage device overall efficiency:

The ESS is built around several key components that each have individual efficiency levels and losses. It is important to understand the impact each of these will have on the overall performance of the ESS, and how the individual losses can be minimised.

The main components that will impact the efficiency of the system are (See Figure 4):

- The 1MVA transformer to step up the voltage from 2.2kV to 11kV. As the transformer is constantly energised, the no-load losses will therefore impact the system efficiency.
- The power conversion system including the harmonics filter.
- The Li-ion batteries.

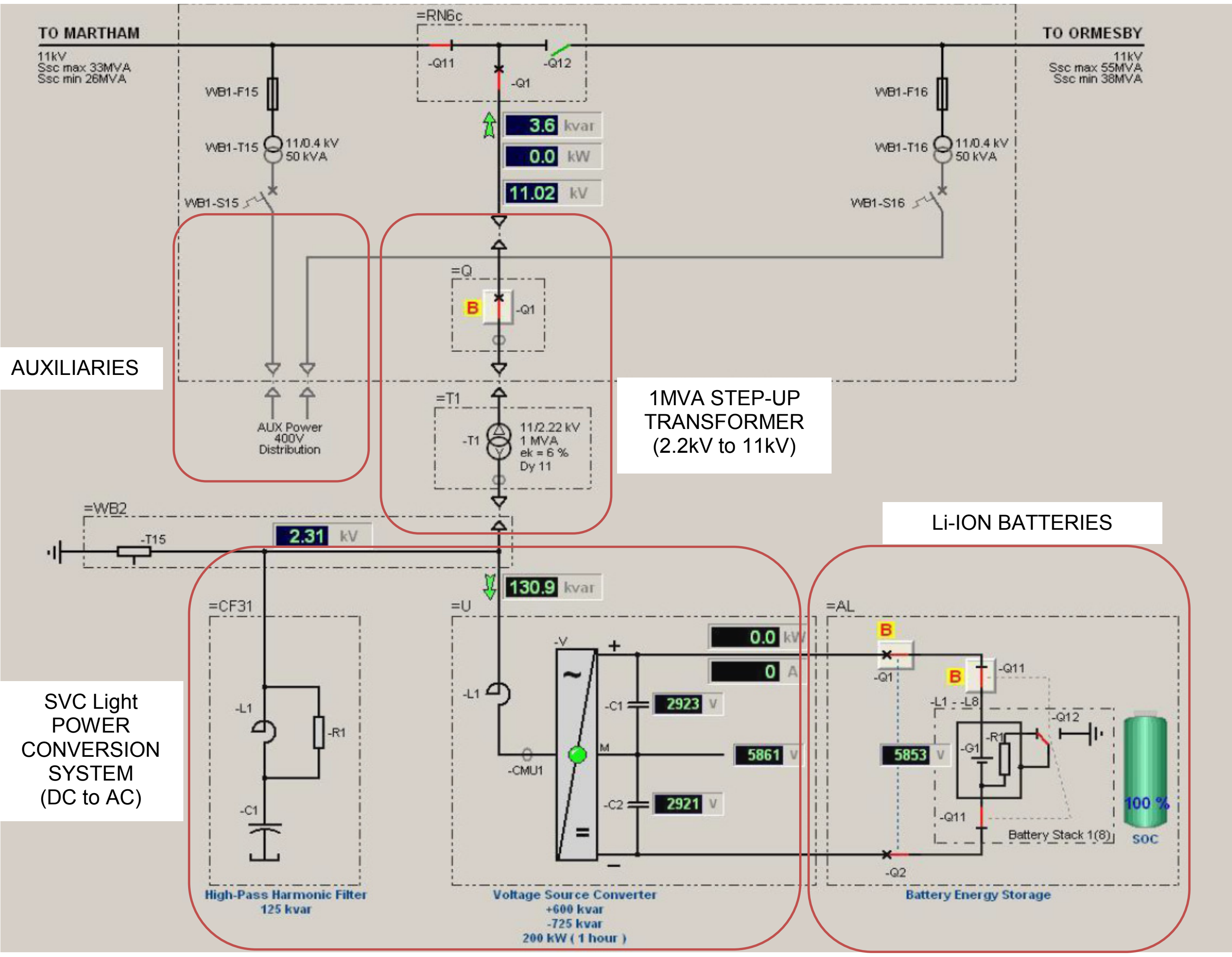

Figure 4: MACH2 control system single line diagram and main components impacting the efficiency

In addition to the system losses, there are two Low Voltage (LV) auxiliary feeds that supply the power required for heating or cooling the battery room, the thermal management system for the power conversion system, supporting IT equipment, and general site loading such as lighting. These auxiliary loads are not classed as ‘losses’, but as an operational requirement, and are accounted for separately when determining the overall system cost of operation.

