WESTERN POWER DISTRIBUTION
INNOVATION

NEXT GENERATION NETWORKS

Industrial and Commercial Project

WPD_NIA_021

CLOSEDOWN REPORT

May 2019

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Contents

Glossary

Abbreviation	Term
AC	Alternating Current
BESS	Battery Energy storage System
CT	Current Transformer
DC	Direct Current
DNO	Distribution Network Operator
DUoS	Distribution Use of System Charges
EFR	Enhanced Frequency Response
ESS	Energy battery system
EV	Electric vehicles
FFR	Firm Frequency Response
HGV	Heavy Goods Vehicle
GSM	Global System for Mobile Communications
HH	Half Hourly
HP	Heat Pump
Hz	Hertz
I & C	Industrial & Commercial
kW	Kilo Watt
kWp	Kilo Watt peak
kVA	Kilo Volt Amp
LCT	Low Carbon Technologies
LV	Low voltage
MW	Mega Watt
MWh	Megawatt hour
NAC	Nortech ANM Controller
O & M	Operations & Maintenance
PQ	Power quality
PV	Photo Voltaic
SMC	Site Master Controller
STOR	Short Term Operating Reserve
UK	United Kingdom
WPD	Western Power Distribution

Executive Summary

The aim of the Industrial & Commercial Storage project was to develop and demonstrate the benefits of installing battery energy storage systems in an Industrial & Commercial environment behind-the-meter.

The battery energy storage trial was conducted at four different depots within our distribution network i.e. Boston, Spilsby, Cardiff and Taunton. The locations were selected with consideration of size of the depots, local network complexity and occupancy of the buildings. The fundamental operation of the BESS was to store locally generated energy at times of low site load and supply energy at times of high site load in order to actively manage the load presented to the DNO network. For this project the demonstrations included peak shaving, frequency response and loss of mains backup (islanding or microgrid).

The Industrial & Commercial Storage Project can more representatively be described as a programme of work that sought to develop and learn to:

- Respond to intermittent generation; and
- To examine the view that as we do not under present arrangements utilise smarter grid solutions such as flexible demand to reduce peaks or to accommodate a rapid take up of generation on the LV network that this may be due to a lack of deployed suitable technology.
- Demonstrate the viability of integrating BESS in an industrial and commercial environment behind-the-meter;
- Trials of the four use cases defined at the start of the project.

A key outcome of the project was that storage can maximise onsite consumption of generation and reduce peak demand, by time shifting and smoothing the demand presented to the DNO network.

There is a significant opportunity for industrial and commercial energy users to use BESS to participate in the balancing mechanism by either working with aggregators or working autonomously. A frequency meter must be installed to achieve this. The key demand side response services being used today are those procured by National Electricity Transmission (NGET) as System Operator, in order to balance electricity demand and supply and to ensure security and quality of electricity across the GB transmission system. In order to ensure a stable frequency of transmitted electricity, NGET has an obligation to maintain frequency to within 1% of normal system frequency (50Hz).

Onsite storage can also provide a secure back-up asset that guarantees that all commercial and industrial activities continue to receive power if the network suffers from a power cut. This was demonstrated by simulating a power failure and using the BESS to power the affected load, the kitchen. However, suitable firmware must be installed on the BESS to achieve this.

1. Project Background

The UK Government has set some ambitious goals for reducing the amount of greenhouse gases that we as a country emit into the atmosphere. The achievement of these goals will require a dramatic change in how electricity is produced and used, and are likely to have profound effects on the way that electricity distribution networks are operated in the future.

With the growth in low carbon generation, such as wind and solar PV, and the introduction of new demand technologies such as electric vehicles and heat pumps, the potential exists for our electricity networks to experience unprecedented swings between peaks and troughs of energy transfers in localised areas. Part of Western Power Distribution's approach to this challenge has been to look at new and more flexible ways to design, optimise and manage the network in the future.

Battery energy storage systems (BESSs) are one of a number of potential options in the future electrical grid systems providing an array of solutions to many key issues that affect the power system. These issues include: maximising local benefit of renewable generation, time-shifting of energy drawn from a network, peak demand shaving/management of supply capacity, frequency control, and islanding/microgrid support.

Industrial and commercial sector is likely to see a number of relatively small storage projects, tailored to the energy user demand profile, but also opening opportunities for aggregation and provision of services to a DNO. The main drivers for storage deployment are:

1. Growing benefits for peak shaving
2. Aggregation propositions are increasing
3. Falling energy storage system costs
4. Growing customer awareness and confidence

2. Scope and Objectives

This project aimed to further our understanding of BESSs connected behind-the-meter and the potential impact of different operating regimes on the immediate sites, and the distribution systems that they were connected to.

Table 1: Objectives and Achievement Status

Objective	Status
Defer network reinforcement investment -	✓
Alleviate constraints on the distribution system by reducing demand peaks.	✓
Maximising on-site consumption of renewable energy resources	✓
Clarifying and streamlining the position of storage in different regulatory environments (behind-the-meter, third party service, grid operation)	✓
Assessing different connection options concerning BESS	✓
Access to flexible markets.	✓

Due to our restrictions in entering into commercial agreements, the project did 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).

3. Success Criteria

The established success criteria reflected the basic project approach. Each criterion has been successfully completed, and they are shown in Table 2. Further information on this is contained in Section 5 and in Section 9.

Table 2: Success Criteria

Success Criteria	Status
Recruitment - Appointment of a supplier through a tender process	✓
Relationship with Supplier – Defining case studies to demonstrate the different applications of BESS. Ensuring that delivery is to time and budget.	✓
Network - Identification of host sites	✓
Technology of Energy Storage Systems (ESS) - A comprehensive review of technology is presented	✓
Demonstration – Demonstration of potentially beneficial capabilities of BESSs	✓
Knowledge - Document and share all key learning	✓
Operational – Provide appropriate training on the management of installed systems	✓

4. Details of Work Carried Out

4.1 Project Overview

The project Installed behind-the-meter BESSs to four separate sites within WPD, each with existing PV, and generated learning from the process. A detailed project plan for each site was created to install and commission the equipment. The four BESS were operated according to site use cases which were defined at the start of the project.

The project team established schedules and undertook manual operations as required to implement the use cases. The data from the four sites was produced and analysed by the project team. In the main, the system architecture was configured as in Figures 1 and 2 below but modifications were made depending on site conditions and the use case.

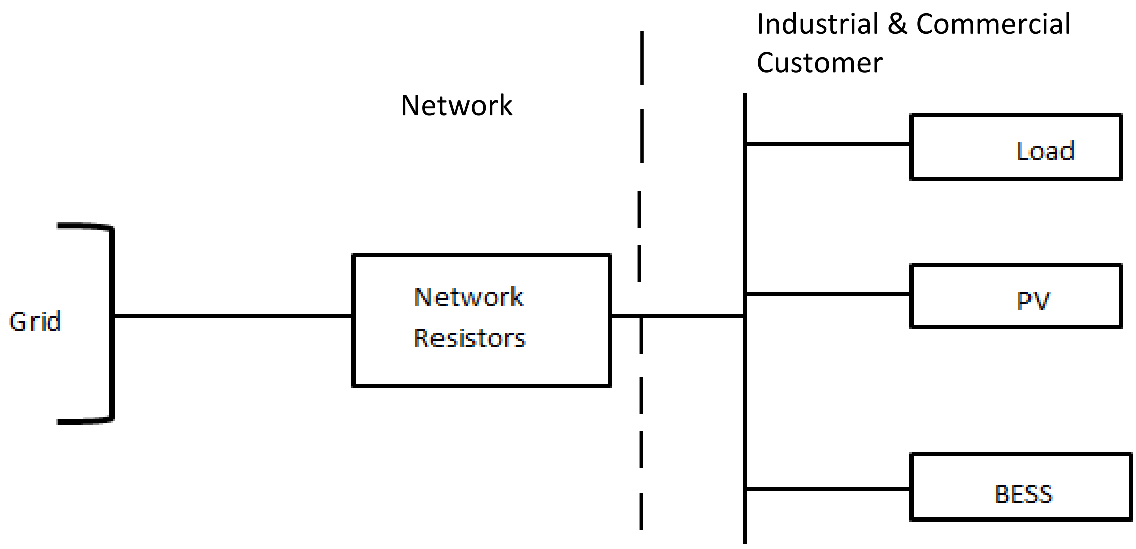

Figure 1: Simplified electrical diagram of the system arrangement

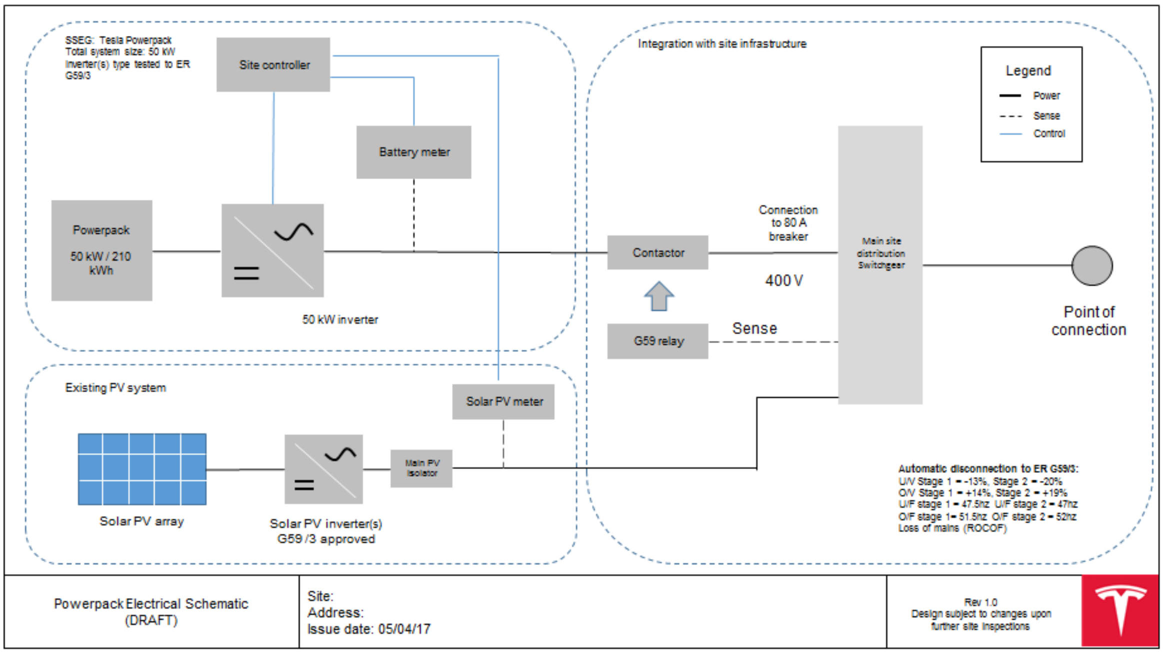

Figure 2: General installation

The installed BESSs were rated at 50kW, 210kWh and could be scaled in terms of energy and power as needed. The rating of the photovoltaic (PV) system was different for each site. The details are included in Appendix A, Table 8.

4.2 Use Cases

Active control by WPD – (implemented at Boston)

This use case was looking at the different control modes available for the active (P) and reactive (Q) power transfer from the Powerpack. A Nortech-supplied ANM (active network management) controller was installed at the Boston depot to interface with and control the Powerpack. The ANM controller was capable of enabling remote control and monitoring of the Powerpack via Nortech's iHost web platform.

