Local Energy Oxfordshire

July 2020 | Version 3.1

MVS A1.1 Oxford Bus Company Technical Report

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Working together with

Report Title:	**MVS A1.1 Oxford Bus Company Technical Report**
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Version:	3.1	Date:	17/07/2020
Workpack*:	4	Deliverable:	4.4.3
Reviewed by:	Project LEO MVS Working Group Oxford Bus Company Off Grid Energy		
Date:	17/07/2020		
Signed off by:	Prof. David Wallom		
Date:	17/07/2020		

Can be shared (Y/N):	Internally	Y	Publicly	Y

Executive Summary

Project LEO is taking an agile approach to developing and testing new flexibility services. This is achieved through minimum viable system (MVS) trials which use the minimum set of requirements to test a new hypothesis or adaptation from previous iterations.

The first type of flexibility service identified as an MVS trial within LEO was based on electrical storage which may or may not be co-located with non-dispatchable generation such as solar PV. This aligns with the OverSolar set of plug-in projects which explore how local energy markets and flexibility can enable additional PV capacity (both financial viability and network headroom) at existing locations.

Oxford Bus Company's Cowley depot on Watlington Road is the location of a 140 kWp PV installation managed by the Low Carbon Hub. There are also two 24 kW, 90 kWh batteries on site which are intended as a buffer for electric bus charging (due to import capacity constraints); due to a limited demand for electric bus charging currently, the batteries are underutilised. Thanks to the strong relationship between the Oxford Bus Company and the Low Carbon Hub, these batteries have been made available to Project LEO for early MVS trials.

MVS A1.1.1 and MVS A1.2.1 were the first set of trials run as part of Project LEO. The primary aim was to test the proposed flexibility service procedure, particularly the interfaces between different participants such as the Piclo market platform, and dispatch communications. Other objectives for the trials included: measuring differences between the flexibility (as measured at the site and at the substation) and understanding what the appropriate level of monitoring needed is. Prior to the trials running, it was discovered that the battery's original design spec did not allow for it to function in the desired way for network flexibility services. The battery manufacturer, working closely with the Low Carbon Hub, were able to re-engineer the software on a temporary basis to enable this functionality. MVS A1.1.1 saw the successful delivery of a -30 kW flexibility service for 1 hour on 18th November 2019, while MVS A1.2.1 saw the successful delivery of a -30 kW flexibility service for 1 hour, operated remotely by the battery manufacturer, on 5th December 2019.

Both trials provided good learning opportunities to test the proposed flexibility service procedure, the flexibility exchange market platform and the interactions between the key parties involved.

Small bugs were discovered on the Piclo platform with the creation of competition areas and bid entry. These, along with some ambiguity in terminology around service delivery were quickly rectified during the trial. The second trial additionally tested the remote control of the batteries by the battery manufacturer. The average process maturity of MVS A1.1.1 was 2.4, this decreased to 2.2 for MVS A1.2.1 despite the advance in remote dispatch. This was due to temporary monitoring equipment being removed prior to the second trial.

High resolution monitoring at both the site and secondary substation feeder, in addition to standard commercial half hourly meters, allowed detailed technical analysis of the service delivered. The collected data provided a use case to begin development of data cleaning and pre-processing algorithms, including the time-synching of temporal datasets and identification of service delivery. As expected, the high-resolution data provided more accurate analysis of the exact service that was delivered compared to standard half hourly energy meters. This will help inform future decisions regarding metering requirements as tolerance and validation criteria are developed. The substation monitoring also provided the opportunity to measure the differences observed in service between the site and substation as a result of line losses.

Although finance was not a core objective to the trial, energy costs of service were calculated including the proxy £1 settlement for service delivery. There was an energy cost of 12p for the site, this is mainly due to the flex event resulting in a small amount of export, where a lower rate is paid to the site compared to imported energy. This was compensated by the £1 service payment, leading to an overall site profit of 88p. This can help to inform future trial bids which focus on the financials of service delivery.

Finally, the trial provided a use case to develop a stakeholder strategy for the MVS process. An initial stakeholder categorisation and engagement heat map are presented. It is also noted that the existing strong relationships between Low Carbon Hub, Oxford Bus Company and Off Grid Energy was critical in getting the trial run so quickly.

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1 Introduction

Project LEO (Local Energy Oxfordshire) will demonstrate a Smart Local Energy System (SLES), at county scale, to maximise economic, environmental and social prosperity for the region. LEO is creating a local flexibility market to maximise utilisation of the electricity distribution network, at minimum cost, to provide best value for energy users, generators and Distributed Energy Resource (DER) owners alike.