Taking the above into account, the round trip efficiency of the ESS is quoted by ABB to be higher than 90%, although this will be conditional on the charge rate and the length of time the energy is stored. **The efficiency of the system is in the process of being assessed and will be quoted for individual components if possible**.

5 Procurement, installation and operating costs

5.1 Equipment approval:

This is the first time an electrical ESS, based on Lithium-Ion batteries, has been installed on an 11kV distribution network in the UK. It is also the first time it has been located at a normal open point (NOP), providing the flexibility to manage voltage and power flows of two feeders from two primary substations.

The ESS approval process was different to the traditional equipment approval process for connection to our distribution networks, as the use of power electronic devices is uncommon and the only time the whole system was fully assembled and could be tested was on site. Our asset engineers are experienced in working with passive devices such as transformers, switchgear, cables, overhead lines, capacitors and reactors, all of which have and can be easily modelled. Nevertheless, power electronic devices will play a greater role in future, particularly if techniques to manage power flows in transmission networks can be cost-effectively translated to distribution voltages.

An Engineering Instruction detailing the various aspects of the operation of the device, including the type of protection used, has been written and approved. **This has been attached in Appendix 3 as a guide to other DNOs wishing to install similar equipment on their distribution networks**.

5.2 Purchase and installation costs:

The total UK Power Networks project cost for the installation was just over £2 million. A breakdown of the cost is presented in Figure 5 and detailed below:

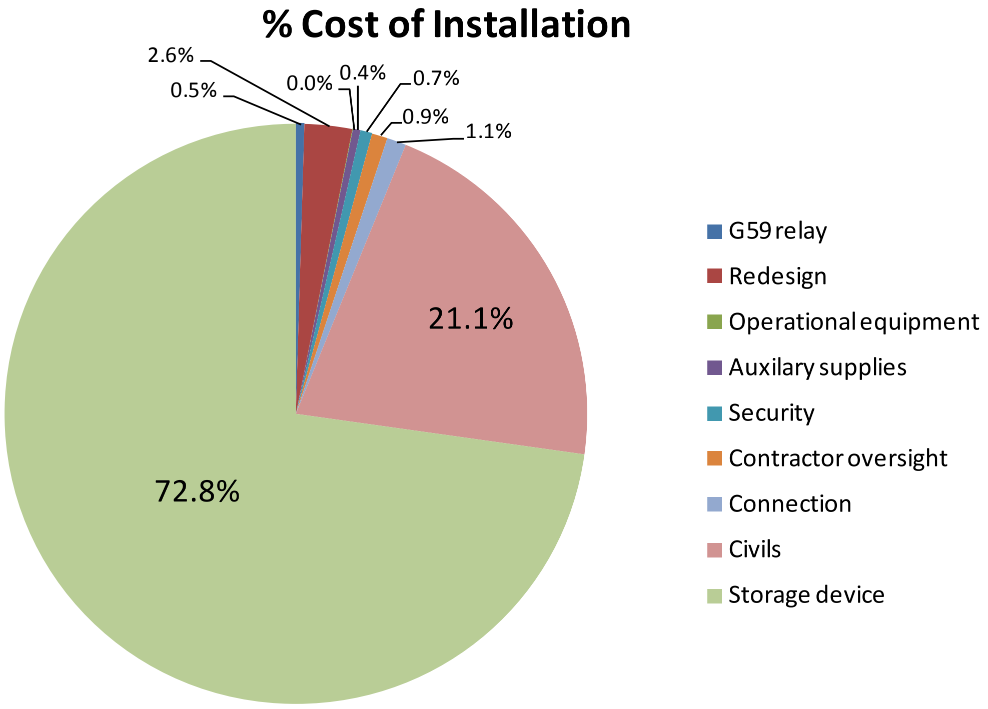

Figure 5: Cost of installation

The Storage device consists of SAFT's Lithium-ion Intensium Flex batteries, ABB's SVC Light power conversion system, a step-up transformer and AC filter components, a thermal management system, a prefabricated building and an integrated control and protection system – all designed and specified by ABB in Sweden. **This includes a significant proportion of development activity to make the system suitable for installation on a distribution network**.