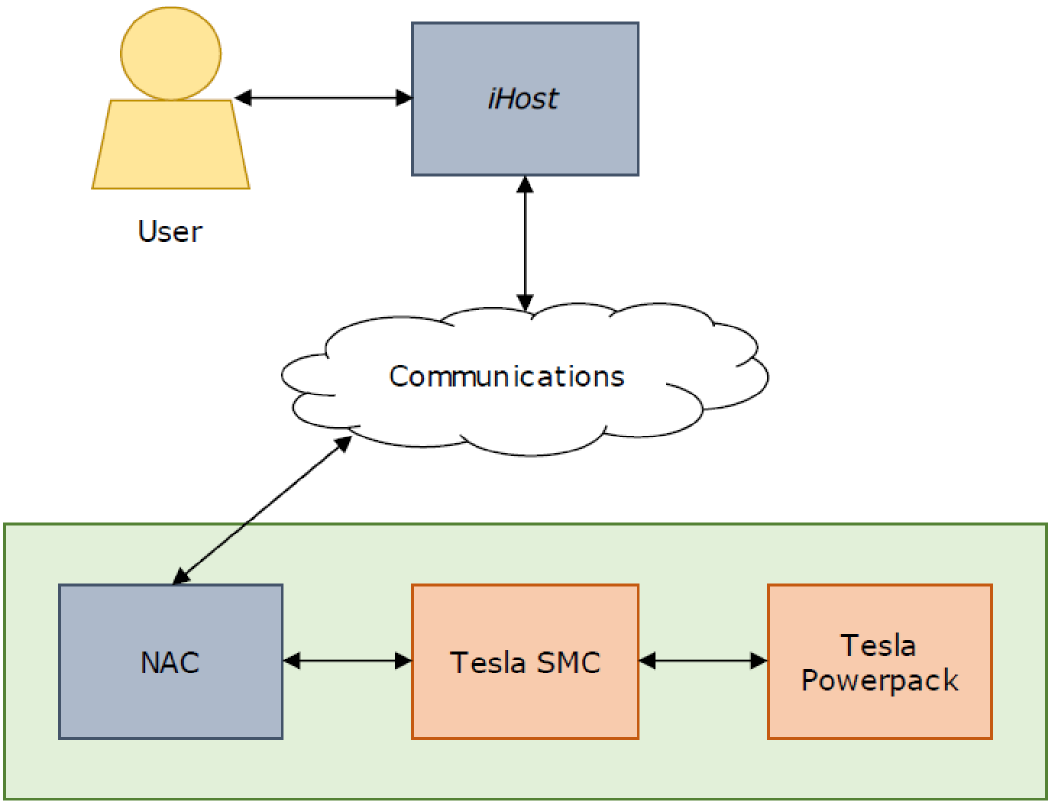

Figure 3: Control system architecture at Boston

Figure 3 above summarises the control architecture that was used to control and interface with the Tesla Powerpack battery storage installation at Boston Depot. The main components are:

- User: an authorised person who can use the iHost web interface to control and monitor the Powerpack.
- iHost: Nortech's server-based control and monitoring platform. This includes a database of monitored data and allows the user to log in and use the web-browser interface to view monitored data and send control commands to the NAC (Nortech ANM Controller).

- Communications: the GSM/3G cellular telecommunications network provides the bi-directional communication link between iHost and the NAC, allowing commands to be sent from iHost to the NAC, and monitoring data to be sent from the NAC back to iHost.
- NAC: located at the Boston Depot, this serves as an interface between the remote control and monitoring system (iHost) and the Powerpack (via the SMC -Site master Controller). The NAC will either act to pass-through commands from iHost or autonomously generate commands locally.
- Tesla SMC: located at Boston Depot, the SMC is the overall controller for the Powerpack and interfaces directly with the battery packs and inverter. It has a MODBUS (over TCP) interface for control and monitoring which the NAC will utilise.
- Tesla Powerpack: this consists of the battery packs, inverter, wiring, and ancillary systems

Control Modes & Algorithms

Two separate control modes were tested at Boston.

1. User-Defined Profile Control

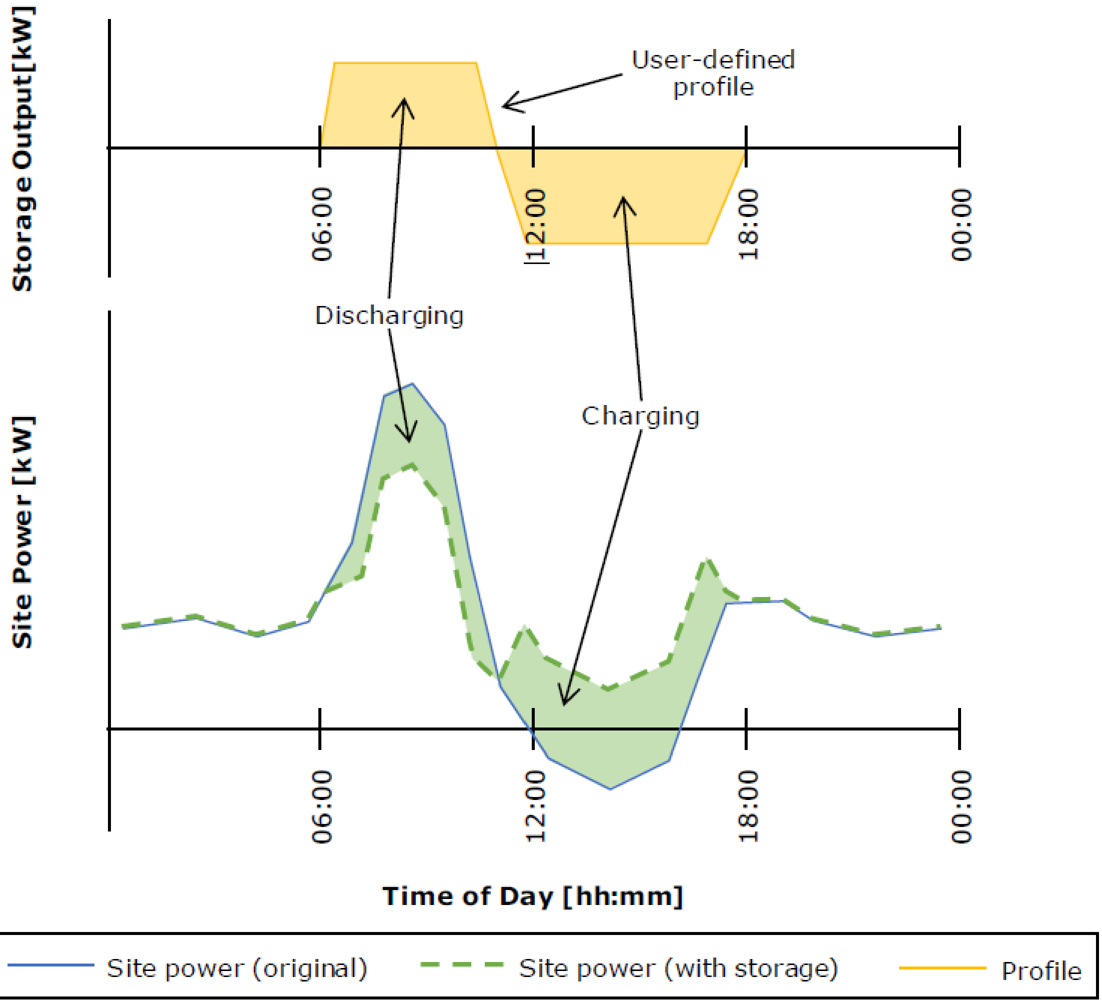

Figure 4: Illustration of user-defined profile for controlling the Powerpack

In this control mode, the ANM controller would control the Powerpack to follow a pre-defined charge and discharge profile.
The profiles were set for different time spans (e.g. individual days or a whole week).

2. Site Import/Export Limiting Control

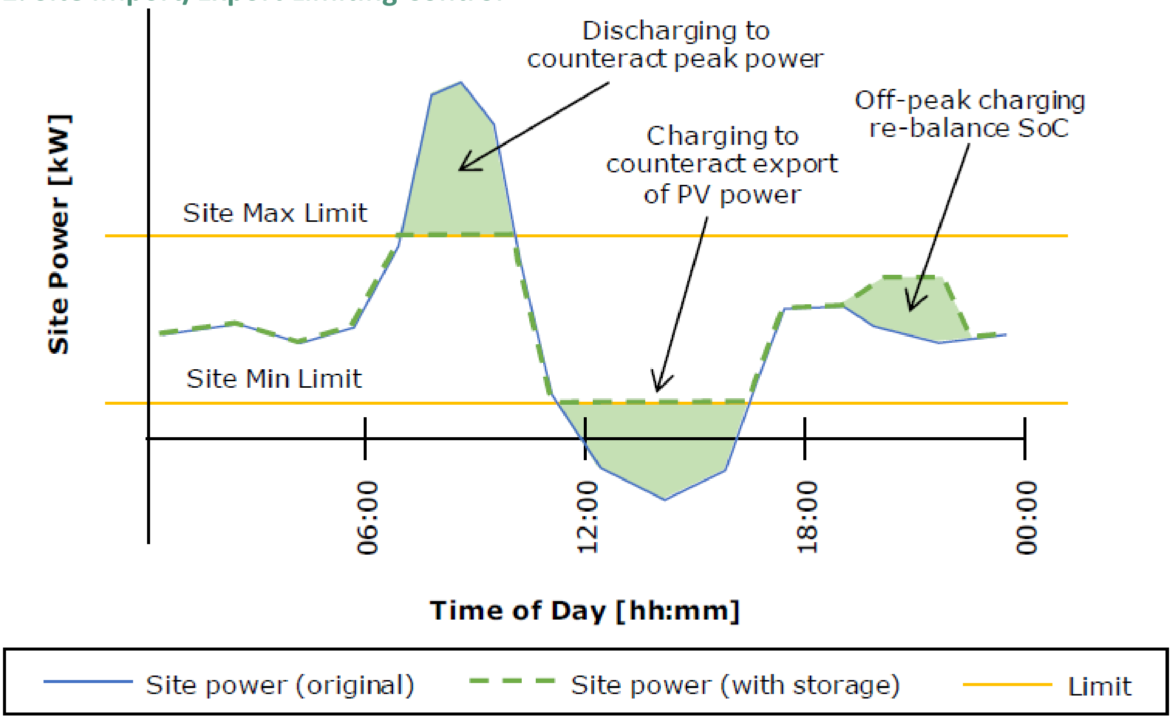

Figure 5: Illustration of site import/export limiting control mode

In this control mode, the Powerpack was used to limit the maximum site import and export. Import would be limited by discharging the Powerpack, which would help reduce the peak energy use. Site export would be limited by charging the Powerpack, which could be used to prevent reverse power flow from the PV and store that energy for later use. Over a day (or a longer time window such as a complete week), the Powerpack SoC would be maintained at a target value by controlled charging or discharging during an off-peak period.
The maximum and minimum site import/export limits would be user-defined parameters that could be changed via the iHost web interface.

Peak shaving - Spilsby

In this demonstration, the Powerpack was actively charging with the excess solar generation during daytime. When the solar output was not enough to cover the load consumption, the Powerpack was discharging so the site was able to use the locally stored energy.

Power demand varies from time to time in accordance with customers' activities. Industrial customers often face peak loads on site by heavy machinery start-ups or other short heavy energy demanding events. Powerpacks help to lower those peaky energy demands by providing additional locally stored energy to create a smoother consumption profile.

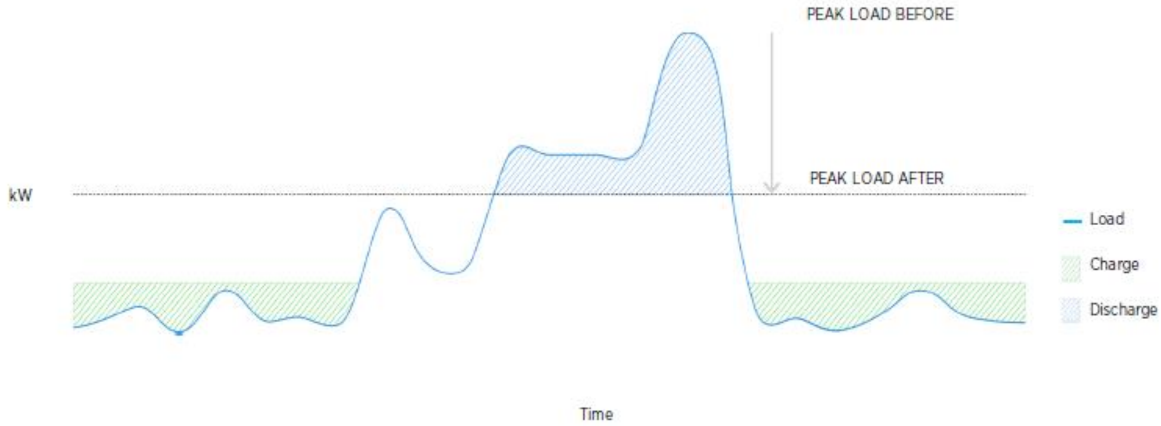

Figure 6: Illustration of peak shaving

UK "standard" battery storage approach - FFR – Cardiff

Two methods were used to demonstrate this use case at Cardiff. The Powerpack was tested autonomously and also in conjunction with an aggregator. Details of this demonstration are covered in later sections.

There is a significant market opportunity for industrial and commercial energy users to use electricity storage, especially as behind-the-meter applications to offer additional options such as frequency regulation. Adding a BESS system to an aggregation setup can bridge the gap in response time for a much large portfolio. A frequency sensitive relay needs to be installed and supplied by the service provider and the minimum requirement is that the relay needs to be within a 0.01Hz tolerance.

Energy storage providers can participate in FFR either by generation increase or decrease based on the system frequency (dynamic) or a static trigger level.
Energy storage providers may have unique characteristics which may be different to the current providers. Aggregators do normally provide support with deployment, including the smart software required.

Figure 7: Illustration of FFR on the KiwiPower platform

Microgrid Test Bed (Backup) - Taunton

In this use case, the load from the kitchen was used for the demonstration. BESS was used as a back-up asset to ensure uninterruptable operation of the kitchen loads by simulating the failure of the network from a power cut. This was carried out manually and observed for prolonged periods. Specialist equipment and software must be included to ensure safe disconnection from the network.

