LCNF Tier 1 Closedown Report

Low Voltage Connected Energy Storage

SSET1008

Prepared By

Document Owner(s)	Project / Organisation Role
Alistair Steele	Project Manager
David MacLeman	R&D Manager

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Glossary

BAU	Business as Usual
CES	Community Energy Storage
COMAH	Control of Major Accident Hazards
DEM	Distributed Energy Manager
EMC	Electromagnetic Compatibility
EV	Electric Vehicle
FEP	Front End Processor
FIT	Feed-In Tariff
G59/2	Engineering Recommendation G59/2
GB	Great Britain
HMI	Human Machine Interface
HV	High Voltage
LCTs	Low Carbon Technologies
LV	Low Voltage
NTVV	New Thames Valley Vision
PCS	Power Conversion System
PEAR	People, Environment, Asset and Reputation
PQ Monitor	Power Quality Monitor
PV	Photovoltaic
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
RTS	Real Time Systems
S&C	S&C Electric Europe Ltd
SCADA	Supervisory Control and Data Acquisition
SEPD	Southern Electric Power Distribution
SWA	Steel Wire Armoured Cable
TRL	Technology Readiness Level
VPN	Virtual Private Network
V	Volts

Scottish and Southern Energy Power Distribution

Executive Summary

This report outlines the learning from the installation and testing of three Community Energy Storage (CES) units on the Low Voltage (LV) network in Chalvey, Berkshire. The units have been installed to investigate their ability to mitigate the effect of load increases or from the widespread adoption of Low Carbon Technologies (LCTs), such as solar photovoltaic (PV) generation and Electric Vehicles (EV)

Project Scope

CES units along with their associated Power Conversion Systems (PCS), have the potential to achieve similar benefits as a cable or plant upgrade:

- Through reducing the peak demand / generation to keep the cable within thermal limits;
- Employing a combination of real / reactive power to buck or boost voltage; and
- Managing network issues such as phase imbalance and power quality.

The work completed within this project is exploring the use of energy storage with four quadrant PCS units to investigate these problems. Three single phase, 25kW / 25kWh lithium ion CES units were installed at Chalvey. The units were supplied by S&C Electric Europe Ltd (S&C) and comprise a PCS unit manufactured by S&C integrated with Dow Kokam battery module. The batteries were installed on the same feeder as the SSE 'Zero Carbon Homes[1]'; which include 65kW of PV generation.

Aims

1. Prove the batteries and power conversion units can operate as intended on an LV network in the UK and have a tangible benefit electrically;
2. Validate the technical specification to inform and de-risk the tendering exercise for the New Thames Valley Vision (NTVV)[2] project;
3. Define, test and prove the communications and the associated data transfer requirements for this small trial and inform that required for a larger array;
4. Inform the safety case and the operational procedures including installation, maintenance and operational work on a network which has storage connected to it (faults, protection. live working, safety procedures etc.);
5. Inform decisions regarding the physical location of storage devices given public perception and acceptance; and

[1] SSE Corporate project investigating homes of the future, more information available - http://www.ssezerocarbonhomes.com

[2] Low Carbon Networks Fund (LCNF) Tier 2 project investigating energy storage and demand response on LV networks www.thamesvalleyvision.co.uk

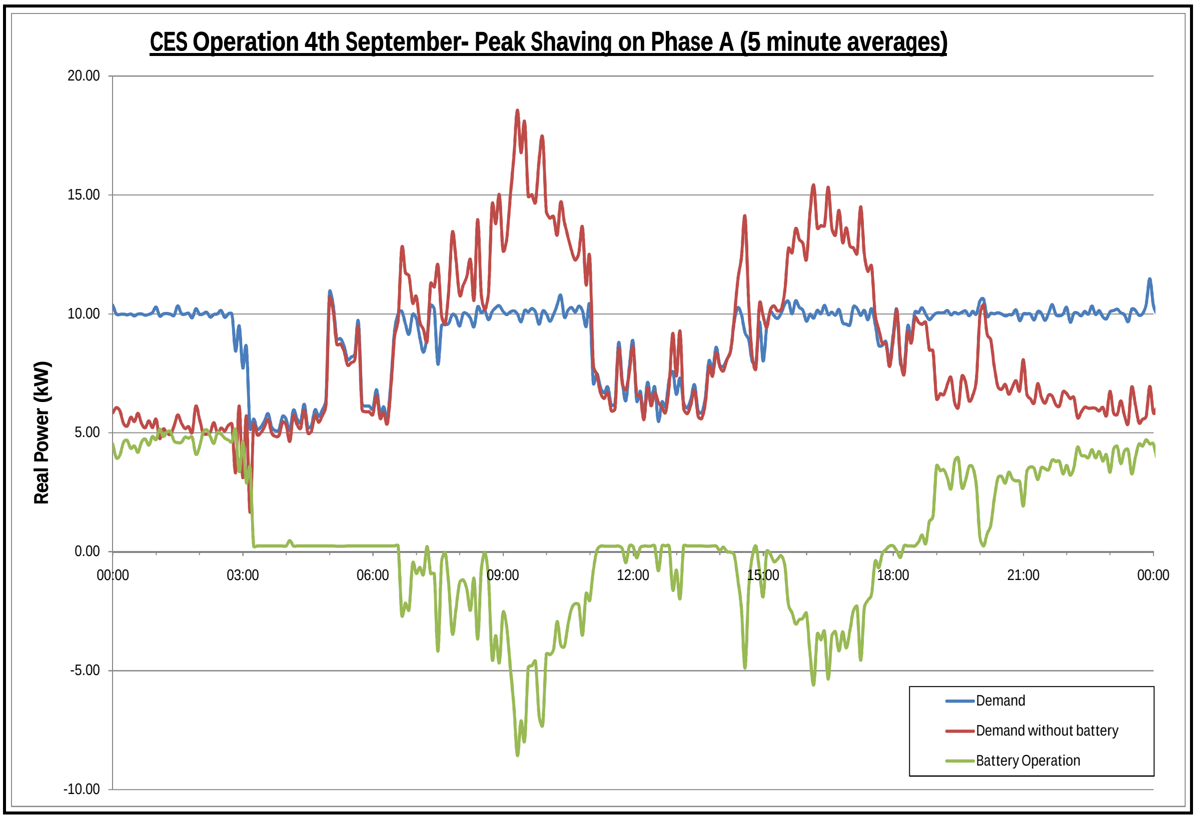
6.Inform the establishment of the economic threshold for this technology.

Conclusions

The project has successfully achieved the original objectives and has helped to inform a number of similar energy storage projects within SEPD and with other GB DNOs. The headline learning points are listed below:

- A structured safety assessment has been carried out demonstrating the system conforms to the existing relevant codes and standards. The system represents a technically credible product offering, for application in the UK market. However, the project identified an absence of standards to encompass the whole energy storage system at a utility scale in the UK;
- The system has been successfully connected to the distribution network and proven to comply with the requirements of Engineering Recommendation G59/2;
- An Operational Risk Assessment has been prepared which shows that the residual risk from the system has been reduced to an acceptable level;
- Tests confirming the operation of alarms and the functionality of the control hierarchy were passed successfully;
- Efficiency of the units has been tested in detail, with figures of around 80-85%, in line with expectations at the start of the project;
- Fully automated peak shaving cycles have been completed successfully with a maximum reduction of up to 100 amps over a 24 hour period (illustrated on page 6);
- Manipulation of network voltage has been achieved up to +/- 7V utilising both real and reactive power; and
- A detailed estimate of the lifetime costs of implementing the units on business as usual basis has been completed over a 15 year period.

The main benefits and knowledge delivered by the project to date relate to the implementation of lithium ion CES connected to the LV network, however much of the learning on the units' operation is relevant to all battery projects. Details necessary to allow project activities to date to be replicated by other GB DNOs are set out in the report. Any additional information required can be requested through futurenetworks@sse.com



Summary figure 1 – example of the batteries successfully operating to reduce peak demand on the LV network over 24 hours

Contents

1.Project background

SEPD seek to understand the potential benefits, practicalities and costs of installing electrical energy storage (ESS) connected via 4 quadrant power conversion systems (PCS) on the LV network. The main objective is to inform and de-risk the larger scale deployment of street batteries as detailed in the NTVV Tier 2 project.

The ESS units with associated PCS have the potential to aid power quality, to manage reactive power flows and to reduce the peak demand / peak generation real power flows, through peak lopping. This has the potential to delay or reduce the need for traditional network reinforcement, thereby preventing the local DNO network from becoming a barrier to the deployment of low carbon technologies. In order to understand the operation of an ESS with relevant low carbon technologies such as solar PV and EVs, SEPD has identified a site with established solar generation and electric vehicle charging points. SEPD is proposing to install 3 single phase 25 kW / 25 kWh lithium-ion batteries at this strategic location on the LV network.

SEPD will monitor, model and analyse the operation of the ESS to understand the technical solutions that this technology can provide to the low voltage network. We will apply shadow cable limits and will not pose any risk to the security of supply. The data and learning obtained will feed directly into the Tier 2 project to support the large rollout of this technology.

As the uptake of the low carbon technologies identified in the Low Carbon Transition Plan increases (solar PV and electric vehicles, etc) the likelihood is that this will cause power quality issues, and problems with voltage and thermal constraints on LV feeder circuits. The present capital intensive solution causes significant disruption to customers, requires full excavation and has long lead times.

There are currently a small number of sites in the distribution area owned by SEPD that are beginning to exhibit the problems discussed. In the SEPD area to date, there are over 12,000 solar PV installations registered under the Feed In Tariff - as the number increases the likelihood is that LV network issues will become more widespread and require network upgrades. This project is the first of two stages exploring the use of batteries and 4 quadrant PCS units to address these problems.

ESS units with PCS on the LV network could manage power quality and reduce the peak demand / generation to keep the cable within thermal limits. The units can also aid voltage regulation to remain within supply guidelines. SEPD wishes to:

- Understand and verify the technical benefits of ESS with reactive power capabilities on the LV network;
- Generate knowledge of the practicalities of locating and operating ESS at street level, to inform NTVV delivery;
- Inform future procurement exercises which will be part of NTVV;
- Demonstrate and learn from the control and operation of batteries on an LV system only; and
- De-risk future street level ESS installations.

2.Scope and Objectives

The objectives of the project, as summarised on the Tier 1 submission pro-forma[3] are as follows:

- Prove the batteries and power conversion units can operate as intended on an LV network in the UK and have a tangible benefit electrically.
- Inform the establishment of the economic threshold for this technology.
- Validate the technical specification to inform and de-risk the tendering exercise for the Tier 2 project
- Define, test and prove the communications and the associated data transfer requirements for this small trial and inform that required for a larger array.
- Inform the safety case and the operational procedures including installation, maintenance and operational work on a network with storage connected (faults, protection. live working, safety procedures etc.)
- Inform decisions regarding the physical location of storage devices given public perception and acceptance.

3.Success Criteria

The Tier 1 submission pro-forma defined the success criteria for the project as follows:

- Complete the G59/2 commissioning and functionality testing of the CES units to pave the way for the large array planned under the NTVV project.
- Prove the ESS devices can successfully support voltage using the 4-quadrant power converter.
- Use the ESS charge / discharge set points to peak lop both demand and generation.
- Confirm communications and remote control of the devices from SCADA

[3] First Tier Pro-forma. Project Title SSET1008- LV Network Connected Energy Storage. http://www.ofgem.gov.uk/Networks/ElecDist/lcnf/ftp/sse/Documents1/Tier%201%20Proforma%20LV%20Connected%20Energy%20AmendedVersion%2011.pdf

4. Details of the work carried out

4.1 Community Energy Storage (CES) units with Distributed Energy Management (DEM) control system

The technology employed in this project consists of three CES units (one per phase) rated at 25kVA / 25kWh each. The three units are managed via the DEM control system which co-ordinates the charge / discharge algorithms and is the link between the batteries and the SEPD SCADA system.

4.1.1 Physical components

S&C supplied the CES units which were deployed at Chalvey. These units comprise an above ground PCS and a below ground battery vault containing a 25kWh lithium ion battery (Lithium Cobalt Manganese Nickel Oxide electrochemistry[4]). The battery component includes an integrated Fire Suppression System. The three elements of the system (battery vault, battery unit and PCS) are shown in figures 1 to 3 below.

[4] Further details of Kokam batteries are available via their website: http://www.dowkokam.com/ Accessed 02/08/2013.

Figure 1 – Close up view of CES units in compound – showing the 3 above ground PCS units in the foreground and LV cabinet in background

Figure 2: Battery being lowered into vault on site

Figure 3: Battery module with side panels removed at S&C factory, Swansea

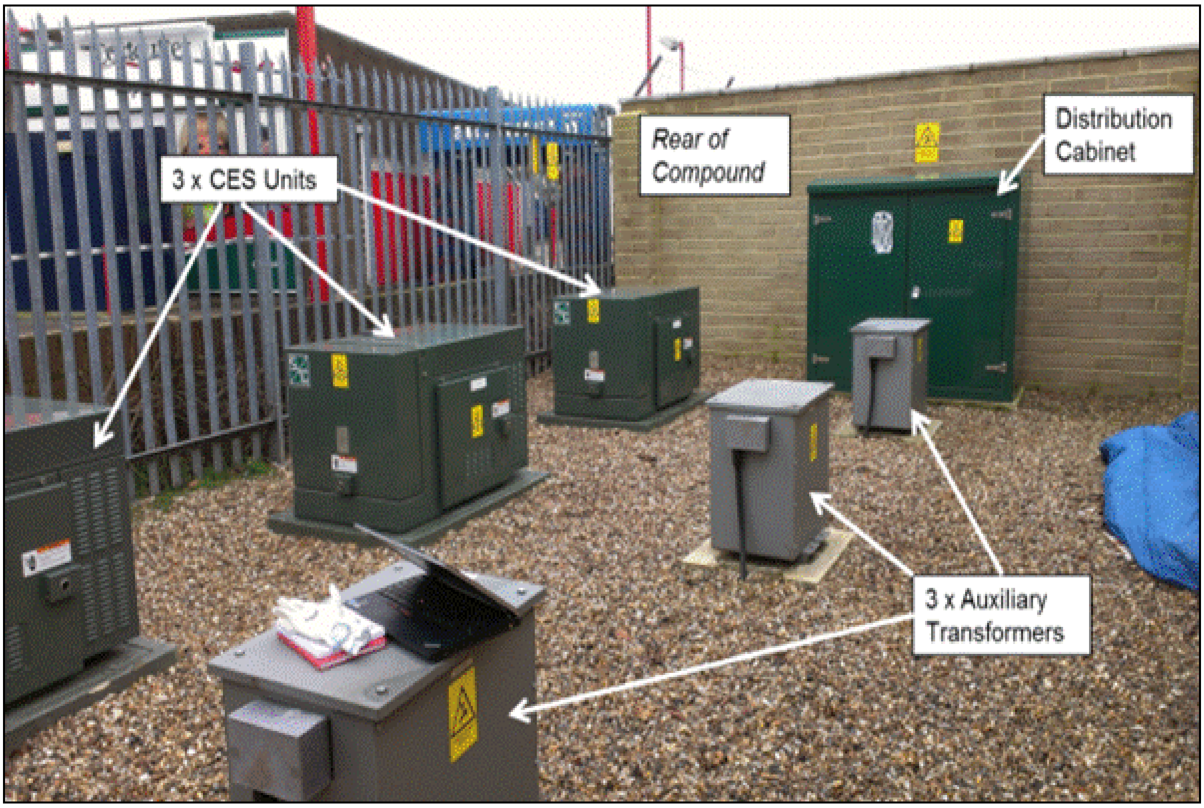


Figure 4 - Finished site - 3 CES units and auxiliary transformers

The units are designed for implementation in North America and have a split phase output of 120V per line with a centre tapped earth; therefore an auxiliary transformer was required at Chalvey (procured and commissioned by SEPD) to increase the voltage to 230V with a neutral leg.

One of the key aims of the installation was to inform the procurement of units under the NTVV LCN Fund Tier 2 project. To achieve this aim within the timescales a unit had to be sourced from North America. The use of units designed for the American market, in conjunction with an auxiliary transformer, offered an acceptable technical solution and met the timescale requirements. Future installations would be specified at a UK voltage and hence not require the auxiliary transformers. Figure 5 illustrates the connection arrangement of the auxiliary transformer to step up the voltage.

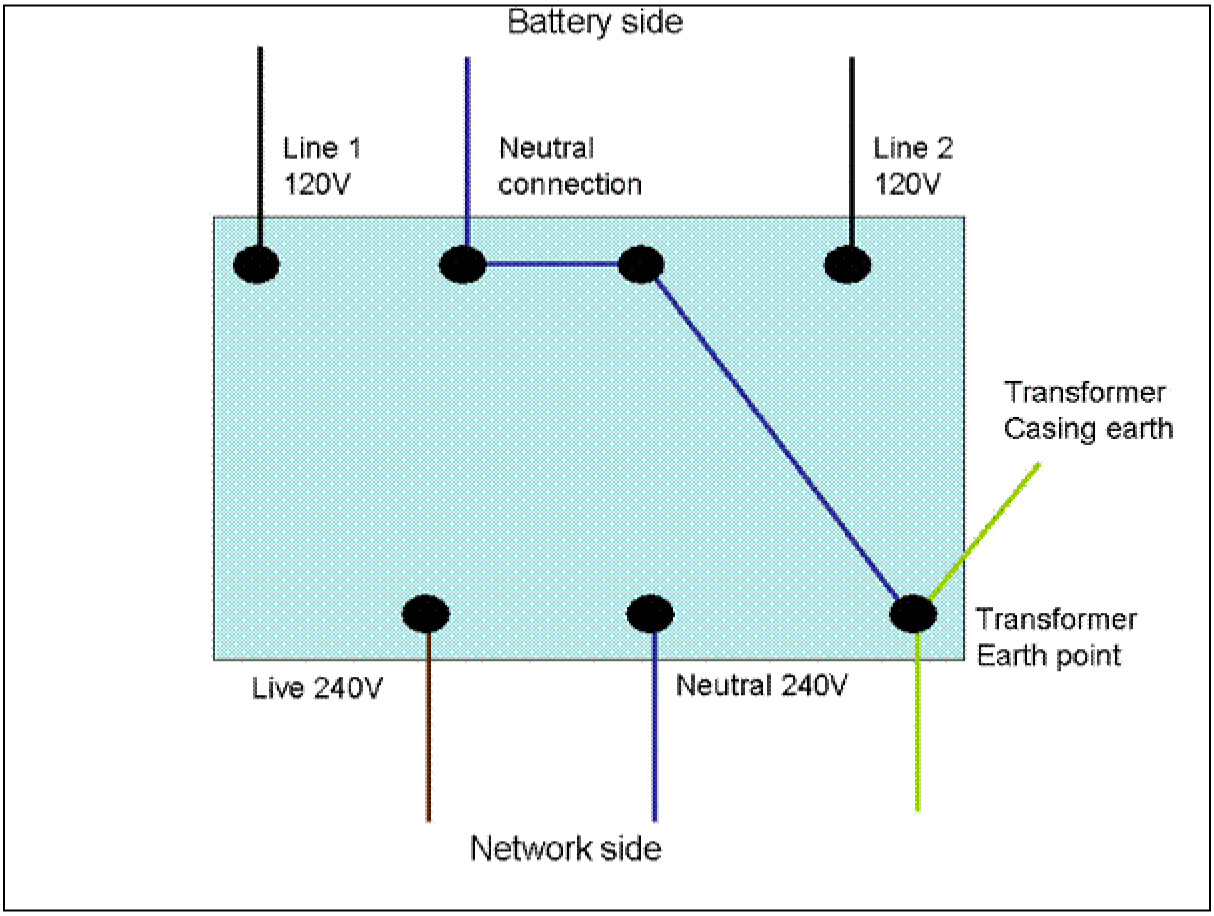


Figure 5 - Auxiliary transformer connection arrangement

4.1.2 Control of CES units' operation: control architecture and options

CES units are designed to be operated as a 'Fleet' (i.e. potentially large numbers of units operating together). This is achieved via the use of a DEM which provides control signals to each unit (using a bespoke radio system) and a Human-Machine Interface (HMI) via which a user can observe the state of the units and issue instructions.

