WESTERN POWER DISTRIBUTION
INNOVATION

NEXT GENERATION NETWORKS

Solar Storage

CLOSEDOWN REPORT

Report Title	:	Solar Storage CLOSEDOWN REPORT
Report Status	:	Draft
Project Reference:		WPD_NIA_004
Date	:	14.02.2019

Document Control

	Name	Date
Prepared by:	Jenny Woodruff	14.02.2019
Reviewed by:	Jonathan Berry	26.03.2019.
Approved by:	Jonathan Berry	29.03.2019

Revision History

Date	Issue	Status

Contents

WESTERN POWER DISTRIBUTION (WPD) IN CONFIDENCE
This is an internal WPD document. Recipients may not pass this document to any person outside the organisation without written consent.

Executive Summary

The increased volumes of generation connected to distribution networks combined with the forecast increases in electric vehicles and heat pumps have prompted Distribution Network Operators (DNOs) to consider alternatives to traditional reinforcement. With DNOs transitioning to Distribution System Operators (DSOs) there is considerable interest in understanding how customer flexibility can be harnessed to support DNOs. For DNOs to benefit from flexibility services, there needs to be a geographically diverse pool of flexible assets to provide services. Solar Storage consisted of installing a battery ‘behind the meter’ of an existing solar park, to investigate the potential use-cases and benefits of co-locating storage in this way. Use cases were tested individually and in combination with a schedule that covered different seasons. Despite a number of technical challenges that delayed the testing schedule, the planned set of tests was completed and during the project and several improvements were made to the control software enabling more realistic testing of the use cases. At the end of the project, learning was extended by selling and relocating the battery, which was not known to have occurred previously in the UK.

The analysis showed that while the battery was technically capable of performing the use cases this rarely provided better returns than the assumed financial base case of frequency response, and therefore the use cases were unlikely to generate a sufficiently profitable and reliable income stream to justify battery investment.

The arbitrage use case offered limited returns due to the site’s power purchase agreement having a relatively flat profile which does not reflect the real differential between peak and off-peak prices. The solar output smoothing use case worked well, but has no obvious paying customer. Where use cases relied on providing a service to the DNO or a third party with a restricted connection, once again these worked well technically but the financial benefits are highly variable. While DNOs have improved their signposting of areas likely to require flexibility services in the future, it may be difficult for developers to find the small number of locations where these third party services provide sufficient dependable income to tip the balance. For the voltage control use cases, the battery size limited the degree of impact.

The project also included techno-economic modelling and regulatory analysis to determine whether there were potential barriers to battery uptake that could be resolved. However, during the project other changes took place with more immediate impacts on battery development, i.e. the large fall in the price of frequency services but also the rationalisation of National Grid services which has opened up the market such that flexibility providers can switch between services more easily, but conversely it is harder to make the business case for investing in storage. The market is continuing to change, with grid charging now also under review which reduces investor certainty still further.

Arbitrage is expected to play a more significant role in the future business case of storage as incomes from frequency response decline due to a saturated market. The arbitrage use case could be combined with network peak lopping for sites which have peak load at the same time as peak prices. The solar output peak lopping use case could also potentially also be combined as the charging and discharging periods are complementary. Reactive power services could also boost incomes while sacrificing little of the battery's real power capacity, though impact would be limited for a small capacity battery. Services to third parties with constrained connection agreements could well be cost effective but are so location specific as to have little impact on the progress of battery development.

1. Project Background

1.1 Overview

This project was initiated at a time when battery storage costs were steadily reducing at the same time as the use of flexibility services by DNOs was predicted to increase significantly as they transitioned to Distribution System Operators (DSOs). The scenario of a battery associated with a solar park was chosen because of the wide range of potential services, listed as the nine use cases below in Table 1, where a battery can provide benefits to different parties.

Usage Case	Beneficiary
1) **Arbitrage** - Sell electricity for a higher price per kWh.	Battery Owner
2) **Peak demand limiting** at the local primary.	DNO
3) **Local demand profile matching** e.g. as a service to a customer with a soft inter-trip connection who would otherwise be constrained.	DNO / load customer
4) **Low demand grid voltage support** - Raise minimum demand to limit voltage rise.	DNO
5) **Voltage control by reactive power.**	DNO
6) **PV Export limiting** - Peak lop generation to enable solar parks with an installed capacity over that of the connection agreement.	Solar Park Owner
7) **Variable PV export limiting -** Change peak lopping level (glass ceiling).	DNO
8) **PV power quality improvement** - Smoothing / Power Quality, Ramp Rate Control	DNO / Solar Park Owner
9) **Multiple storage system control** - (Not trialled, included for discussion only).	Multiple parties

Table 1: Use Cases

The project does not include the provision of services to National Grid, such as;

- Enhanced Frequency Response (EFR);
- Firm Frequency Response (FFR); and
- Short Term Operating Reserve (STOR).

While these services are currently major drivers of storage connections, it was considered that to trial these services would cause duplication of the Smarter Network Storage project[1] carried out by UK Power Networks.

As well as evaluating the efficiency and efficacy of the battery at delivering the use cases, the project also estimated the financial benefits and considered how these use cases reflected the potential for layering revenue streams.
To support the understanding of issues around battery sizing, investment and impact, the project also included some complementary elements which were;

- techno-economic modelling, provided by SRI Technologies;
- regulatory framework assessment, provided by Utilities Insight; and
- power quality monitoring, provided by Argand Solutions

1.2 Location

The solar park, where the battery was installed, is electrically connected to a clean 11kV feeder supplied by the Millfield primary substation near Glastonbury in Somerset. This has been altered to introduce an additional ring main unit to provide isolation between the battery and the solar park.

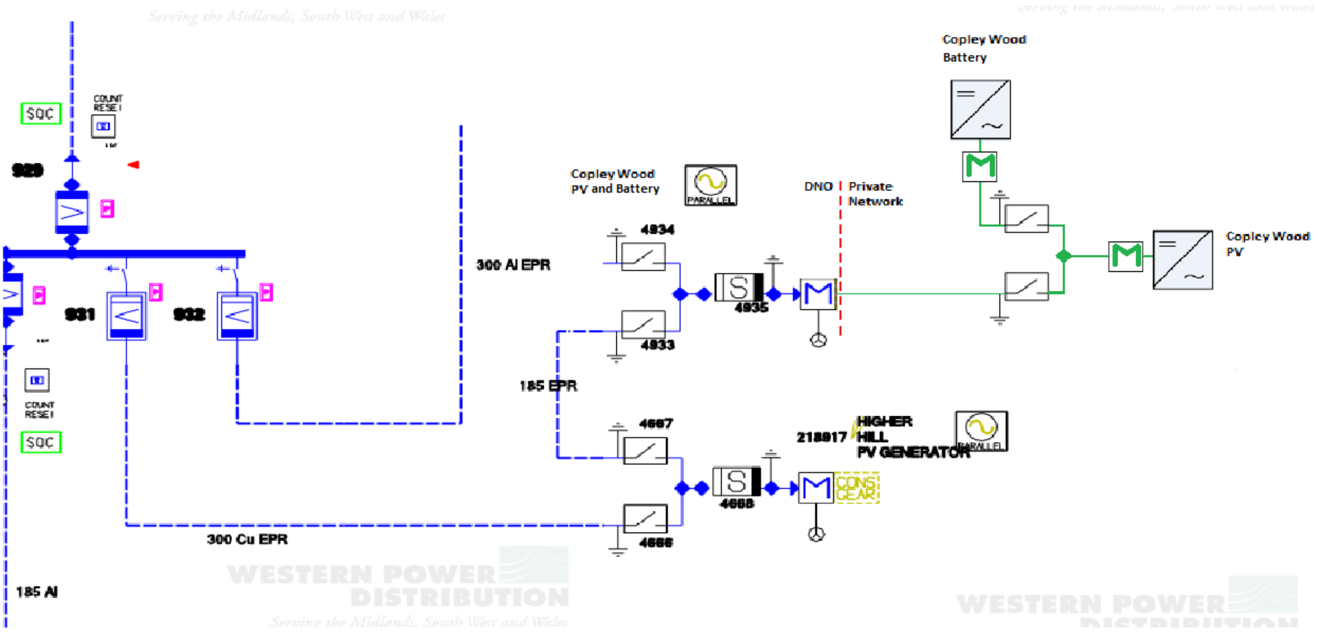


Figure 1: Electrical connection to Copley Wood battery

---

[1] https://www.ukpowernetworks.co.uk/internet/en/news-and-press/press-releases/Trailblazing-storage-project-leads-the-way-to-low-carbon-future.html