4.3 Site selection, Site Connection Agreements, and construction

Four sites with PV generation were identified for the trial. An application to connect to the distribution network for each site was submitted and a connection agreement with the local Distribution Network prior to the connection of any energy storage device was made. Further details on site selection and connection agreements including modelling can be found in Appendix A.

4.3.1 Construction

Working with local personnel, was important in ensuring that the most suitable siting was achieved. This was achieved in different ways as four sites were all different. The eventual location and arrangement of the battery storage system was dictated by the pre-existing arrangement of other equipment and availability of space. The siting considerations took into account:

- Visibility: The design and layout of a battery storage system should not adversely affect the views in the vicinity of its location and other surface mounted equipment
- Environmental conditions: Appearance
- Access: Battery system modules should be mounted where it is possible to improve self-cleaning and access to various units and modules

Boston – Construction Activities

Figure 8: Before installation

Figure 9: Plinth

Cardiff

Figure 10: Position for the plinth

Figure 11: Battery Units Lifted by Crane

Spilsby

Figure 12: Location of Battery Units

Figure 13: Plinth for the Battery Units

Taunton

Figure 14: 75m cable run at Taunton

Figure 15: Basement at Taunton

4.3.2 Commissioning

Table 3: Construction Activities and Commissioning

Site name	Delivery date	Install start date	Install completion date
Boston	30/06/2017	17/07/2017	25/07/2017
Cardiff	29/06/2017	17/07/2017	21/07/2017
Spilsby	30/07/2017	03/07/2017	27/07/2017
Taunton	29/07/2017	21/08/2017	25/08/2017

Commissioning procedures included full inspection and testing (visual, electrical and functional testing) of the complete system according to the requirements and the appropriate ENA Engineering Recommendations, G59/G100. The witnessed test of the operation of the G59 relay was carried out prior to connecting the system to the distribution network.

A complete operations and maintenance (O&M) manual was provided to each site and that included:

- Copies of all commissioning, inspection, testing and risk assessment documents
- Copies of the grid connection agreement and protection settings, G59 Test results & report
- System technical specifications

- Copies of as-built system drawings
- Component manufacturer's manuals
- Warranty/ guarantee details
- Operating instructions
- Maintenance instructions and schedule

4.3.3 Earthing Provisions in Off-Grid Operation

Additional independent earthing was provided (as required by BS 7671 and BS 7430) to ensure a continuation of earthing when the system was disconnected from the distribution network at Taunton.

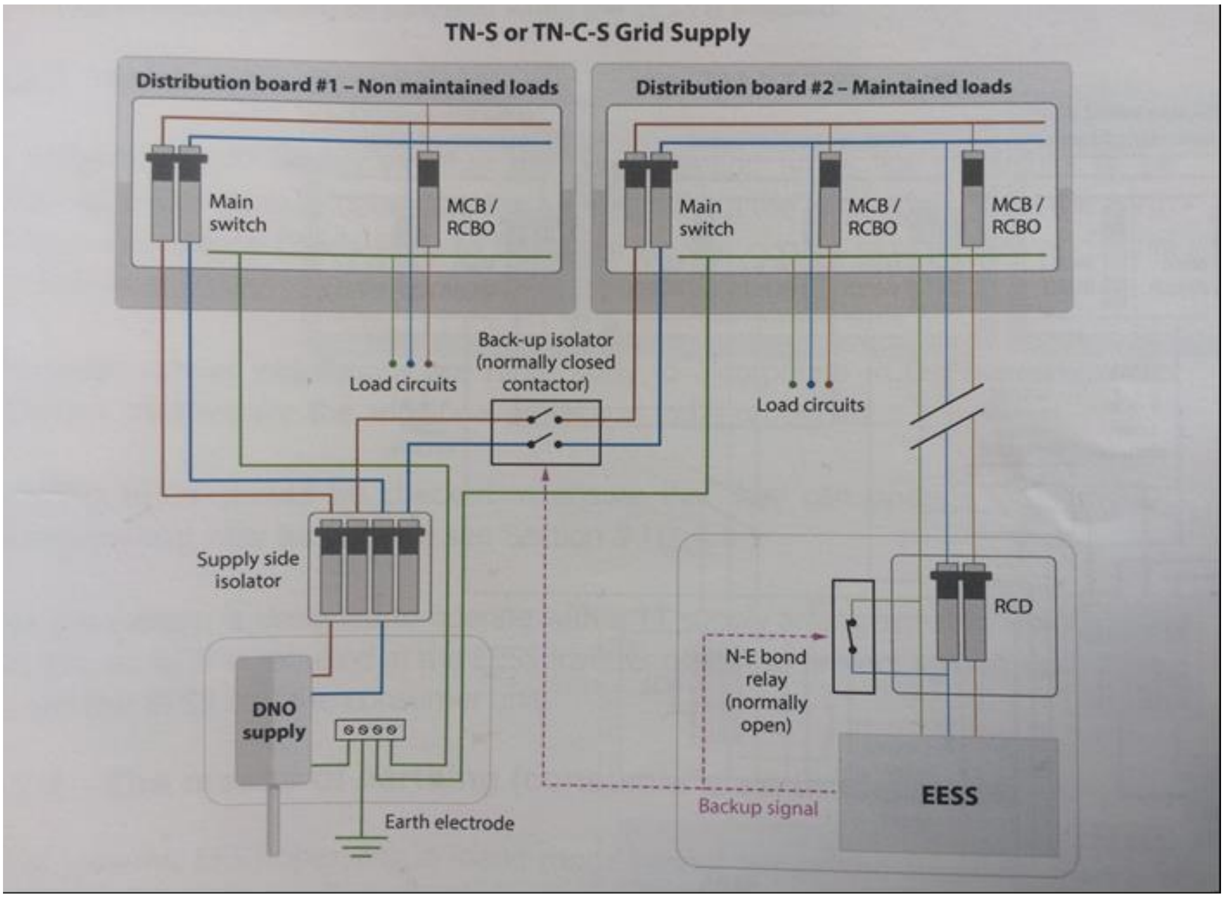

Figure 16: Earthing Arrangements at Taunton

4.4 Use Cases explained

4.4.1 Use Case 1: WPD Control – Boston

Below is the schematic for the electrical wiring at Boston.

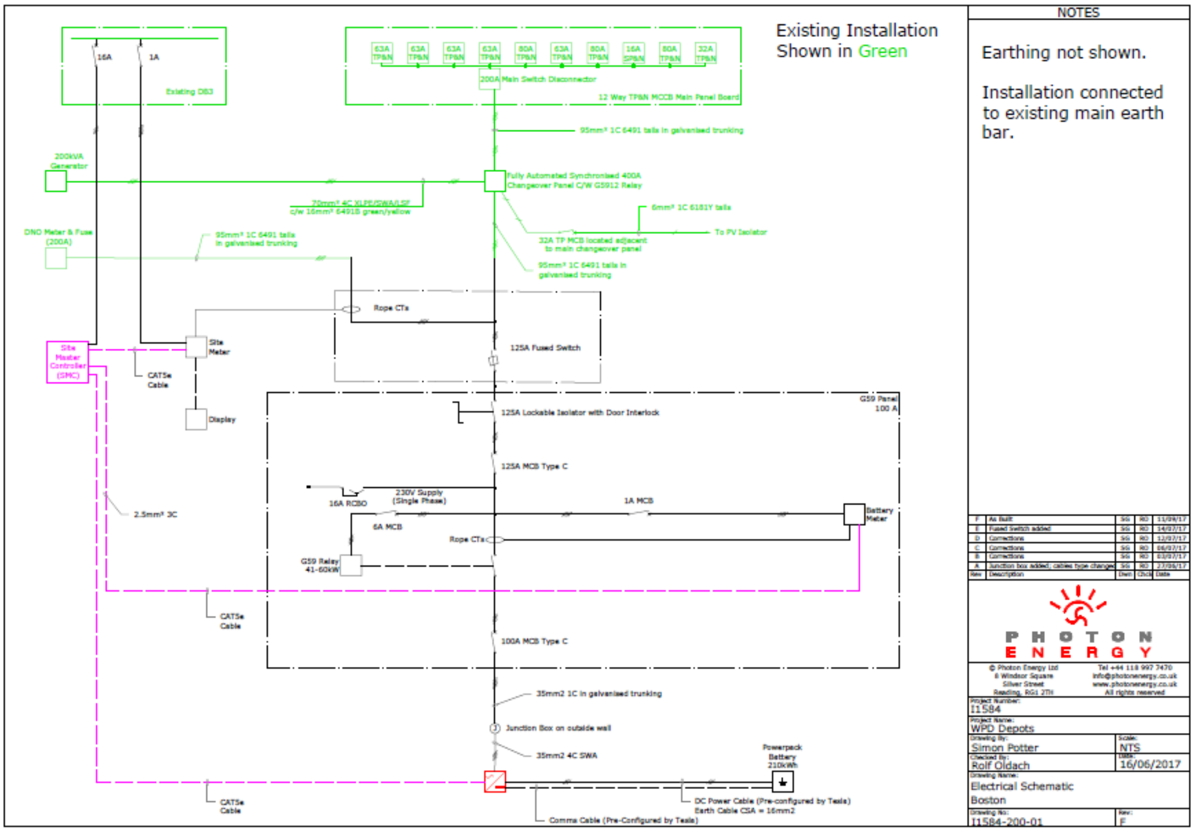

Figure 17: Electrical schematic Boston

Boston was set up to trial different schedules using the Nortech controller. This required commissioning the controller interface with the Powerpack. There were a couple of configuration changes made in order to get all signals and commands working with the BESS. Third party controller integration allows the Powerpack user to change the batteries behaviour during the operations. Therefore the battery will respond to active / reactive power commands given by the user / Nortech through the installed controller. As shown in Figure 18, the Nortech controller was installed next to the Tesla Powerpack Site Master Controller, with Modbus protocol over Ethernet used as the interface between the two. The Nortech controller has a 3G cellular connection in to Nortech's iHost web platform for remote control and monitoring.

Figure 18: Controller Installation at WPD Boston Depot; Tesla Powerpack Site Master Controller is on the left, Nortech Controller is on the right.

The Nortech controller was installed in December 2017 and initially ran in a monitoring-only role, collecting data on power use on site and on the behaviour of the Powerpack, which was operating using an internal program.

Two operation modes were developed and trialled for the Nortech controller:

1. Remote control, where a remote user can directly adjust the output of the Powerpack through Nortech's iHost web platform; and
2. Autonomous control, where the Powerpack was dispatched based on a schedule held locally to the controller.

Remote Control Operation

The Nortech controller was set to command the Powerpack autonomously from a schedule by default but this could be interrupted at any point for remote operation from Nortech's iHost web platform. The iHost interface, illustrated in Figure 19, allowed the user to view many parameters reported back from the Powerpack and also to send remote control commands to the Powerpack.

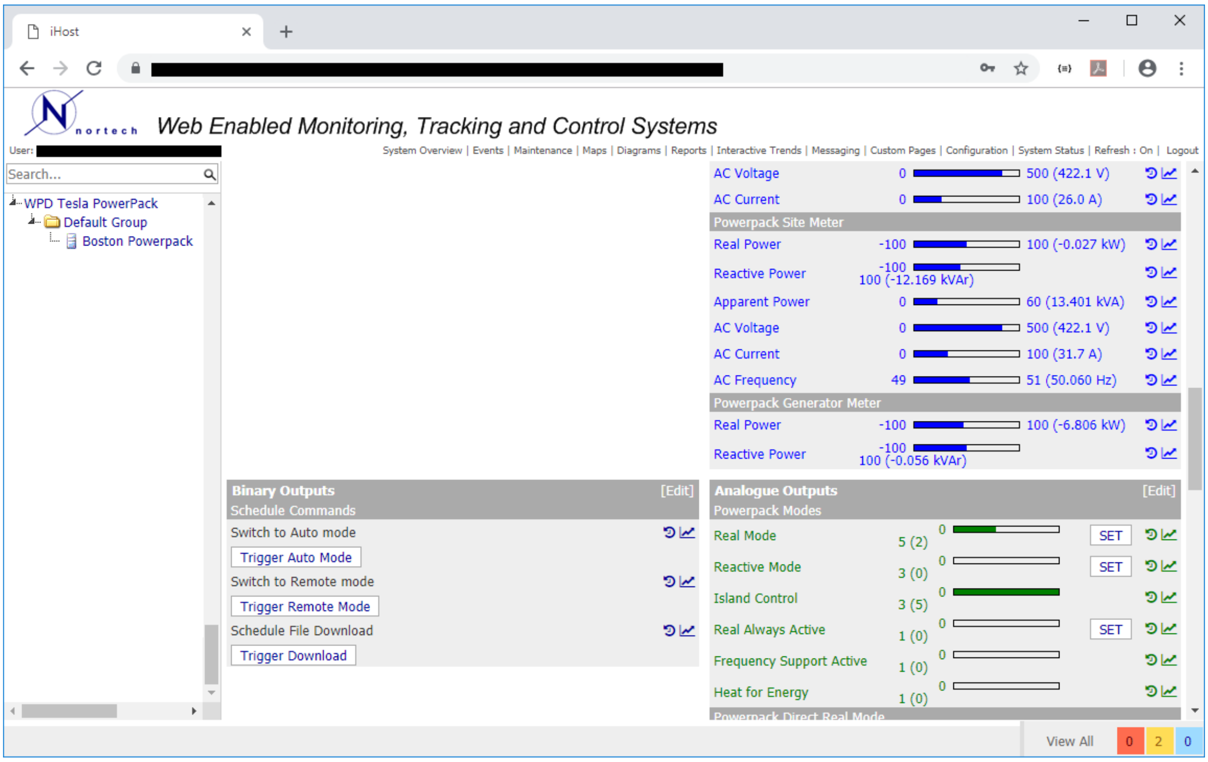

Figure 19: Example Remote Control View on Nortech's iHost Platform

The remote control functionality was tested on 7th September 2018, and the results are presented in Figure 20. Initially the Nortech controller was running on a schedule, which was interrupted by a remote user setting a new real power command (20 kW) for the Powerpack at 10:39 and then sending a remote command to the Nortech controller to switch from schedule to remote operation.