Outside of specific troubleshooting or commissioning, the energy storage units are operated via the DEM Controller. The DEM Controller is a self-contained rack mounted Windows PC and has been installed in the communications room within the Chalvey 11kV substation. The DEM has interfaces to the CES units, substation instrumentation and the SCADA system used by SEPD.

The power output of the CES units are controlled via a variety of algorithms and the combined total (real and reactive) is limited by the nameplate rating of the inverter (25kVA per unit in this case), with priority given to the dispatch of real power.

The test programme implemented under this project has been designed to test the operation of the units under these modes. The results of the test programme are described in Section 5.

4.2 Trialling Methodology

The core of the project is to understand the operation of the batteries under differing network scenarios; three different algorithms are available for charge and discharge, as follows:

- **Fixed Power:** Under this schedule type the user sets a desired power input or output. The unit will continue to charge / discharge as commanded until the end of the schedule, or until it becomes fully charged / discharged. This schedule type has been used for testing purposes to determine the round trip efficiency of the units. In a 'business as usual' scenario a series of fixed power schedules could be used to support demand. If a good understanding of the demand profile on a particular feeder existed then a series of fixed power schedules could be used to peak lop at different rates at different times during the day. For example the units could charge at a relatively slow rate during the long overnight 'off-peak' period, discharge at a high rate to support a short peak period (e.g. 6-8 in the morning and 5-7 in the evening) and discharge more slowly to support some demand either side of this peak. It would be likely that schedules would need to be altered throughout the seasons.
- **Fixed Duration:** Under this schedule the user sets the time for which the unit should charge / discharge. The power input / output is calculated by the DEM to ensure the unit can supply /

absorb power for the whole period without reaching an ‘empty’ or ‘full’ state before the end. For example, the duration could be set to cover the evening peak period to peak lop the demand during this time.

- **Demand:** Under this schedule the user sets ‘demand limits’ for both charge and discharge. The purpose of this algorithm is to charge the batteries when demand is low and discharge at high demand times to hence reduce peak demand. This algorithm must be calculated carefully to ensure enough charge is provided to the battery to meet the discharge requirements. This is the most dynamic schedule and provides real time alterations based on network demand, it does however require separate measurement equipment to be integrated with the DEM.

A theoretical example showing the impact of demand limits on Phase C is shown in the figure below. The purpose of the graph is to show how strategic charging / discharging of energy storage can reduce peak demand over a 24 hour period.

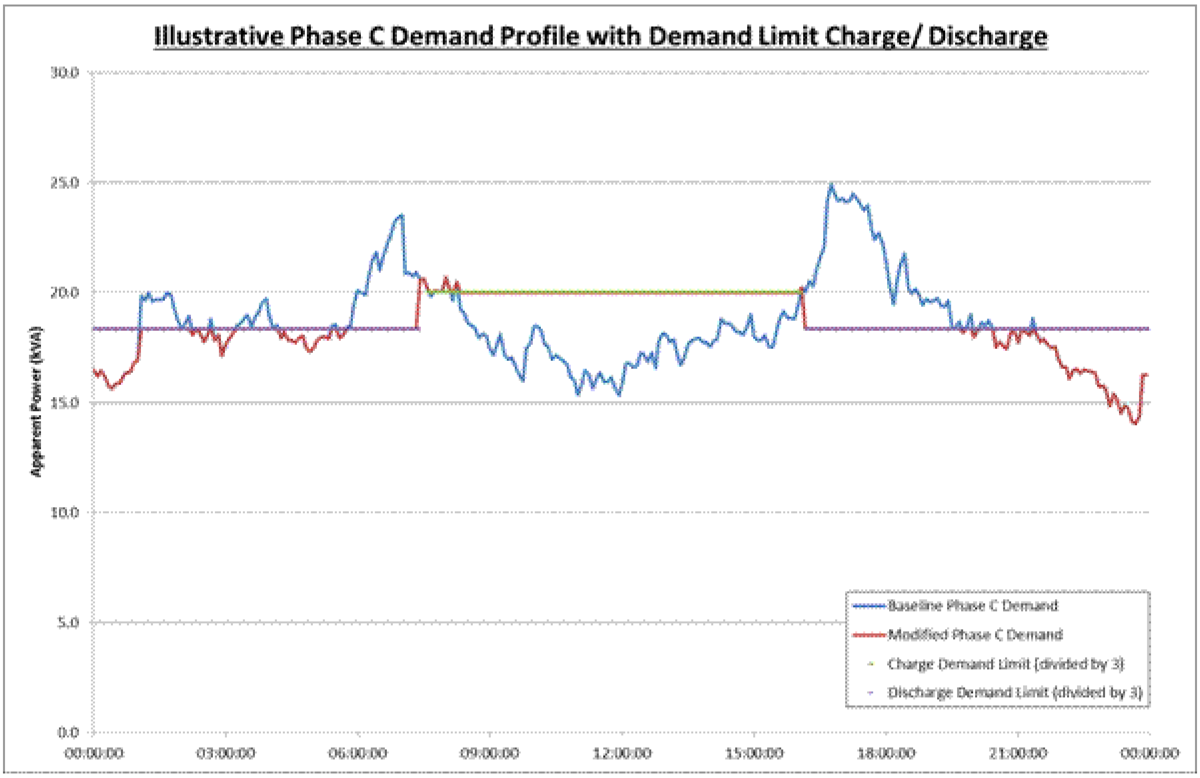


Figure 6: Theoretical impact of demand limiting cycles

The blue line shows the baseline demand varying over the course of a day between 16 and 25kVA. In this example a charge demand limit is set at 20kVA per phase between 07:30 and 16:00 (the green straight line). When the demand is less than the charge demand limit between these times the units will charge, increasing demand to 20kVA. Similarly in the example above, a discharge demand limit of 18kVA per phase applies between 16:00 and 7:30 (the purple line). When demand is greater than this, the units discharge to support this demand. The predicted operation of the unit is therefore shown by the red curve- demand is always less than the discharge limit between 16:00 and 7:30 and equal to the charge demand limit between 07:30 and 16:00.

4.2.1 Project Timeline

The actual project work to date is shown on the following timeline.

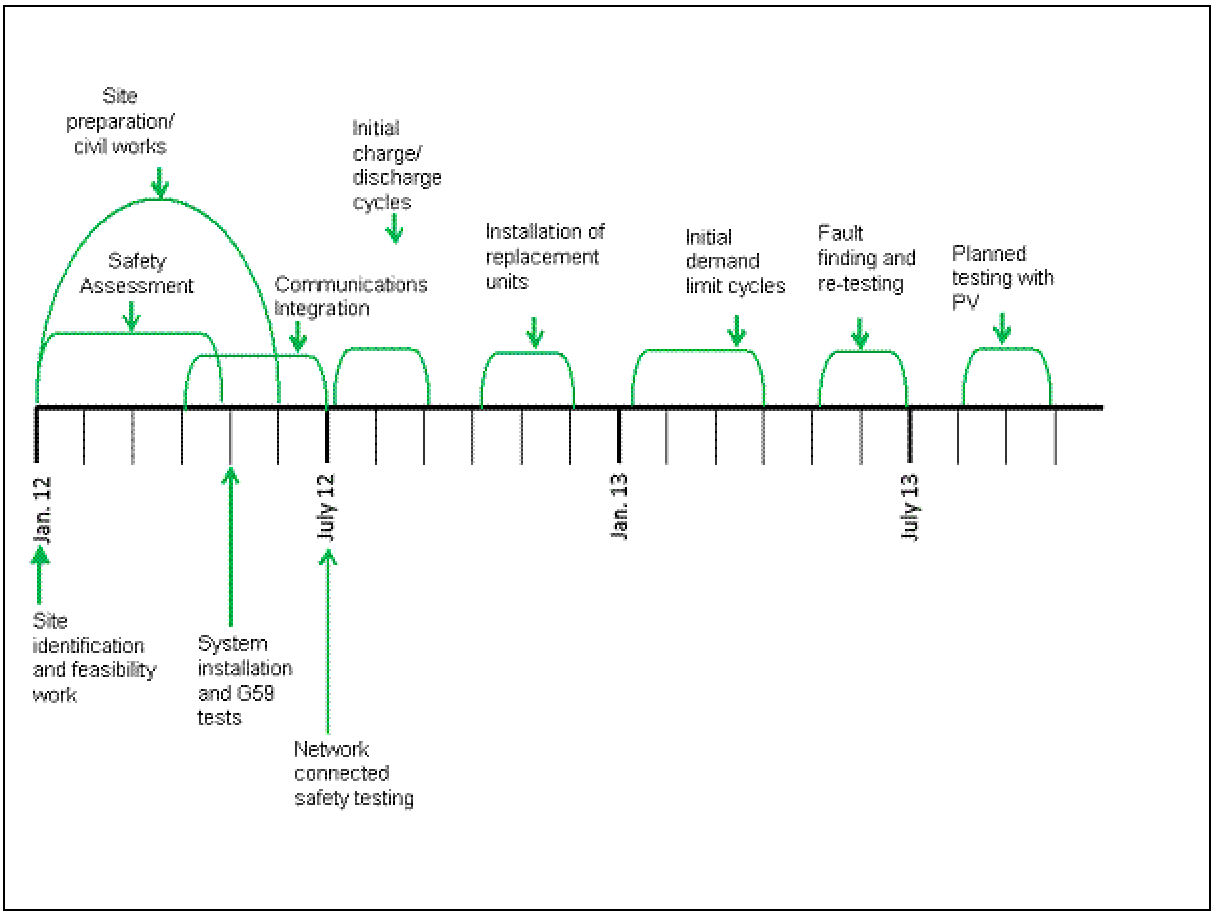


Figure 7 - Project timeline

A number of delays have been encountered during the project. The completion of safety, basic and functionality testing was restricted following various issues with two of three units in June 2012. Results were obtained via the operation of one unit only in July 2012. A communication fault developed in two of the three units between the battery module and PCS. If such a communications fault exists the unit in question will go into a safe shutdown mode and hence will not charge or discharge to prevent further potential malfunctions. The system supplier investigated this fault and all three battery elements were replaced in November 2012. Further testing was carried out following the replacement, however in July ’13 unit 3 faulted once more. This required the voltage control boards on the batteries to be replaced by the manufacturer. Since July ’13 the units have operated at least one charge / discharge every day without any significant problems or deviations form what was expected. The results from extensive testing are described in the following section.

5. The outcomes of the project to date

This section describes the work completed, and results of each of the elements described in the timeline in section 4.

5.1 Site Identification and Network Feasibility

A suitable site at the SSE Zero Carbon Homes (Chalvey, Slough) was identified as an essential precursor to the trial. This site offered the chance to test the units in conjunction with significant solar PV generation, electric vehicles and other low carbon technologies. Substation monitoring equipment has also been installed on this feeder circuit as part of another LCNF Tier 1 project[5]. This allowed benchmark network data to be collected and the impact of the storage units to be analysed, without the installation of further monitoring equipment, thus reducing the overall cost of the project.

Suitable land was available adjacent to the Zero Carbon Homes development in Chalvey and a compound was designed and constructed to contain the storage devices. This land was donated to the project for the duration of the trial from SSE Property department. Planning permission was granted as the compound was considered to be a ‘permitted development’, following a number of meetings with Slough Borough Council. This compound provides additional security beyond that normally used for similar installations in North America, where CES devices have been installed on verges and drive-ways, without substation-type containment. As this was a trial project with American specified units, additional equipment was required (auxiliary transformers, isolation points, monitoring etc). The compound also allowed safe access to the site for commissioning, testing and fault finding. For future deployments, the compound and additional components would not be required.

5.1.1 Results

To ensure the network was suitable to allow the connection of the CES units a detailed network study was completed. The analysis focused on the worst case situation where the combination of load and generation pushes the voltage close to the statutory limits. In this particular network, it is summer minimum load with the solar PV feeding onto the network at full output. In the analysis, the CES units at full output are added and the voltage rise calculated. As this is a new housing development the LV main cable feeding the homes is a 185 sqmm Wavecon which is reasonably large and hence is able

[5] SSET1002_LV Monitoring
http://www.SEPD.co.uk/uploadedFiles/Controls/Lists/Innovation/LV_network_monitoring/SSET1002LV_NetworkMonitoringCloseDownReport130228.pdf

to manage the additional generation from the CES units without putting the network voltage out of limits.

In addition to the network calculations, the most appropriate three phase cable to supply the CES units and the single phase site cabling / earthing arrangement had to be evaluated. The results indicated a 95 sqmm Wavecon cable could supply the site without significant volt drop. The single phase cabling on site needed to be 16 sqmm Steel Wire Armoured (SWA) or greater to take the maximum output of approx. 100 Amps. The earthing arrangement required a 70 sqmm copper cabling around the site perimeter with spikes in two corners and a connection back to the combined neutral / earth connection. Additional earth spikes were located next to each CES and a direct connection made to the battery. The image in Figure 8 displays the site cabling arrangements.

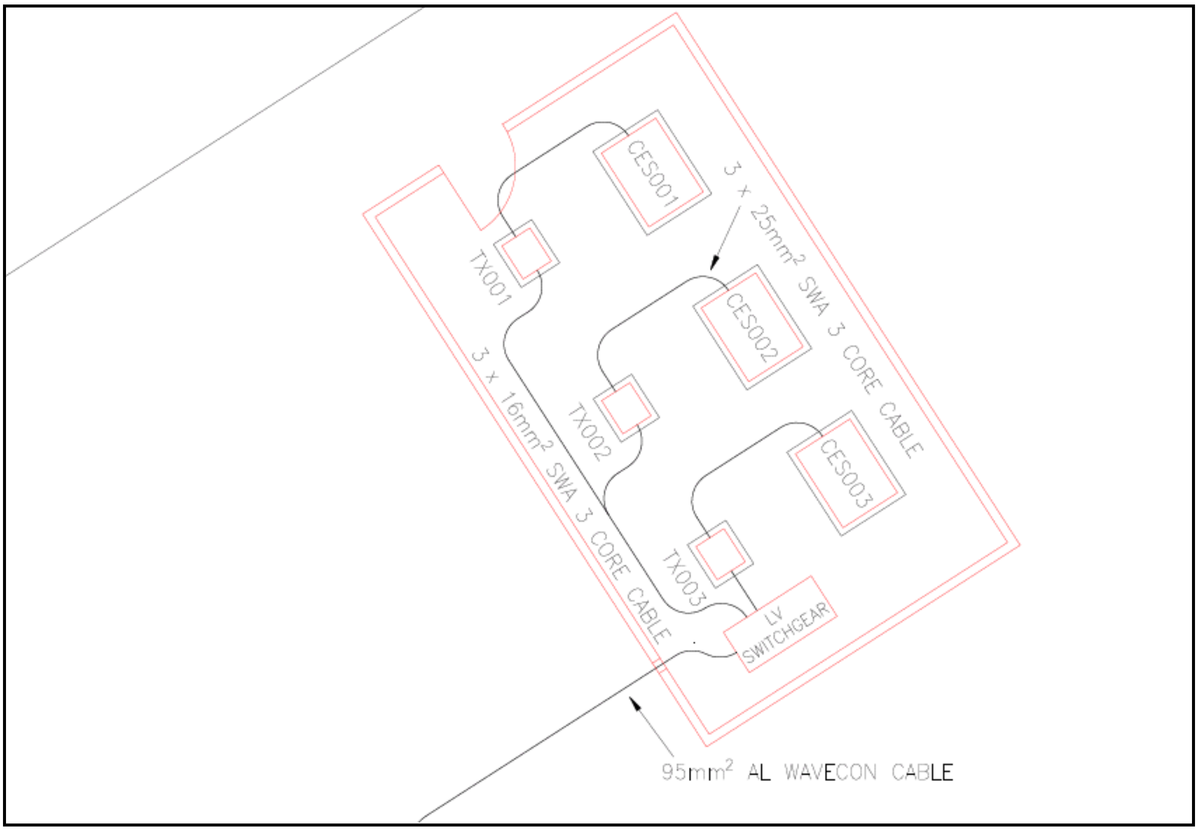


Figure 8 - Site layout with cable sizes

The image in figure 9 indicates where the energy storage is located electrically in relation to the distribution substation and the local generation / loads. The battery compound is located at the top of the schematic and electrically connected ¾ of the way down the radial feeder.

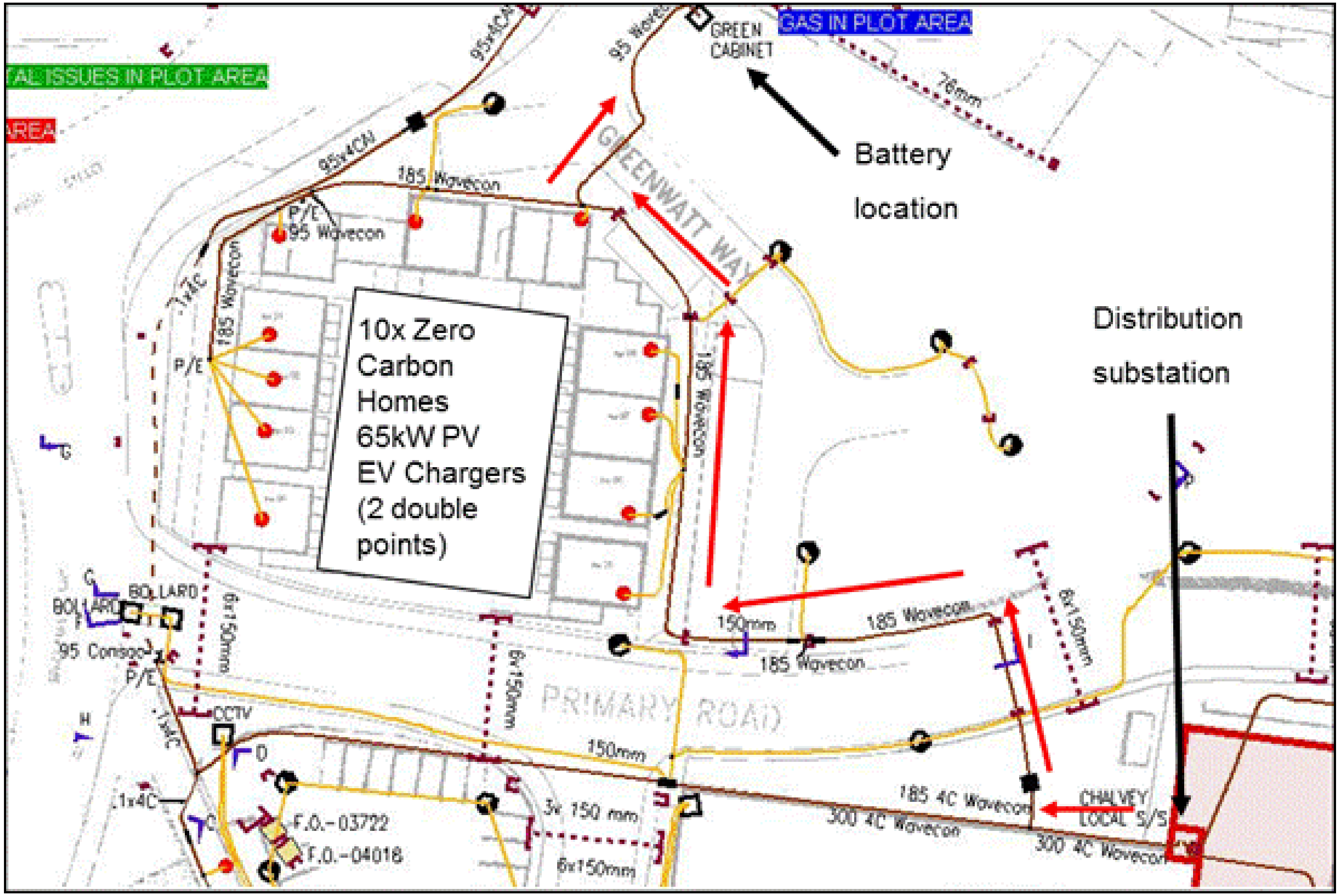


Figure 9 -Connection Diagram (black arrows indicate position of the CES units and the distribution substation; red arrows show the cable route to the CES compound)

5.2 Site Preparation and Finishing Works

This site preparation included the following activities:

- Clearing of debris / foliage and breaking up the hard standing
- Excavations for battery vaults and levelling of the site
- Installation of distribution cabinet to house 200 Amp cut out and distribution board with energy monitors
- Installation of 120 / 230V transformer and cabling between the transformer and CES and distribution board.
- Perimeter wall constructed around site

5.2.1 Results

The project civil works all went according to plan and were completed within the required timescales. The first stage was to remove the existing debris / foliage form the site and begin the excavations for the battery vaults and transformer plinths. During the initial site excavations there were a number of LV, High Voltage (HV) and telecoms cables found. It was discovered that a number of the LV cables were live; these cables had to be cut and pot ended to allow the civil works to continue. Channels were also created at a depth of 1 meter to allow the cabling for the units and earthing to be laid.