Figure 2a: Battery Geographical location

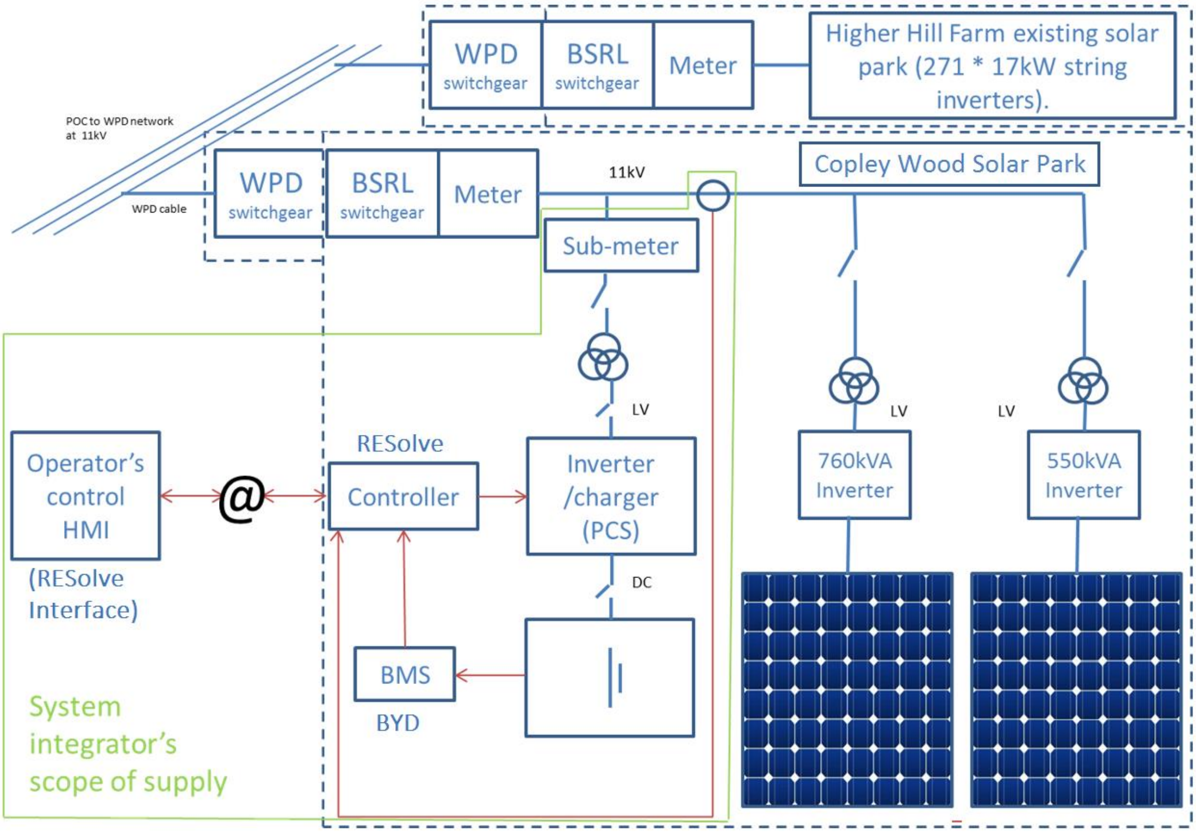


Figure 3b: Battery site schematic

The battery was metered separately and connected via a low voltage (LV) isolating transformer.
The operator's control (HMI) was a system called RESolve, provided by RES. This umbrella term covers a diverse array of control modes and a SCADA data storage system that was also managed by RESolve. The key components discussed within this report are the state of charge (SoC) manager, the use cases/modes and the underlying SCADA data storage system.

1.3 Battery specification

The factors affecting battery sizing were potential impact and cost. Anything smaller than 300kW would not make a measurable difference to voltage levels on an 11kV network. A prototype on this scale was considered desirable to give industry stakeholders sufficient confidence for a larger roll out to be possible. The battery capacity (731kWh at 0-100%) was such that it could run at full power for two hours as this is more likely to represent the type of usage by DNOs for peak lopping applications.

No particular battery chemistry was specified as a requirement of the procurement process. The battery chemistry of the successful bid was lithium iron phosphate.

1 Scope and Objectives

Objective	Status
1) Quantify the potential value to network operators and others of integrating storage with DG.	✓
2) Demonstrate safe, reliable operation of the system under operational conditions	✓
3) Use real-world operation of an integrated utility scale storage:generation system to provide data to regulators and potential investors.	✓

.

2. Success Criteria

Success Criteria	Status
1) Complete Design of BESS. 2) Procure equipment, install and commission. 3) Run trials and write report. 4) Identify changes necessary for participation on the Balancing Mechanism. Phases 1 to 4 above completed safely to time and on budget.	✓
All usage cases are investigated and a comprehensive analysis of all data collected undertaken.	✓
Useful and applicable conclusions generated from the data analysis.	✓

Effective communication of the project's results and conclusions to the UK renewable energy and power distribution community.	✓
Successful engagement with stakeholders, influencing the development of relevant governing mechanisms such as the grid code or balancing mechanism (BM).	✓

3. Details of Work Carried Out

The project can be divided into the following phases:

- Design and procurement.
- Construction.
- Testing.
- Data analysis.
- Decommissioning / transfer.

The activities undertaken in each of these phases, and the learning generated is detailed below. The use case learning is then summarised.

3.1 Design & Procurement

3.1.1 Design & procurement phase activities

British Solar Renewables Limited (BSR), who were at the time owner operators of the solar park at Higher Hill Farm and had an interest in investigating options for storage, were already confirmed as project partners at the time of project initiation. The battery was procured via a competitive tender process to ensure value for money for customers. There were four submissions for the tender, and after evaluation RES was the successful bidder.

The process of obtaining planning was relatively onerous and non-material amendments to the planning permission were required when the fenced area was altered due to site conditions. The total area of the enclosure was reduced to allow for improved access across the BSR site without compromising vehicle access to the battery itself.
The design sign-off was a two-stage process that covered the battery itself followed by the balance of plant.

Examples of the drawings from the design process are given below in Figure 3: Example Design Drawings. It can be seen that the container was divided into two compartments for safety reasons, such that the battery operator was separated from the battery itself and the fire suppression system. The drawings also show that only part of the usable space within the battery compartment was used and that it would have been possible to approximately double the battery capacity if desired. The capacity of the project only required a standard 20ft container, but a 40ft container was available with significantly less lead time at a similar price which is why there was additional space inside.