The Powerpack responds to the command and outputs 20 kW at 10:41. Next, from 10:53, the reactive power output is varied by remote command: first to -10 kVAr, then to +10 kVAr. The response to these commands by the Powerpack is clearly shown in the figure. At 11:08 remote commands set the Powerpack to zero output. Finally, at 11:12 the Nortech controller is set back in to schedule mode and the schedule is re-established by the controller issuing several commands (not shown in the figure) to set up the correct outputs for that point in the schedule.

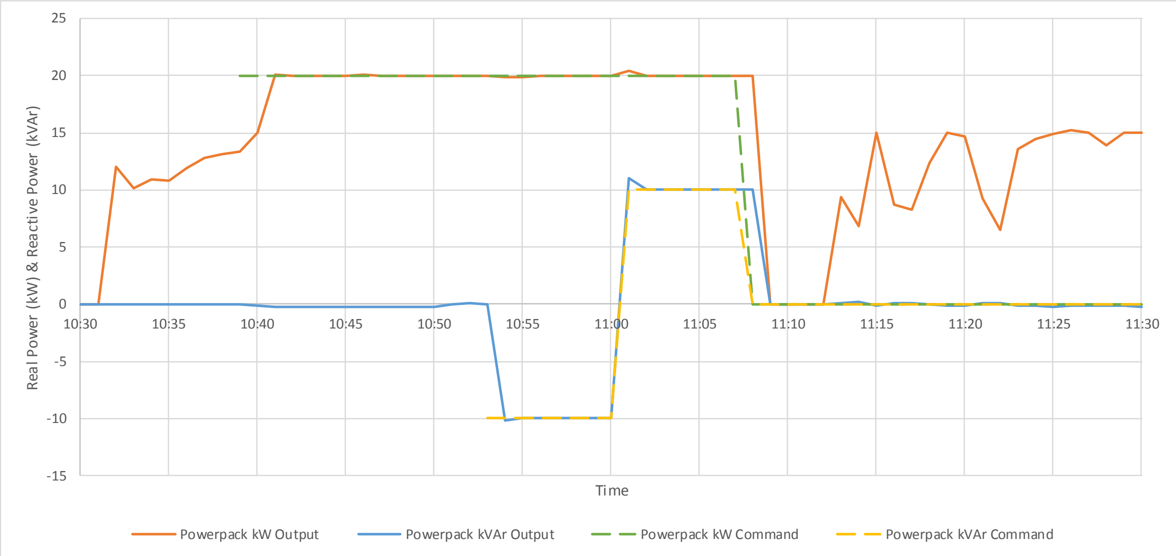

Figure 20: Illustration of Remote Operation Interrupting Scheduled Commands

Autonomous (Schedule) Operation

The functionality of the Nortech controller was developed to allow commands to be dispatched to the Tesla Powerpack based on a schedule held locally to the controller. The schedule was in the form of a JSON file, which could be remotely uploaded on to the controller to change the schedule. Each schedule contained a number of "sequences", which were time-ordered lists of commands to execute, with second-by-second resolution. Each schedule also contained a number of "triggers", which initiated a particular sequence depending on certain conditions, such as the start of the new week.

A weekly schedule was created to run on the Nortech controller. This schedule had several simultaneous objectives that were achieved by sending the relevant commands to the Tesla Powerpack:
Energy time shifting: The Boston site had different energy tariffs for on-peak (7 am to midnight) and off-peak periods. It was therefore financially useful to use the Powerpack to time shift energy use from on-peak hours to off-peak. This was achieved by charging the battery overnight and discharging during the day. Some battery capacity was reserved at the top and bottom of the range meaning a target of 150 kWh could be offset every day.

1. Self-consumption / export limiting: Using the energy produced by the on-site PV installation was more cost efficient than exporting any of that energy to the grid, so the battery was commanded to charge in the event of any net power export from site.
2. Peak limiting: During on-peak hours, the battery was commanded to operate in order to limit the net site import to a maximum of 25 kW, thus reducing the peak power.

The figures below illustrate the operation of the schedule for an example day, in this case the 1st August 2018.

In Figure 21, the export and peak limiting commands from the schedule are shown. During the off-peak hours, the battery is commanded to charge whilst respecting a 40 kW net import power limit for the site. At 7am, the on peak period begins, and the battery is commanded to limit net site import power to 25 kW. During this time the battery is also set to discharge as part of energy shifting; however, whenever the net site import approaches zero the Powerpack reduces its output to prevent a net export.

In Figure 23 the battery state of energy over the course of a day is shown, along with the state of energy targets. During the off-peak period, the battery is commanded to charge to reach 190 kWh at a maximum charge rate of 30 kW (the charge power can be seen in Figure 21). Once the state of energy target is reached, the Powerpack stops charging. Once the on-peak period begins at 7am, the Powerpack is commanded to discharge to a target of 40 kWh at a maximum rate of 15 kW, which is achieved by 6pm for the example day shown. At all times the Powerpack is allowed to exceed the scheduled charge and discharge limits in order to keep the net site power within the import and export limits.

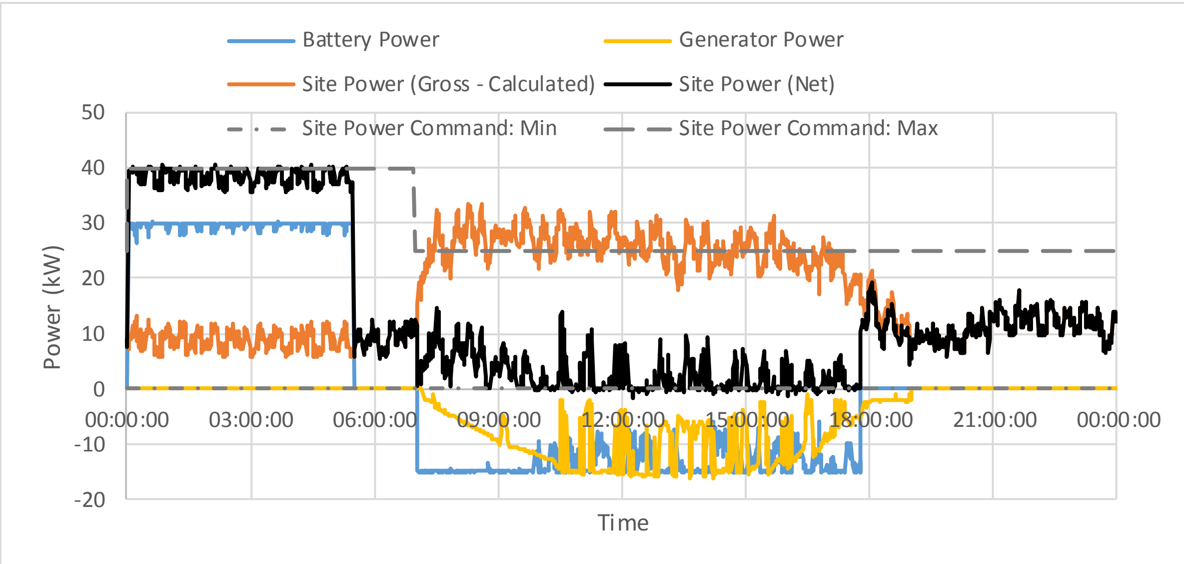

Figure 21: Illustration of Export and Peak Limiting during Schedule Operation at Boston Depot, 1st August 2018

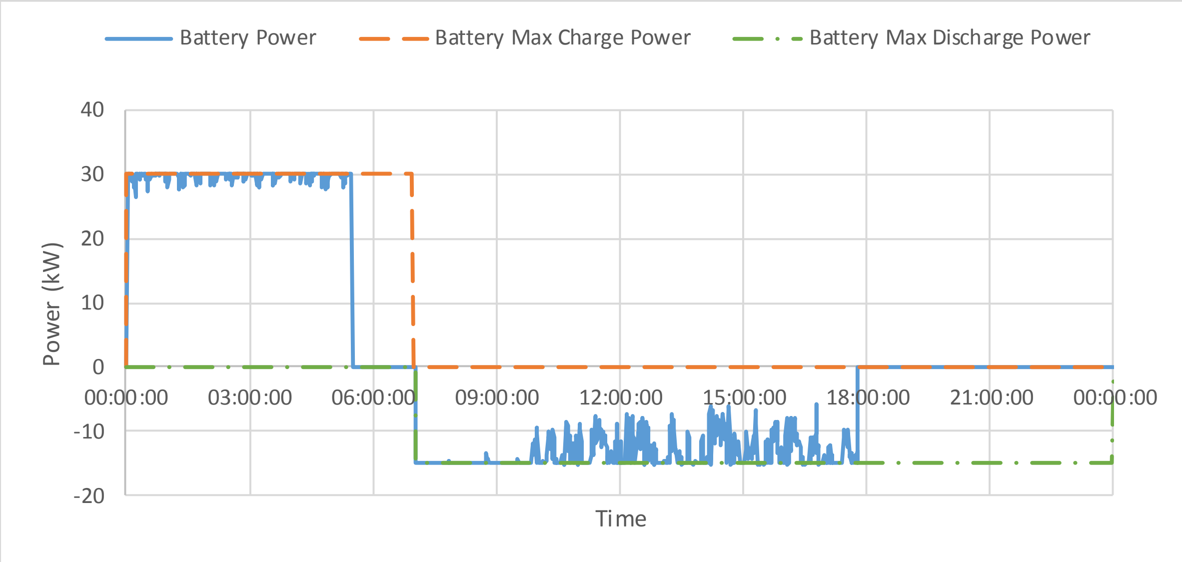

Figure 22: Showing Battery Charge/Discharge Limits

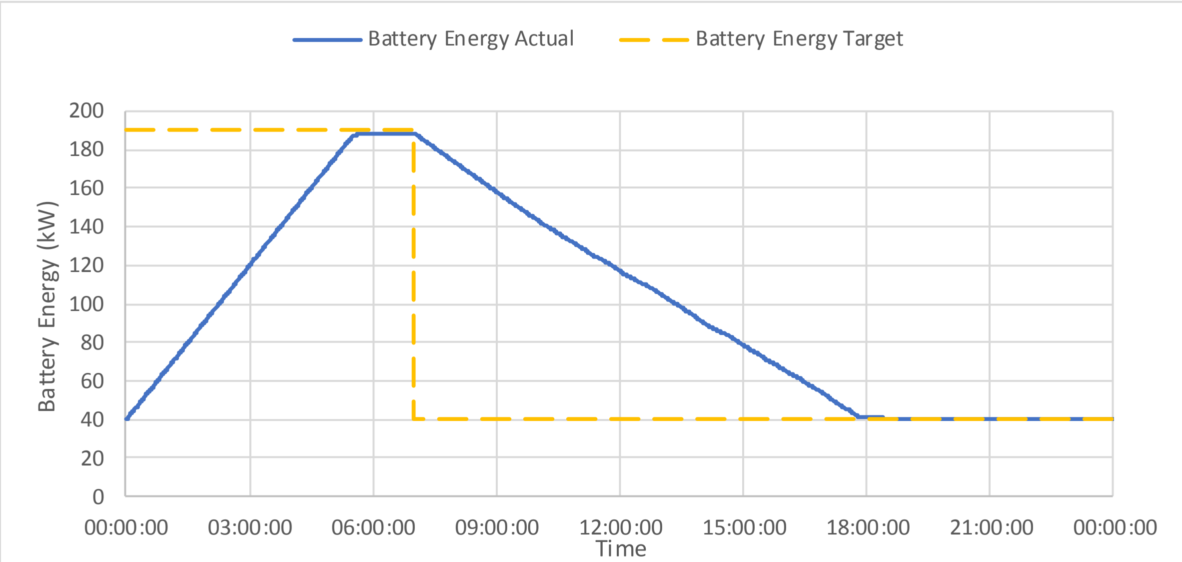

Figure 23: Illustration of Energy Shifting during Schedule Operation at Boston Depot, 1st August 2018

Results

The schedule was first set up in March 2018, so the 6 month period from April to September 2018 for which full months of data were available have been analysed.