Figure 10 - The existing site November 2011

Figure 11 - Site after initial excavations and perimeter wall foundations

The second stage in the civil works was to install the battery vaults, distribution cabinet and level the site. The distribution cabinet was installed to house the network connection and associated isolation points and distribution board. The CES units can be isolated individually using the 100 Amp miniature circuit breakers. The cabinet also has provision for a generator connection and two load banks to allow testing before connection to the live network. At this point the auxiliary transformers were installed with the appropriate cabling from distribution board.

Figure 12 - Internal view of the distribution cabinet

A distribution board with 100 Amp breakers was installed to facilitate the initial commissioning and testing. The board allowed for independent operation of the units and multiple isolation points without the need to remove the cut out fuses. The distribution board also allowed connection of a generator and two load banks (real & reactive) to aid with the G59/2 proving.

Figure 13 - Site levelled with transformers and distribution cabinet installed

The final stage in the civil works was to install the perimeter wall around the site to make it secure. In addition to making it secure the intention was for the site to blend in and not appear as a substation. The wall was installed upon completion of the battery installation to make the lifting of the CES units simpler and safer.

Figure 14 - External view of rendered perimeter wall (rendered to blend-in with the nearby Zero Carbon Homes using the same colour and style)

Figure 15 - Internal view of completed site

5.3 Safety Assessment

Under this element of the project a structured safety assessment of the system, for installation within the compound at Chalvey, was carried out.

The approach followed for the safety assessment was:

- An assessment of the codes, standards and licensing requirements applicable to a Lithium ion battery system such as the CES units in the UK building on work SEPD had completed on previous battery projects;
- A review of the manufacturer (S&C / Kokam) documentation to ascertain the compliance of the units with legislation and the formulation of questions for S&C; and
- The use of the information gained from a site visit and the review of documentation to produce an Operational Risk Assessment for the CES units at Chalvey, and a Method Statement for fire fighting / containment activities.

5.3.1 Results

The key conclusions from the review of codes and standards were:

- The work did not identify any insurmountable issues which precluded the satisfactory implementation of the CES units at Chalvey.
- System suppliers have various duties including "the provision and maintenance of plants and systems of work that are, so far as is reasonably practicable, safe and without risks to health[6]". This places a number of responsibilities upon the supplier, including (but not limited to):
    - Ensure compliance with the Batteries and Accumulators and Waste Batteries and Accumulators Directives[7]; and
    - Ensuring appropriate CE marking of the product prior to commissioning. Both the Low Voltage[8] and Electromagnetic Compatibility (EMC) Directives[9] were found to be applicable to the units installed at Chalvey.
- The make-up of the battery and the inventory of its reagents place it below the relevant threshold values, for both Control of Major Accidents Hazards (COMAH) Regulations[10] and Hazardous Substances Consenting[11], under Planning Regulations.
- The construction of the cells within a battery as "articles", mean that they do not fall under the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) regulations[12].

There is a relative absence of effective Standards, directly applicable to the implementation of completed Electrical Energy Storage Systems on the power distribution networks. British Standard 50272-2:2001 –"Safety Requirements for Secondary Batteries and Battery Installations" states it "applies to Lead-Acid and Nickel-Cadmium" systems, and is therefore not directly relevant to the installation at Chalvey. However, a number of elements of this standard were identified as being applicable at Chalvey, and so were suggested as "good practice".

Following this review of codes and standards, the documentation provided by the system manufacturer was reviewed. The main conclusions from this review were:

- The documents detailed a number of key pieces of information in relation to the extent of safety testing carried out, various hazard warnings and precautionary measures for the operation and maintenance of the CES units, details of the Fire Suppression System, and information

6 Health and Safety at Work etc. Act 1974. Section 2.
7 http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:266:0001:0014:EN:PDF
8 http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:374:0010:0019:EN:PDF
9 http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2004:390:0024:0037:EN:PDF
10 http://www.legislation.gov.uk/uksi/1999/743/contents/made
11 http://www.legislation.gov.uk/uksi/2009/1901/pdfs/uksi_20091901_en.pdf
12 http://ec.europa.eu/environment/chemicals/reach/reach_intro.htm

relating to fire fighting and first aid in the event of a leak of reagents from the battery assembly.

- No significant issues were identified which would preclude the compliance of the system with the relevant codes, standards and legislation identified previously.
- Relevant issues identified for consideration were:
    - The system voltages are such that it falls within the range applicable to the Low Voltage Directive. The unit was therefore 'CE Marked' under the Low Voltage Directive.
    - The system was defined as "apparatus" under the EMC Directive and the manufacturer arranged for the assessment of the units with respect to this Directive. The units were therefore 'CE Marked' under the EMC Directive.
    - The system manufacturer has an obligation under the Waste Batteries and Accumulators Directive (specifically, The Batteries and Accumulators (Placing on the Market) Regulations 2008 and The Waste Batteries and Accumulators Regulations 2009) to take responsibility for the disposal/ recycling of the battery modules at the end of their life, under the "take-back" obligations.

The outcomes of this document review, and further questioning, were used to develop the Operational Risk Assessment and Method Statement. The Method Statement addressed the actions to be taken in the event of a fire.

The Operational Risk Assessment was conducted in a format consistent with SEPD's existing Risk Assessment documentation set, involving the structured identification of hazards, their risk ratings prior to the application of any mitigation measures, a summary description of the mitigation measures (both those inherent to the system design, and additional mitigation measures applied) and a re-assessment of the risk after the application of the identified countermeasures. The scoring used was consistent with that adopted by SEPD and therefore considered an assessment of risk to People, the Environment, Assets and to Reputation (i.e. a PEAR methodology). Statutory obligations require consideration of people (under the remit of the Health and Safety Executive) and the environment (under the remit of the Environment Agency). A variety of hazards were identified including those more "generic" hazards to be expected with such an electrical installation (and which are therefore relatively familiar in the DNO environment) and others specific to either battery energy storage (such as DC electric shock hazard) or the use of lithium ion technology.

One such potential hazard is the phenomenon of thermal runaway and the associated possibility of a series of cascading cell failures leading to a battery fire[13]. A range of measures are employed by the system manufacturer to reduce the probability of such an occurrence including:

[13] A Review of Hazards Associated with Primary Lithium and Lithium Ion Batteries. Lisbona D., and Snee, T. Journal of Process Safety and Environmental Protection. 89 (2011) 434-442.

- The use of a Battery Management System to maintain the cells within the correct operational range (measuring a range of metrics including cell voltage and temperature),
- Testing to ensure that cell ignition does not occur even if such limits are breached and the inclusion of a Fire Suppression System.
- Installation of the battery module in a below-ground "vault", providing further protection for both the external environment in the case of a fire emanating from the battery and for the battery in the event of a fire from its surroundings.

The majority of hazards were identified to be of a 'Low' severity following the application of suitable countermeasures, with only two hazards being rated as 'Medium'. These relate to a battery or PCS fire. Countermeasures are in place to reduce the probability of such an event and the risk to people from this hazard would be low given the application of suitable countermeasures such as the attendance of appropriately trained Fire & Emergency Service personnel to site and the removal of personnel from the vicinity of the units. However, the rating remains 'Medium' as should this occur the destruction of the whole asset would remain likely. The other hazard with a 'Medium' risk rating concerns DC Electric shock. Whilst the design measures reduce the probability that such an event would occur; the DC voltage itself is inherent to the technology.

The Operational Risk Assessment identified a variety of design measures which are in place to manage and control the risks associated with the system in so far as is reasonably practicable. The following measures have been applied to reduce the residual risk:

- Dialogue with the Royal Berkshire Fire and Rescue Service, inclusion on their "register of sites" and the preparation of a Fire Containment Operational Method Statement;
- Training of personnel who will operate the CES units; and
- Clear placarding of the CES compounds and units, indicating the potential electric shock hazard and key points to note in the event of a fire.

The Method Statement acts as guidance for the Fire & Emergency Service (Royal Berkshire Fire and Rescue Service) and SEPD employees. It is addressed in two stages:

- Guidance for Fire Authorities for training and when arriving on site; and
- Actions to be taken following the discovery of a fire.

Overall, it was concluded that the system represented a technically credible product offering, for application in both the UK market context and for the site at Chalvey. The Operational Risk Assessment has shown that the residual risk from the system is low and can be acceptably managed.

5.4 System Installation and G59 Commissioning Tests

Prior to the battery modules and CES units arriving on site, the following preparation work had been completed:

- Installation of battery vaults
- Installation and connection of a distribution cabinet at the rear of the site. This connects the compound to the LV feeder serving the SSE Zero Carbon Homes via a 95mm^2 Wavecon cable.
- Installation of three auxiliary (120 / 230V) transformers and connection to the distribution board.

The battery modules and PCS were delivered to site by the system supplier and were installed and connected over the course of two days in w/c 7th May 2012 (i.e. connecting the battery, PCS and LV network). The units were initially connected to a small island network consisting of a 100kVA generator a 100kW load bank and a 100kVA reactive load bank to allow tests to be completed before connection to the live LV network.

Following the physical installation of the units at Chalvey the system manufacturer undertook some basic charge / discharge commands to ensure basic functionality of the units. The manufacturer first instructed the unit to charge at increasing rates (1, 5, 10kW etc.) and then discharge (also at increasing rates).

The next stages of commissioning consisted of testing to ensure compliance with G59/2. As the units installed at Chalvey are designed for use in the United States the necessary settings and alarms were discussed with the system manufacturer prior to commissioning. The output of the generator was altered in order to simulate scenarios in which the unit should trip according to its protection settings for Over / Under Frequency, Over / under Voltage and loss of mains. An additional Power Quality (PQ) monitor was connected to the CES units (between the output of the auxiliary transformer and the distribution board) and this was used to observe the tripping behaviour of the units in response to the changes in generator output.

5.4.1 Results

The physical installation of the units and the basic charge / discharge testing by the manufacturer was successfully completed in approximately two days (within the timescales expected). The results of the G59 testing are summarised in the following table. A full briefing note showing the results of this testing was completed and is available to other GB DNOs on request.

Table 1: Summary of G59/2 Testing Results

Test	Unit Performance	Test Successful?	Notes
Over frequency (Stage 1- Increase frequency to 51.5Hz)	When frequency increased from 51.5 to 51.8Hz all three units stopped discharging within one second (relative to the requirement of tripping within 90 seconds at 51.5Hz).	P	
Under frequency (Stage 1- Decrease in frequency to 47.5Hz)	When the frequency decreased from 47.4 to 47.3Hz all CES units stopped discharging.	P	Units exhibited 'Under Frequency' alarm.
Very Under frequency (Stage 2- Decrease in frequency to 47Hz)	When frequency decreased to 46.5Hz the units stopped discharging within three seconds.	P	Units exhibited 'Very Under Frequency' alarm.
Over voltage (Stage 1 Over voltage Limit= 264V)	Units stopped discharging real power at a voltage of 258V within 3 seconds.	P	
Under voltage (Stage 1 Under voltage Limit= 209V)	Units stopped discharging real power within 3 seconds of voltage decreasing to 209V. The test was also successfully completed when the units were discharging 25kW prior to tripping.	P	Initially this test was unsuccessful. Export of reactive power was disabled and CES voltage limits were modified to a maximum of 160V and minimum of 80V. Units exhibited 'UnderVoltage' and 'VeryUnderVoltage' alarms.
Loss of Mains (carried out by tripping the generator)	Test 1: Units entered 'Shutdown' mode but did not open AC breaker (expected with settings during this test). Test 2: Settings on Unit 1 were modified prior to test. Unit 1 opened AC breaker as expected.	P	

An example of the unit behaviour observed during these tests is shown below for the Very Under Frequency test. In addition to monitoring the output of the units via the PQ monitor, the status of the CES units was observed by the system manufacturer using the local HMI laptop. The HMI shows both the status of the unit (charging, discharging etc), the position of the AC and DC breakers and any alarms.

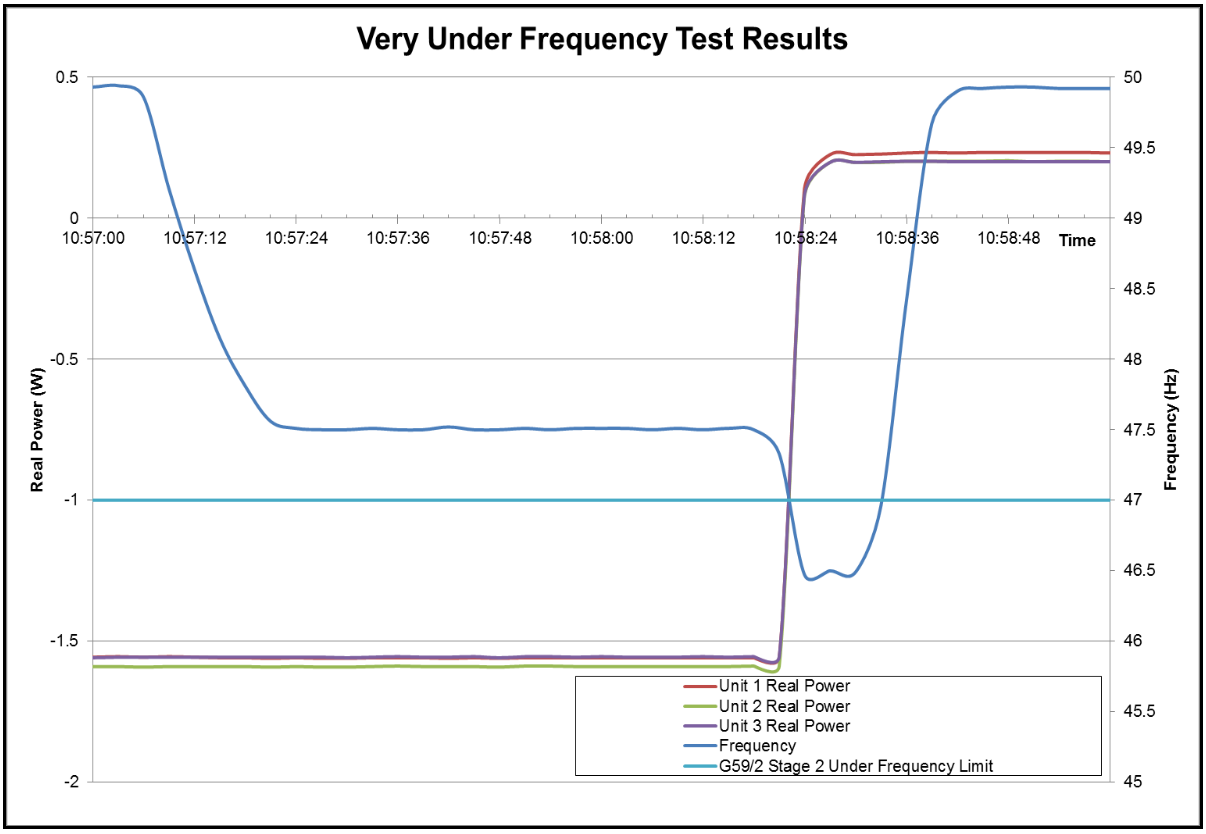


Figure 16: Example of G59/2 Testing Results (showing all units no longer discharging when frequency decreased below the Stage 2 Underfrequency limit)

All the G59/2 compliance tests were completed successfully and therefore the units were considered suitable to be connected to the live distribution network. The example in figure 16 illustrates the discharging at 1.5kW, the frequency is then reduced by the generator to below 47Hz at which point the batteries cease discharging as expected.

5.5 Communications Integration

The communications works were split into four main sections:

- **Link between SCADA control and the DEM**
  - The SCADA system used by SEPD provides control and signalling to plant on the HV network. The DEM functions as a control hub to communicate with the CES units and operate the various charging and discharging algorithms
- **Link from DEM to CES**
  - This is a radio link from the substation to the CES units using a bespoke radio system – link approximately 400 meters.
- **Remote access**

- This is access to the DEM data and control interface over a secure internet connection and hence the ability to alter charge / discharge parameters, perform fault analysis, firmware updates etc.

- **Integration with substation monitoring equipment**
  - The DEM has the ability to take real time voltage / power values to inform charge / discharge algorithms. Advanced monitoring was already installed at the local substation[14] – the integration work is detailed below.

5.5.1 Results

The image in Figure 17 shows the basic layout of the communications architecture from the SEPD SCADA system server at the top through to the three CES units at the bottom of the diagram.