Civils costs consist of the ground work for the foundations of the prefabricated building, installation of cables, ring main unit, auxiliary supplies, and the assembly of the storage system following the instructions of the ABB site engineer. Civil work and CDM welfare facilities were provided by Freedom Electrical contractors.

Connection costs include the network equipment to provide the 11kV network connection, e.g. ring main unit with a five limb VT, metering unit, cables, GRP enclosures, jointing materials, etc.

Contractor oversight was carried out by UK Power Networks and included CDM compliance visits.

Security includes a survey by UK Power Networks security and the provision of enhanced perimeter protection.

Auxiliary Supplies includes the 11kV and LV cables connected to pad mounted and pole mounted transformers to provide the LV auxiliary supplies. Jointing and ground work were included in the civils work category.

Operational equipment consists of the earthing equipment necessary to earth the 2.2kV outdoor busbars and the Seaward KD1E/19 voltage testing device for both the AC and DC busbars supplied by Norwich Instrument Services. This device was selected as it was able to detect voltages less than 100V AC and DC. A risk assessment was carried out on the earthing procedures for the ESS, in particular the testing of voltages before applying flexible earths. Instead of having separate AC and DC testing devices a decision was taken to have one voltage testing device to avoid the risk of an AC device being used on the DC busbar or vice versa**.** Whilst a relatively simple measure, this removed a potential hazard to operational staff and contractors carrying out work at the ESS.

"First of a kind" costs included a redesign of the freestanding circuit breaker that had insufficient secondary contacts to provide status signals to the integrated MACH2 control system.

Additional first-of-a-kind costs were incurred to augment the MACH2 control system. The MACH2 control system is based on two computers, offering redundancy, and running a Windows XP Embedded operating system. The redundancy is not implemented on a programme instruction-by-instruction basis, or requiring an unanimous vote from both computers before initiating a trip signal, but instead provides a typical UPS-style function so that one computer picks up where the other left off, if the other fails. **As such, this leaves the finite but extremely remote possibility that one computer could malfunction, but not visibly fail and therefore not trigger a fail-over to the remaining computer**. Without experience of the Windows XP Embedded operating system, this risk was difficult to quantify. The decision was taken to add additional back-up protection in the form of a G59 protection relay to protect the ESS from the network, and the network from the ESS and to provide additional resilience against the unlikely event of the MACH2 malfunction. Assessments are being planned to increase the time delays set within the G59 relay to prevent nuisance trips.

In retrospect, this may have been a conservative position to have taken, and indeed should not remain the position for future installations. We recognise that colleagues within the Powerlink organisation providing supplies to London

Underground have experience with an earlier version of the MACH product in a different application, and that the MACH2 control system has been installed in an increasing number of HVDC installations[3].

5.3 Ongoing costs to be considered when operating an energy storage device:

In addition to the purchase and installation costs, a number of additional costs should be considered by ESS operators.

- **Operating cost (excluding energy import cost)**: The anticipated annual operating expenditure associated with the operation of the Hemsby energy storage device is presented in Figure 6. Most of the cost is associated with the ESS maintenance and includes emergency response by ABB, inspection and trip tests, plant and cooling system maintenance, and battery maintenance by SAFT.

  It is expected that some of these costs, more specifically the maintenance cost and DNO field staff required to support the operation of the device, would reduce for future installations, as experience in operating such network devices is gained and operating cost is optimised. A particular area of optimisation is in deciding which of the infrequent maintenance procedures are sufficiently complex to continue to need support from the manufacturer, as opposed to the more frequent maintenance procedures which can be brought in-house.