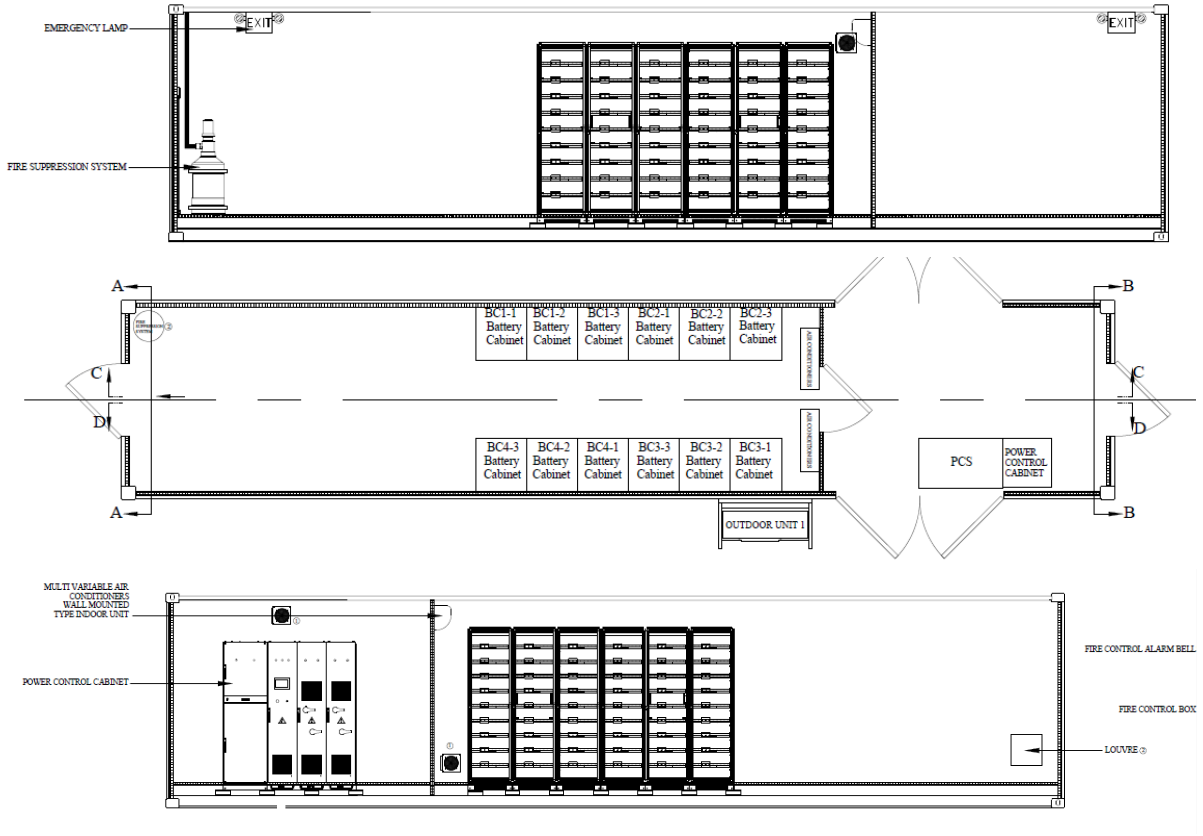


Figure 4: Example Design Drawings

The design phase also included negotiating a lease for the battery site. This proved to be a far more lengthy and complex process than had been anticipated for this research project. In order to avoid lengthy delays preventing installation, a ‘Licence to Occupy’ was used as a temporary measure until the lease negotiations were complete. Timescale pressure of this nature was due to the nature of the research project, and it is not believed that this would occur for a standard commercial project.

3.1.2 Design & procurement phase learning

The learning points from this phase are summarised below.

- The use of a partner to assist with the procurement of the battery was essential as DNO staff were not yet sufficiently familiar enough with battery technology to carry out procurement unaided;
- Including more flexibility in the Statements of Works would have avoided the significant work of updating the documents and getting the updates signed off;
- Having as much access to technical detail as possible during the procurement stage is beneficial;

- The contractual conditions covering the battery operation should have included a clause concerning the imbalance between strings. It appears this is a standard clause in other battery contracts; and
- Identify any issues with the contractual limits for items such as power factor early on. This required modelling by Western Power Distribution (WPD) staff to ensure that if the algorithm were to fail to operate correctly, that the reactive power element would not cause network issues. The selection of a clean feeder for the trial has limited the potential impact on other customers from voltage fluctuations during testing.
- While the process to negotiate a lease started very early in the project, this aspect took far longer than anticipated. Future projects might benefit from the use of template legal documents to flush out potential issues at the feasibility stage.

3.2 Construction

3.2.1 Construction phase activities

Construction was completed in October 2016, with the exception of a couple of minor snagging items which were resolved within three months. Initial values from the commissioning tests are included in section 3.5.3 Pre-sale battery performance testing. A further description of the commissioning tests is given in the Final Report, Appendix D **Error! Reference source not found.**.

Issues encountered during the construction phase included;

1) location of cables differing from plans;
2) damage to communication cables during the erection of fencing; and
3) the requirement for a specialist driver to transport the battery due to its hazard rating.

The following photographs show some key stages of the construction and the battery internals.

Figure 5: Battery Arrival

Figure 6: Battery Offloading

Figure 7: Battery on plinth before and after fencing

Figure 8: Secondary Access Door (Battery Compartment)

Figure 10: Local Control Panel

Figure 9: Circuit Breakers and Emergency Stop

Figure 11: Battery Strings

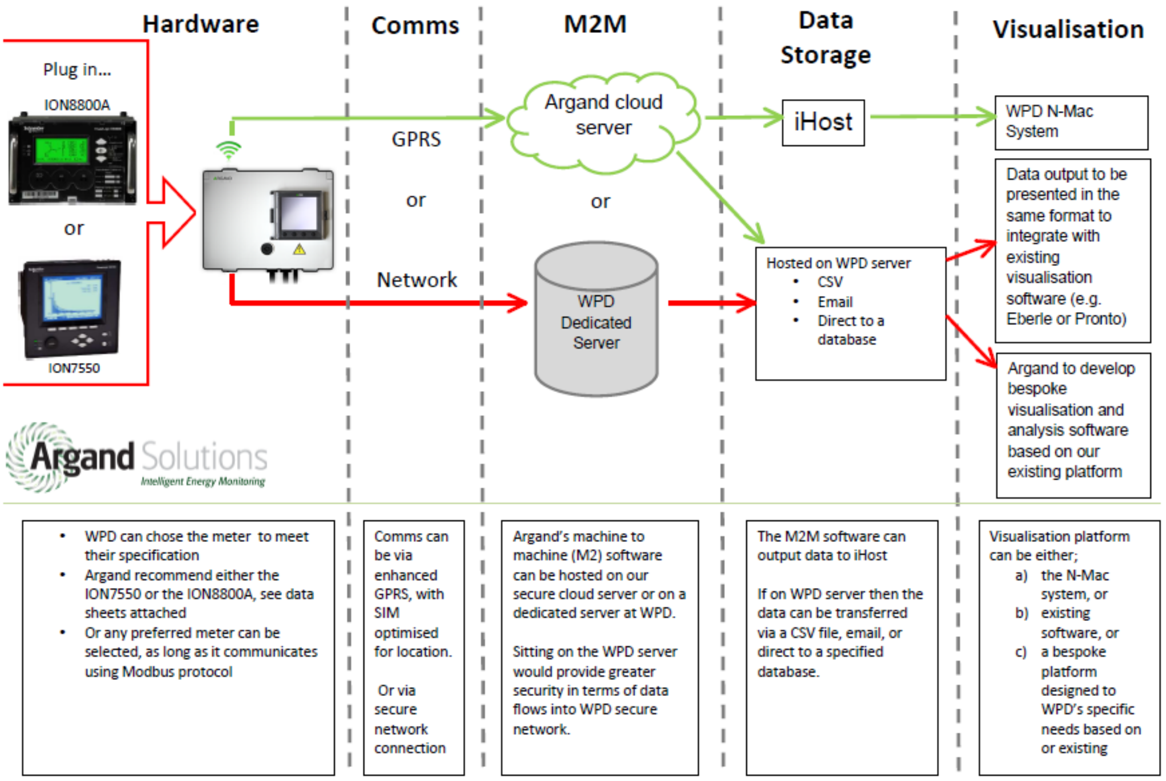
Figure 12: Fire Suppression Equipment

The additional external inter-trip signal was originally going to be provided by a standard WPD inter-trip device. The lead time and cost of this was relatively high, and it was agreed to replace the signal generated from the modified soft inter-trip panel with a surrogate signal. The surrogate signal was generated by an enhanced Raspberry Pi device built by a BSR member of staff which was equally valid for the testing

Argand Solutions was commissioned to install some advanced power quality monitoring equipment at Millfield Primary. This served two purposes, firstly it provided high resolution data to support detailed analysis of the impact of the battery operation as measured at the primary substation, but it also allowed for WPD to assess the potential benefit of a different type of power quality monitoring solution. To enable high quality monitoring, a specialist current transformer was purchased due to space limitations around the existing Millfield switchgear.

Figure 13: Power quality monitoring and communications equipment installed at Millfield Primary

An overview of the Argand solution is given in Figure 13. While traditional power quality monitoring relies on analysis software and hardware provided by the same supplier being used together, the solution implemented allows greater flexibility by making the data available to other software and other purposes via a cloud server.



- WPD can chose the meter to meet their specification
- Argand recommend either the ION7550 or the ION8800A, see data sheets attached
- Or any preferred meter can be selected, as long as it communicates using Modbus protocol

Comms can be via enhanced GPRS, with SIM optimised for location.

Or via secure network connection

Argand's machine to machine (M2) software can be hosted on our secure cloud server or on a dedicated server at WPD.

Sitting on the WPD server would provide greater security in terms of data flows into WPD secure network.

The M2M software can output data to iHost

If on WPD server then the data can be transferred via a CSV file, email, or direct to a specified database.

Visualisation platform can be either;
a) the N-Mac system, or
b) existing software, or
c) a bespoke platform designed to WPD's specific needs based on or existing

Figure 14: Argand Power Quality Monitoring system architecture.