[14] SSET1002 'Demonstrating the Benefits of Monitoring LV Networks with embedded PV Panels and PV Charging Point'
http://www.smarternetworks.org/Files/Benefits_of_Monitoring_LV_Networks_130327132144.pdf

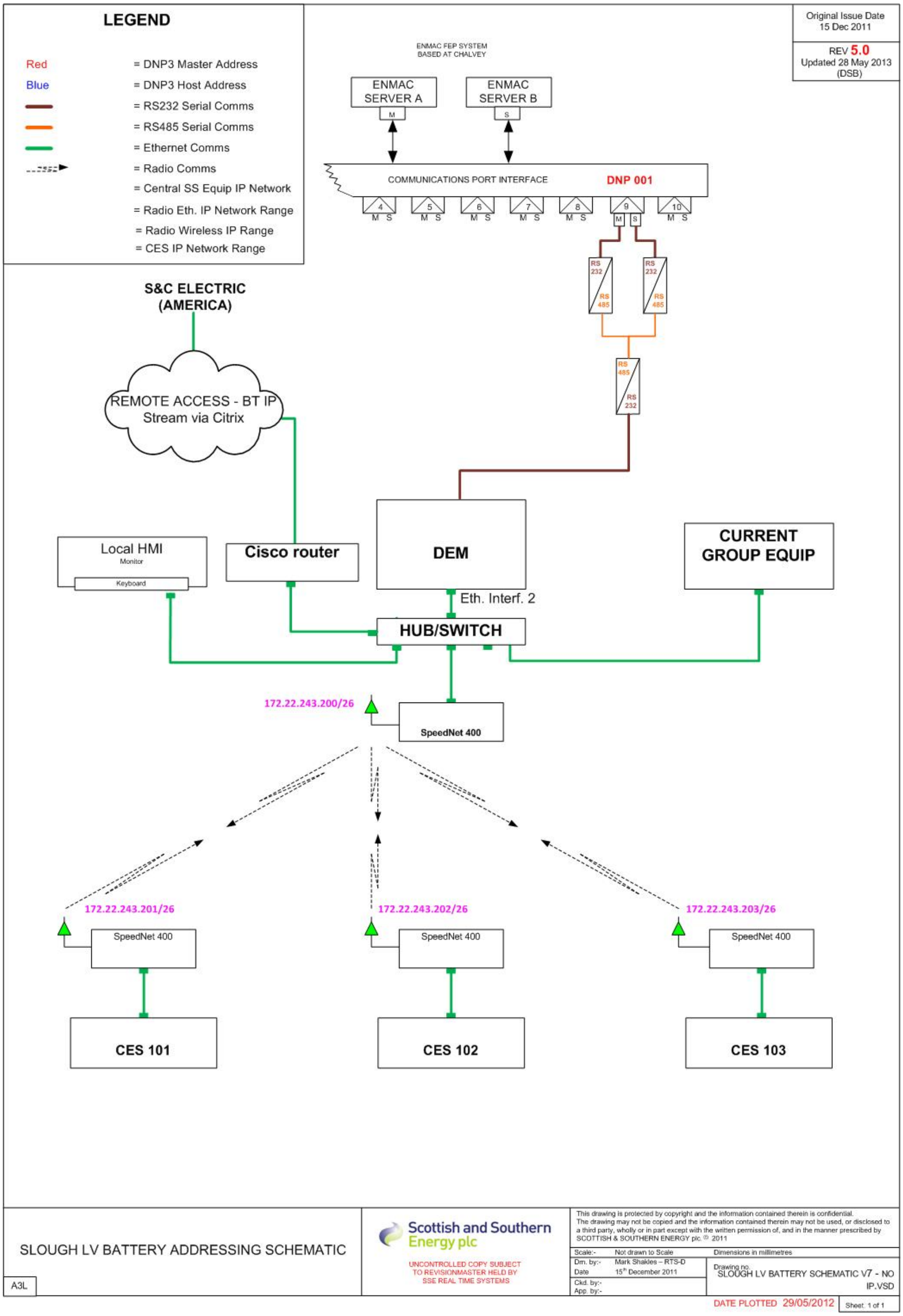


Figure 17 - Communications architecture showing path from SCADA to each CES unit (all key IP addresses have been hidden)

5.5.1.1. DEM to SCADA

It was firstly necessary to establish control and signalling from the SEPD control room to the DEM. The communications route from the control room to the site in Slough follows the same path as the normal substation signalling and control over a serial link. The DEM is simply connected onto the Front End Processor (FEP) like a normal piece of plant or apparatus on the HV network.

Figure 18 - DEM plus Cisco router for remote access installed at Chalvey 11kV substation

A significant amount of work was completed to define the number of digital and analogue control points to bring back to the SCADA system. The CES units offer many points and it was not feasible to bring all these back to the control room, therefore only critical points were brought back to the SCADA system; 15 analogues and 15 digitals. The full list of points is available to GB DNOs on request. Figure 19 illustrates the view of the battery in SCADA.

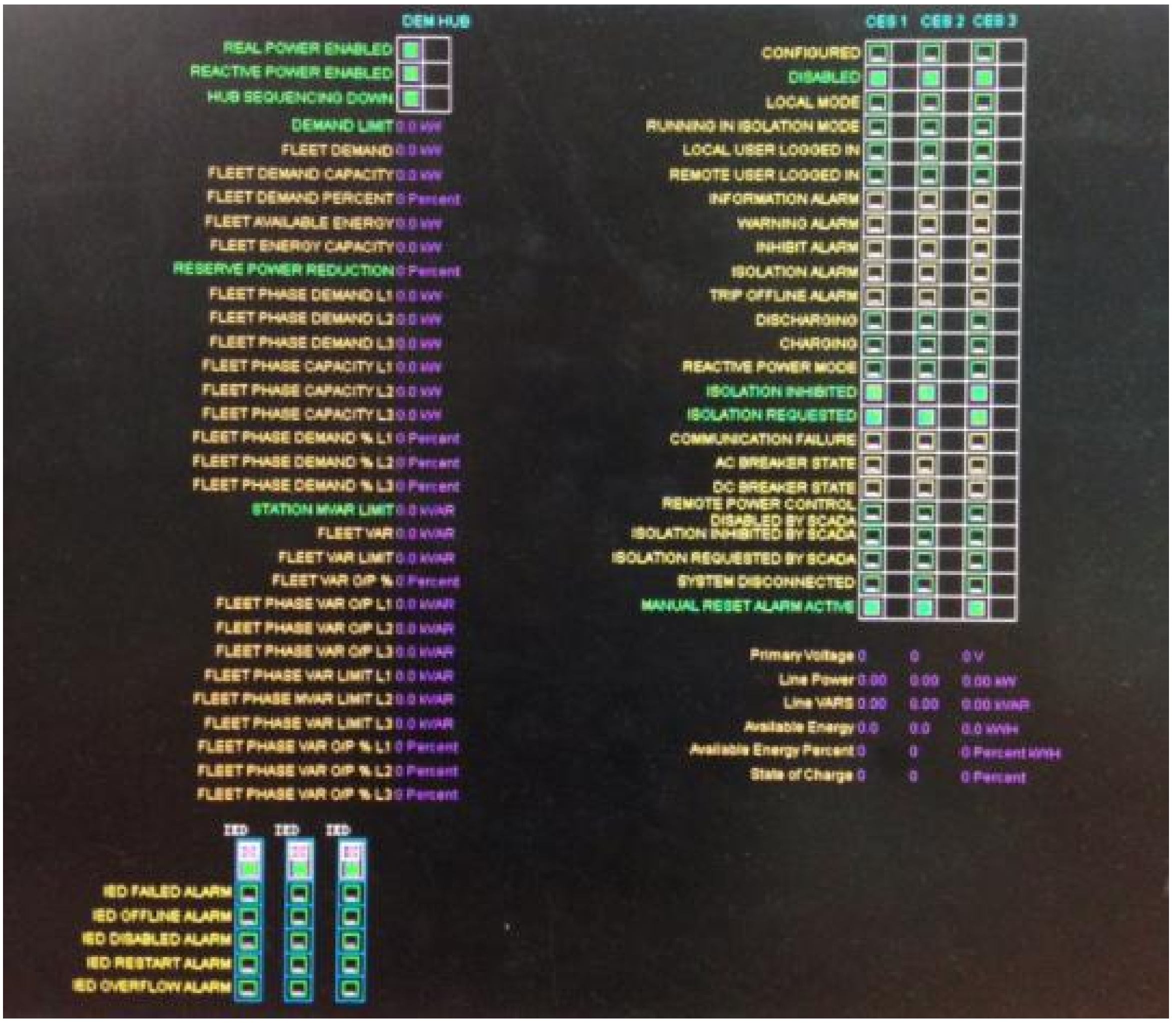


Figure 19 - SCADA view of the DEM and CES units, showing digital and analogue points. Left hand column shows the DEM points and right hand column shows the CES points.

Initial commissioning was completed at the control room within a test environment to prove the link was established between SCADA and the DEM with commands flowing in both directions. Upon completion in the test environment the DEM was installed in the RTS (Real Time Systems) room at Chalvey substation and connected to the FEP to provide the link to the SCADA system. The system now allows the control engineer to send commands to the units to inhibit operation or reset alarms. The system also allows analogue values to be sent to the units e.g. maximum power output – this is the first time this has been accomplished on SEPD's SCADA system for the SEPD licence area.

5.5.1.2. DEM to CES Units

The second part of the link was to integrate the DEM with each of the CES units. This was completed using a bespoke radio system manufactured by S&C. The system is called 'SpeedNet Euro'[15] and

[15] http://www.sandc.com/products/automation-control/speednet-radio.asp

essentially uses 4 different Ultra High Frequencies to send the packets of data. A Speednet radio was installed in the same rack as the DEM and connected to an external aerial installed on the outside of the substation. The CES units themselves also have a SpeedNet radio inside and a 'hockey puck' style aerial mounted on the top of the outer casing. The SpeedNet radio is shown in figure 20.

Figure 20: View of SpeedNet Radio in Chalvey RTS Room

5.5.1.3. Remote Access

To allow secure access to the DEM from external location, a Virtual Private Network (VPN) was created. The VPN is created using a separate broadband line with the BT product; IP Stream. A secure tunnel through SEPD's corporate firewall allows access to the VPN via a Citrix remote login web portal. This allows the authorised user full access to the DEM and the ability to operate the CES units remotely. The remote access has operated as expected and allows the S&C staff in the U.S. to perform software updates, help with fault finding, and check the device status. In addition it allows SEPD staff to alter schedules, charge / discharge rates etc and to download data for analysis without the need to visit site.

5.5.1.4. Integration between substation monitoring and DEM

The substation that supplies the CES units has advanced monitoring equipment, supplied by Current Group, from a previous SEPD LCNF Tier 1 project[16]. In order to utilise the real time data from this monitoring equipment it was decided that it would be integrated with the DEM. This required some significant modifications and a number of meetings between S&C and Current Group IT staff. The end result was that the DEM can now record real power and reactive power values for all three phases in real time. This allows these real time values to be used as set points in demand limiting algorithms, e.g. if feeder demand increase above 20kW discharge battery. Without this feature it would not be possible to automatically run the peak lopping schedules.

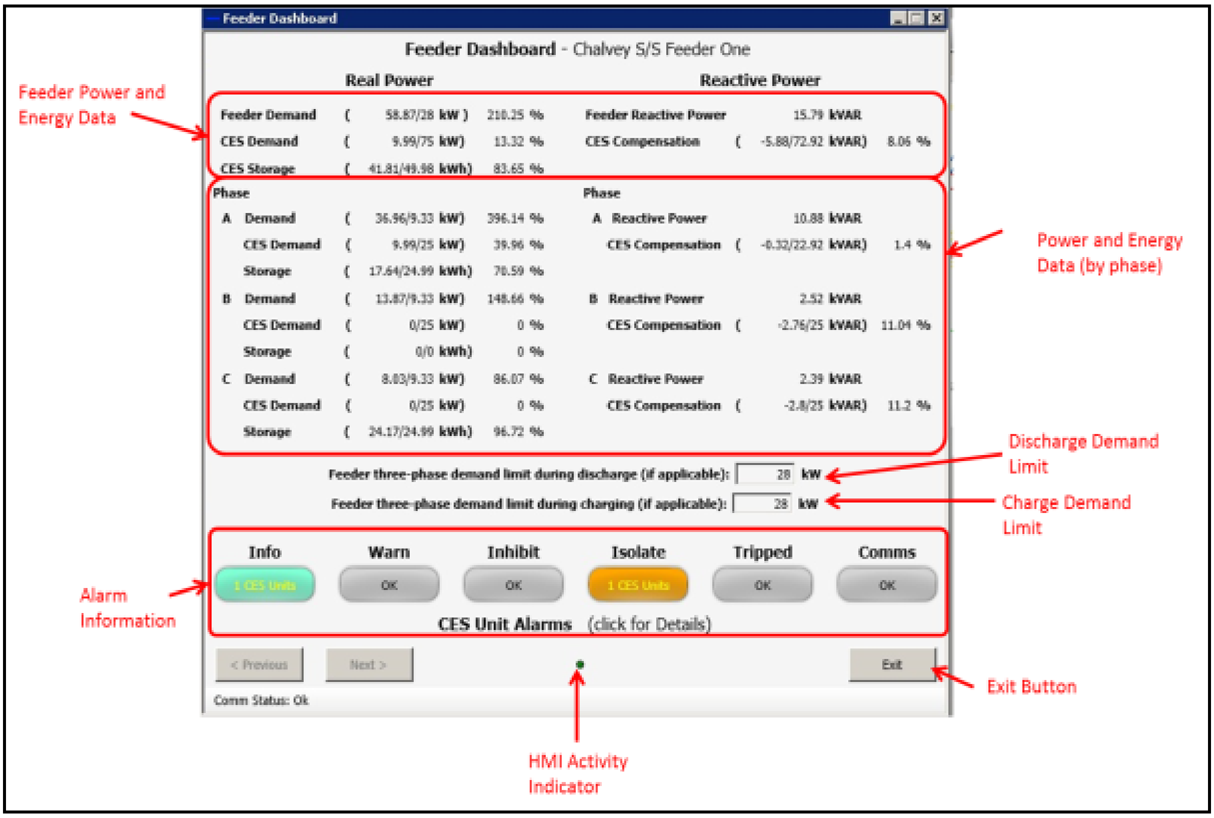


Figure 21 - DEM Feeder Dashboard displaying real time values from substation monitoring equipment

5.6 Network Connected Safety Testing

Following successful completion of the G59 tests, the units were connected to the distribution network. A structured test plan was then completed, whereby it was necessary for the units to pass each stage before proceeding to the next. The stages of this testing were:

[16] Demonstrating the Benefits of Monitoring LV Networks with embedded PV Panels and EV Charging Point,

- Safety functions - confirming the unit operates, and can be shut down safely. This included tests to demonstrate the shutdown procedure for all units, the isolation procedure and showing that the 'Local' mode (i.e. when the unit is controlled the Human Machine Interface (HMI) connected to each CES unit) cannot be overridden by commands dispatched remotely (e.g. from the DEM or control room via SCADA).
- Basic Tests - confirming the unit will respond appropriately to commands from the Distributed Energy Manager (DEM), this testing included items such as use of the DEM interface, the receipt of alarms, and ability to enable / disable the system from the DEM; and
- Functionality Tests - confirming the simple functionality of the system, including basic performance verification against the specifications (such as round-trip efficiency). Tests have been conducted to determine the round-trip efficiency at various charge and discharge rates.

All the 'safety' and 'basic' tests were undertaken using Unit 3 only, but the same results could have been obtained by Units 1 or 2. The purpose of these tests was to confirm that the units performed in the manner expected, based on the information provided by the manufacturer. It is therefore valid to test on one unit only; all three units were available for functionality testing.

5.6.1 Results

The tables below summarise the testing completed under the 'Safety' and 'Basic' parts of the testing:

Table 2: Safety Testing Results

Test Description	Results	Test Successful?
Shutdown procedure Purpose: To confirm the shutdown procedure as instructed by S&C during the commissioning period.	The instructions provided by the system supplier were followed the unit was observed to open both AC and DC breakers and report the change in state to the DEM. The unit restarted when commanded to.	P
Inhibit procedure Purpose: To confirm the units are inhibited (i.e. prevent charge/ discharge) when instructed to by either the DEM or via SCADA	The unit was inhibited by both the DEM and via SCADA. In addition the DEM can be used to open the AC breaker.	P

Test Description	Results	Test Successful?
Local mode prevents dispatch of remote commands Purpose: To confirm that the unit will not react to any commands received remotely when in 'Local' mode for testing.	The unit responded as expected and would not respond to any commands from the DEM or SCADA when in Local mode. This would give a local operator priority during testing/ troubleshooting. A number of variations of this test were completed to verify that the unit would hold commands issued remotely when it was in local mode to implement once in remote mode again and vice-versa.	P

Table 3: Basic Testing Results

Test Description	Results	Test Successful?
'Do Nothing' Purpose: To confirm that the CES units will go into standby mode and not operate if no command to dispatch real or reactive power is received	This test was deemed to be successfully completed as the unit did not exhibit unwanted behaviour when left in an idle state with no command to charge or discharge real/ reactive power.	P
Loss of communications Purpose: To demonstrate the CES unit behaviour in the event of a communications interruption.	The unit was commanded to discharge 5kW of real power and then communications were disabled (power was removed from the SpeedNet radio). The unit entered 'Idle' mode and stopped discharging after 30 minutes. When power was re-applied the units began to discharge again, as expected (Figure 22).	P
Alarm display and status Purpose: Confirm that CES units communicate alarms locally at the units, at the DEM HMI and via SCADA at the SSE control room.	The float switch (used to indicate the presence of water in the PCS unit) was activated and the unit opened the AC and DC breaker and communicated the alarm to the DEM. When released the unit operated normally. Testing has also shown that alarms are shown at the control room.	P
Inhibiting the CES unit via SCADA prevents dispatch of power via the DEM Purpose: To confirm that if the control room has inhibited the action of the CES units that this cannot be overridden by the actions of a user at the DEM.	The control room followed the procedure for inhibiting the units and a charge command was issued via the DEM. The unit did not respond. When the inhibit command was removed by the control room the unit could be operated via the DEM.	P

The results of these tests were analysed through observation of the unit behaviour at the DEM control screen and via the use of a hard-wired PQ monitor. The graph in figure 22 shows the loss of communications test; the unit operating as expected going into a safe state after 30 minutes and returning to normal operation after communications are restored.

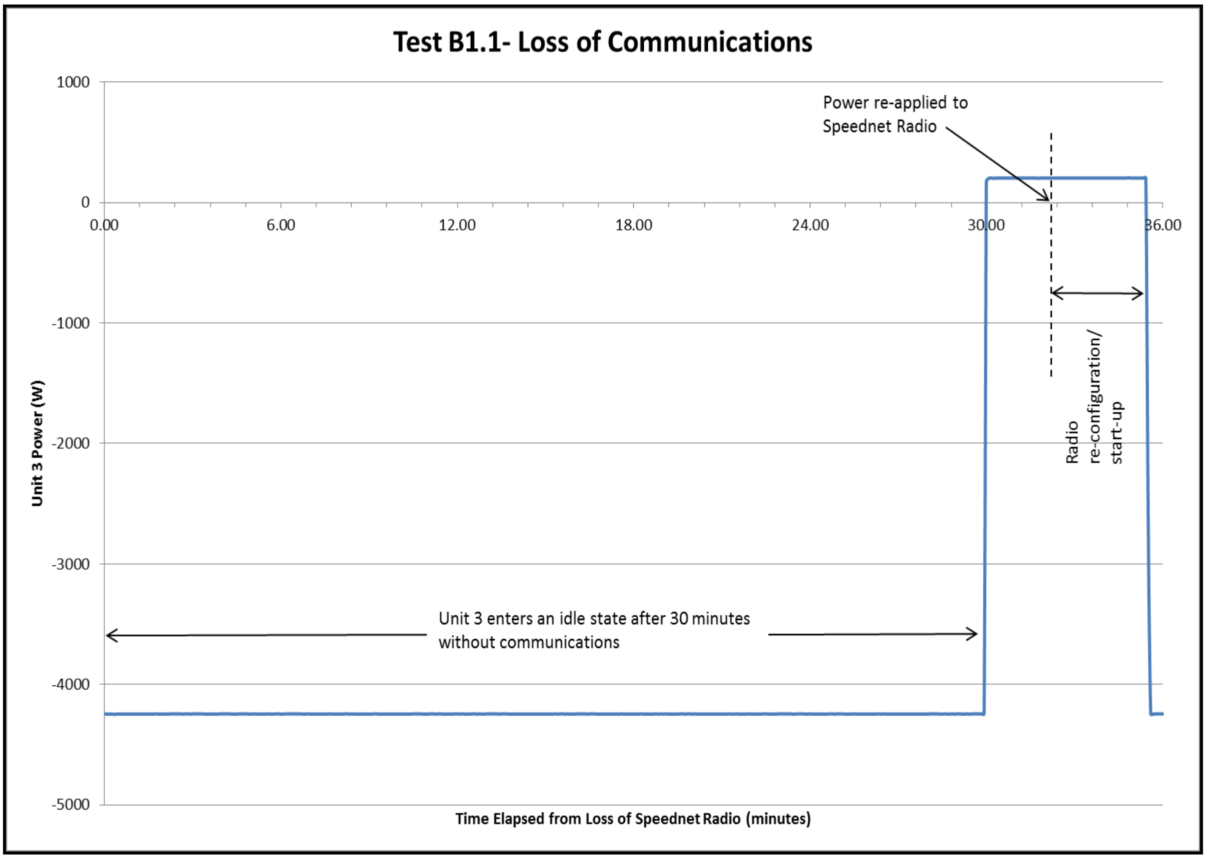


Figure 22: Loss of communications test results

5.7 Initial charge / discharge cycles (functionality testing)

Following successful completion of the tests described above a number of charge and discharge cycles were completed at different rates. These were carried out to gain confidence in the use of schedules and operation of the CES units and to determine the round trip efficiency of the system. Round trip efficiency has been calculated by measuring the amount of energy required to fully charge the units (from minimum to maximum state of charge) and comparing this to the amount of energy which can be discharged from the units (from maximum to minimum state of charge) over a 24 hour period. This has been measured by a standalone PQ monitor and instructed using 'Fixed Power' schedules. The monitor is positioned within the distribution cabinet, as shown in figure 23.