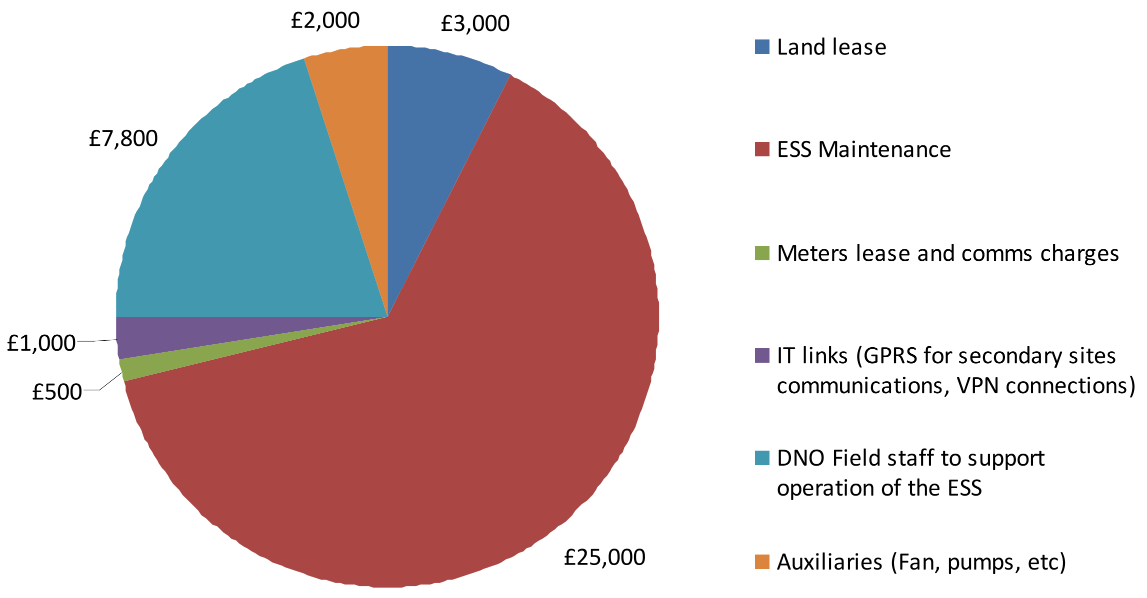

Figure 6: Annual Operating cost

- **Energy import cost**: The cost associated with charging the energy storage device also needs to be taken into account as it is not being treated as losses, but as an operational requirement. The relatively small size of the device has meant that it has been challenging in obtaining competitive standing charges for energy import/export

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[3] http://www.abb.com/industries/ap/db0003db004333/718bfd4f5d7fa84bc12574ad00302100.aspx

from suppliers. The inability to predict scheduled operating profiles and time of use prior to the installation of the device, means that suppliers typically have been prepared to offer only standard energy tariffs. The import price of the seasonal time of use tariff used at Hemsby varies between 6.2p / kWh to 27.8p / kWh.

Although an income can be expected from the energy exported back into the network (approximately 80% of the system sell price for the Hemsby energy export contract), it is expected that considering only the import charge and export revenue, a loss will be made when considering the tariffs involved in this particular project. Depending on the time of day selected to charge/discharge, this net cost can be minimised. This is illustrated for two opposing scenarios in Figure 7.

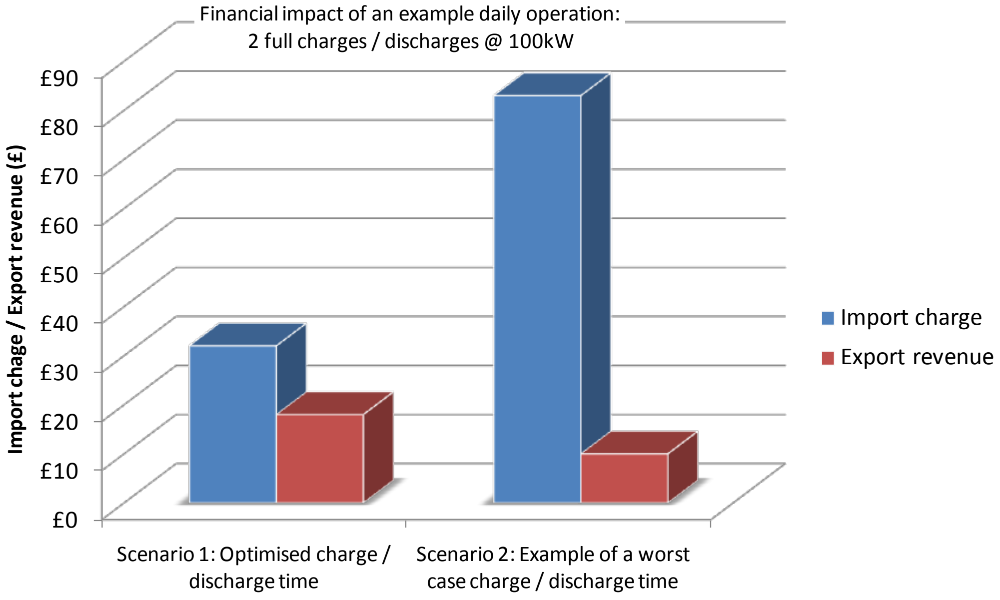


Figure 7: Cost of charging and discharging the ESS.