Project LEO is taking an agile approach to developing and testing new flexibility services, business models and the multi-organisation procedure and communications required to operate a local flexibility market. Each minimum viable system (MVS) trial should represent the minimum stress set of participants and processes which are required to test a new process modification or asset use case. In doing so, new value can be identified and confirmed at a small, quick scale, before significant investment in time, money and user relations are committed; it is intended as a way to manage the risks associated with innovation in an uncertain, changing environment. All trials within Project LEO will be in response to artificial constraints.

The first type of MVS flexibility trials established within Project LEO centre around the use of electrical storage (the others included flexible generation and demand side response) co-located with non-dispatchable generation such as photovoltaics (PV). Electrical storage is likely to be one of the most common technologies for providing flexibility services at a local level. It's ability to respond quickly, provide a power shift in both directions and easily installed at many locations (both physically at sites and with respect to network topology), makes it an attractive technology. It is also interesting to prosumers, both domestic and commercial, who wish to increase self-consumption of non-dispatchable renewable generation or avoid high network costs. This increase in self-consumption is important in the wider Oxfordshire context, as it will enable more non-dispatchable renewable generation such as PV, to be connected throughout the county. However, despite declining technology costs, the financial case for fixed battery storage is marginal.

The Low Carbon Hub (LCH), a social enterprise who develop community-owned renewable energy across Oxfordshire, have 46 renewable energy installations with an annual generation potential of 4.4 GWh; 44 of these are PV installations with roof lease. Along with the wider community they support, the LCH are interested how smart storage technologies combined with a local energy market, can create additional value (financially, socially and environmentally) for a distributed portfolio of non-dispatchable generation assets.

One of the LCHs PV installations, a 140 kWp array, is located on the roof of the Oxford Bus Company's (OBC) Cowley depot on Watlington road. There are also two 24 kW, 90 kWh batteries on site which are intended as a buffer for electric bus charging (due to import capacity constraints); due to a limited demand for electric bus charging currently, the batteries are underutilised. Along with the co-located PV, the OBC site can provide LEO ample opportunity to investigate how electrical storage can operate within a local flexibility market and the benefits thereof.

This report details the learnings captured from MVS A1.1.1 and MVS A1.2.1, the first and third MVS trials run as part of Project LEO. The Oxford Bus Company's Cowley depot on Watlington Road hosted the first two MVS trials (with the notation MVS A1.1.1 and MVS A1.2.1), coordinated between the Low Carbon Hub (LCH) on behalf of the Oxford Bus Company, Scottish and Southern Electricity Networks (SSEN), and Piclo. The first trial ran on 18th November 2019 with the aim to demonstrate dispatch of a LEO flexible storage asset in response to Distribution System Operator (DSO) advertised flexibility service request via a market platform and analyse the value of the service. The second trial (MVS A1.2.1) ran on 5th December 2019 with the aim to demonstrate a modified process for the remote activation of asset dispatch following a dispatch signal from the DSO. The following sections will comb through the technical insights and learnings from these trials to better understand the main successes and challenges faced in the use of electrical storage for local flexibility services.

2 Oxford Bus Company Cowley Depot

OBC operates a network of bus services in Oxford and the surrounding areas. This includes the local Oxford fleet, the BROOKESbus (in partnership with Oxford Brookes University) and park&ride services which connect the five car parks with the city centre. The 160 strong bus and coach fleet is the lowest emission fleet of its size in the UK with about half being electric-hybrid buses.[1] OBC is

[1] Oxford Bus Company; http://oxfordbus.co.uk; accessed: May 2020

part of the Oxford Bus Group which also includes Oxford City Sightseeing, Thames Travel and Carousel. Oxford Bus Group operates 286 vehicles from 3 depots across Oxford, South Oxfordshire, Reading and Buckinghamshire.

Figure 1: Left - Luke Marion (OBC), Chris Jardine (Joju Solar) and Barbara Hammond (LCH) at the installation of the 140 kW PV array at the OBC depot. Photo credit: Low Carbon Hub. Right – The 48 kW battery installation at OBC depot. Photo credit: Oxford Bus Company.

OBC operates from its Cowley depot on Watlington Road, south east of Oxford. In 2013, OBC became the first Oxfordshire business to develop a community-benefit renewables project with the LCH. The setup is: OBC leases LCH the roof space. LCH pays the cost of PV installation and maintenance for the full 20-25 year term. LCH owns the solar panels, the electricity generated and the feed-in tariff (FiT) revenue. The LCH sells the electricity to OBC at a discounted rate and sells any surplus energy to the grid. The 140 kW PV installation was the biggest PV scheme in Oxford at time of installation and generates about 123 MWh annually.[2]

OBC has a commitment to reducing the impact of its services on the environment. As part of a £1m programme to update its fleet, 5 fully electric double decker buses will be introduced. To support this, OBC invested £80,000 in a depot charging system which includes two 90 kWh, 24 kW batteries which are owned by OBC. The intention is the batteries can act as a buffer so as not to violate import capacity limits for the site while charging multiple buses and increase self-consumption of the on-site solar energy. The first of these five electric buses were introduced into service in March 2020. While current demand for electric bus charging is low, the batteries are often idle and have been offered by OBC for early trials within LEO.