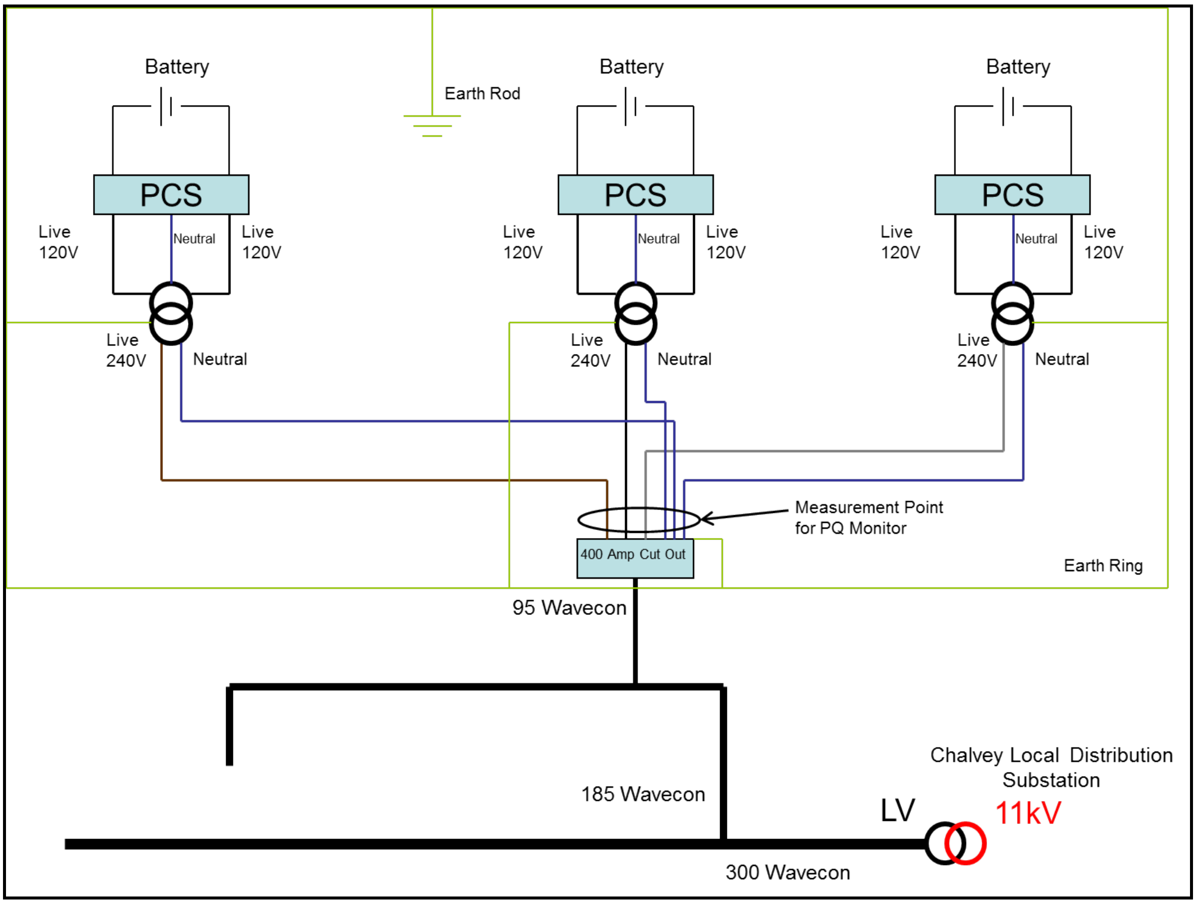


Figure 23: Measurement point for PQ monitor

5.7.1 Results

The efficiency values were measured after the initial installation in May 2012 – illustrated in table 4. All three units reported back average figures between 81% and 83%. The results show that the figures returned are fairly consistent across the varying power levels and in line with manufacturer expectations. Further analysis showed that there was a slight discrepancy between the three CES units, with unit 3 performing slightly higher than the other units – up to 6% higher.

Table 4 - Average efficiency across all units at multiple power levels

Charge / discharge rate (kW) May '12	Efficiency (average % across all units)
12.5 / 25	82
15 / 15	83
20 / 20	81

The battery modules were replaced in November 2012 and a number of fixed power charges at varying charge / discharge levels were implemented. Efficiency values were recalculated in summer 2013 following the resolution of faults on the replacement units. The efficiency figures over 20 cycles averaged over 80%. Again the performance of unit 3 was higher as displayed in table 5.

Table 5: Round trip efficiency

CES	Charge / discharge rate (kW) July '13	Efficiency (%)
Unit 1	10	79.8
	10	79.8
	10	80.8
Unit 2	10	80.9
	10	81.9
	10	80.9
Unit 3	10	86.6
	10	86.7
	10	86.6

At the end of the project in May 2014 the efficiency tests were completed once more in the same manner. The purpose of the repeated test was to determine if after approximately 450 cycles, the units had begun to degrade in terms of efficiency or capacity.

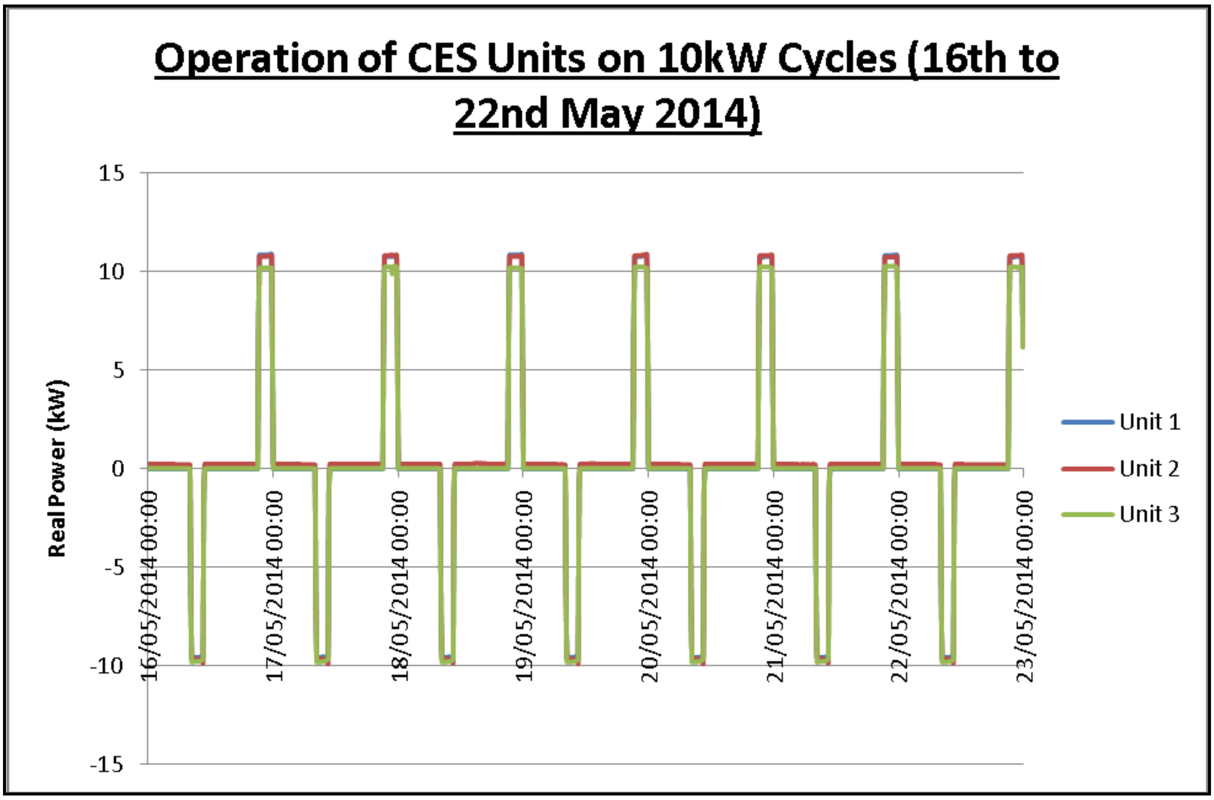


Figure 24 - 10kW efficiency cycles

Table 6 - Efficiency data May 2014

	Energy Out During Discharge (Wh)			Energy In During Charge (Wh)			Round Trip Efficiency			Average Power when Charging (W)			Average Power when Discharging (W)		
Date	Unit 1	Unit 2	Unit 3	Unit 1	Unit 2	Unit 3	Unit 1	Unit 2	Unit 3	Unit 1	Unit 2	Unit 3	Unit 1	Unit 2	Unit 3
16/05/2014	23,608	23,863	24,202	29,234	28,959	27,404	81%	82%	88%	10,318	10,221	9,672	-8,853	-8,948	-9,076
17/05/2014	23,575	23,843	24,196	29,230	29,319	27,711	81%	81%	87%	10,320	10,348	9,780	-8,841	-8,941	-9,073
18/05/2014	23,549	23,810	24,202	29,233	28,966	27,397	81%	82%	88%	10,318	10,223	9,670	-8,831	-8,929	-9,076
19/05/2014	23,549	23,784	24,189	29,273	29,312	27,698	80%	81%	87%	10,332	10,345	9,776	-8,831	-8,919	-9,071
20/05/2014	23,575	23,804	24,163	28,907	28,972	27,417	82%	82%	88%	10,202	10,225	9,677	-8,841	-8,926	-9,061
21/05/2014	23,608	23,863	24,189	29,230	28,966	27,718	81%	82%	87%	10,320	10,223	9,783	-8,853	-8,948	-9,071
22/05/2014	23,588	23,817	24,209	29,214	29,279	27,718	81%	81%	87%	10,311	10,334	9,783	-8,846	-8,931	-9,078
Average	**23,579**	**23,826**	**24,193**	**29,192**	**29,110**	**27,580**	**81%**	**82%**	**88%**	**10,303**	**10,274**	**9,734**	**-8,842**	**-8,935**	**-9,072**

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From the results it is clear that the unit's efficiency is still consistent with the original measurements and has, as expected, not deteriorated over the 450 cycles. The manufacture's system rating is 4000 cycles therefore the units have approximately 90% of their usable life left.

The round-trip efficiency figures have been relatively consistent and are in line with expectations at the start of the project based on manufacturer figures, and other lithium ion CES systems. It should be noted that owing to the use of a unit intended for the United States market an auxiliary transformer (120 / 230V) has been installed. This will increase losses compared to a power converter with an output of 230V. The magnetising current for the auxiliary transformers equates to an instantaneous power of approximately 30W. As this figure is very low it is not measured accurately by the Rogowski coils used with the PQ monitor. The result of this inaccuracy is that all the measured efficiency figures are between 1.5 – 2% lower than is stated. Future installations will however be specified with a GB compliant voltage and hence would not need the auxiliary transformer. This learning has been fed into the requirements for the NTVV tender process for 25 units.

Efficiency figures were also calculated for the units operation in the dynamic demand limiting mode (section 5.8.2). The figures calculated with the units operating in this manner were averaging between 68% - 72%, approximately 10% lower than the fixed power mode. This is to be expected as the batteries are operating with a non linear charge / discharge curve. This provides a more realistic assessment of the losses and hence the cost of operating the system.

5.8 Peak shaving

The project has undertaken numerous peak shaving scenarios very successfully. Firstly utilising historical data to set week ahead charge and discharge periods; hence charging when demand on the network is low and discharging to cover the peak period. This would be considered a static peak shaving as the charge / discharge periods are set and the unit does not respond dynamically to demand fluctuations. The use of reducing peak demand in this mode requires an understanding of the historical network demand and using that data to predict the future demand. If however, demand is not as predicted it is possible that the peak demand will not be reduced and has the potential to make the situation worse.

The integration with real time values from the 'Current Group' substation monitoring equipment to the DEM allowed for fully dynamic control of the CES input / output. This means as demand increases the battery output will increase in order to meet a predefined demand target, up to the output limit of the CES – in this case up to 25kVA. The results from the implementation are detailed in section 5.8.2.

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5.8.1 Static peak shaving results

The first demand limiting charge / discharge cycles were set up in February 2013 based on the network benchmarking study completed in the early stages of the project (using network data from 2011/12). The charge / discharge schedules were therefore set according to the demand present in January 2012. Analysis of the data from the PQ monitor during these first cycles indicated that the units had not reduced peak demand as expected. Further network data was collected and it was observed that demand was significantly lower in 2013 than in 2012. The average demand on a weekday on Phase C was 18.5kW and 9kW in 2012 and 2013 respectively. This is shown in Figure 25.

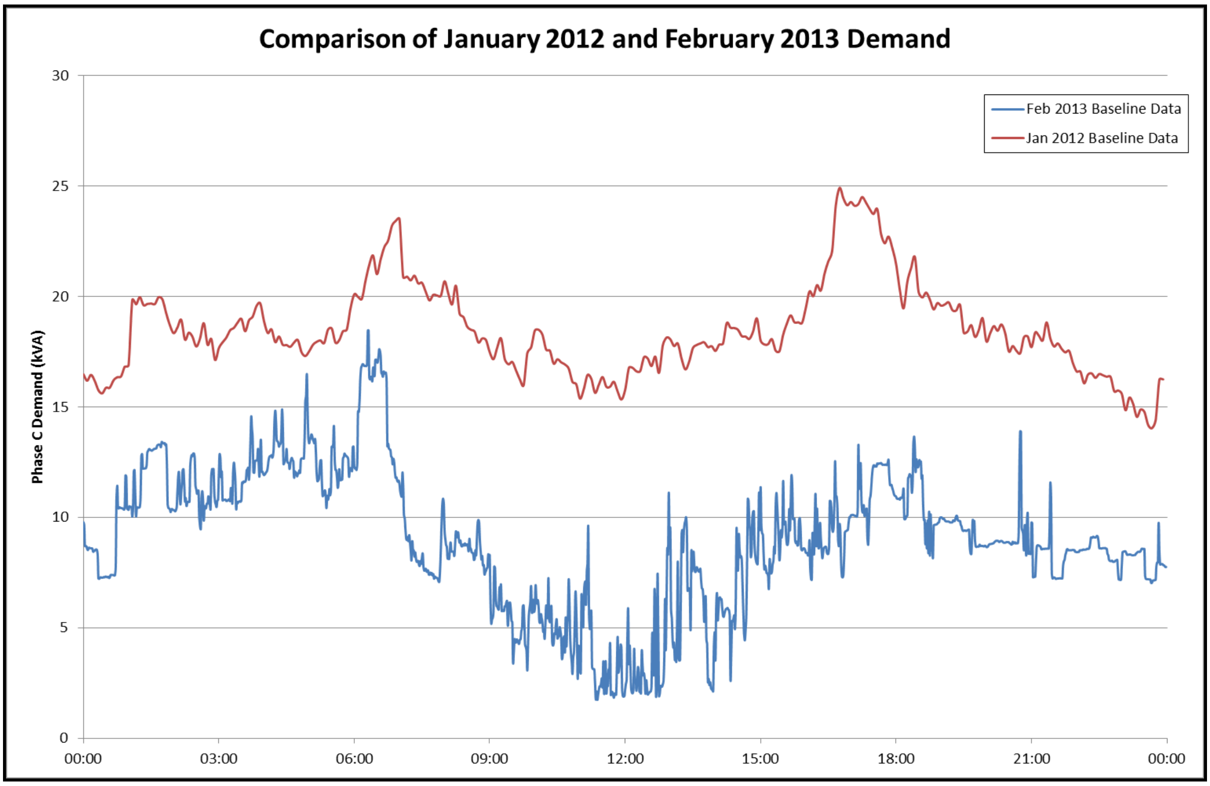

Figure 25: Changing demand between 2012 and 2013 on phase C

Additional analysis was completed in order to understand the recent historic demand; this data provided the limits to perform the static peak shaving. The graph in figure 26 shows that it is possible to perform peak shaving using the fixed power schedules; the units begin charging at 9am for close to three hours. Utilising this method does produce a reduction in peak demand however it is difficult to cover the complete 24 hour period with the battery capacity.

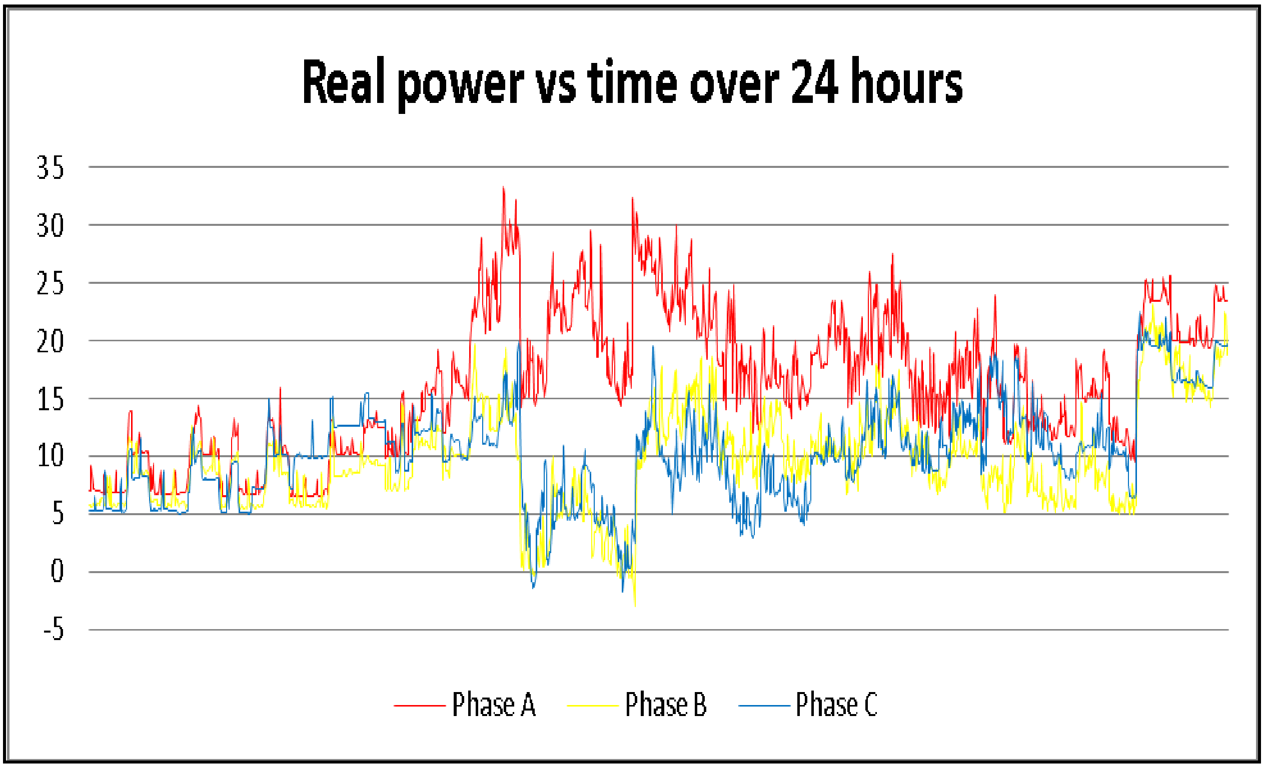

Figure 26 - Peak shaving utilising a fixed power schedule on all three phases

5.8.2 Dynamic peak shaving

The majority of the work in relation to dynamic peak shaving was completed in the summer months when demand was lower and solar PV generation was higher. The graph in figure 27 provides an approximate benchmark for demand across all three phase on a sunny day with minimal cloud coverage.