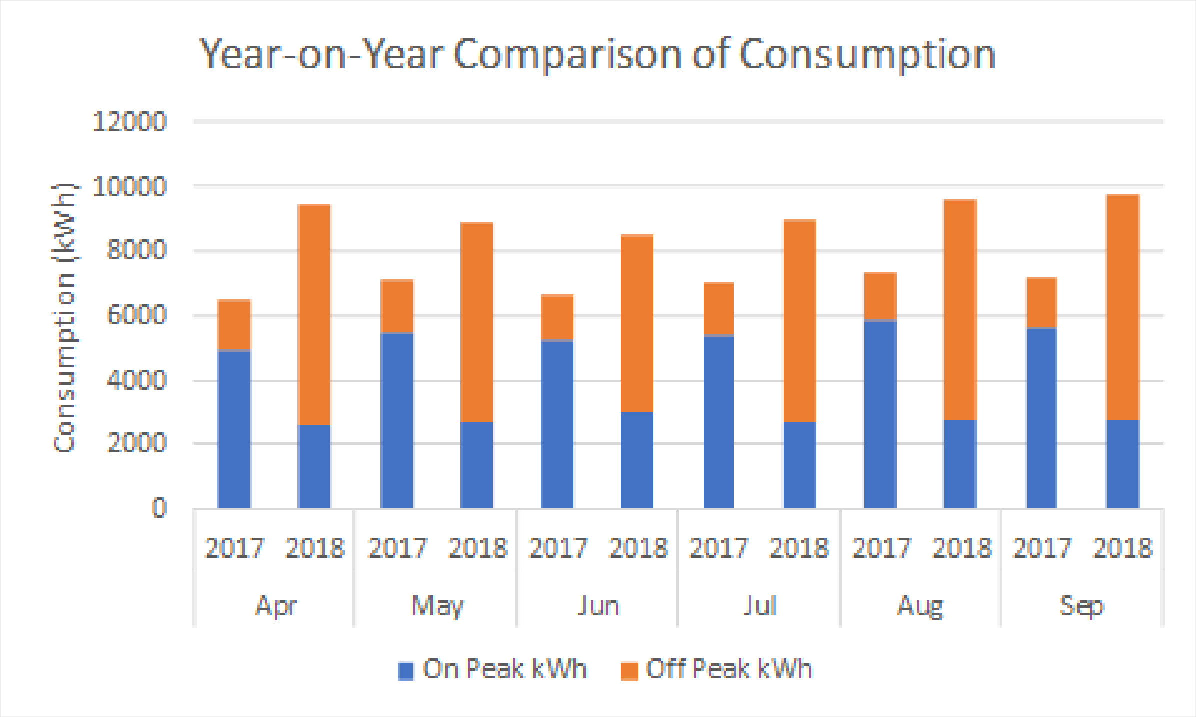

Figure 24: Year-on-Year Comparison of Boston Depot Energy Consumption

One of the objectives of the Powerpack schedule trial was energy shifting. Figure 24 shows a comparison of the metered energy consumption at the Boston depot for the months in 2018 where the Powerpack was operating under the schedule to the same months in 2017 before the Powerpack was operational. The figure shows clearly that energy has overwhelmingly been shifted from on-peak to off-peak periods, which is the result of the Powerpack and the schedule that commands it. For the months in 2017 an average of 22% of consumption was off-peak, whilst for the same months in 2018 an average of 70% of consumption was off-peak. From detailed 1 minute resolution data collected from the Powerpack and stored on iHost, it is possible to estimate that on average 124 kWh of energy was shifted every day.

Also shown in Figure 24 is a marked increase in total consumption. For example, April has the largest increase of 44%. In total, consumption was 13273 kWh (32%) higher for the same 6 month period in 2018 than it was for 2017, an average of 72.5 kWh per day. Detailed analysis of data from iHost revealed that the losses from the Powerpack only accounted for approximately 15.7 kWh increased consumption per day (22%) so the change in consumption must be from a change in site use or equipment unconnected with the trial.

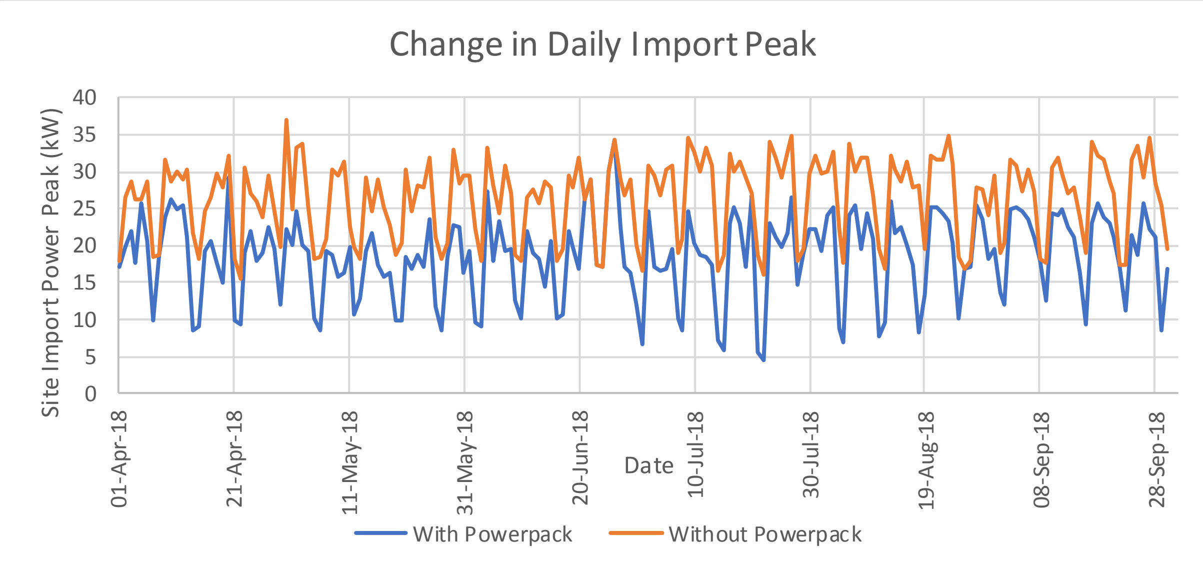

Figure 25: Daily Import Peak at Boston Depot with Powerpack and Without (estimated)

Another objective of the Powerpack schedule was to peak limit. Figure 25 shows the daily peak site import power, taken from 1 minute resolution data collected on iHost. The peak that would have occurred if the Powerpack was not operating is also shown, which has been estimated from subtracting the Powerpack power measurements from the site power measurements. Without the Powerpack, the daily peak is estimated to be on average 26.4 kW, and would have exceeded the 25 kW target on 121 (66%) of days within the 6 month period. However, with the Powerpack, the average peak was 18.6 kW and the 25 kW target was exceeded on only 21 days (11.5%), and the excess was often less than 1 kW for a short period of time.

Alongside energy shifting and peak shaving, the Powerpack schedule also had the objective of preventing export. Figure 21 below illustrates all three of these objectives in action. The figure is a cumulative frequency plot of the net site import power for all the on peak periods in the 6 months based on 1 minute samples. The two curves are for the cumulative frequency of the net power as measured on site ("With Powerpack") and an estimate of the net power if the Powerpack was not operating ("Without Powerpack").

To the far left of Figure 21, there are negative values of net import – in other words, when power was being exported from site, which will have been when the solar PV power was greater than the site load. Over the 6 months, the Powerpack stored 330 kWh of energy from the solar PV and out of this, 322 kWh would otherwise have been exported to the grid. This energy was stored and used later, and prevented imports, as can be seen in the figure the frequency of export with the Powerpack is much less than the estimate for the export with no Powerpack.
The effect of energy shifting can be seen in Figure 26 by the "With Powerpack" curve being lower than the "Without Powerpack" for almost all the time. The area between the curves represents the energy shifted. Interestingly, with the Powerpack in operation, there was zero net site import for over 35% of the time, whereas that would have been extremely rare with no Powerpack.

Figure 26 also shows the effect of peak shaving, in that the maximum power values to the right are much lower with the Powerpack, and less than 0.1% of the time did the net site import exceed 25 kW. Without the Powerpack, 25 kW import or greater would have occurred an estimated 2.2% of the time.

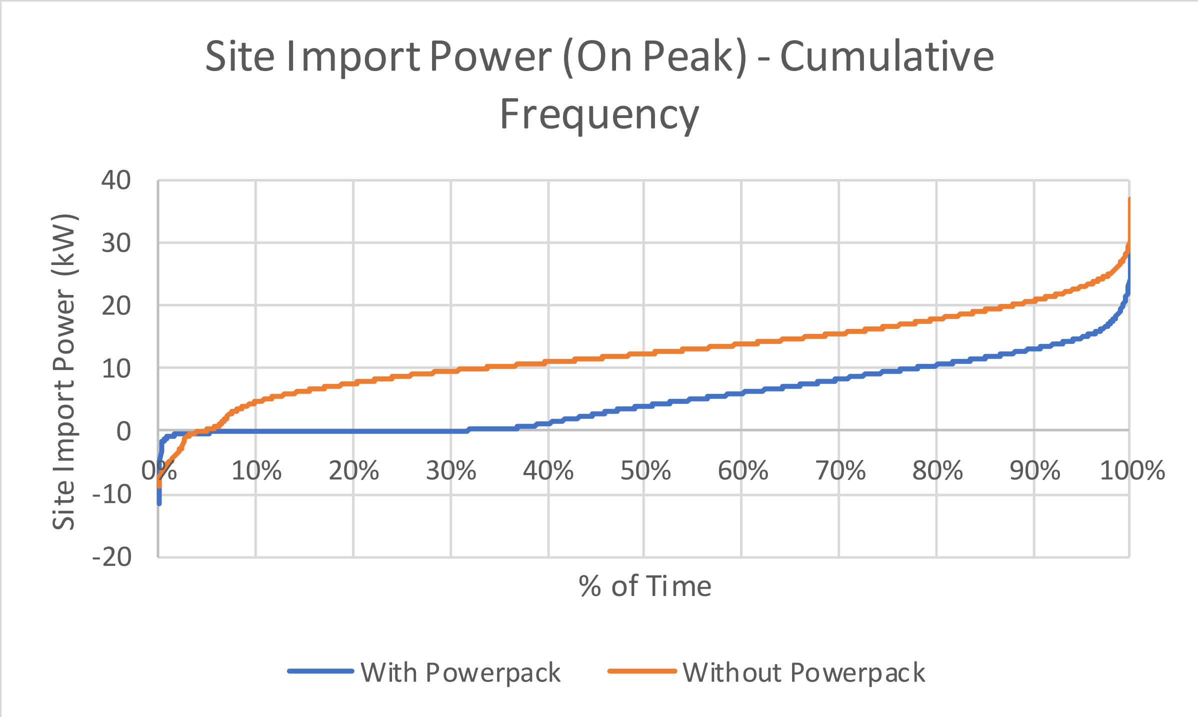

Figure 26: Cumulative Frequency Plot of Site Import Power, based on 1 Minute Samples

MP Visit Press Release and Photos

The area MP for Boston and Skegness, Matt Warman, paid a return visit to Western Power Distribution (WPD) on Wednesday 27 September 2018 to find out more about the future of the energy industry. Matt Warman also spoke to staff from the Boston depot including apprentices to learn about WPD's Industrial and commercial project as well as other sustainability activities at the depot.

Matt Warman commented:
"The Boston Depot is one of the four in the country to be using a new Tesla battery to both store energy generated by solar panels and produce energy at times of peak usage, helping smooth out the peaks and troughs of demand and, in extreme circumstances, provide emergency power.

I also took a look at some of WPD's power lines that form their East Midlands network, in one of the five helicopters used to inspect over 1 million poles and towers since 2015"

After the visit, Matt Warman posted some good pictures on twitter, including one in front of the battery:
https://twitter.com/mattwarman/status/913340794739871744

Warman also posted a more extensive write up on Facebook:

https://www.facebook.com/WarmanforBostonSkegness/posts/1562425580447152

WPD's Faithful Chanda, who was leading the Industrial and Commercial Storage trial, said: "Innovation has always been a key part of WPD's development strategy and our ability to take an innovative approach to day-to-day working and the problems that we face has made us a leader in our industry. We were delighted to host this visit. This trial will help us determine the feasibility of this type of exciting new technology in supporting the electricity network in the future. Funded through Ofgem's Network Innovation Allowance, the project is designed to understand the potential role of installing and using battery storage systems".