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[2] Low Carbon Hub; http://lowcarbonhub.org/p/projects/oxford-bus-company; accessed: May 2020

2.1 Trial Suitability

The OBC site is a useful asset to start LEO trials. It has a flexible asset which was already installed at the start of the project which has allowed the consortium to get trials up and running quickly. The learnings of these early trials can directly influence the design and installation of assets being developed as part of LEO. The site represents a typical prosumer which one might expect for Oxfordshire (limited to solar as the primary renewable resource) where a flexible asset such as a battery has been installed alongside non-dispatchable PV generation. It will allow the project to understand the additional value (financial, social and environmental) which comes with co-location of dispatchable storage within a local energy system and explore the control strategies to extract this value.

The smart control of the battery can enable flexibility services for the local distribution network which could increase utilisation of the network for all connected. The OBC site is connected to Bridge View Watlington Road secondary substation, on a feeder which only serves the OBC site. Monitoring placed at the site, and at the substation will allow us to measure the real impact the procured service has on the network.

OBC and LCH have worked together for a number of years, and although OBC is not directly part of the LEO consortium, they have helped by offering their assets to be used within these early stages of LEO MVS trials. Through these trials, the initial flexibility service delivery procedure can be established and debugged as unforeseen issues arise and processes for cross-communication between multiple parties involved in service delivery developed. The potential for the battery to be controlled remotely allows further insights on requirements for end-to-end service automation.

In addition to network flexibility services, storage assets can also be used to increase the self-consumption of the onsite solar generation at times of surplus generation. Along with the financial and environmental benefits of this, it can also unlock additional PV capacity for the site without violating potential connection capacity constraints; this concept, known within LEO as OverSolar, is of particular interest given the LCHs PV portfolio. The roof lease for PV between commercial company and social enterprise was unique when first setup by the LCH and OBC but has since been replicated by the LCH with other business, particularly schools, across Oxfordshire. The learnings from the OBC trials can be used to inform a large number of similar OverSolar potential projects within the LCH portfolio, along with many other PV-battery co-location opportunities both larger (e.g. Westmill Solar Farm) and smaller (domestic households).

2.2 Project LEO Network Context

OBC's Cowley depot is located in Blackbird Leys parish to the south east of Oxford City Centre, just outside the ring-road. The OBC site is connected to Bridge View Watlington Road secondary substation, which itself is fed from Cowley Local primary substation. The LEO partnership has identified 12 primary focus areas for the LEO and TRANSITION trials which will see further monitoring installed. These areas are defined by the approximate area fed by SSEN's primary substations and selected based on the number of LEO's potential plug-in-projects which are within the areas. The OBC site is not currently within one of the 12 primary focus areas identified for the LEO and TRANSITION trials. However, Cowley Local is supplied by the same Bulk Supply Point (Cowley Local BSP) which feeds Rose Hill, Kennington, Berinsfield, Milton and Wallingford LEO primary substation focus areas.

2.3 Further details on Asset Setup

An approximation to the energy financial setup between OBC and LCH is as follows. The solar panels and the energy generated is owned by the LCH. When generating, this energy is consumed by OBC's depot demand and the LCH charges OBC a favourable rate relative to their standard import price. Any additional demand imported to the site is paid for by OBC at the rate set by their energy supplier. If there is surplus generation, this is exported to the grid and the LCH receives payment for this. The LCH also receive the FiT payments for generation. This is settled based on 3 meters, one measuring the output of the solar array (E_{PV}) an import meter for the site (E_i) and an export meter for the site (E_e). While the LCH owns the solar PV, the batteries are owned by OBC. This, along with the FiT rates for when the system was installed, leads to an interesting arrangement whereby different operational modes of the battery will favour one party over the other.