Whilst the discharge periods required for network support will be non-negotiable, this emphasises the need to optimise the choice of when to charge the device, and maintaining the device in the appropriate state of charge. Furthermore, as stated earlier, we expect the interaction with suppliers to look substantially different in the case where larger installations are being discussed with a supplier, and in which services are being offered or agreed at the same time as agreeing a settlement mechanism for round-trip losses incurred whilst the device is supporting the distribution network.

5.4 Installation footprint:

The footprint of the site for the Hemsby ESS is 625m^2 (25m x 25m) for a capacity of 200kWh. It is important to note that for larger Li-ion battery installations, and for energy storage devices with power ratings of similar magnitudes (i.e. <10 MW), the physical size of installations will only marginally increase.

This is illustrated in Figure 8 where the footprint of Li-ion battery options considered as part of UK Power Networks Smarter Network Storage (SNS) 2012 Tier 2 bid are compared to Hemsby, as well as examples of the physical footprint of other battery technology installations. It should be noted that Li-ion has a broad family of technologies with different chemistries, energy densities and operating requirements which may impact the footprint.

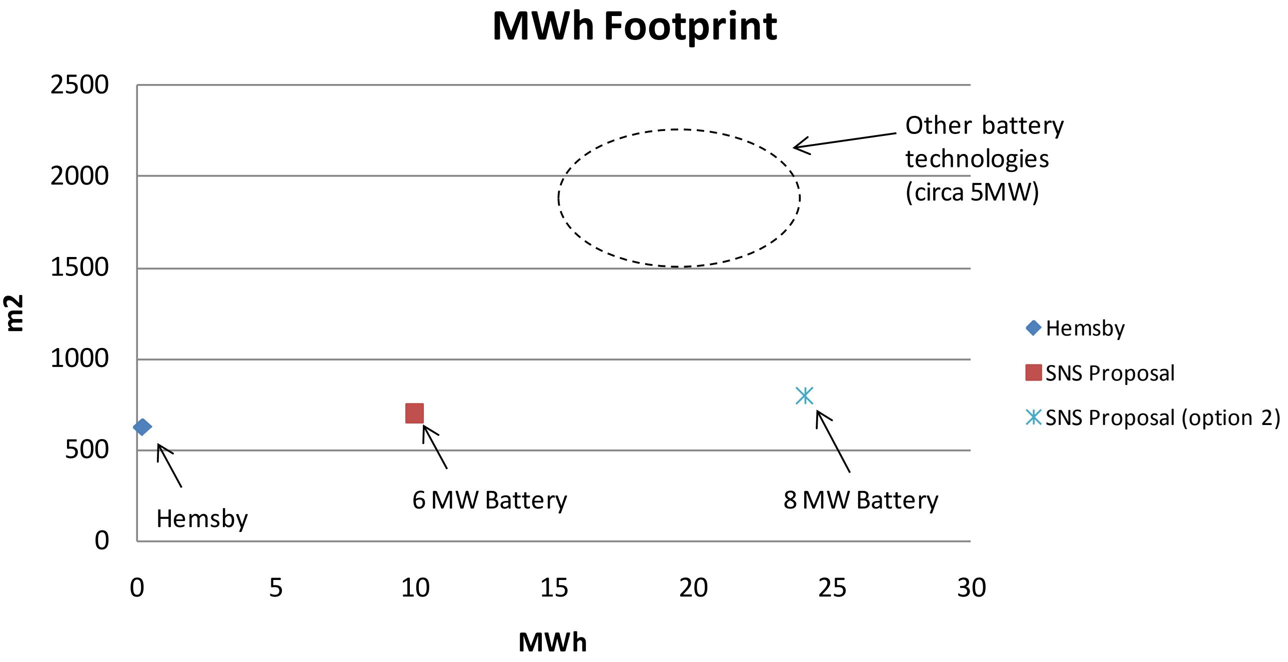


Figure 8: MWh footprint

It should be noted that the footprint of the physical installation could be further reduced by using a more advanced power conversion system, and removing the need for harmonic filters. This option would increase, however, the overall cost of the installation.

5.5 Li-ion battery life and performance:

Although the condition and remaining life of the battery could only be assessed at the end of the project and following intense use of the ESS, an analysis of the characteristics of the battery and what impacts its performance has been carried out by Durham University.