Figure 27: MP Visit to Boston

4.4.2 Use Case 2: Grid Services (Firm Frequency Response) - Cardiff

This use case was demonstrating the application of BESS to achieve Firm Frequency Response. The key demand side response services being used today are those procured by National Electricity Transmission (NGET) as System Operator, in order to balance electricity demand and supply and to ensure security and quality of electricity across the GB transmission system. In order to ensure a stable frequency of transmitted electricity, NGET has an obligation to maintain frequency to within 1% of normal system frequency (50Hz).

The bulk of the aggregator's resources are currently sourced through contracts with onsite generators, although increasingly aggregators are entering into contracts with demand sites. Currently there are a small number of aggregators operating in the UK electricity market. Some of the more established actors include Flexitricity, KiwiPower, Open Energi, and Energy Pool. Procurement of FFR is via a competitive tender process which runs once a month.

A key feature of the electrical installation at Cardiff was the installation of the frequency meter which was required to manipulate the frequency. The schematic for the electrical connection at Cardiff is in Appendix B.

Part 1: Providing Grid Services Autonomously

The Powerpack is capable to run autonomously in frequency support mode, which let the system measure the frequency locally and react to that by charging or discharging power. One of the advantages of the stationary battery systems is the reaction time, which allows them to perform fast grid frequency support to stabilize the grid to 50Hz.

Part 2: Integration of KiwiPower Third Party Controller

The following hardware was installed at Cardiff to enable testing FFR using the KiwiPower controller:

Table 4: KiwiPower hardware

Item	Overview	Purpose	Power requirements
KiWi Fruit + metering segment	KiWi Proprietary Hardware for controlling battery systems	Control System reads power/frequency measurements and issues power/kW setpoint commands to the Tesla controller.	10W, 230V
Switch	Ethernet switch	Ethernet network switch/hub to enable the KiWi Fruit to communicate with multiple devices	10W, 230V
Ethernet cable (X4)	Local MODBUS TCP	Connection between	N/A

	connection	KiWi Fruit and the Tesla Powerpack controller to enable 2way communications (MODBUS)	
	KiWi Cloud Services connection	Connection to the internet to enable Fruit to connect to the KiWi servers	N/A
Multicore and wiring works	Switch connection	Connection between KiWi Fruit and Ethernet switch	N/A
Electrical cold commissioning	Power metering connection	Connection to power meter(s) to enable Fruit to measure power	N/A

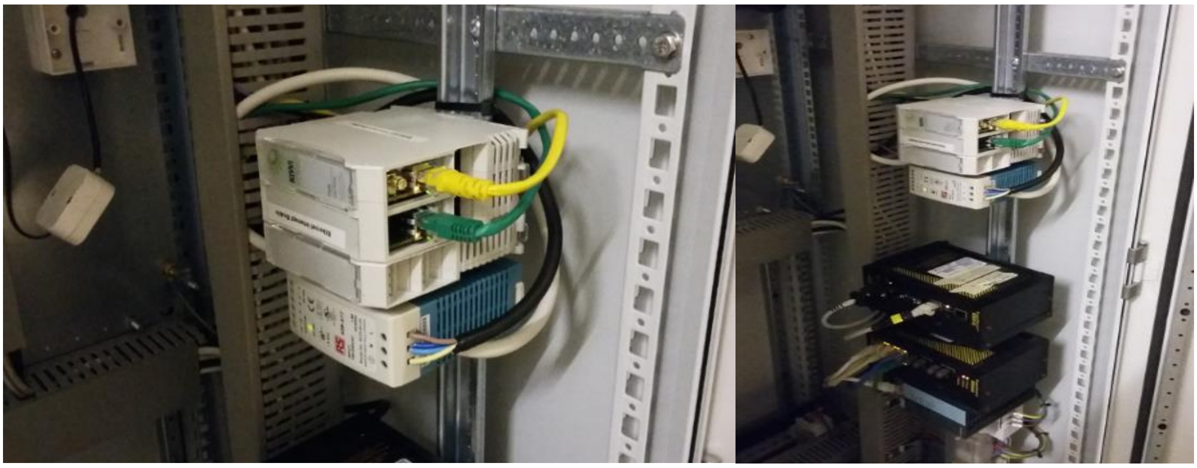

Figure 28: KiwiPower Fruit Controller

Figure 29 below shows the locally measured frequency (purple) and the resulting battery power output (blue) in frequency regulation mode.

The battery energy storage system receives the power target through a locally installed third party controller, the KiwiPower Fruit Controller. The controller sends power commands to the battery energy storage system based on a measurement of grid frequency.

The diagram shows how the battery energy storage system power output is dynamically adjusted to react to frequency fluctuations and to stabilise the grid frequency to 50Hz.

The controller provided and installed by Kiwi was used to demonstrate that the battery could respond to an external signal. The Fruit Controller was installed and tested on the 12th of December 2017 and has remained onsite. The tests ensured that the interface with the Tesla battery was able to run initial test sequences.

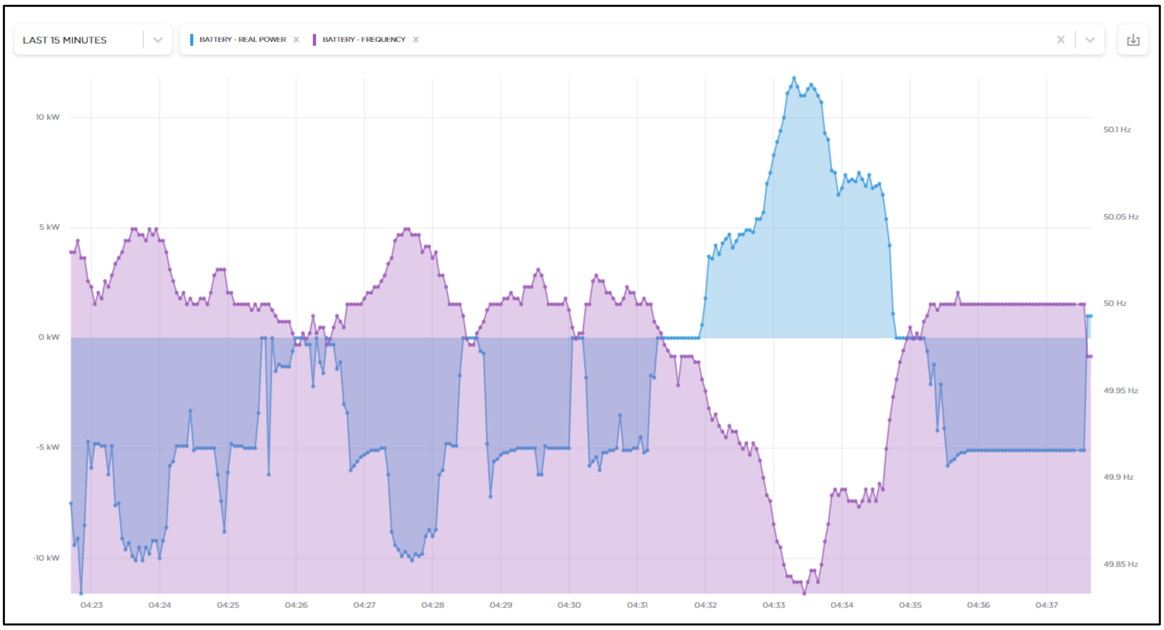

Figure 29: Battery Power Output and Frequency Correlation

The battery at Cardiff, however, was not engaged in any commercial programs as this was not the requirement of the project, but rather to prove that the batteries did have the capability to offer that service. However, it was possible to access all the operational data as csv files in the KiwiPower platform, KOMP – this shows all of the kW set points (that we instructed the battery to do) and the systems measured responses.

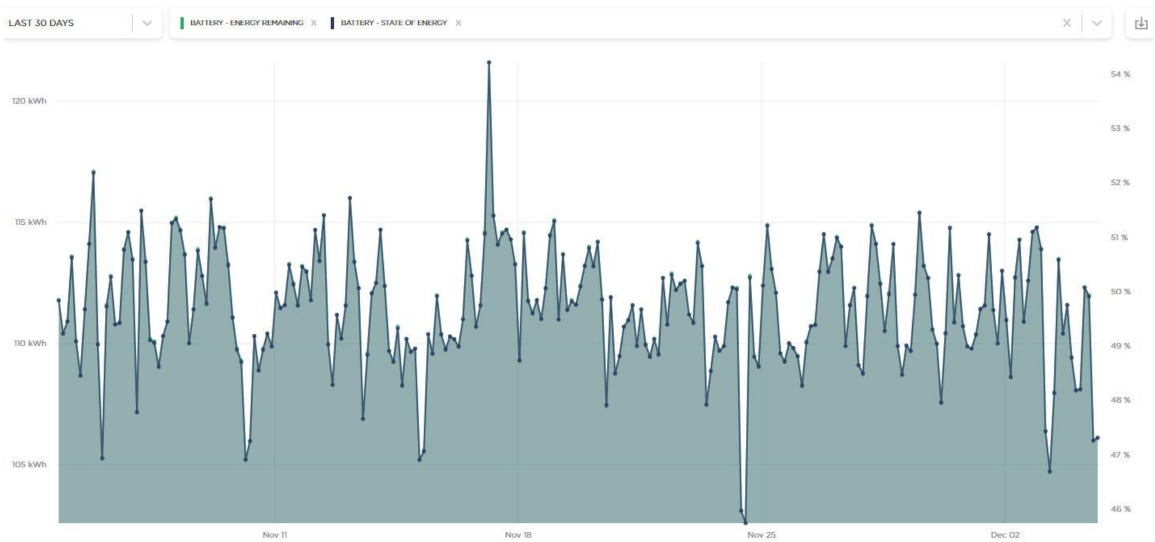

Figure 30: SOC History Over 1 Month

As the battery energy storage system can charge and discharge power to the grid, the system can provide a symmetrical FFR service and stabilises the energy level State of Charge (SoC) of the battery automatically.

Figure 30 above shows the SoC over a full month of symmetric FFR service operation during the trial phase. Over the entire period it has been achieved that the battery energy storage system state of charge stays between 46% and 54%. By that the battery storage energy system ensures it has sufficient energy stored to charge or discharge around 2hr of full power in the worst case scenario.

4.4.3 Use Case 3: Peak Demand Shaving and PV Self-Consumption – Spilsby

A BESS can help to increase the sustainability of industrial and commercial customers by increasing the usage of locally produced energy via the installed PV system. Maximising the use of locally produced energy reduces the amount of electricity needed from the grid and gives the user some financial savings and reduces the stress on the grid.

To achieve this, the BESS charges with the excess of solar generation during daytime when the site consumption is below the locally produced solar generation. During the evening when the solar output is not sufficient enough to cover the load consumption, the BESS discharge to use the locally stored energy.

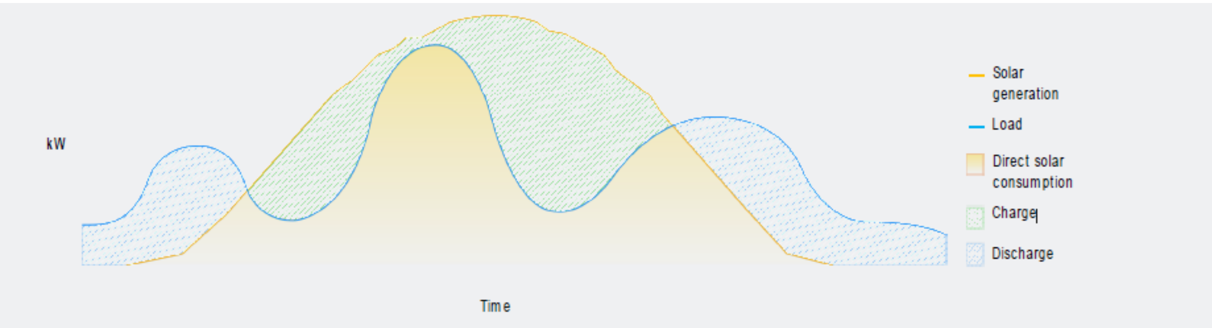

Figure 31: Energy Pattern Showing Solar PV Self-consumption

A monitored week in figure 32-1 below, July 10th – July 15th in 2018, shows how the grid consumption can be reduced to a minimum by adding the BESS to the solar generation. In the morning the BESS (blue) is discharging to cover the local loads. The result is a net zero grid load (green).
During the day the BESS is getting charged from excess solar generation, while loads are completely covered by the direct PV consumption.