3.2.2 Construction phase learning

The key learning points from the construction phase are;

- ensure that legal issues are resolved early in the construction schedule;
- expect a degree of inaccuracy in plans; and
- power quality monitoring was something of an afterthought to the project, and procurement and installation took longer than expected.

3.3 Testing

3.3.1 Testing phase activities

A test schedule was produced that would ensure that each use case would be tested for sufficient iterations in different seasons both individually and combined with other appropriate use cases. The test schedule was originally drawn up with a significant amount of days where the battery was not scheduled to operate, allowing time to resolve minor issues and giving an opportunity for early analysis of the data to inform the rest of the testing schedule. Due to the high number of technical issues that were experienced, these non-operational days provided a useful contingency allowing the test schedule to be re-planned several times during the project.

During the testing phase there were also a number of site visits from parties interested in the battery technology. These included Innogy and the local MP. Innogy are a renewables subsidiary of the German energy company RWE. The collaborative visit shows the ability of innovation projects to share learning between companies that are competitors.

MP is energised by the potential of firm's battery project

JAMES Heappey MP paid 'ambitious' British Solar Renewables (BSR) a visit and learn about its innovative battery storage project.

The company, which is now based in Shepton Mallet, has developed one of the first industrial-scale battery storage facilities in the UK.

The project is in collaboration with Western Power Distribution. Mr Heappey said: "It is great to see such an ambitious and quickly growing company relocated to Shepton Mallet. Clean technologies are the heart of the Government's industrial strategy and companies like BSR are leading the way in delivering clean growth for our economy.

"British Solar Renewables' partnership with WPD is a great example of how the energy industry is working together to understand this technology and what it can do for our energy system and how they can be used to ensure security and supply to drive down prices for consumers."

Managing Director at BSR Graham Harding, said: "It was fantastic to hear James Heappey's enthusiasm for our services to the low-carbon industry.

"James was particularly interested in the energy storage research we're undertaking with WPD. And rightly so – this study is providing fascinating insight into how batteries can benefit the UK's power supply as the grid decarbonises and becomes increasingly decentralised."

Figure 15: Press coverage for MP visit

Figure 16: James Heappey MP visiting

3.3.2 Technical issues encountered

The commercial battery industry was much less developed or advanced in 2016, compared to the end of the project. While the hardware itself was relatively similar (although newer cells have greater energy density), the most recent major advances have been in software. Monitoring of State of Charge (SoC), communications between different manufacturers equipment, advanced and multi-use control systems are significantly more common now.

The battery received numerous software and occasional hardware upgrades throughout the test process, as flaws and edge-conditions were discovered as the tests became more advanced. One of the earliest challenges was that the battery strings appeared to be becoming unbalanced, a single charge-discharge cycle could report imbalance by up to 2%. After several tests the resulting imbalance could reach up to 15%, although this didn’t appear to directly affect any operations of the battery. It did, however, limit how far the user was prepared to charge the battery as at a 90% overall SoC, at 15% imbalance one string would appear to be at 97.5% SoC, which is considered high within the industry. A similar problem would occur at low SoC. In retrospect, this issue was more of a concern for the operators of the battery rather than being a direct problem or fault, but it caused delays and significantly more cautious operation of the battery than anticipated.

BYD, the battery manufacturers, stated that the cell strings themselves were not out of balance, but rather that it was merely an artefact of the State of Charge calculation algorithm. They were able to install a software update which rectified the issue and, from that point onward, all strings remained completely balanced, without even a percentage difference between them.

The RESolve State of Charge manager was not properly functioning at the beginning of the project due to an unset parameter. The issue manifested itself during the start-up of the battery when various subsystems falsely reported erroneous state of charge readings at different points, which RESolve would then try to act upon. To avoid this issue, the manager start-up has a delay parameter (usually set to 30-60 seconds). In this case the value had been set to zero, effectively infinite, meaning it never started. Even though there was a simple fix, the problem was not spotted immediately due to the imbalanced string readings. This meant that each test had to be carried out carefully, trying to ensure that no schedule would excessively charge or discharge the battery as the programming issue meant that RESolve would stop this.

During the early testing there was an issue with the battery discharging at midnight, despite no schedules being set. This was reported as an unusual occurrence, with an ‘invisible’ export schedule set for every day at midnight. This ghost schedule was deleted and caused no more problems. This issue has not been encountered with RESolve on any other site and it did not manifest itself again during the rest of the project. This delayed testing by approximately a week.

A very short-term problem appeared to be that RESolve was ignoring an import instruction. There was a missing parameter in a particular import schedule, even though this should have been impossible. The parameter was set, and the schedule functioned normally after this. This caused test failures only if tests were carried out on the day that that particular schedule was used.

RESolve used the BYD Master State of Charge output for most of its calculations. A fault developed where RESolve read the true SoC, then 50% and 25% of the SoC, every few seconds. To avoid any further testing delays, RES altered their software so that it read the SoC calculated by the Battery Management System (BMS) instead. This fix remained in place until the completion of the testing programme and it remains unknown whether this issue with the BYD Master was properly fixed. This issue caused a three-day delay.

Each of the control methods in RESolve were custom-written for the project. The standard use case for RESolve was previously operating one service, so the use of so many advanced schedules, some of which took inputs from local sensors and set a response set point, was a significant undertaking. Some of the schedules had small software issues which would have been discovered and fixed quickly in a fully commercial battery but were left unnoticed for a significant time due to not being required in the test schedule until later.

The solar peak lopping algorithm initially produced exactly 50% of the required response from the battery. This was easily fixed with an extra term within the internal algorithm. Later in the process, the response of the algorithm was also improved with some optimisations aimed at speed of response. This was found before testing started in earnest, so had minimal impact

When using reactive power control in a combination method, the system erroneously ignores the level of reactive power limits set, responding only to the inverter limit. This issue was not noticed until the very last stage of testing as the reactive limits had not been used before. This impacted the effectiveness of the combination methods, as RESolve prioritises reactive power modes over active power. However, it is expected that this issue is easily fixed, and the maths behind the reactive-active power output of inverters is well understood, so it is not considered a major impediment to the usefulness of the project.

There was an issue with the connection agreement for the Copley Wood battery. The connection agreement prohibited operating outside the standard power factors, however the WPD test schedule required reactive power testing. This was resolved after discussions with WPD's network management team, which ran additional simulations on the local network to investigate the impact of the reactive power flows. They granted specific limited permission to operate outside of the confines of the existing connection agreement, but only for the purposes of the reactive power tests. This delayed reactive power testing by three weeks, although this time was used for other active power tests.

A major problem that prevented successful testing was an air conditioning unit failure. This allowed the system to heat up to its official limit, 40°C, after which the inverters de-rated to prevent further detrimental effects due to excessive heat. There were two air conditioning units, but only one external condenser. This single point of failure, the condenser, is where the issue occurred. Visibility of this issue was hampered by a lack of dedicated SCADA communications between the air conditioning units and RESolve, in addition high and low temperature alarms were not set. The battery at this point was operating at 1.5-2 cycles per day, a heavy work load, so the units were replaced with larger systems that had separate external condensers. RES installed temporary air conditioning to reduce down time to 6 days.

Another single point of failure became apparent with the design of the system, in that only one remote control unit was provided for the two air conditioning devices. The loss of the remote control caused further delays whereas providing an additional remote control would not have been expensive.

The combination method had a relatively naive way of calculating the combined setpoint. Regardless of which active power use cases were selected, RESolve would sum the setpoints to tell the battery what to do. While this initially sounds logical, it causes problems when trying to stay within network limits, as each control mode was unaware what the other control mode was doing. The most obvious occurrence was this was when combining ramp rate control and solar peak lopping. When the solar generation was below the peak limit (e.g. 800kW) the ramp rate control worked as expected and the peak lopping algorithm was idle. However, if the generation was above the limit, at 950kW, the peak lopping mode would maintain the export at 800kW. If the generation dropped from 950kW to 850kW quickly, the output should still be stable at 800kW with an associated reduction in import from the battery. However, the ramp rate control algorithm responded to the drop in generation, increasing export to try and reduce the ramp, **even though** the actual site export was already being held stable. The site export then increased above the peak limit, which in the real world would be a breach of export limits. This suggests that a more complex combination method is required, with additional safeguards and potentially allowing the control modes to become ‘aware’ of each other’s actions.