Some key points have been extracted from this analysis:

- **Discharge and charge rate** – discharging at higher rates reduces the amount of energy delivered. Charging must be more gradual than discharging. This would need to be built into any scheduling algorithms for the device, if it were to serve multiple purposes and try to make best use of free time when not required for network support by providing ancillary services.

  It can be seen from Figure 9a that as the discharge rate is increased (13A, 41A, 82A and 150A), the voltage (per module) drops more rapidly and ultimately, the final capacity reached is reduced. This demonstrates that discharging the battery more slowly yields more energy during the cycle.

- **Depth of discharge** – Battery lifetime is increased by limiting the depth of discharge (this is shown graphically in Figure 9b). A high depth of discharge causes a reduced lifetime of the battery, due to damage to the battery's internal structure.

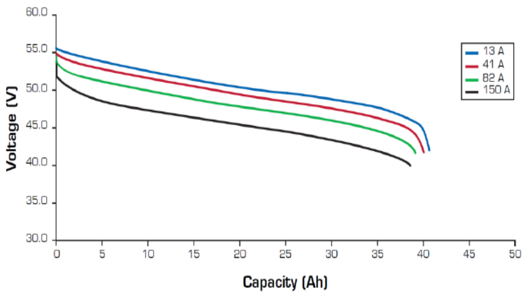


Figure 9a: Discharge curve

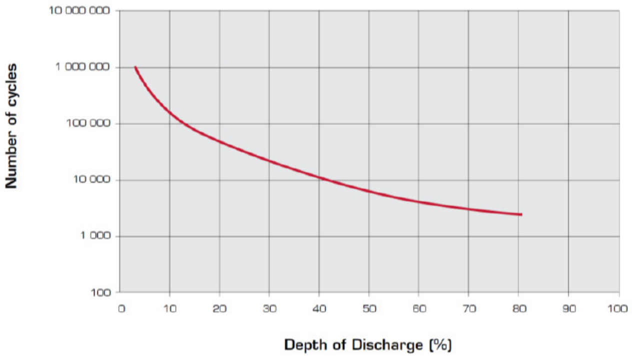


Figure 9b: Depth of discharge curve

- **Internal heating** – power rating is ultimately limited due to internal heating that must be controlled to prevent damage to the cells.

- **STATCOM operations** are a function of the voltage source converter only; they do not have significant implications for the lifetime of the installation.

For the duration of the project, a model will also be used to assess the impact of each mode of operation on the life of the energy storage system.

6. Miscellaneous

The following is a brief summary of additional learning points or aspects that should be considered by other DNOs:

- **Engagement with local communities**: During the construction phase of the project, the local residents have shown an interest in being informed of progress and timing of expected disruptions e.g. to the surrounding roads during the delivery of the equipment and any outages that may be necessary to connect the ESS.
- **Planning permission** may define the outward appearance of the ESS and should be considered as early as possible in the project.
- **Regular engagement and communication** with relevant UK Power Networks business units (Asset management, control, IT, and the local operational team) was key to getting this new type of distribution equipment approved and installed on the distribution network.
- **A complex and secure IT architecture** needs to be in place in order to obtain the full benefits of the ESS. This is particularly important for the algorithmic control of the energy storage device when data from remote sites is automatically analysed, and charge/discharge operations automatically triggered.
- Putting in place **an energy supply contract** was not easy as most electricity suppliers are unfamiliar with energy storage, and UK Power Networks was unable to provide detailed energy consumption profiles for suppliers to propose appropriate import and export tariffs. Future Low Carbon Networks Fund projects are likely to explore alternative arrangements – including having sufficient capacity and/or energy to have an impact at system level and be of interest to ancillary service or other markets.

7. Next steps

The immediate next steps for the project are to complete the installation of additional instrumentation on the distribution network (sites highlighted in green in Appendix 1), and enable all the necessary IT links. This will enable algorithmic control of the energy storage device, i.e. operation of the energy storage device based on network conditions and wind farm output.