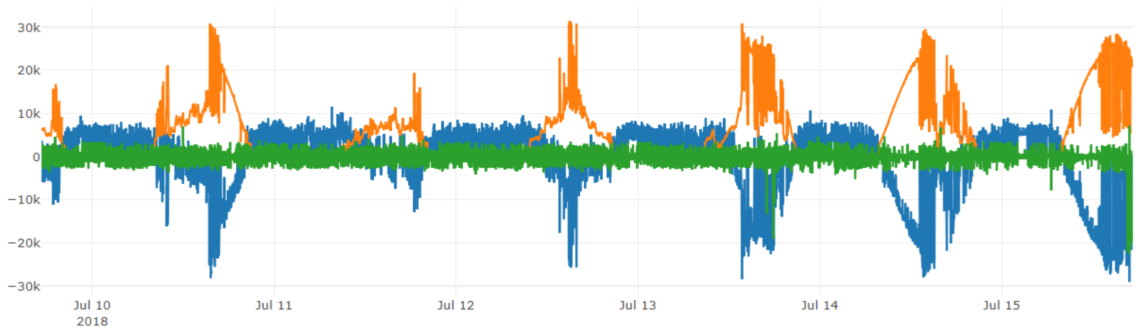

Figure 32 -1: Charge and Discharge of Battery against PV Self-consumption

Solar generation Charging/discharging Net grid load

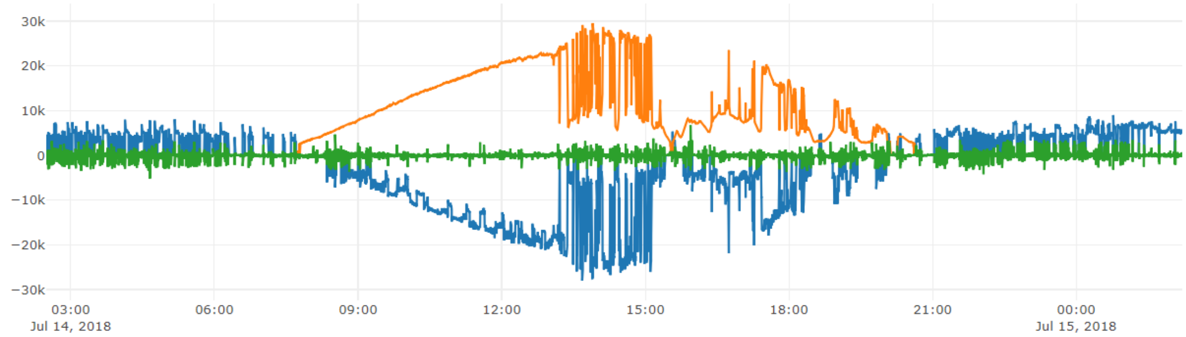

Figure 32 - 2: Charge and Discharge of Battery against PV Self-consumption

Solar generation   Charging/discharging   Net grid load

The figure 33 below shows the stored and directly consumed energy from the PV generation. During the monitored 41 days (September 23rd – October 28th 2018), the directly consumed PV energy was 1.4MWh while the additional stored and afterwards consumed energy was 1.61MWh. As a result the BESS was able to more than double the self-consumed PV energy on site. With a correctly sized PV system and a site load, a BESS can be sized to achieve limited reliance on a grid connection.

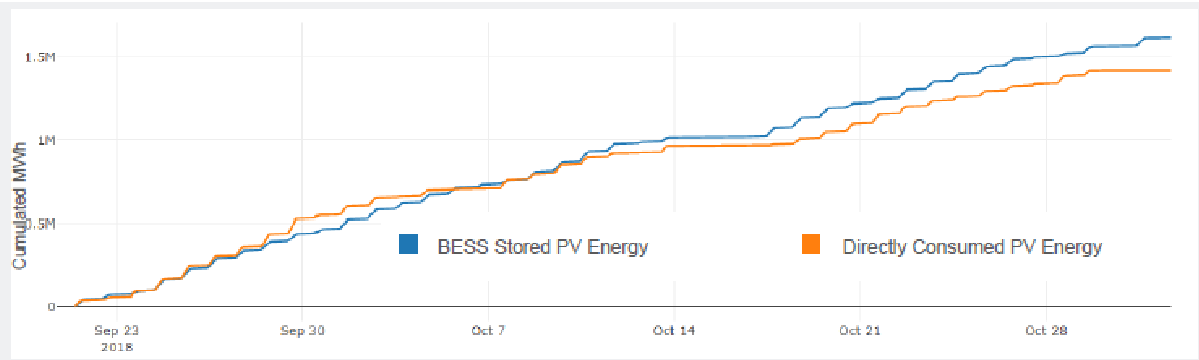

Figure 33: Charge and Discharge of Battery against PV Self-consumption

4.4.4 Use Case 4: Microgrid (Backup) – Taunton

Taunton has a standby generator that comes on when there is loss of mains supply. However, in order to test the kitchen in microgrid mode, the Standby Generator at Taunton was disconnected from the kitchen circuitry during the trial period. The idea was to feed the kitchen from the battery when there was loss of mains. An additional Contactor was installed in the basement to allow remote simulation of back-up / Island mode. The schematic for electrical wiring at Taunton is in figure 34 below.

The kitchen at Taunton was chosen as a load that could be manually controlled during testing. While the normal approach would be to place critical loads on a specially configured and independent distribution board (with dedicated controls, bypass arrangements, etc.), for Taunton, an existing distribution board (DB) feeding the kitchen was identified and connected to the BESS system. This allowed demonstration of backup and testing of islanding without requiring a full re-wire. Due to operational restrictions on site, the demonstrations were carried out after hours.

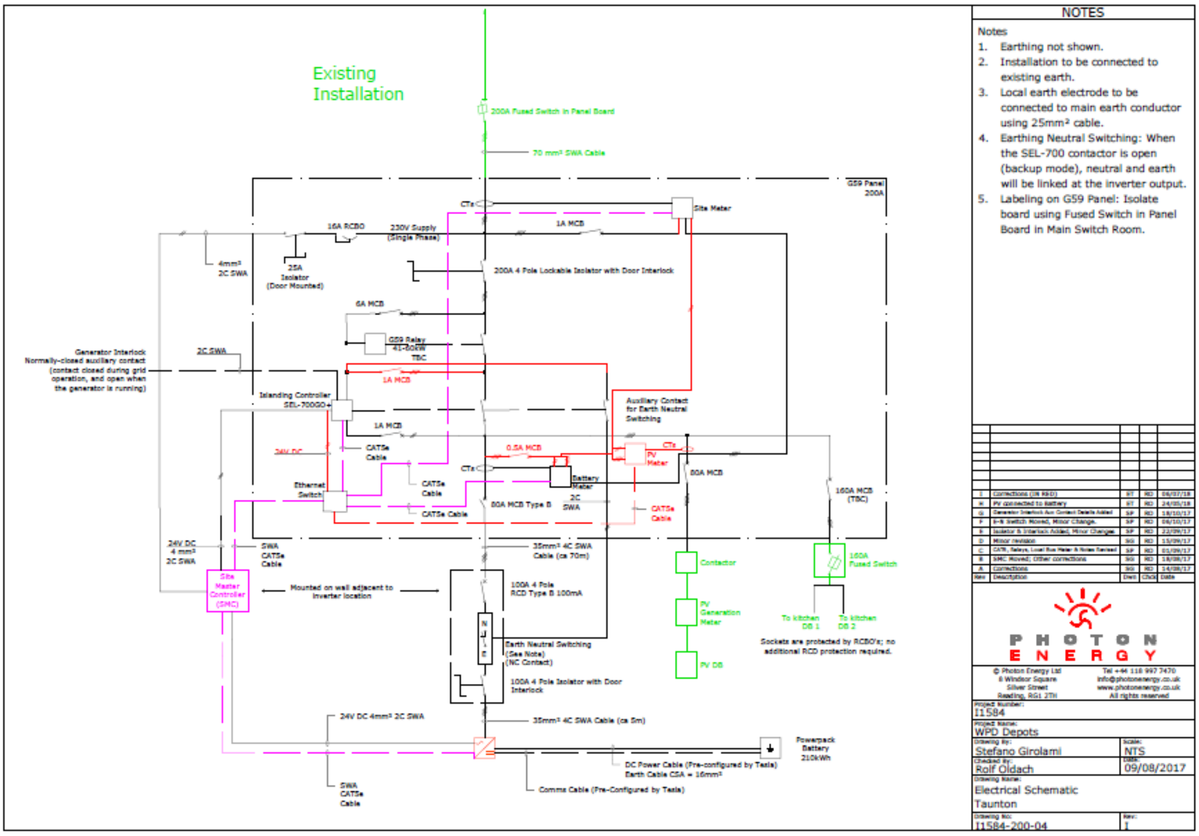

Figure 34: Electrical Installation at Taunton

Results

Manual switching of the grid supply feeding the backup DB (grid=off, generator=off) resulted in a smooth transition to backup. The sequence of operation was as follows:

1. Grid supply lost.
2. G59 relay and 3rd party islanding controller detect outage and open relay between DB and grid (islanding portion of the building).
3. Tesla inverter transitions to support islanded loads.

The demonstration was carried out multiple times and apart from minimum light flicker there was no noticeable loss of supply during the switchover.

System stability in backup mode (grid=off, generator=off, PV=on)

The BESS was demonstrated to support multiple load profiles whilst in backup mode and provided a stable grid for the connected PV system to re-start and facilitate solar charging of the battery. Due to the limited length of the test window, only power testing was undertaken (switching loads on/off), no energy capacity testing was undertaken.

Manual reconnection of the BESS

Manual reconnection of the grid supply feeding the backup DB (grid=on, generator=off) resulted in a seamless transition back to “on-grid” mode. The sequence of operation was as follows:

1. Grid supply returns.
2. G59 relay and 3rd party islanding controller detect supply and when both have completed their independent re-start sequences, the transition is signalled to the BESS over Modbus and the relay between the DB and grid is re-closed.
3. Tesla inverter transitions to normal “grid connected mode”. Like the off-transition, this sequence was tested multiple times and resulted in a smooth switchover to the mains apart from minimum light flicker.

Simulation

Back-up was simulated by disconnecting the supply and the energy storage system powers the kitchen.

At 18:39:36, grid voltage is removed
At 18:39:27, transition to island mode
At 18:40:07 grid voltage restored

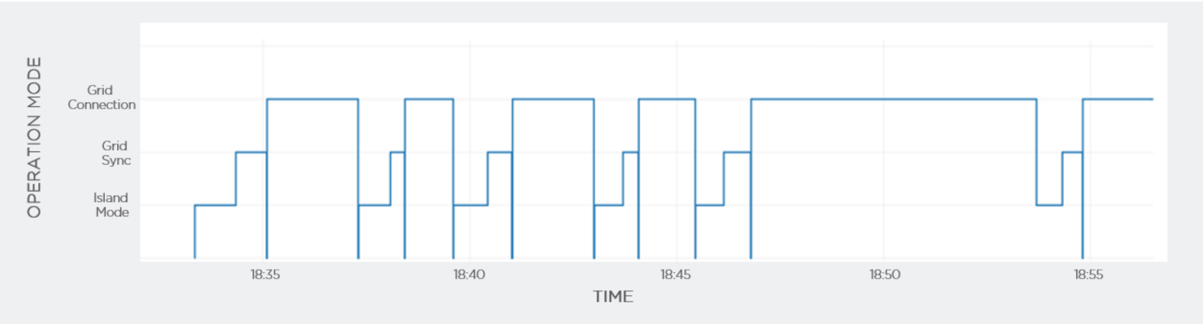

Figure 35: Simulation of loss of grid at Taunton

Figure 36: Simulation of loss of grid at Taunton

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

The project aims were to investigate the use of I&C storage behind-the-meter in four depots within WPD. The aims were met as the project was able to demonstrate the use cases. More information is contained in the Final Report.

Table 5: Success and status

Success Criteria	Status
Technology of Energy Storage Systems (ESS) - A comprehensive review of technology is presented	During the selection process six developers were asked to provide information on their equipment capability including their benefits, limitations, installation, operational and repair procedures and costs.
Recruitment - Recruiting the supplier/partner through tender	Through the tender process, Tesla were appointed as the technology provider and partner.
Relationship with Supplier - A case study of how the technology can bring benefits to WPD's networks is demonstrated and a relationship with suppliers has been established	Delivery of the various milestones was achieved on time. The four use cases agreed at the start of the project were delivered on time and schedule.
Network - Identify trial areas/sites and Customers - WPD depots engaged for trial	Four WPD sites were identified for the trial.ie. Boston, Spilsby, Cardiff and Taunton.
Commercial - Connection Agreements agreed	Studies were carried out by the local planners to determine the viability of connecting new generation in those areas. The connection agreements were only issued after satisfying the connection requirements.
Demonstration - Demonstrate enhanced value to the DNO and the customers from deployment of I&C Storage - such as network investment deferral, constraint alleviation and energy savings;	The demonstrations have proved that there are benefits to the customer. Maximising onsite consumption, time shifting, reducing the peaks on the Industrial and Commercial storage user means that there is increased capacity on the DNO network. Time shifting from normal to off peak ensures savings in energy costs to the I & C storage user.
Knowledge - Document and share all key learning that is achieved in order that results should be replicable across the UK.	All knowledge from the project has been shared at various seminars (see Section 8.1) and in the final report from Tesla.

Systems - Identify, develop and demonstrate new policies, processes and systems that are required in order for WPD to operate I&C Storage (monitor, control, meter and settle), development of business processes (polices, standard techniques etc.)	Policies taking into account all the findings of the project are now being developed for eventual adoption. The policies will provide options for a new connectee.