3.3.3 Testing phase learning

The number of technical issues experienced was unexpected and initially the process to report and resolve these issues was ad-hoc. When initially reporting the peak lopping issue, for example, a screenshot of RESolve and an email would be sent to RES from the BSR operator. There would then be some follow up emails and phone discussions if the issue wasn’t obvious, or didn’t have a simple solution. In addition, initially all issues were sent directly to the project manager, who then had to pass them on to the software engineers. While issue reporting had been anticipated, the process to share the issues encountered was improved during the testing phase and this led to improved issue resolution. This included emails sent to both the project manager and the software engineers at the same time, so the project manager was aware there was a problem and the software engineers could begin investigating immediately

Realistically, if the battery was installed today it is likely most of the issues would not be encountered. Advances in control systems and wider adoption of energy storage has driven improvements in reliability. Running several brand-new algorithms on a control system for a research project meant that some minor issues were inevitable, and it reflects more on the nascent nature of the industry rather than a specific failing of any component. However, one of the key learning points was linking the air conditioning system to RESolve so that an alarm could be raised if there was an issue. Under the original configuration, the only way to detect an over-temperature de-rating was to observe the battery and ensure it was following its setpoint appropriately. It wasn’t possible within the budget and timeframe of the project to install SCADA communication between the air conditioning units and RESolve, but high and low temperature alarms were set up for the cells after discussions between BSR and RES, providing a fast, low-cost solution. Alarms such as this should be standard on all new systems, as should an alert function when the system has de-rated itself. This would make it significantly easier to remotely identify problems and minimise downtime, which, if the battery was to be used for DSO services, would be essential.

The problem with over-heating (and the resulting issues with the air conditioning) was exacerbated by the choice of paint colour for the battery container. While the dark green colour was intended to minimise the visual impact of the battery container a lighter colour would have reduced the solar heat gain, thus reducing the load on the air conditioning. One option that could have been a compromise between visual impact and heat gain could have been to only paint public facing faces of the battery containment green and paint the faces that are not visible to the public (i.e. top, rear and furthest end) in white.

The single point of failure with the air conditioning remote control could have been prevented by providing multiple units and tethering the handset to the battery container to prevent its removal.

3.4 Analysis

3.4.1 Analysis phase activities

The original project plan was to carry out much more of the analysis alongside the battery testing, making use of the planned battery down-time. However due to the technical issues the analysis of the data did not start until the battery operation was largely completed.

The analysis activity involved downloading the operational data from the battery and completing analysis on the technical performance and economic value of the services.

The analysis phase also included the calculation of the net impact of the solar storage project on the revenues of the solar park, i.e. the additional costs of charging the battery from either the grid or the solar park output, less any additional value gained from the energy released from the battery as it discharged, either to supply the solar park or to export to the grid.

3.4.2 Data sources for analysis

The main resource for the analysis was the data recorded in the RESolve SCADA system. This system recorded all of the schedules programmed for the battery, and all parameters required for the performance analysis (power in and out, battery setpoint etc). The SCADA also receives information from two Power Quality Meters (PQMs), one for the battery and one for the solar park. In this way it is possible to separate the effects each asset has on the network. These can include harmonic disturbances, investigation of sources of power flow, voltage fluctuations and impacts on the power factor.

A secondary source of data was the Argand power quality monitoring device installed at the Millfield substation. This monitors the 11kV feeder that was connected to the solar park and battery, as well as one other solar park (Higher Hill). This allows us to independently verify any effect (or lack thereof) that the various use cases have on the network, rather than solely relying on the instruments installed on the battery site.

To help with the financial analysis, the details of the import agreement for the solar park have been obtained. Due to commercial interests, exact figures could not be provided, though close approximations were given by the energy supplier. The export power purchase agreement (PPA) has not been altered, and is based on the N2EX next day auctions, which have an hourly price.

For comparison, and with the knowledge that were this battery a commercial concern the import/export agreements would be altered, the half hourly system price of power (also known as the wholesale price) has also been used. This is the price that energy is traded at on the energy market, although renewable energy doesn’t actively take part in this trading. The wholesale price cannot be directly accessed by an asset: it is the pure price without supplier margins or network costs added. In this way energy can be traded in a location-agnostic way. PPAs which follow this price ‘live’ are available, although the standard is to fix at a more consistent and predictable pricing structure. It is expected that the system price plus network costs and supplier percentage would be a more accurate import charge for an energy storage system, while solar parks usually have simpler (but costlier) arrangements as they import so little. For example, Copley Wood solar park had a flat set-level day-night tariff, with adjustments for summer and winter.

3.4.3 Data cleansing

The RESolve SCADA system used in the project had an unexpected method of recording data which was used to conserve space. The system checked each sensor and compared the value to the last recorded value. If nothing had changed, no value or timestamp was recorded. This meant that when downloading the data, there were large gaps of time with no values recorded. In addition, when downloading months of data at a time, the 1 second data quickly grew beyond the limits of Microsoft Excel and became unmanageable. A Python script was written to extract the data and place it in a form that could be easily analysed. This software translated standard calendar dates into Epoch-milliseconds, which is what was used by the server[2]. It then only extracted data that fell between the user set dates, and only for the data that matched a pre-written list, rather than downloading the 200+ system values that are recorded. The software also extracted the data for the previous day, so that values which had not changed on the current day could be forward filled from the previous day. This, in nearly all cases, allowed a complete dataset to be extracted. The software also averaged each half hour as a separate comma de-limited file (CSV) so that the data could be visualised by Excel.

3.4.4 Calculation methodology for financial gain / loss

Each use case has been compared against the ‘base-case’ for energy storage in the UK, which was the Fast Frequency Response (FFR) and capacity market contracts. The values for these in 2016 (when the battery was constructed) and 2018 (when the testing ended) were calculated and given as a simple £/hour for a battery of this size and capacity.

This gives a single value against which all the other cases can be measured, as well as an opportunity cost which can be reduced as required (e.g. if a use case required half of the power output, the battery can still bid half of its capacity into the FFR auction and receive half the standard income). It has been assumed throughout the analysis that the battery can receive FFR contracts whenever it isn’t operating in other modes, although changing market conditions mean this is no longer necessarily true.

The amount of income that the battery will miss out on can be used for investigating if DSO network services (such as network demand peak lopping) are commercially viable. The cost/benefit of providing this service, plus any administration costs and required profit levels, must be above the threshold that the energy system can generate by staying within the FFR base case.

---

[2] Epoch-milliseconds are the number of milliseconds that have elapsed since midnight on January 1st, 1970. This is how several operating systems keep time, including Unix/Linux variants and macOS, and many programming languages. For example, the Epoch Millisecond date stamp 1514764800 is equivalent to 01/01/2018 at midnight, in Greenwich Mean Time. The software conversion made the data extraction process significantly easier.

3.4.5 Calculation methodology for round trip efficiency / battery efficiency

The commissioning efficiency tests involved charging or discharging the battery to 25% SoC, then charging for a set amount of time at a target rate. This can be seen in more detail in Table 2: Efficiency test charging durations. All these tests except the one at 310kW were carried out during commissioning. The battery was then discharged to 25% again, and the kWh used to charge the battery are compared to the kWh exported while discharging the battery. Charge power divided by discharge power gives the effective round-trip efficiency. These values were read from the PQMs, which were installed on the HV side of the transformer. This gives a real-world round-trip figure, including transformer losses, which is the figure that investors and developers will be most interested in.

3.4.6 Testing for seasonal impacts

The original test plan included testing of all the different use cases with an equal spread throughout the year. The impact of the technical issues meant that the majority of testing was carried out in the Autumn/Winter, although there were some successful tests in the summer. This was not considered to be a problem, as variables such as temperature, solar production and network load have been monitored throughout the year, and tests have been completed under all weather conditions. Thus, tests can be theoretically run based on the existing data, using real world battery behaviour to inform the results. In addition, battery operation (other than auxiliary loads) appears to be similar regardless of the season.

3.4.7 Base case for comparison

One of the initial challenges of financial analysis of the different use cases, was creating a base income for them to be compared against. Without this anchoring the analysis, it is difficult to draw any meaningful conclusions about the viability of the operating modes. Peak lopping could have twice the value of arbitrage, but that wouldn't necessarily make it profitable.