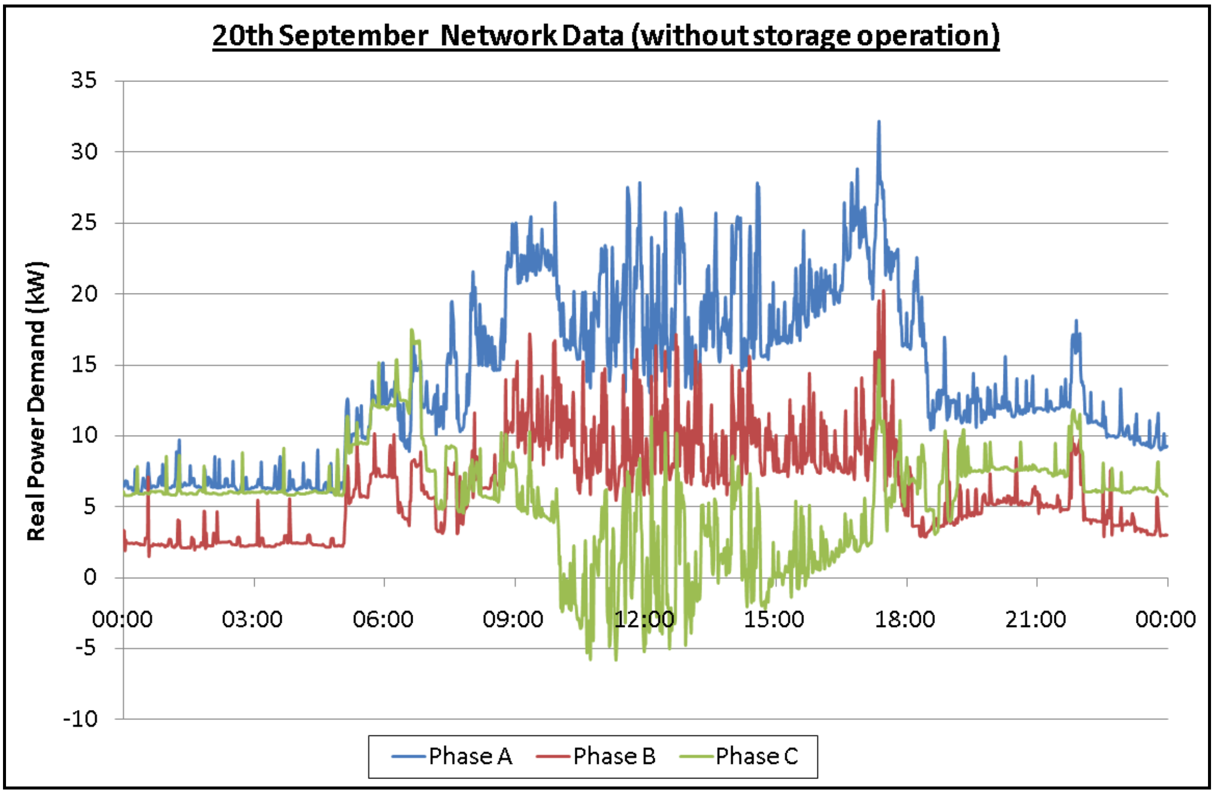

Figure 27 - Single phase demand for clear sunny day

The graph in figure 28 illustrates the system performance with a 10kW maximum demand limit set at the substation. This means that if demand increases above 10kW the battery will discharge to meet this target. The red line on the graph shows what demand would have achieved without the battery support and the blue line showing the actual demand measured at the substation over the 24 hours. It is clear to see that the peak demand has been reduced significantly at two periods throughout the day with the battery discharging. Conversely at times of lower demand the battery has charged at a rate equal to 10kW minus the real time demand. The green line on the graph displays the battery operation with a positive value showing the battery charging and a negative value denoting discharge.

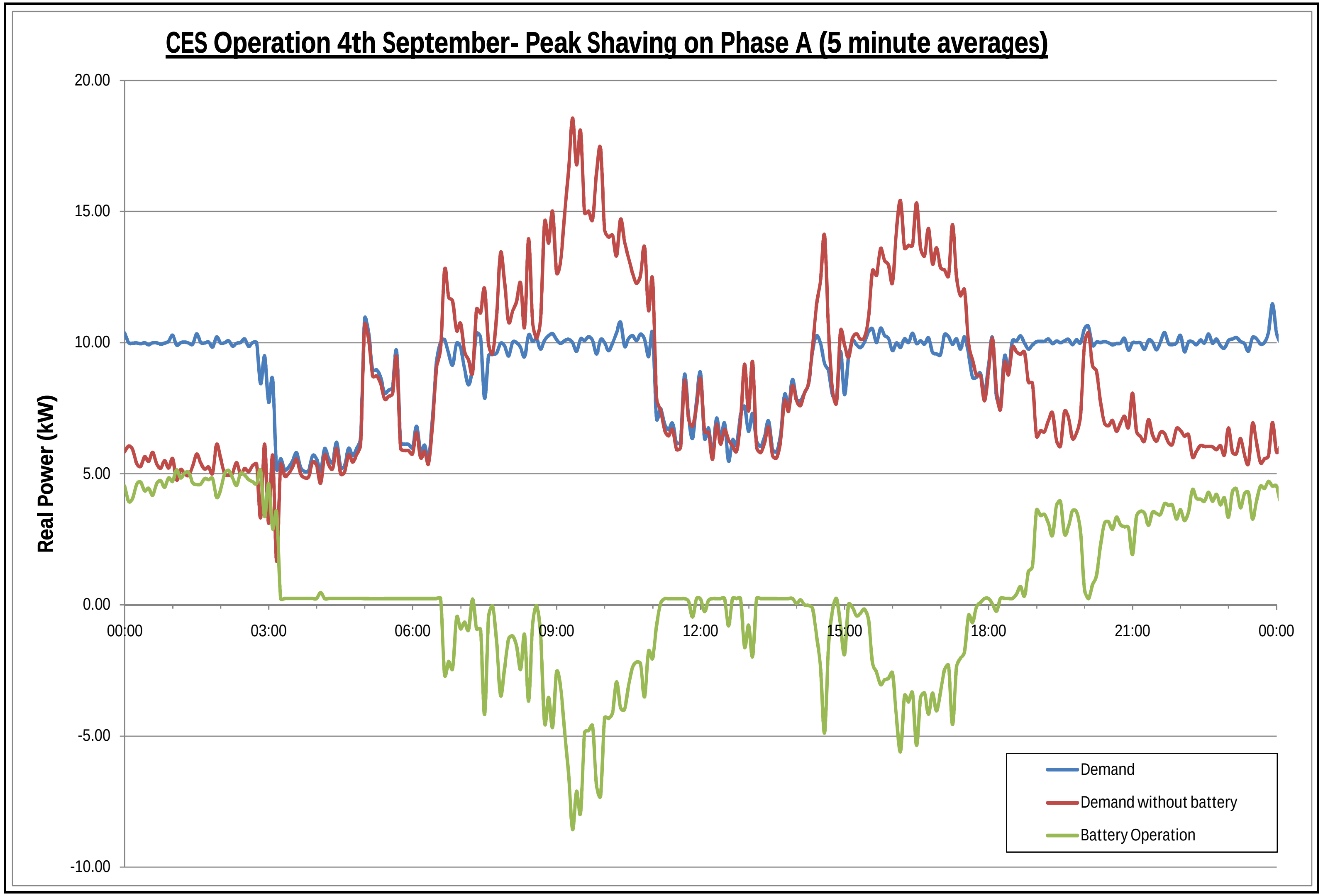

Figure 28 – Substation power flow demonstrating phase A peak shaving (10kW demand limit)

The graph in figure 29 is another example of successful peak shaving over a 24 hour period. The substation demand limit has been set at 9kW on phase B. When demand picks up in the morning before 09:00am as expected the CES unit begins to discharge at irregular intervals to keep the substation within the 9kW limit. As demand reduces the battery starts to charge up to the 9kW limit and hence be ready to discharge for the following 24 hour period.

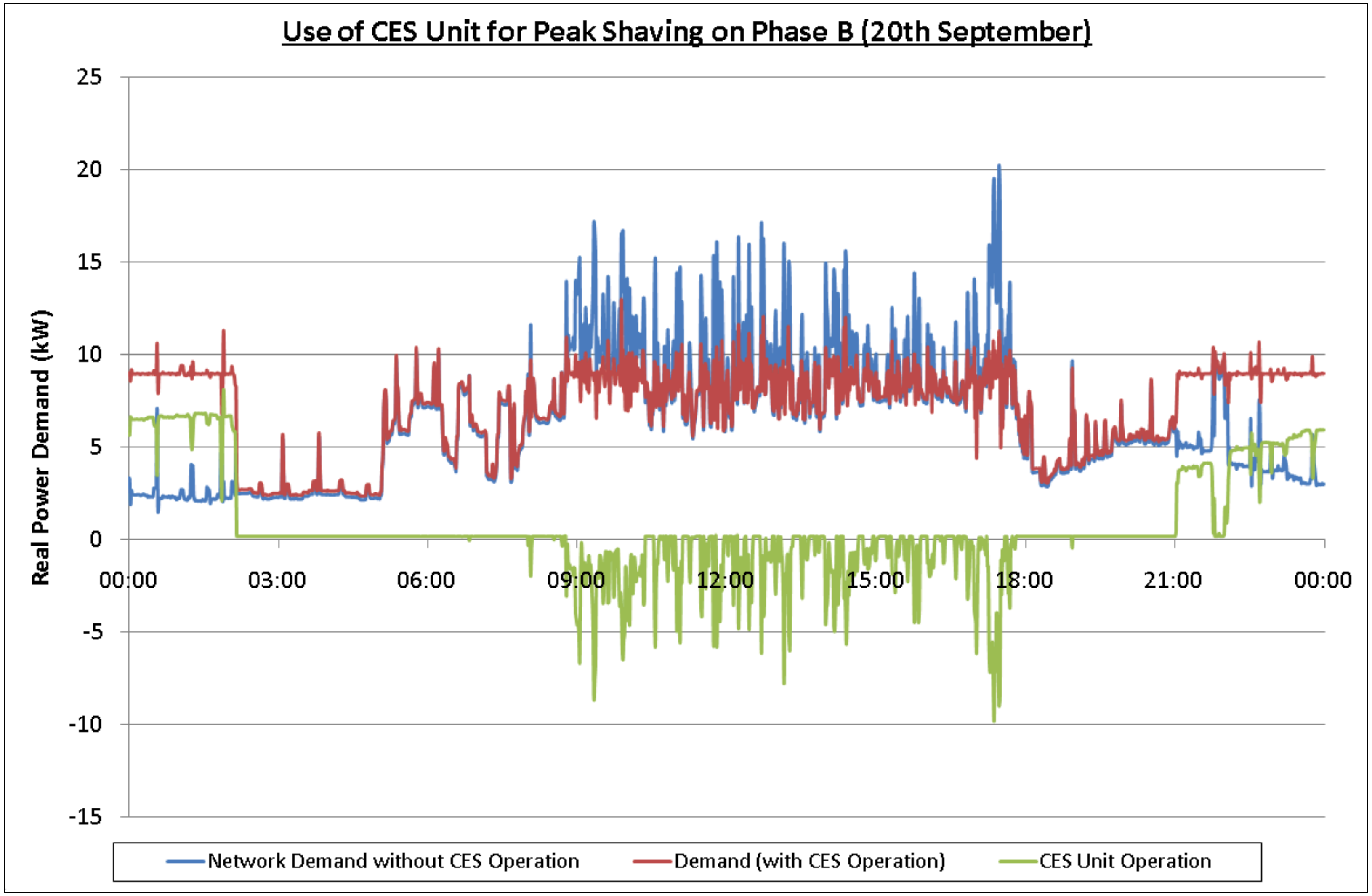

Figure 29 – Substation power flow demonstrating peak shaving on phase B (9kW demand limit)

Multiple dynamic peak shaving scenarios were implemented with varying network loading conditions across all seasons. The CES units in combination with the substation monitoring equipment never failed to function as expected. The limits of the system were pushed hard and at times the peak shaving was too extreme as the batteries ran out of capacity and hence did not cover the total period of high demand. The most successful, consistent peak demand reduction was approximately 90 Amps over a 24 hour period. It must be noted that the extent of the peak lopping is dependant on the network loading and will differ from circuit to circuit.

5.9 Reverse power absorption

The set up with the DEM and substation monitoring equipment not only allows for dynamically reducing peak demand – it can also be used to absorb reverse power feeding from the LV up to the HV network. This phenomenon occurs when the level of generation output is greater than demand and is an almost daily occurrence on phase C at Chalvey in the summer months. When demand is low and generation is high it can cause a voltage rise towards the end of the radial circuit which could potentially be outwith statutory limits. The graph in figure 30 shows the CES unit operating in this mode.

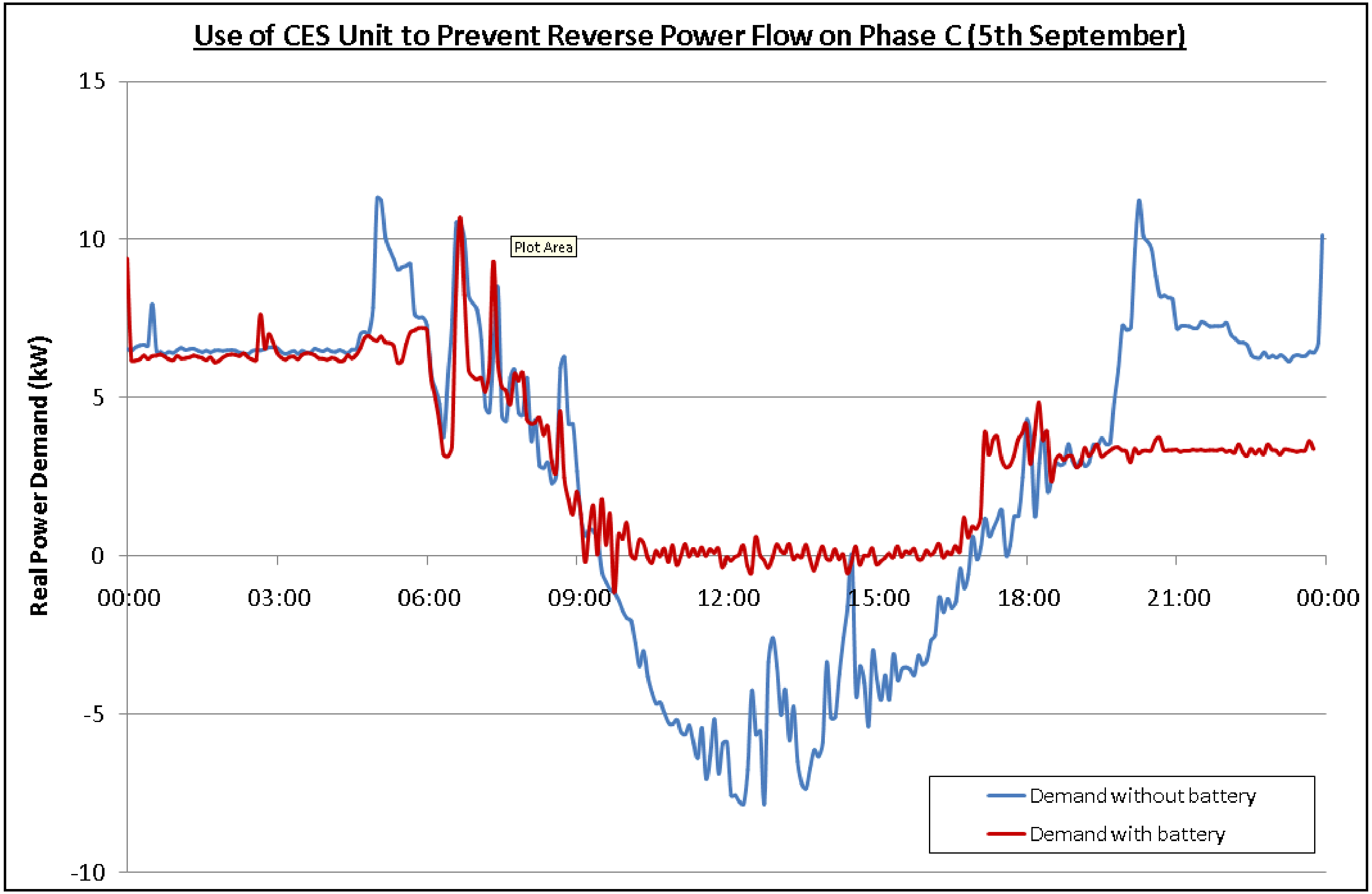

Figure 30 – Substation power flow showing absorption of reverse power on phase C

The blue line on the graph is what the demand curve would have looked like without the battery operation. The generation picks up around 9:00am and demand remains negative until approximately 5:00pm. The CES unit has been instructed to charge at any point demand is negative up to 0W. This effectively means the battery will absorb all the reverse power flow on the circuit. The red line on the graph indicates that this has been successful and has kept the demand close to 0W. As the generation from the solar reduces and evening demand begins to pick up the CES devices starts to discharge and hence reduce the evening peak to 3kW. This demonstrates the strong capability of the system to operate in differing modes and to keep demand within very tight tolerances. To illustrate the actual network benefits from this scenario the graph in figure 31 displays a detailed look at the voltage profile with and without the CES unit absorbing reverse power.