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

Industrial & Commercial Storage project did not require any changes to its approach. No change in Methodology was required throughout the project.

7. Project Costs

Activity	Budget (£)	Actual (£)	Variance
WPD Project Management/Engineering costs	300,000	93,734	69%
Tesla batteries	728,000	346,069	52%
Install costs	116,000	36,347	69%
Total	1,144,000	476,150	58%

Table 6: Project Costs

The total project was successfully delivered approximately 58% under the project budget. This was due to the accepted tender price of the BESSs being much lower than budget quotes, and installation costs being lower than originally allowed for. WPD project management and engineering costs were also lower than initially budgeted.

8. Lessons Learnt for Future Projects

A summary of the key lessons learnt is itemised below:

- Microgrid operation: Commissioning of Taunton for microgrid operation was completed by the 6th of November 2017 but we were not able to simulate the functionality for some time as the needed firmware was still being developed by Tesla. Once the firmware was supplied, in the Q2 of 2018, we were able to simulate grid failure. Testing was carried out on the 8/9th of August 2018; the battery at Taunton was completely disconnected from the Grid. The tests involved running the microgrid over different time durations. The learning here is that battery storage systems needs to be equipped with suitable 'off-grid' functionality in order to be used for islanding or microgrid capabilities.

- Grid failure at Taunton: On the 4th of December 2018 we experienced a power outage at the entire Taunton site, and including the kitchen area as well. The switchover to the Tesla battery took place as normal but when power from the grid was restored, the switch back to the mains failed to take place. The Tesla batteries continued to operate until they were depleted and at this time the kitchen was now without power. Investigation work continued at Taunton following real-time power outage events and it was then decided to remove the site from backup functions until isolation/restoration was rectified. The key learning here is that the system successfully worked for real, despite the limited trial periods. Secondly, when mains power returned, the changeover to mains supply didn't occur as expected, suggesting that further modifications were required to the system.

- Communication failures at Spilsby: In the early stages of the trial phase at Spilsby we encountered periods of loss of communication with the BESS systems. A new high gain antenna was installed to improve communications. The antenna was installed on the 20th of April 2018. As signal strengths can vary with time it would be beneficial for future projects to include monitoring and alarms systems at all BESS locations.

8.1 Dissemination Events

Throughout the project there were a number of visits, including the Member of Parliament for Skegness and Boston, and Cummins.

Listed below are some of the dissemination events on the project.

Table 7: Project Dissemination

Event	Date	Location
WPD Balancing Act	20/06/2017	Westminster
Solar Energy Storage	06/06/2017	Birmingham, NEC
Excel Seminar	09/10/2017	London
Battery Storage Seminar - Internet of Business (IoB)	04/12/2017	Coventry
Solar Energy Storage	28/02/2019	London

9. The Outcomes of the Project

9.1 Key Learnings from the Project

Industrial & Commercial Storage project has demonstrated that BESS systems can deliver a suite of uses to the user of industrial and commercial storage.

Impacting Network Reinforcement costs: The project proved that, time shifting by industrial and commercial users ensures that network utilisation is reduced and capacity is increased. This means more can be connected to the network.

Providing Grid services: There is a significant opportunity for industrial and commercial energy users to use BESS to participate in the balancing mechanism by working with aggregators. National Grid has expressed an ambition to use BESS to bridge the gap in response time for a bigger portfolio. This area of DSR is likely to see considerable development going forward, however aggregators may be able to support with deployment, including the smart software required. The trial showed that BESS can provide grid services with a response comparable to conventional assets response. The BESS at Cardiff supported the grid with frequency regulation.

The integration of the BESS will lead to an improvement in the building's energy sustainability. While originally a major portion of the generated PV energy had to exported to the grid, it can now be stored locally and be consumed directly onsite later on, which is a financial benefit to the storage user.

Microgrid/back up: Onsite storage can also provide a secure back-up asset that guarantees that all commercial and industrial activities continue to receive power if the network suffers from a power cut. By simulating grid outages, successful transitions to battery back-up under test conditions were achieved.

Flexibility in System integration: The other learning from the project was that it was possible to include multiple controller types and communication protocols during the trial. With this success it has been shown that the BESS technology is flexible in integration and also allows local as well as remote system control by the system operator.

10. Data Access Details

The scale and timeframe of the project has remained consistent with the registration document, a copy of which can be found here: Data associated with the project has been archived. Requests for data should be made via the following link:
www.westernpower.co.uk/Innovation/Contact-us-and-more/Project-Data.aspx)

Data associated with the project has been archived. Requests for data should be made via the same link above.

11. Foreground IPR

No new foreground IPR has been developed during the project.

12. Planned Implementation

Production of policies for the facilitation of customers connecting batteries / storage.

13. Contact

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

Innovation Team
Western Power Distribution,
Pegasus Business Park,
Herald Way,
Castle Donington,
Derbyshire
DE74 2TU
Email: wpdinnovation@westernpower.co.uk

Appendix A

Application for a Distribution Network connection

A separate G59 relay was installed at all 4 sites despite installing type-tested inverters. A G59 relay is a voltage and frequency monitoring device which is located between the inverter(s) and the point of connection with the distribution network. A G59 relay will disconnect the inverter(s) from the distribution network when a fault is detected (for example when the grid voltage is too low/ high, a step change in frequency, or loss of mains power) and reconnect when normal operation is resumed.

Sizing and Modelling

In order to appropriately size and understand the potential performance of a battery storage system Tesla were provided the following site specific information:

- PV array size (kWp) and Inverter size (kW)
- Estimated solar generation profile –half hourly (HH) data (kWh)
- Onsite energy consumption profile – HH data (kWh)
- Site peak power requirement (kVA)
- Distribution network connection voltage (V), frequency (Hz) and power factor requirement
- Use cases

Details contained in the Generator Response Letter (Connection Agreement) are as follows:

The generation unit/s may be connected and remain connected to WPD's distribution system subject to the following:-

1. Providing it complies with the requirements of The Electricity Safety, Quality and Continuity Regulations 2002 (as amended from time to time).
2. Providing it complies with the requirements of Engineering Recommendation G59/3 Recommendations for the connection of generating plant to the distribution systems of licensed Distribution Network Operators (as amended from time to time).
Please note: over and under voltage protection settings should be based on 230V
3. The customer signs a site specific Connection Agreement.
4. This agreement to connect the generation unit/s is only valid for 90 days from the date of this letter. If you do not provide confirmation that the installation of the generation unit/s is proceeding, WPD may release the export capacity to other customers and you will need to re-apply for permission to connect generation at this location. This action could result in the customer having to fund some or further reinforcement in order for WPD to accept the connection of the generation unit/s.
5. In the case of Application For Connection for Micro Generation that has been type approved to G59/3, the installer should submit Commissioning Confirmation – Micro Generation form.

PV sizes

Table 8: PV Sizes at the 4 Sites

Site name	Generator	Size (kW)
Boston, 13 Endeavour Park	PV	21
Cardiff Mardy Ind Estate, Lamby way	PV	8.4
Spilsby, Vale Road	PV	30.75
Taunton, Priorswood Rd - Depot	PV	56

Accessibility

During both construction and operation, access to a battery system was carefully considered. This included specific access requirements for construction equipment, large delivery vehicles (i.e. HGVs), and vehicles accessing and traversing the car park. Consideration was also given to specific access requirements for intended additional uses of the area in the vicinity of the battery, e.g. any operational requirements (facilitating deliveries, etc.).

Transportation

The modular nature of the Powerpack System means that it does not need to be transported all the way to site in a container, nor installed in one. This allows easier loading and off-loading, which can be advantageous in areas with restricted land, where materials handling is made more complex by constrained infrastructure such as access roads. Transportation of the battery was carried out by DSV.

Figure 37: Battery Arrival

System Signage

We ensured that all the four installations were appropriately labelled. System signage is important for informing users, maintenance engineers and other services of the system, its operation and any potential hazards it may introduce. Drawing attention to the presence of a hazard or potential danger is a minimum requirement for mitigation of most health and safety risks associated with any battery storage system.

Electrical schematics showing how the system was connected and the location of all key components and isolation devices were also affixed at the four locations including adjacent to any isolation devices explaining their operation.

Appendix B

Scheduled Maintenance

The requirements of product warranty conditions, service contracts, performance guarantees etc., demand that periodic inspections are carried out on the batteries.

Table 9: Periodic Inspections

Equipment	Activity
External & System integrity checks	Torque checks within the Powerpack System, calibration checks, visual inspection (rodents, etc.)
	Harness inspection or replacement in kind if damaged (protective sleeve failure, rodents, etc.)
	Enclosure integrity – touch up paint and gasket inspection or replacement in kind if damaged
	Cabinet cleaning
	Cabinet ventilation system inspection – radiator area cleaning
	Coolant level check
	Battery and meter communications check
Powerpack Units	Refrigerant Refill
	Pump Replacement

BESS Updates

The Tesla battery received numerous software and occasional hardware upgrades throughout the trial, as improvements continued to be made. The rollout of the new software package mainly involved updating the Powerpack controller and system firmware. The software would have undergone internal validation at Tesla; including operating at Tesla's owned installations for at least over eight weeks. The major improvements in the updates included:

- Support for additional grid codes
- Improved heat mode operation
- Improved connectivity management
- Improved power accuracy readings

- Improved operational performance of controller
- Several bug fixes

System Access

WPD was set up with a login into Powerhub, which is a Tesla Platform, iHost which is the Nortech system and the KOMP which is the KiwiPower platform to be able to view the data coming back from the Tesla Powerpack at the four depots.

Tesla: https://energystorage.teslamotors.com

KiwiPower platform: https://prod.kompv2.kiwipowered.com/

Nortech: www.nortechonline.net

Electrical schematics

Table 38: Installation at Spilsby

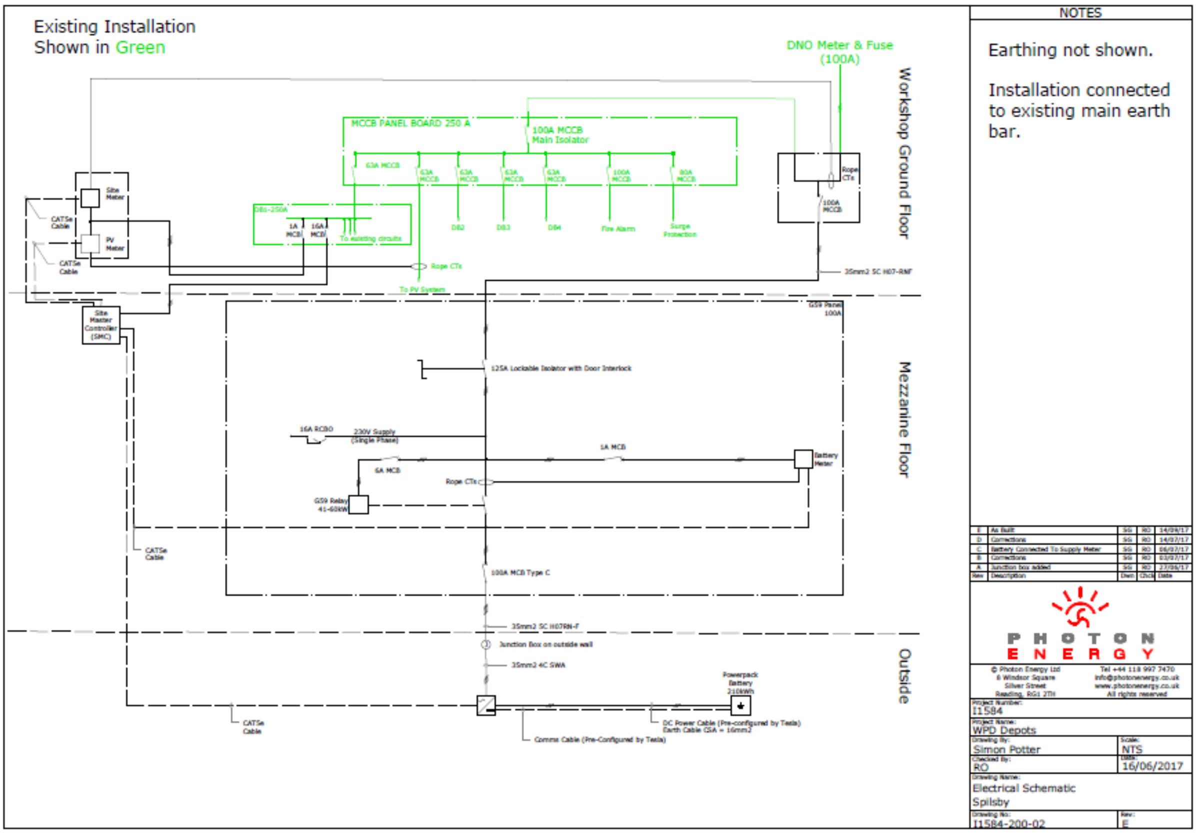

Table 39: Installation at Cardiff