To provide the base income, the current income streams of energy storage were investigated. The standard business case for most commercial batteries currently relies on the National Grid FFR contracts and the Capacity Market Auction. These combined created the investment case for batteries - however there has been a significant shift in the market since this project was envisaged and installed. FFR rates have plunged from over 20 £/MW/h (pounds per MW per hour of service) to less than 10 £/MW/h between 2016 and 2018, while the capacity market has seen a similar reduction. Further to this, the capacity market payments are now de-rated based on the number of hours the installation can discharge at maximum capacity for, further reducing payments.

To highlight the difference between when the battery was built and current market conditions, two base incomes have been calculated. One uses 2016 FFR and Capacity Market rates, free from de-rating, while the other reflects the latest FFR and Capacity Market auction incomes from 2018. When scaled to the size of the Copley Wood battery, the 2016 figures equate to £7.31/hour, while current rates provide an income of £2.79/hour for being available in these markets. The calculations for this can be found in the virtual PPA appendix B, and are based on what was considered the usual commercial business case for energy storage at the time that the battery was operating (i.e. 24/7 FFR contracts and Capacity Market revenue). These are considered the hurdle rates which must be met by DSO/ third party contracts to incentivise battery operators to make their business models more complex.

These two figures give a baseline number with which to compare the cost of operation and expected payment price for each use case. By providing an hourly figure, use cases such as peak lopping, that take several hours during the day, can have a 'lost opportunity' cost associated with them, demonstrating whether they are economically viable or if there are more profitable options available to a battery asset.

3.4.8 Analysis phase learning

This section only includes the learning that was gained in the process of analysing the data.

For the results of the analysis of the individual use cases please see sections **Error! Reference source not found.** to **Error! Reference source not found.**.

The format of the data storage within RESolve, while reducing the volume of data recorded made data transfer and analysis more complex.

It is difficult to provide business case analysis when prices are changing rapidly which is both the case for batteries but also for the value of services that can be provided. It is also very difficult to estimate the future values of services to DNOs or third parties that are very specific to a location. The services may differ in value or not be required at all at different locations or at the same location at different times.

Another learning point related to the various metering points that were used to calculate the net impact on the solar site revenues. It had been assumed that the various meters, though installed at different times by different parties, would be synchronous. It became clear from the data that the values for the total import and total export of energy were not summing correctly. Ignoring the impact of losses, it was expected that the total power through the site meter would equal the sum of the import by the battery and the solar park. This value would often have a large error in one time period followed by a large error in the opposite direction in the next time period suggesting that the meter synchronisation was causing problems.

3.5 Decommissioning

3.5.1 Decommissioning phase activities

The decommissioning phase of the project was delayed due to the testing phase taking longer than anticipated. The lease for the battery site included stipulations about the site being restored to its prior condition and therefore it was necessary to understand the work required to remove the battery and restore the site. There was provision for the battery to be sold to the owner of the solar park, negating the need to restore the site.

However, due to the planned sale of the solar park it was preferable to be able to transfer the entire site unencumbered from other leasehold arrangements.

Much of the work in the decommissioning phase related to managing the tender process to sell and relocate the battery which are covered in a separate report[3]. This was a 'first of its kind' activity which allowed for greater learning about the commercial and technical issues surrounding the sale and removal of a containerised battery.

The project team supported the sale process by providing interested parties with information about the batteries performance and having an "open day" for bidders to see the battery and assess the site for removal and reinstatement works.

The following section describes the process completed to test the battery condition at the end of the project.

3.5.2 Capacity fade / age-related battery degradation.

The project lifetime was significantly shorter than that of expected commercial installations (~2 years versus 10 years), giving less time for the energy capacity to be diminished. Commercial installations are governed by their warranties, which tend to be structured such that they guarantee a residual capacity at the end of the warranted life, which is commonly before the expected end of the project life, so developers will plan for replacement of all cells. It is unusual that a battery would reach the end of its project life before the end of its usable life, as this would suggest an over engineered (and therefore overpriced) project, leading to lower project returns than could have been achieved.

However, in this case the battery was specifically being used for a research project and exposed to an unusual operating regime that had never been tested on a battery before. In addition, the testing requirements changed over the life of the project, making the usage impossible to simulate or predict at the beginning of the project.

This, coupled with the desire to sell the battery after the research was complete, meant that a complete health check-up was required. This would be valuable in reassuring potential purchasers that the systems were still functioning correctly and provide a valuable insight into the ways the new use cases affected an energy storage asset.

3.5.3 Pre-sale battery performance testing

When the battery was installed it had undergone a series of commissioning tests, ensuring the system was working as intended and meeting all its contractual obligations. These included a full capacity test and a suite of roundtrip efficiency tests, demonstrating the performance across a range of charging rates.

It was decided that these tests would be suitable for the end of project tests, as direct comparisons could be drawn with the asset as originally installed, and any differences or degradation should then be attributable to the testing regime.

The efficiency tests involved charging and discharging at the same rate and calculating the difference between the imported and exported energies. Each test was started at 25% SoC to ensure that the testing wouldn't be interrupted by the State of Charge

---

[3] https://www.westernpower.co.uk/innovation/documents Solar Storage - Battery Disposal Report - January 2019

Manager. The battery then imported for a set time, then exported until the SoC read 25% again. The times for charging are listed in Table 2: Efficiency test charging durations.

Efficiency Testing Plan	
Rate of charge/discharge (kW)	**Time for charge (mins)**
310	60
300	60
200	90
150	120
75	240
30	600

Table 2: Efficiency test charging durations

The commissioning tests were completed on-site, while the end of project tests were conducted remotely, using the kWh import and export readings of the battery power quality meter to record the energy.

3.5.4 Decommissioning phase learning

Pre-sale battery performance test results

The initial results are taken from the commissioning paperwork and are shown in Table 3.The efficiency rate of the battery at 30kW was not recorded, but it was agreed that it was higher than the contractual hurdle rate of 32%. All other percentages were recorded. The battery was not tested at 310kW in the commissioning tests as officially it was a 300kW battery that had been specified. The 310kW inverters were oversized to ensure sufficient capacity. However, throughout the project the battery has frequently been used at 310 kW and so this was included in the final tests.

The battery was well in excess of its contractual efficiency obligations and had a surprisingly high efficiency at 200kW, compared with the other efficiencies recorded. While lithium batteries can technically reach this level of round trip efficiency, it is usually not achieved on grid-connected batteries due to auxiliary loads. It is possible that the storage system had no need for engaging the cooling systems during this test, giving an inflated efficiency score. The capacity recorded at commissioning was 702kWh on a discharge from 98% to 2%, giving a calculated capacity of 731kWh for a 100% to 0% discharge.

The end of project tests are listed in Table 3, demonstrating a very reliable efficiency of approximately 88% over a wide range of charging rates. The efficiency only drops off over the 30kW charging rate, at which point, with a charge-discharge time of 20 hours, the parasitic loads have a greater impact.

End of Project Tests										
				Import meter readings		Export meter readings		Calculated values		
Rate of charge (kW)	Start SoC (%)	Max SoC (%)	End SoC (%)	total kWh start	total kWh end	total kWh start	total kWh end	kWh imported	kWh exported	Roundtrip efficiency (%)
310	25	64	25	251078	251388	208371	208645	310	274	88.39%
300	24	62	25	249069	249369	206943	207206	300	263	87.67%
200	24	63	25	249392	249692	207233	207498	300	265	88.33%
150	24	63	25	250774	251074	208101	208367	300	266	88.67%
75	25	64	25	250451	250751	207809	208075	300	266	88.67%
30	24	61	25	250124	250424	207539	207782	300	243	81.00%
Capacity Test	99	N/A	1	N/A	N/A	208969	209632	N/A	663	N/A
Calculated 0-100% Capacity (kWh):									676.53	

Table 3: End of Project Round Trip Efficiencies

All tests were conducted at unity power factor for import and export.

The more consistent test results are potentially due to a change in the batteries hardware partway through the project an air conditioning unit failure resulted in the replacement of both units with those of a different manufacturer, with additional systems put in place to allow one to operate in the event of total failure of the second. This greater redundancy may have resulted in a more consistent power draw for cooling, rather than the longer, more intense on-off cycle of the previous units. In addition to this, the settings for target temperatures have been changed on the project twice to optimise the internal temperatures.

The capacity of the battery was still well above its nameplate capacity of 658kWh, although the heavy-duty cycle of the testing has reduced it from 731kWh to 677kWh. From this the capacity fade[4] can be calculated to be 7.4%, over 320-350 cycles (depending if calculated using starting or final capacity). This can seem relatively high compared to current commercial models and predictions, but the battery has been charging to 90% and discharging to 10%, sometimes as often as two cycles per day. Whereas commercial batteries which engage in the FFR market usually operate at approximately 50% state of charge, with small deviations as they are called on, which is significantly less harmful to the battery.