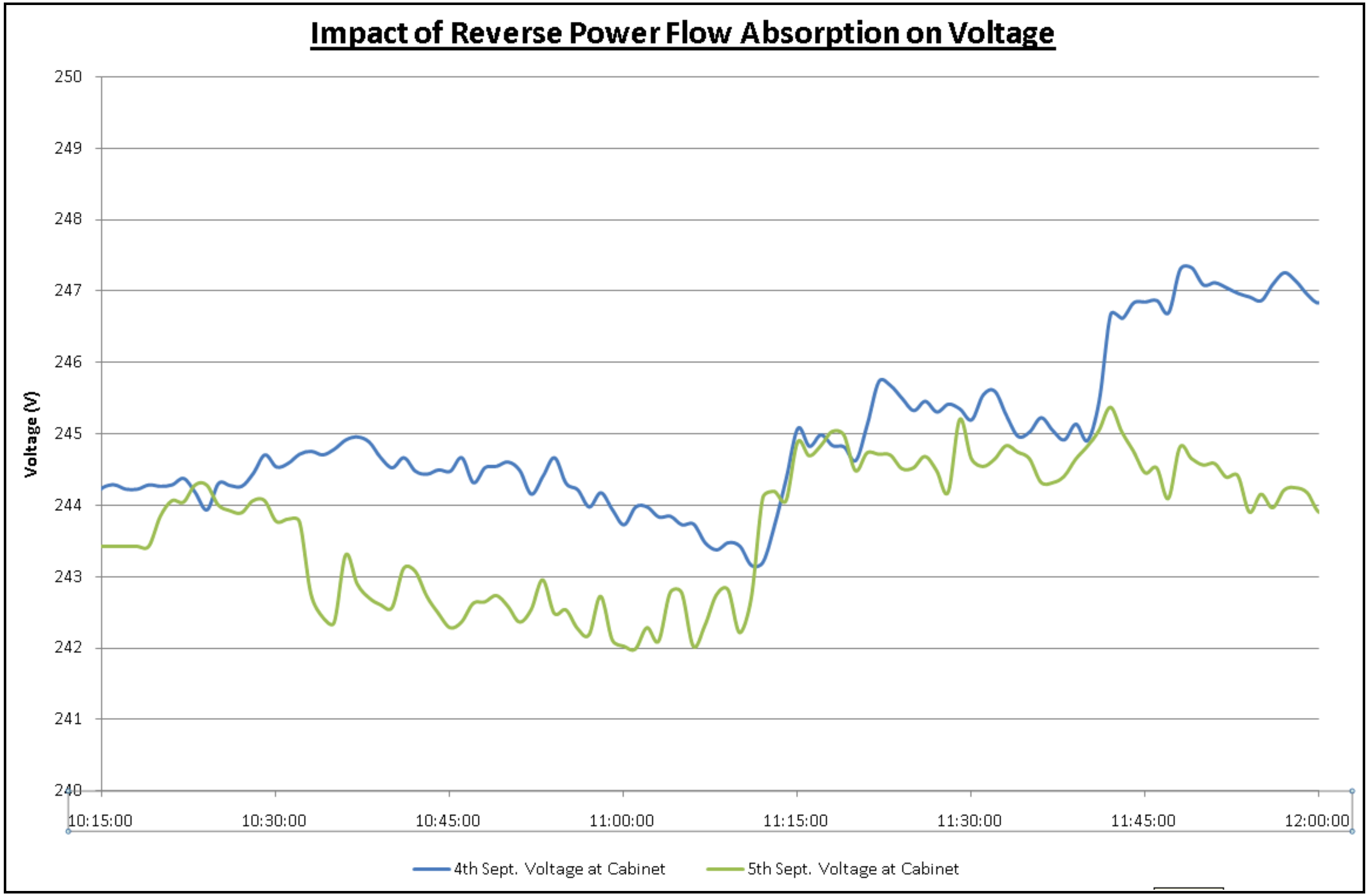

Figure 31 - Detailed view of the voltage reduction from the reverse power absorption

As is clear from the graph in figure 31 the voltage profile with the CES in operation (green line) is consistently lower than previous day's voltage profile – the peak reduction is close to 3V. It must be noted that although weather conditions were similar between the two days, there are many network factors that can effect the voltage. However this does go some way to demonstrating the concept that utilising real power from the batteries can help to mitigate network voltage fluctuations caused by high concentrations of solar PV.

5.10 Voltage manipulation

A critical part of the project testing was to consider to what extent the CES units could be used to buck or boost the feeder circuit voltage. This can be achieved using two different methods; firstly employing the use of real power from the batteries and secondly utilising reactive power only from the four quadrant power converter. Both methods have unique advantages and disadvantages with associated limitations.

The voltage values at the substation are not representative of the voltage towards the end of the feeder and hence using the voltage values from the substation monitor was not sufficient for the test plan. Voltage was therefore measured at two location as close to the end of the radial feeder circuit as possible; the battery compound and in the energy centre. The figure 32 illustrates these measurement locations.

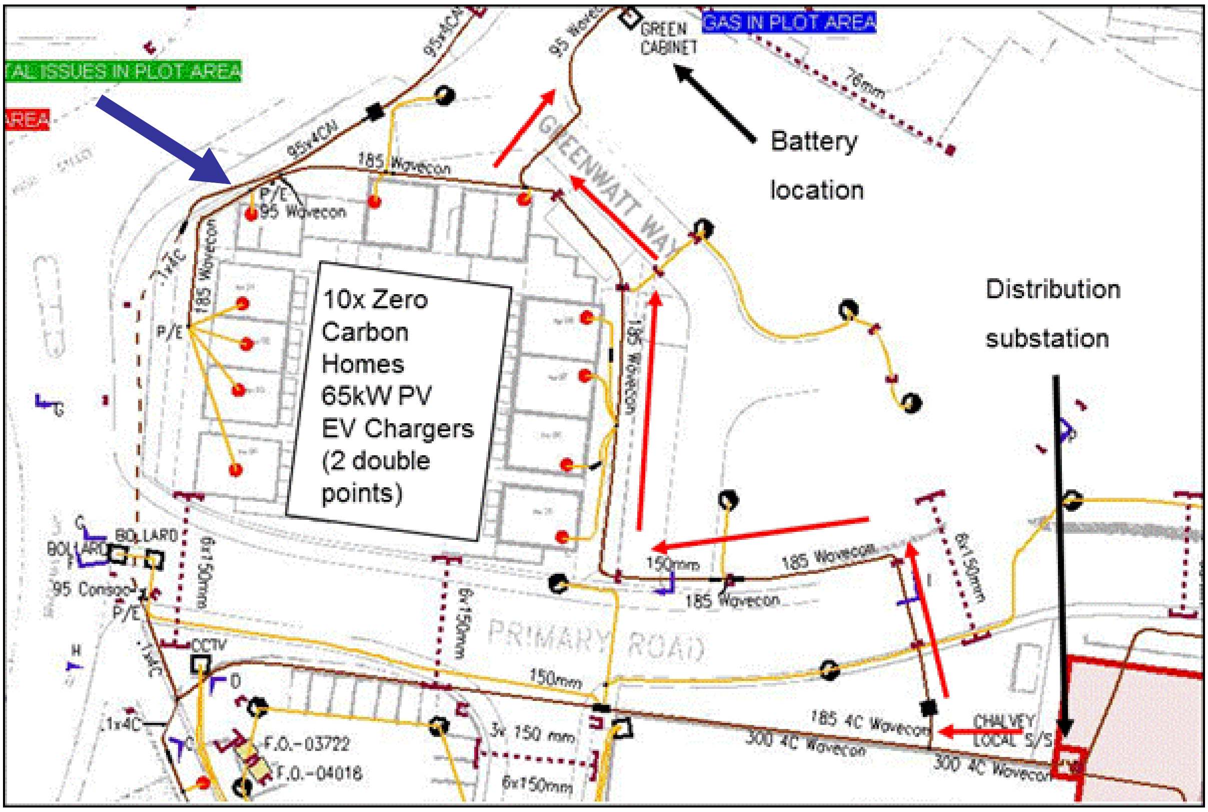

Figure 32 - Schematic highlighting the location of the 2nd voltage monitoring point at the energy centre (denoted by the blue arrow)

5.10.1Results real power

The first set of tests investigated to what extent real power from the CES units could have an impact on feeder voltage. The results of the testing are captured in figure 33. The blue line is the real power output / input from the CES; firstly the unit discharged 5kW, this was then stepped up to 15kW and finally full power at 25kW. The resultant effect on voltage (measured at two locations) is easily interpreted in three steps based on each power level. The opposite test was performed with the CES charging in steps up to 25kW and again the effect on the voltage is displayed on the graph. The last part of the graph is the CES unit going from full charge to full discharge to demonstrate the largest voltage manipulation possible.

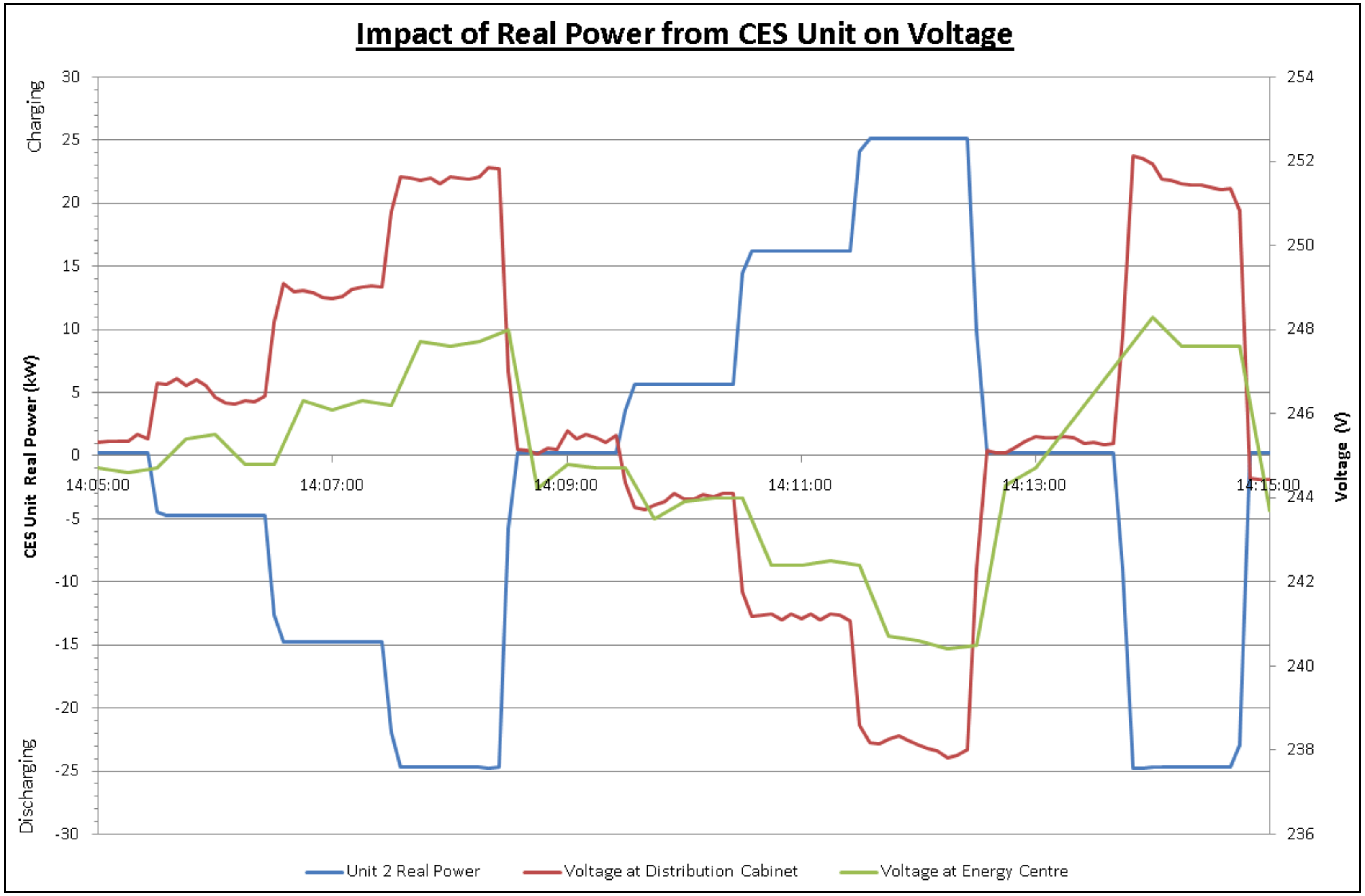

Figure 33 - Voltage manipulation using real power

The results from the real power manipulation have proven that it is indeed possible to alter the network voltage with a maximum boost of 7V and approximately the same for the voltage buck (2.9% of nominal voltage). These figures are measured at the distribution cabinet, close to the CES network connection point. The figures at the energy centre were approximately 50% lower, providing the ability to buck or boost the voltage by 3.5V or 1.4% of nominal voltage.

The same tests were replicated with reactive power instead of real power and a similar graph produced (figure 33). Firstly the PCS was instructed to operate in an inductive load in steps up to 25kVAr to buck the voltage – the opposite test was then conducted with the unit acting as a capacitor to boost the voltage. It is clear from the graph that although not as significant a manipulation as with real power it is possible to alter the voltage with an approximate maximum impact of 3V at the cabinet and 2V at the energy centre, 1.2% and 0.8% of nominal voltage respectively.

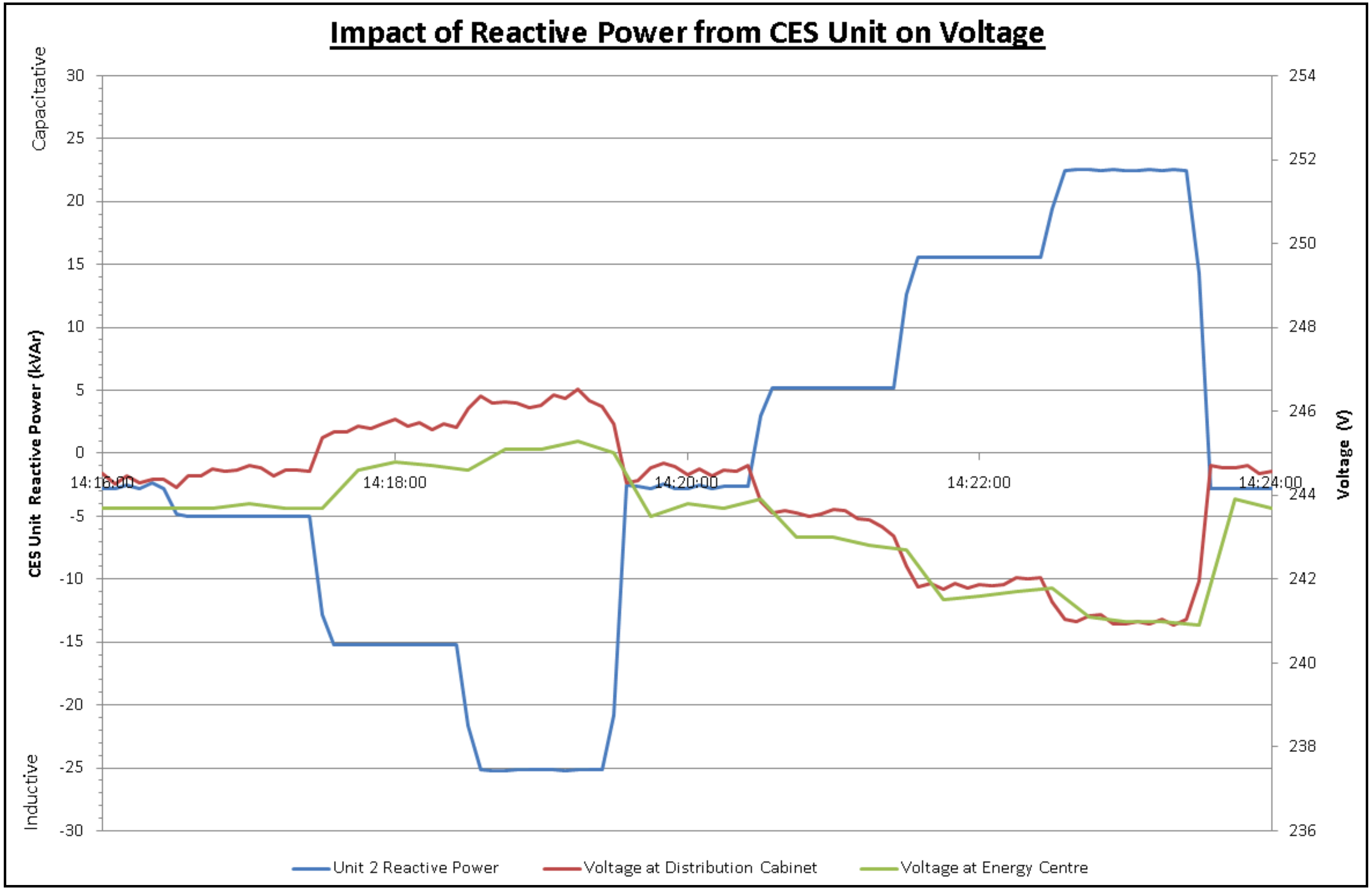

Figure 34 - Voltage manipulation using reactive power

It must be noted that the network voltage is constantly changing and to ensure consistency the tests were completed multiple times at various periods throughout the day over as short a timeframe as possible to reduce the error factor. The results, in terms of the ability to manipulate the percentage of the nominal voltage remained consistent throughout the testing.

As would be expected the extent to which voltage can be altered is significantly with real power than with reactive power. There are however a number of advantages to utilising reactive power:

- Cost – the PCS alone is approximately 20% of the cost total CES unit
- Losses – the losses and associated costs of operating reactive power in comparison to real power are significantly lower
- Capacity – the use of real power will eventually run out of capacity, however the PCS can continually operate providing reactive power to support voltage

In summary the results prove that the CES units can support voltage using two differing methods with varying levels of manipulation available. It is not anticipated that voltage control would be used as primary driver for installing energy storage with reactive power capabilities, however is an additional benefit that can help to justify the total system cost. In addition the results prove that it may be worth further investigation of the use of larger reactive power devices on the LV network to manage network voltage.

5.11 Phase balancing

Three phase LV networks are likely to have some degree of imbalance, e.g. the loading on each phase will not be perfectly equal at all times. The imbalance on a 3 phase network creates additional resistive heating losses from increased peak loading on the phase conductor and also current flowing through the neutral conductor. Implementing a device to balance the network would reduce these losses significantly and hence save operating costs. In addition balancing phases would provide additional capacity and reduce the likelihood of voltage breaching limits.

The existing site connection arrangement has three single phase units. This set up although not perfectly suited, will facilitate three phase demand balancing. As the site has three units with single phase inverters, it is not possible to take power from one heavily loaded phase and pass to a lightly loaded phase. It is however possible to target a demand level with all three CES units either charging or discharging and hence the result is a balanced three phase network. An additional drawback is that it is only possible to balance phases for as long as there is capacity remaining in the battery.

Despite the less than ideal connection arrangement the project has carried out numerous phase balancing scenarios over a 24 hour period. The graph in figure 35 illustrates the results from a 24 hour period.