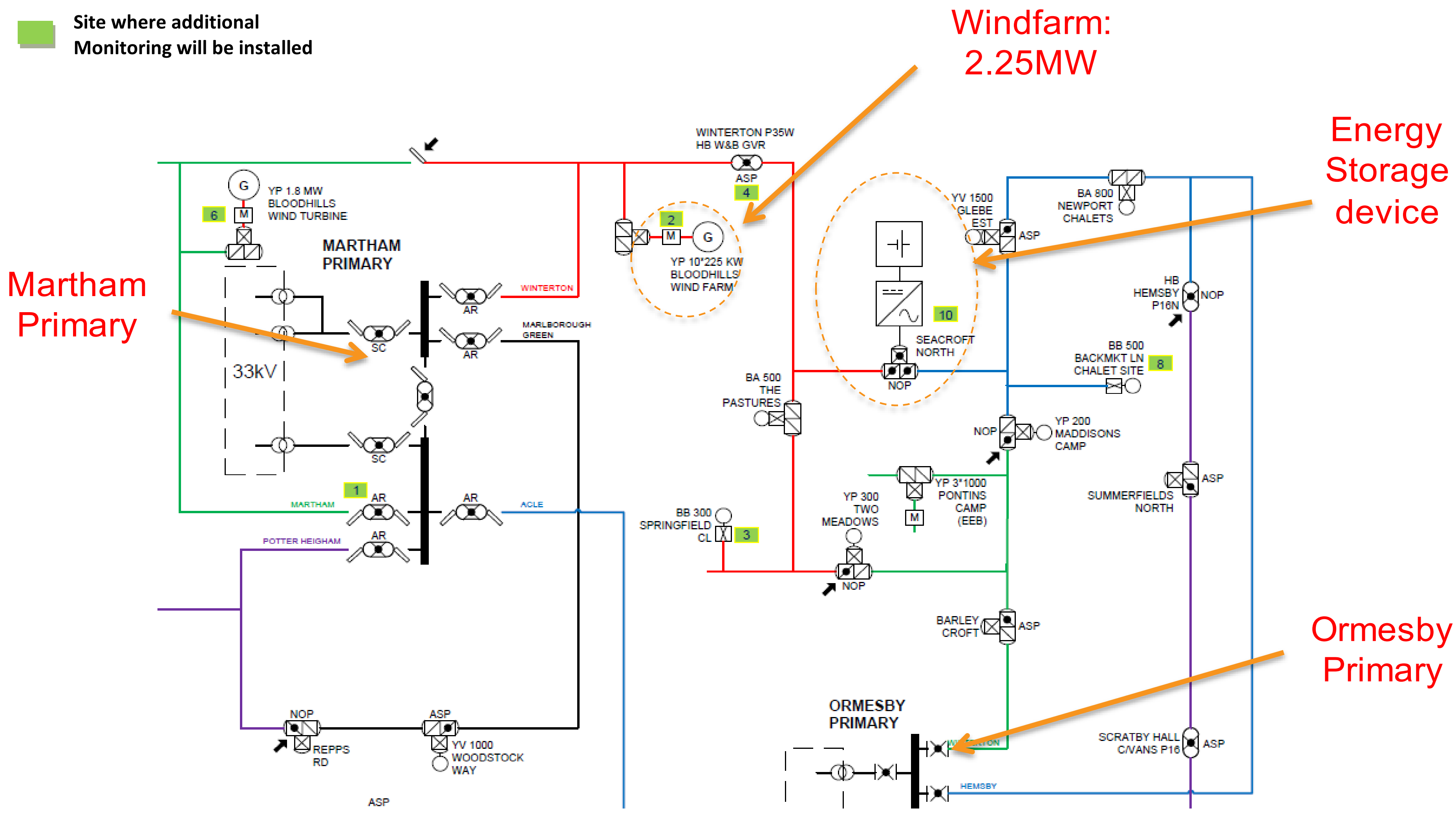
Working with our project partners, we will continue to concentrate on evaluating the benefits of an ESS for a DNO. We shall run a number of tests to demonstrate how we can manipulate a number of network parameters, more specifically:

- Voltage stabilisation (based on different set points).
- Management of peak power flows.
- Combination of voltage stabilisation and real power exchanges.
- Switching power exchanges between feeders (as the storage device can be connected to two different 11kV feeders).
- Management of voltages across the two feeders.
- Management of reverse power flows.
- Improvement of power factor.

Finally, a number of other technical aspects such as the optimisation of losses, the validation of the efficiency and potential lifetime of the device will be fully assessed.

Appendix 1 (Network diagram)

🟩 **Site where additional Monitoring will be installed**



Windfarm: 2.25MW

Energy Storage device

Martham Primary

Ormesby Primary

Appendix 2 (Frequently Asked Questions)

- **What is the anticipated lifespan of the battery installation?**
  Although the battery technology has a lifespan of up to 20 years, it will depend on the number of charge/discharge cycles carried out, depth of discharges and calendar ageing. According to the manufacturer's guidelines, a constant depth of discharge of 80% would typically result in a life of approximately 3,000 cycles; whereas a depth of discharge of 40% would result in a life of approximately 10,000 cycles.