3.5.5 Conclusions

It is not easy to directly compare the results of the re-run of the commissioning tests[5] with the initial commissioning test results due to the interim change of hardware.

---

[4] (1-(new capacity / original capacity)) x 100

[5] Tests completed on the 30/7/2018 as part of the end of project/pre-sale performance testing

However, it was clear that the battery was performing consistently and efficiently, with no significant problems in absorbing or releasing energy. The calculated capacity fade is not unexpected from a two-year-old asset, especially given the tougher services it has been providing vs current commercial energy storage systems, and it was still above its initial nameplate capacity. The inverters were able to produce/absorb power at their peak ratings and showed no signs of faults or thermal derating. The replacement air conditioning systems were keeping the cells within their thermal parameters, aiding efficiency.

It did not appear that the use cases tested had caused excessive capacity fade from the lithium iron phosphate cells, albeit degradation was considered to be at a higher rate than that expected from the delivery of services such as frequency response.

3.6 Battery Use Cases Summary

The full analysis and conclusions for each use case is given in the Solar Storage Final Report available on the WPD innovation website.

3.6.1 Use case 1 - Arbitrage.

Arbitrage is the simplest of the use cases tested, requiring no complex software or data feed to operate. However, it is apparent that to capture the fluctuations in the marketplace, the battery needs to be under the control of energy trading companies who can predict with accuracy the direction of the short-term future prices. Even with this dedicated professional team, it is unlikely that all opportunities will be captured.

The high round trip efficiency of the battery helps smaller price gaps remain profitable, as only 12% of the power is wasted. This only holds true at high charge speeds, but if a half-hour trade is profitable then the battery will be operating at full rated power to gain the most volume possible at those prices.

Arbitrage offered only a fraction of the potential incomes from FFR and the Capacity Market. This fraction increased in 2018 due to the fall in FFR prices such that if a battery failed to get an FFR contract it could recoup a third of the expected income from arbitrage but this mitigation may not be sufficient to tip the balance in investment decisions.

Finally, arbitrage is significantly affected by being connected behind the meter of the solar park. The existing power agreements with the solar asset effectively block the batteries access to the variable price market. With new build solar parks this may be mitigated by drafting an agreement between the park and the battery, making the battery responsible for any loss the solar park experiences by selling and buying at system price versus being locked into a more stable market, but this is unlikely to work with retrofitting batteries to solar parks. These assets are now often owned by institutional investors whose attitude to risk is extremely cautious, making them unlikely to give up the long-term certainty provided by their current agreements.

3.6.2 Use Case 2 – DNO Network Peak Lopping

This use case is often complementary with arbitrage as it is likely to require exported power to match the typical evening peak. If the requirement is to manage a winter peak constraint then this will coincide with the time that solar parks are least likely to have excess power available from solar peak lopping and therefore the battery economic case is not improved by co-locating with a solar site.

There will be a small number of locations where the value of flexibility services would exceed that of other services, however batteries are normally averse to locating where their own import or export may be limited by network restrictions. Given the seasonal nature of the services, then other income streams providing a year round income would have a greater sway on battery location decisions.

DNOs should continue to improve their signposting of locations where future flexibility services are anticipated and the hours of operation.

3.6.3 Use Case 3 – Local Demand Peak Lopping

The use case demonstrated that the battery could respond to an external signal. The financial case is largely the same as for DNO Network Peak Lopping in that the value in deferring the cost of an upgrade needs to exceed the price paid for services. It is not possible to determine simple rules of thumb for where this may be valuable because the costs depend on a large number of variables including;

- The time and duration for which the power delivery is required
- The seasonality of the requirement
- The cost of upgrading the customer's network
- The availability and attractiveness to the customer of other alternative connection options such as ANM, that would reduce the cost of upgrade
- The ability for the customer to operate their own alternatives to network upgrade i.e. a local generator or battery

This use case is expected to provide additional value in some cases, but it is not possible to estimate what proportion of cases that would apply to. There is also the problem of optimising battery location. While DNOs are creating flexibility heat maps, other means are required for customers to publish their own requirements for flexibility services. This could be achieved via the new platforms being developed such as the Cornwall Local Energy Market, which is open to any flexibility service purchaser.

3.6.4 Use Case 4 – Low demand grid voltage support

For this use case the battery was charged overnight to determine whether this helped reduce the voltage. The assumption was that the network could be configured to provide high voltages at the solar park to enable export, but that at times of low demand this might cause the system voltage to exceed statutory limits.

While the battery consumed power according the planned schedule, the impact this had on the system voltage was negligible due to the relatively small scale of the battery. If the battery were providing arbitrage services it would be likely to charge overnight anyway so to some degree night time load could be increased generally via time of use tariffs rather than commissioning specific services from batteries that would need to be very large. The scale and cost associated with large batteries suggests that, where required, other voltage control solutions such as that developed for the Network Equilibrium project may be more appropriate.

3.6.5 Use Case 5 – Voltage control by reactive power

Once again, the impact of this mode of battery operation was limited by the battery size and while the battery set point could be seen to respond to voltage inputs correctly, it was not possible to discern any change in the voltage measured at the local primary substation. However, this use case has the advantage that the import or export of reactive power can be combined with other use cases relatively easily and would certainly be of interest to the owner of a larger battery. The Power Potential project involving National Grid and UK Power Networks demonstrates that it is possible for DNO connected assets to provide reactive power services to National Grid, but once again the opportunities to provide this service are location specific.

3.6.6 Use Case 6 & 7 PV export limiting (fixed and variable thresholds)

The testing methodology for both these use cases was the same, simply with a different threshold. The fixed threshold version represents a scenario where the solar park is in danger of exceeding the export limit for their connection whereas the variable threshold would be a voluntary service offered to the DNO that required generation turn-down. Some improvements were needed to the RESolve software as the initial version responded too slowly requiring the effective threshold to be set lower to ensure compliance with the threshold level being tested.

Where the use case was used to fill the battery for later discharge then a certain degree of skill was required to translate the weather forecast into an appropriate threshold level. These services did offer the opportunity for small returns the value being higher for fixed threshold limiting at around £3750 a year compared to £2700 per annum. Higher returns may be achieved by using a more sophisticated control algorithm. The time for which the battery needed to be available to lop the peak generation was generally under two hours, but this resulted in the battery being unavailable for FFR for four hours due to the FFR contracts being specified in four hour blocks. Once again the opportunity for returns is seasonal with winter outputs being unlikely to breach the fixed threshold for the PV site. This offers options to top up incomes but would not provide an investment case for the battery alone.

3.6.7 Use Case 8 – Solar Output Smoothing (Ramp rate control)

This use case demonstrated the batteries ability to respond in changes in the output of the solar farm and by smoothing out the export, help reduce the variations in voltage.

The control algorithm could be seen to work correctly but the impact, while detectable, was small in scale compared to the variations that were driven by the neighbouring solar parks which had a combined capacity of approximately 6MW compared to the 310kW battery. Even if the battery had been larger, it is not clear that a DNO would be willing to pay for this service. While it reduces the voltage fluctuations, which should result in fewer tap change operations this does not necessarily correlate directly with lower tap changer maintenance costs and it would be difficult to determine the degree to which the service provider was responsible for a reduction in tap change operations. Another viewpoint might be that if the large degree of volatility in solar output resulted in a high number of tap change operations then this could be treated in the same way as power quality problems which apply the “polluter pays” principle.

3.6.8 Combining Use Cases

It was possible to combine several use cases by means of sequential operation. Thus the battery could combine arbitrage with solar peak lopping, solar output smoothing and reactive voltage control while supporting either the DNO or a local load customer by exporting at the evening peak. Seasonal variations in service requirements limit the combinations that would be performed in real life.

Use cases were also combined concurrently by using the ability to virtually split the battery capacity and use two control algorithms to create a combined set point. This was not found to work well from a control algorithm standpoint, but would also have limited opportunities in reality as it is likely that one service would have a higher value than the other so combination would be sub optimal.

4. Performance Compared to Original Aims, Objectives and Success Criteria

The project aims are given as;

1) Quantify the potential value to network operators and others of integrating storage with DG.
2) Demonstrate safe, reliable operation of the system under operational conditions
3) Use real-world operation of an integrated utility scale storage:generation system to provide data to regulators and potential investors.