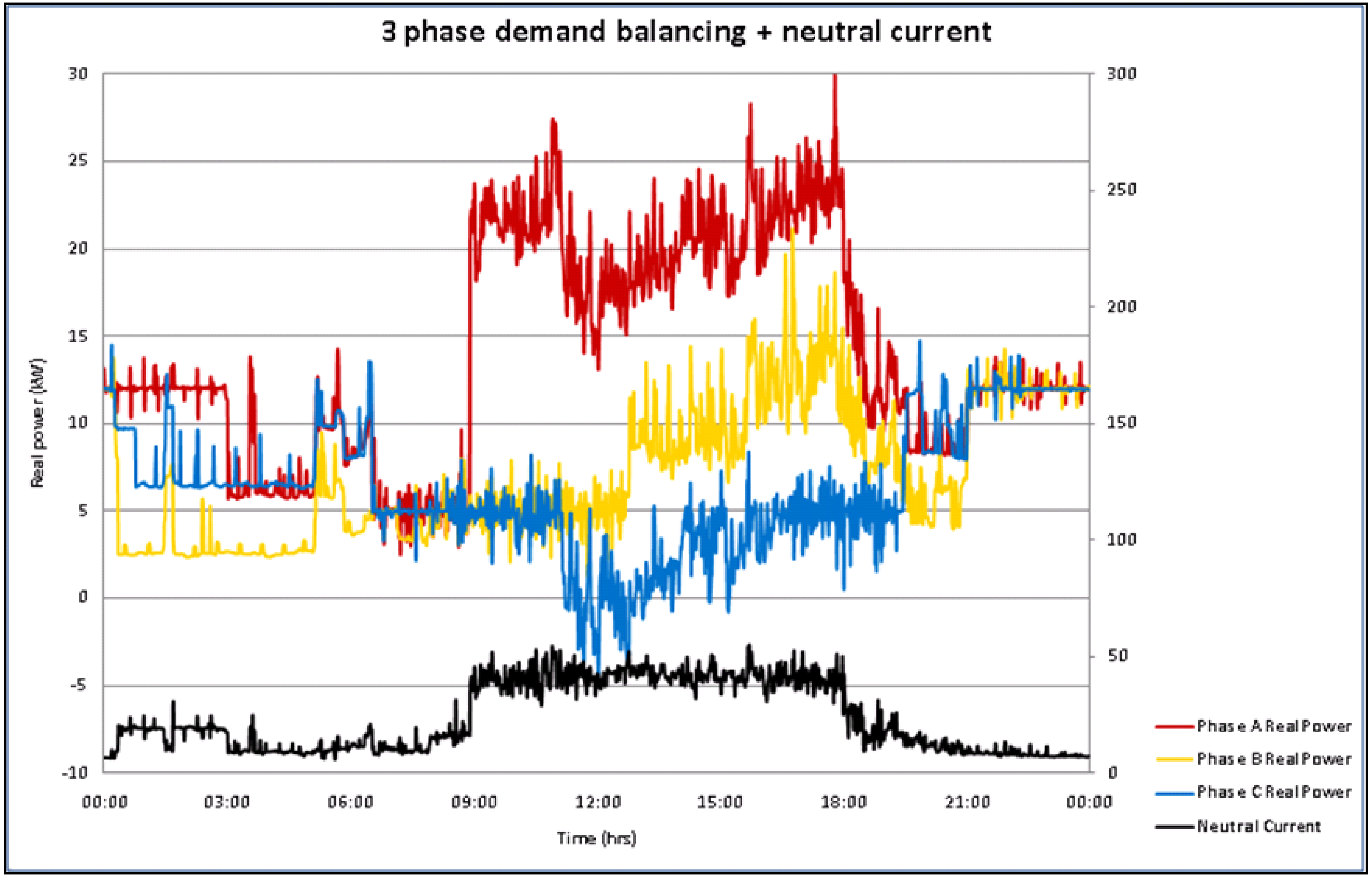

Figure 35 - Effect on neutral current on 3 phase balancing

The graph in figure 35 displays the system beginning to balance at 6:30am and continues to remain balanced until the CES unit on phase A runs out of capacity at approximately 9:00am. The loading on phase A is significantly higher the other phases, therefore the CES unit connected to this phase has to discharge at a higher rate and hence runs of capacity first. As the load on phase A is not being supported by the battery the demand increases from 5kW up to 23kW. At this point the effect on the neutral current can be seen clearly – increasing from approx 10 amps up to 50 amps. Later that day after all three CES units have completed discharging, the demand limit is set to 12kW, the units charge up to this value and the network is balanced. Again this effect is best illustrated by the reduction in neutral current to less than 5 Amps starting at 9:00pm. It should be noted that as demand is constantly changing and the CES units have to react to this change it will be unlikely to achieve a perfectly balanced network and reduce neutral current to 0 amps.

The phase balancing testing has demonstrated that it is functionally possible to use energy storage devices to balance phases on the LV network. The results have confirmed the theoretical benefits, from balancing LV networks, can be achieved in practise and has highlighted the practical limitations.

5.12 Economic case

Energy storage is a very difficult medium to quantify the cost over the lifetime of the plant and even more difficult to compare with traditional solutions such as; transformers, cables and associated equipment. The simplest way to quantify the cost is to capture the capital, installation and predicted lifetime costs against the benefits the device can provide to the network. This will allow an approximate benchmark against traditional solutions.

Capital cost x1 CES unit £65,000
Installation £1000
Lifetime costs of losses £1051

Cost of a single phase CES unit over 15 years = £67,051
Total cost of three CES units = £201,153

The additional capacity potential provided by the CES units in this project is similar to that of an SEPD cable upgrade in the loading levels of the standard cables currently procured. Increasing a 95 mm² to 185 mm² provides approximately 100 Amps capacity as highlighted in table 7. This allows for a comparison between a cable upgrade and this innovative solution.

Parameters:

Up to 100 amp reduction in peak demand per phase

Up to 7V increase / decrease in network voltage

Table 7 - SEPD LV cable ratings (document reference TG-PS-123)

Cond. Cross-sectional area	Cond. Material	Summer Continuous		Summer Cyclic		Winter Continuous		Winter Cyclic	
		Amps	kVA	Amps	kVA	Amps	kVA	Amps	kVA
95 mm²	Al	235	169	254	182	262	188	298	215
185 mm²	Al	335	241	362	260	373	268	425	306
300 mm²	Al	435	313	470	338	484	348	552	397

Cost of traditional cable overlay:

450m of cable @ £178 per m[17]

Total cost of £80,100

Assumptions made:

- A UK compliant voltage PCS will be provided eliminating the need for an auxiliary transformer;
- The capital cost is the same as the initial purchase price in 2011 (this is likely to have reduced as the cost of lithium batteries has fallen sharply over the last 3 years);
- The unit will operate at 1 cycle per day, at a depth of discharge of 80% for 15 years;
- The average efficiency is 80%;
- The cost of losses is taken as a static figure of 4.8p per kWh; and
- The costs of the control system are not included as this is split across multiple storage units

[17] SSEPD ED1 Business Plan http://www.yourfutureenergynetwork.co.uk/03_reliable2014.pdf

5.12.1 Cost summary

The costs for the battery system at Chalvey is in the order of 2.5 times more expensive than the traditional cable overlay alternative. In addition the traditional solution will potentially last three times longer than the energy storage solution. However as stated the costs of lithium ion are falling sharply and there is also the potential to earn additional revenue from energy storage systems outside of the core network requirements that has not been accounted for but is being investigated by multiple LCNF projects. There are a number of additional benefits that are difficult to put a monetary figure on:

- No need to excavate an entire street and hence reduced customer inconvenience;
- Customers do not need to go off supply to be reconnected;
- Limited traffic management requirements, without need for a permit to complete works from local council; and
- Solution can be re-redeployed in a new location easily if the network problem is no longer present.

The view of SEPD is that there may be niche applications at present where this solution may be attractive to a traditional cable overlay – areas where it would not be possible to excavate for example. However if this solution is to become economically viable against traditional solutions it needs to be cheaper than the traditional alternatives. At this cost level in conjunction with the discussed benefits and suitable electrical parameters it has the potential to be implemented as business as usual.

6.Performance to date compared to project aims, objectives and success criteria

This section reviews progress to date against the scope, objectives and success criteria set out on the Tier 1 registration pro-forma.

Stated Objectives:	Progress to Date
Prove the batteries and power conversion units can be operated as intended on an LV network in the UK and have a tangible benefit electrically.	**Complete** The CES units have been successfully operated and installed on the LV network at Chalvey. Tests have proven the devices can successfully reduce peak demand over a 24 period up to 100 Amps. The absorption of reverse power flow has demonstrated a reduction in voltage rise at multiple points on the LV feeder. The use of 3 units to balance the power flows has demonstrated the benefits that can be achieved in terms of reducing network losses from lower peak demand and neutral current loading. Voltage manipulation has been achieved through the use of real power and reactive power separately.
Inform the establishment of the economic threshold of this technology.	**Complete** The total costs of operating the system over 15 years operating on a daily charge / discharge cycle has been calculated. The figures must be considered an estimate as the actual operating regime is likely to change according to varying network conditions. The figures do however provide a insight into the costs of the system and could be used to compare against traditional solutions.

Stated Objectives:	Progress to Date
Validate the technical specification to inform and de-risk the tendering exercise for the Tier 2 project.	**Complete** A specification has been completed for the procurement of a greater number of units of varying capacities and a mixture of three and single phase. The learning from this project has fed into this specification, as follows: • The units for NTVV are to be installed outside of a substation compound, on the side of the pavement and so a rigid height and depth restriction (maximum of 600mm high and 150mm deep) has been included within the specification to ensure this is possible. • If the units at Chalvey require battery replacement, maintenance or inspection then it is necessary to remove the above ground PCS, requiring the use of a small crane ('HIAB' type). The energy storage modules for the NTVV project will be installed above ground so modules can be replaced more easily if necessary. • A staged implementation is planned, with type testing for a period of two weeks, followed by a small number of trial units before procurement of the remaining units. • The NTVV unit will incorporate a 3 phase inverter with a common DC bus as opposed to three single phase units. This allows for constant efficient balancing of demand and is a direct result of the learning from this Tier 1 installation.
Define, test and prove the communications and associated data transfer requirements for this small trial and inform that required for a larger array.	**Complete** The communications methods used have been successful. A SpeedNet radio interface is used to communicate between the CES units and the DEM and this has been reliable. Remote access to the DEM over the internet has also proved consistent. A link between the DEM and SEPD's SCADA system has been successfully established and tested. This communicates the system status, including alarms, to the control room and allows the units to be inhibited remotely. The process of setting up this link was time-intensive however has not failed since the system was implemented in 2012. Although the specific radios will not be used in the NTVV rollout the SCADA implementation and learning around data transfer and alarms has provided significant benefit to the larger array.

Stated Objectives:	Progress to Date
Inform the safety case and the operational procedures including installation, maintenance and operational work on a network with storage connected (faults, protection, live working, safety procedures etc)	**Complete** A rigorous safety case has been prepared and it has ensured that the units comply with relevant codes and standards. An Operational Risk Assessment for the system has judged the vast majority of hazards to be 'Low' risk, and mitigation measures have been applied to the remaining 'Medium' risk hazards to reduce their probability as far as is reasonably practicable. The system settings have been modified to comply with the relevant protection requirements and testing has shown this to be effective.
Inform decisions regarding the physical location of storage devices given public perception and acceptance.	**Complete** There has been no adverse reaction from the local community to the presence of the CES units. Dialogue with the local Fire and Rescue service was positive. The switching frequency is 5kHz which can be picked up by the human ear. The original inductors were quite loud when charging / discharging at full power – these items were replaced in 2013 and made a noticeable reduction to the noise.

Stated Success Criteria:	Progress to Date
Complete the G59 commissioning and functionality testing of the CES units to pave the way for the large array planned under the NTVV project.	**Complete** These tests were completed successfully in May 2012. As an alternative design of unit is to be installed under the NTVV project then G59/2 acceptance tests will require repeating - the learning from the work completed throughout this project will support that testing. A briefing note describing this testing in full is available to other GB DNOs on request.
Prove the CES devices can successfully support voltage using the 4 quadrant power converter	**Complete** Tests have been carried out in relation to voltage support. A direct control based on voltage was not available from the DEM. However, the impact on voltage can be monitored during the operation of other schedules. Manual voltage support was demonstrated by adjusting the CES output in response to real time readings of voltage. The tests completed proved that running purely reactive power could alter voltage by +/- 3V at the point of connection at full power.

Stated Success Criteria:	Progress to Date
Use the CES charge / discharge set points to peak lop both demand and generation	**Complete** Numerous scenarios were completed showing that the units can respond to set points and reduce peak demand to defined limits. Reverse power on unit 3 was shown to be absorbed successfully and provided a significant reduction in voltage on that phase.
Confirm communications and remote control of the devices from SCADA	**Complete** These communications have been established and tested as part of the structured test plan. The communications although difficult to implement initially have proved to be very reliable. Some suggestions for improvements to this were made to the system supplier and were implemented as part of a planned upgrade to the control system in 2013.

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

No significant changes to the planned approach have been required. A number of delays were encountered in relation to the more advanced stages of testing due to issues with the core technology. These have been recently been addressed by the system supplier via the replacement and upgrade of a number of components. As a result some of the testing was delayed, however all the objectives have been completed successfully.

8.Significant variance in expected costs and benefits

The project was broken down into various sections with associated costs before the registration process. SEPD made engagement with the supplier S&C to obtain accurate figures for the cost of the storage units and related equipment. The final equipment costs did not differ significantly from these initial quotations. Costs were then estimated for the remaining parts of the project based on previous projects or known equipment / staff costs. Again these costs did not differ to any great extent from the initial figures. The main cost differences were in relation to the project management and SEPD staff costs – these figures would have been higher if not for the manner the contract was set out, meaning it was the requirement of S&C to complete and fund the troubleshooting work and subsequent replacement of the battery packs. In addition the use of remote access and S&C staff in the US helped to keep SEPD costs low. The preliminary network studies and the analysis work on the performance of the units was completed as part of an SEPD Innovation Funding Incentive project; '2011_03 LV Connected Batteries'.

Table 8 - Total project cost breakdown

Item	Forecast (£)	Actual (£)	Variance (£k)	Variance (%)
Project Management	30,000	24,000	6,000	-20%
SEPD staff	10,000	8,000	2,000	-20%
Purchase of 3 x CES units	195,000	195,000	0	0
Civil / electrical works	15,000	11,500	3,500	-23%
Communications	50,000	37,000	13,000	-26%
Overheads	10,000	9,000	1,000	-10%
Total	**310,000**	**284,500**	**25,500**	**-8%**

8.1 DNO expectation of benefits

The main focus of the project was to prove that the theoretical functionality of energy storage was true in practice and from this small trial installation inform and influence the larger rollout under NTVV. The project has successfully achieved these goals.

The extent to which stored electrical energy could be used to mitigate problems on the LV network was larger was untested and hence it was unknown whether or not it could be utilised in a beneficial manner. The project has proven that storage can indeed aid with thermal and voltage constraints on a live LV network – up to 100 Amps reduction and +/- 7V respectively.

The levels of manipulation available on the trial network were in line with expectations fit neatly with the additional capacity offered from a standard SEPD cable upgrade. This allowed for as close a comparison as possible within the economic case (section 5.1.2).

In addition the work has highlighted a number of key areas to focus on and de-risk the NTVV rollout from basic safety considerations to the connection arrangement. The expectation is that the learning fed into the NTVV project from this Tier 1 should result in a solution fit for business as usual rollout in 2016.

9. Lessons Learnt for Future Projects

There are a number of lessons which can be applied to future storage projects undertaken by either SEPD or other GB DNOS, as follows:

- Units which are installed as a 'first of kind' in the UK (or EU) should be compared against the relevant codes and standards as early as possible in the process (ideally in procurement) to ensure that the necessary certification is in place in advance of the supply of the equipment.
- Three independent single phase units have advantages and disadvantages over a combined 3 phase system. This must be carefully considered at the design stage as to the intended operation of the system with particular reference to phase balancing.
- The underground battery vaults have significant advantages with regard to thermal stability and fire containment however it necessitates a mini crane with high costs and physical space requirements to replace modules on the battery etc. Future installations will investigate the potential of above ground battery modules.
- The implementation of the communications took approximately twice as long as had been planned for. Early engagement should be sought with all the different departments before implementation – particularly in relation to IT Security.
- The project utilised a DNO owner operator model throughout the project. This means that energy is not metered on the storage devices – the losses are simply calculated as technical losses in the same manner as transformers or cables. SEPD feel that this is an acceptable method to operate energy storage provided it is only performing a function for the distribution network benefit. If the device is operating in other markets, such as energy arbitrage, metering would be required.
- The project work has successfully taken the system from TRL 5 up to TRL 7. In order to move the technology to further towards business as usual a GB compliant voltage PCS and a demonstration of the unit operating on a constrained network would be required. The validation of a real network problem would prove the technology is ready to be deployed on mass.

10. Planned implementation

The main conclusions are:

- A structured safety assessment has been carried out and this has shown that the system conforms to the existing relevant codes and standards. The system represents a technically credible product offer, for application in the UK market. However, there is an absence of standards which encompass the whole energy storage system at utility scale in the UK. An

Operational Risk Assessment has been prepared which shows that the residual risk from the system is generally small if managed effectively.

- Prior to connection to the distribution network the units were tested against the requirements of Engineering Recommendation G59/2 using a load bank (resistive and reactive) and generator. Through dialogue with the system manufacturer the unit settings were configured to ensure compliance with G59/2. This test was completed successfully and did not require the installation of an additional G59/2 relay.
- Tests confirming the operation of alarms and the functionality of the control hierarchy were passed successfully. Significant numbers of cycles have been completed successfully and have resulted in good round trip efficiency figures of around 80-85% - in line with expectations at the start of the project.
- The communications methodology selected for this project has proven to function as intended with no reliability issues to date. To encompass a larger rollout and hence provide suitable communications coverage to a larger area would require further investigation.
- Due to its co-location with photovoltaic generation, the storage at Chalvey can be used via the setting of demand limits at the substation to absorb generation during the day and provide this for peak shaving later in the day.
- A 25kW / 25kWh single phase unit was capable of reducing peak demand up to 100 amps over a 24 hour period. The critical part of this set up was the integration with substation monitoring equipment and any future implementations must have this functionality to facilitate peak shaving.
- A 25kVA single phase CES unit can successfully buck or boost network voltage by up to 7V using real power and 3V utilising purely reactive power.
- The system at Chalvey consists of three separate units, installed one per phase. This allows a certain amount of phase balancing (e.g. discharging on a phase with higher demand than the other two to reduce the difference). The amount of phase balancing is however limited by the capacity of the storage unit as power cannot be transferred between phases. The comparative benefits of three phase and single phase units will be investigated further as part of the NTVV Tier 2 project.

10.1 Next steps

The project has successfully completed the required objectives and has aided the larger rollout of 25 units under the NTVV project. The current options for the existing site at Chalvey are:

- To complete further testing in relation to lifetime capacity and potentially look at more dynamic voltage control to create a fully active LV network;
- To remove the units and potentially deploy in a location to solve an existing network constraint;
- Relocation of the units for further testing analysis at a new site; and
- To remove the units and return to the manufacturer for recycling.

A decision on the future outcome of the Chalvey site will be made in the coming months.

11. Facilitate replication

The following table lists all the physical components and required to replicate the outcomes of this project, showing how the required data can be accessed by other GB DNOs. All physical components are either commercial products available for purchase or SEPD-specific resources / systems for which other DNOs have equivalents. The appendix details the specific knowledge / data generated across the project and references all the available documentation. Further details are available on request from futurenetworks@sse.com

Component	Products used in project or commercially available equivalents
Energy storage modules, power conversion units and control system	This project used the S&C CES units which include an energy storage module (manufactured by Kokam) a PCS and a control system (DEM) to manage a fleet of units. Other commercial energy storage products are available, with varying capacities, ratings and control systems. Another DNO would need to consider the needs of their project or network with regard to size (both capacity and physical size), rating and control options. A further procurement of energy storage devices of a similar size is ongoing as part of the SEPD New Thames Valley Vision Tier 2 LCN Fund project which will test the solutions available on the market.
Auxiliary 120 / 230V transformer	Bought from the UK firm A.M. Tech Transformers. The transformer is bespoke and hence had to be specified specifically for this function.
Substation monitoring	Requires advanced monitoring equipment to be installed and then integrated with the battery control system. Current Group equipment was used at the Chalvey set up.
Communications between units, control system and SCADA	Communication between the CES units and the DEM at Chalvey is achieved using an S&C product ‘SpeedNet’ radio. This proved to be reliable at Chalvey. The requirements of other sites (e.g. the distance across which signals are to be transmitted etc) would need to be considered if the project was to be replicated. The system can accept almost any communications medium that supports DNP3. The link between SCADA and the DEM requires the appropriate points list. A ‘whitebook’ detailing all the DNP points and particular alarms that are returned is available on request.
Control system	To control the units at Chalvey, although it is not essential, a Distributed Energy Management (DEM) was deployed. The DEM provides significant additional functionality in controlling multiple devices and setting up schedules etc remotely.