- **How often are we anticipating using the energy storage device?**
  The frequency of operation of the ESS will vary depending on external parameters (e.g. network conditions, wind farm output), and the control objectives. For example, if the ESS is set up to only reduce peak levels of consumption, one or two cycles of operation per day could be expected. If the device is set up to achieve a multitude of control objectives (voltage control, reduction of reverse power flows, etc.) and depending on the settings of the ESS, it is entirely possible that many operations involving real and reactive power would take place every day. The modes of operation and settings will be optimised to preserve battery life.

- **How will the losses be modelled?**
  A modelling and simulation environment has been built using physical network data (lines, cables, transformers) and operational data (voltages and currents). This includes a load-flow capability that can report the losses that are present in the system under given operating conditions. By running the simulation with the ESS operating as defined in the trial cases, and then repeating the simulation without the ESS operating, the change in losses will be evaluated. The storage and wider network monitoring deployment will give inputs and checks to the modelling system which will provide verification of the model results and allow a process of refinement to take place. Network losses information will be combined with the parameters that describe the ESS energy consumption (auxiliaries, battery charge characteristics, converter efficiency) to give an overall assessment of the impact of the ESS on whole-system losses.

- **How is the battery connected?**
  The battery system is connected to the SVC Light voltage source converter, as well as a harmonic filter. The voltage is then stepped up through a transformer to 11kV, and passed through a circuit breaker to act as protection for the entire ESS. A ring main unit connects the installation to the Martham primary 11kV network, with the option of feeding Ormesby.

- **What data is going to be recorded?**
  Various metering devices are installed to record how much energy is being imported and exported, as well as the auxiliary power consumed and the local wind farm's output. In addition to this, data is available for the local primary network and monitoring equipment is being installed at strategic points across the distribution network. Finally, all the parameters relating to the ESS installation such as Real power (kW), Reactive power (kVAr), Voltage (V), Current (A), state of battery charge, settings, circuit breaker operation and other fault signals will be logged.

- **What safety measurements are in place?**
  A circuit breaker is acting as protection for the ESS, and is located at the 11kV side of the installation before connection to the distribution network. DC circuit breakers connect the battery stack to the power conversion system, and a G59 relay is protecting the system against over-voltages and potential island conditions.
  The auxiliary systems, including the thermal management cooling system, are fed by two independent LV feeds. Should one supply fail, an automatic changeover switch operates to maintain the auxiliary supplies. Access to the site is restricted, and only trained staff can obtain entrance to certain enclosed areas, such as the valve room. Further details on this can be found in Appendix 3 of the Engineering Instruction. Finally, the batteries are protected by a CO_2 fire extinguisher system which must be disabled before access.

- **What is the physical size of the installation?**
  The installation consists of a structure to house the battery system and control equipment, and external space for components of the cooling system and connection to the 11kV network. The footprint of the installation is approximately 625m^2 (25m x 25m).

- **Why was a Li-ion battery chosen?**
  This particular technology was chosen due to its lifespan and quoted high round-trip efficiency. All of these factors will help to increase and prolong the maximum levels of performance. Originally, a ZEBRA battery system was intended to be used, but upon considering the higher operating temperatures and after sales support, the decision was made to use a Li-ion battery.

- **What is the construction/arrangement of the battery?**
  The system is based on Li-ion cells (ranging from 3V - 4V depending on charge level). 14 of these cells complete a module (42V - 56V) and 13 modules complete a unit (546V - 728V). There are eight units in this system, which can deliver 200kWh of energy at approximately 4.3kV - 5.8kV DC.

- **Is there a solid financial business case for the ESS at Hemsby?**
  The installation of an ESS at Hemsby was not intended to have a strong financial return (given its relatively small scale), but to be an opportunity to further understand the effects of energy storage on the 11kV network and hence the potential for future larger scale devices, with sufficient economy of scale, to be economically viable as network support devices. As such, the main outcomes of this project have been learning and understanding.

- **How is the charging for the battery paid for?**
  Rather than considering the energy used for charging the battery as network operational losses, it was decided to measure the kWh required during charging and discharging, and enter into a supply agreement with an energy supplier. This will enable us to gain a better understanding of the relationship between financial energy charges and usage patterns.

Appendix 3 (Engineering Instruction)

Please see separate file