These aims have been met as the project has demonstrated the safe operation of the battery system and provided an assessment of the use case value in the Final Report and webinar. Underlying datasets that were used in the analysis are available as outlined in section

The success criteria have been met as evidenced below.

Success Criteria	Status
Complete Design of BESS. Procure equipment, install and commission. Run trials and write report.	All achieved as evidenced in this report, the Final report and the dissemination webinar.
Identify changes necessary for participation on the Balancing Mechanism.	The Balancing Mechanism was not found to be an obstacle to battery investment as per the Utilities Insight report published on the WPD innovation website.
Phases 1 to 4 above completed safely to time and on budget.	No accidents or near misses as a result of the battery installation, operation or removal. Project completed well within budget. Despite the delays due to the battery reliability issues most of the deliverables were achieved to time, however the compression of the testing schedule meant that there was no time for analysis in the testing phase and subsequently the delivery of the final report was delayed. This delay was also partly attributable to the decision to sell the battery as this required BSRL involvement.
All usage cases are investigated and a comprehensive analysis of all data collected undertaken.	Achieved, as evidenced in the final report and webinar.
Useful and applicable conclusions generated from the data analysis.	Achieved, as evidenced in the final report and webinar.
Effective communication of the project's results and conclusions to the UK renewable energy and power distribution community.	Positive feedback received from the dissemination webinar. Comprehensive final report published. Webinar slides published Recording of webinar published
Successful engagement with stakeholders, influencing the development of relevant governing mechanisms such as the grid code or balancing mechanism (BM).	Learning from battery installation phases fed into the call for evidence in 2016

5. Required Modifications to the Planned Approach during the Course of the Project

The battery suffered from a large number of technical issues which prevented testing taking place to the original schedule. While the initial plan was to intersperse data preparation and analysis alongside the battery testing, the work was rescheduled so that battery testing was completed before the expiry of the lease for the battery site.

This mean that the work to compile the datasets, analyse the data and compile the final report took place after the battery testing was complete and exceeded the projects intended duration.

Another change was necessitated by the sale of the solar park to which the battery was connected. This required removal of the battery, as outlined in section 3.5 but this was seen as an opportunity to extend the learning from the project by investigating how a battery sale process could take place. A separate report titled “Solar Storage: Battery Disposal” has been written to cover the battery sale process which is available from the Documents and Links section of the webpage at https://www.westernpower.co.uk/innovation/projects/solar-storage

Other changes were made, not because they were required, but on a voluntary basis where this would to improve the output from the project. One example is the installation of Argand power quality monitoring equipment, rather than the WPD standard solution. This enabled greater learning about the pros and cons of other monitoring options. The web interface allowed for BSR to have improved access to the data for analysis than would otherwise have been the case. A second example is the changes made to the dissemination method for the final learning. This was originally intended to be presented by BSR at local events relevant to the solar community. Changing this to a webinar gave a far wider reach than Somerset and as the webinar was recorded, this is available to any interested party at any time.

6. Project Costs

Activity	Budget	Actual
RES – Battery design & supply	358,787	359,802
BSRL - Project oversight, battery operation and analysis	246,109	111,442
BRE – Quality control review of test plan and results	14,025	14,483
Argand – Power quality monitoring	17,760	14,550
Utilities Insight – Regulatory / Code analysis	22,222	20,000
SRI Tech –Techno-economic modelling	11,000	11,000
WPD installation work	3,080	3,466
WPD Project Management	143,000	113,731
SGC Project Management of Battery Sale	10,000	8,505
Contingency	38,199	0
Total	864,182	656,979

The project costs are within the budget. The RES contract values have been amended to reflect the receipt of the proceeds of the battery sale. The BSRL contract underspend reflects the partner contributions of approx. £103k.

7. Lessons Learnt for Future Projects

The learning from each phase of the project has been summarised in Section 3.

An additional lesson learned is the difficulty of using a relatively long duration project to inform developments in a rapidly developing market. Dramatic shifts to the services provided by National Grid and the prices for these services significantly changed the backdrop against which the project was operating. This made the analysis significantly more complex with price comparison being necessary for both 2016 and 2018 to put the use cases in context.

8. The Outcomes of the Project

The outcome of the project is the learning that it has generated.

The learning from the battery issues will help others to specify battery requirement s with these issues in mind. The learning from the use cases has been applied to improve the battery control algorithms used. The benefits of containerised battery construction have been illustrated by the relative simplicity of the battery relocation at the end of the project. Learning from the sale of the battery is already being used to help with the sale of the battery installation at Leighton Buzzard that was used for Smarter Network Storage.

The analysis and investigation has shown that the financial assessment of the use cases is often complex and not suited to producing a simple rule-of-thumb estimation tool to determine whether battery installation at solar sites is viable or to calculate the optimum battery capacity. However the calculation methods have been provided in a way that other installers can replicate for their own projects which they will need to be able to tailor to take account of the highly locational nature of the services that can be provided and local variations in load profiles and voltage headroom.

2 Data Access Details

Financial analysis and data relevant to the project is available via the Excel Attachment to the final report which is published on the innovation website.

Additionally six datasets are available which can be shared on request. These include values extracted at five minute snapshots (rather than five minute averages) for the battery power, state of charge and readings and cumulative import/export meter readings.

Some data from the underlying battery database has been extracted which is at higher resolution than half hourly datasets. This is stored as Microsoft Sequel Server backup files so the user will need to have an appropriate licence and provide a suitable external drive in person for the data to be copied to. The information to support analysis or extraction of this data is limited to a list of data tags.

www.westernpower.co.uk/Innovation/Contact-us-and-more/Project-Data.aspx)

3 Foreground IPR

No new foreground IPR has been developed during the project.

4 Planned Implementation

WPD, as a DNO, is unable to own significant generation assets and therefore would not own solar farms on which to install batteries. Similarly DNOs are expected to act as neutral market facilitators in terms of flexibility services and therefore it is unlikely that regulatory frameworks will permit DNO battery ownership other than in cases of last resort.

We have found that customers are not always aware of the potential of batteries to reduce their connection costs, but how they can provide other benefits such as reducing the cost of electricity supplied and DUoS charges, avoiding triad charges, maximising self-consumption of renewable generation, improving resilience and providing opportunities for additional incomes through flexibility services. While WPDis unlikely to become a significant battery owner, the findings of Solar Storage, alongside the findings from the Industrial and Commercial Storage NIA project, will feed in to technical policies and the information presented to customers requesting new or altered connections. .

5 Other Comments

6 Contact

Further details on replicating the project can be made available from the following points of contact:

Future Networks Team
Western Power Distribution,
Pegasus Business Park,
Herald Way,
Castle Donington,
Derbyshire
DE74 2TU

Email: wpdinnovation@westernpower.co.uk

Glossary

Abbreviation	Term
AAHEDC	Assistance for Areas with High Electricity distribution costs
ANM	Active Network Management
BMS	Battery Management System
BRE / NSC	Building Research Establishment / National Solar Centre
BSR	British Solar Renewables Limited
BSUoS	Balancing Use of System
BYD	Battery manufacturing company that supplied the solar storage battery.
CCGT	Combine Cycle Gas Turbines
CCL	Climate Change Levy
CfD	Contracts for Difference
CM	Capacity Market
CMZ	Constraint Management Zone
Co-Located	Within this report, co-located storage refers to energy storage that has been installed behind the meter of a solar park or other distributed generator.
DG	Distributed Generation
DNO	Distribution Network Operator
DUoS	Distributed Use of System
DSO	Distribution System Operator
DSR	Demand Side Response
EFR	Enhanced Frequency Response
EMS	Energy Management System
FiT	Feed in Tariff
FFR	Fast Frequency Response
GB	Great Britain
GSP	Grid Supply Point
HMI	Human Machine Interface
HV	High Voltage
LCNI	Low Carbon Networks and Innovation
LCF	Levy Control Framework

LV	Low Voltage
NIA	Network Innovation Allowance
PEA	Project Eligibility Assessment
PCS	Power Conversion System
PoC	Point of Connection
PQM	Power Quality Meter
PV	Photovoltaic
RCRC	Residual Cashflow Reallocation Cashflow
RES	Renewables company that managed the battery installation and developers of the RESolve control software.
ROC	Renewable Obligation Certificate
SOC	State of Charge
STOR	Short Term Operating Reserve
TNUoS	Transmission Network Use of System
WPD	Western Power Distribution