Table 1: Energy unit price breakdown

Energy Component	Symbol	Payee	Receiver	Example Rate (p/kWh)

PV Generation	λ_{FiT}	FiT	LCH	13
Site Import	λ_{imp}	OBC	OBC Energy Supplier	12
Site Export	λ_{exp}	LCH Energy Supplier	LCH	6
Self-Consumption	λ_{sc}	OBC	LCH	9

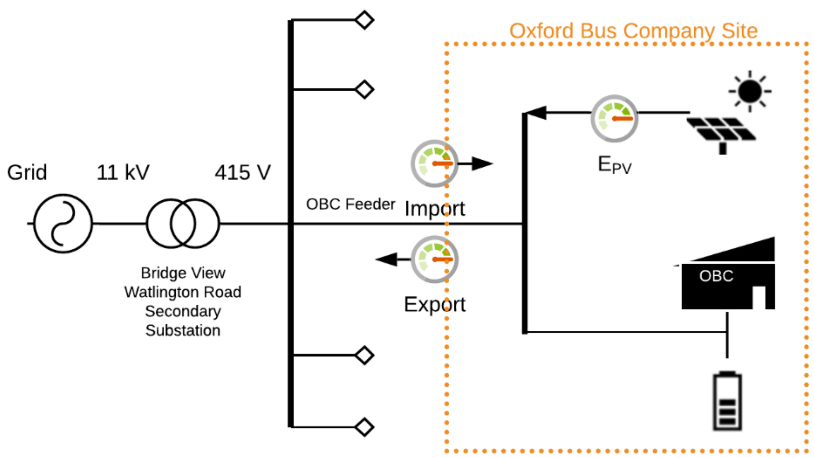

Figure 2: OBC site network connection and meter diagram

2.4 Site Specification

Table 2 contains the LEO site specification data for the Oxford Bus Company. Certain fields may not be applicable to this site, while others are currently unknown or yet to be determined.

Table 2: Oxford Bus Company Site Specification Data

Address	Oxford Bus Company, Cowley House, Watlington Road, Cowley, Oxford, OX4 6GA
Location (Lat, Long)	51.727324, -1.197568
Solar Generation Capacity (kW)	140
Other Generation Capacity (kW)	0

Storage Type	Lead-Acid Battery
Storage Asset Model	Off Grid Energy, Ingenium Series
Storage Capacity (kWh)	90 (2×45)
Storage Power (kW)	48 (2×24)
Flexibility Type	Electrical Battery Storage
Flexibility Capacity (kW)	48
Supply Connection Capacity (KVA)	220
Export Connection Capacity (kW)	143.25
Voltage Connection (V)	415 V
Connection Offer Reference (SSEN)	DYB881
MPAN (Import)	REDACTED
MPAN (Export)	REDACTED
Secondary Substation Name	Bridge View Watlington Road
Secondary Substation Code	4600007020
Primary Substation Name	Cowley Local
Primary Substation Code	4600
HV Feeder Name	Bridge View Watlington Road
Other Information	N/A

3 Potential for Flexibility and Constraints

The site's flexibility is provided by the two on-site batteries which can provide a power response in the range ±24 kW each. At full power, this could be sustained for 3 hours 45 minutes as each battery has a capacity of 90 kWh. The site does have import and export capacity limits of 220 kVA and 143.25 kVA respectively which, unless otherwise agreed with the DNO, would need to be obeyed. At present, the batteries are unused and as such have no time constraints for when they can be operated. OBC's long-term plan for the batteries is to use them to support electric bus charging. This usage will need to be considered as an availability constraint in future analysis and optimisation.

4 MVS A1.1.1 & 1.2.1 Trials at Oxford Bus Company

The MVS trials at the Oxford Bus Company were the first trials for Project LEO and utilised a real-world asset to test the proposed flexibility service procedure. The first MVS trial, MVS A1.1.1, took place on the Monday 18th November 2019, with the second trial, MVS A1.2.1, taking place on Thursday 5th December 2019. The MVS notation at this stage of trials takes the form of 'MVS [MVS Group {A}][Flexibility Service Type {1}][Trial Number {2}]' where the entries in the ' {} ' indicate the equivalent notation for the second trial of the first flexibility service type as a reference. A later addition to the MVS notation following these trials includes an 'Attempt Number' after the trial number. This section will discuss the main findings, both generic procedural and trial specific, from both of these trials, presenting the key learnings and hurdles experienced in the execution of the OBC trials.

4.1 Trial Details

The objective of MVS A1.1.1 was to demonstrate dispatch of a Project LEO flexible storage asset in response to an SSEN advertise flex request through the Piclo platform and analyse the value of such a service. The additional objective of MVS A1.2.1 was to demonstrate a modified process for the remote activation of the dispatch of an asset, learnings from which will inform the design of future automated control software being developed under WP3.

4.1.1 Participants

Below is a list of the key trial participants with the form: **Role**: Company [Persons responsible (Initials)] for both trials:

MVS coordinator: Low Carbon Hub [Adriano Figueiredo (AF)]

Distribution System Operator (DSO): SSEN [Brian Wann (BW), Andrew Waterston (AW)]

Flexibility Market: Piclo [Kelsey Devine (KD)]

Service Provider: Low Carbon Hub [Adriano Figueiredo (AF)]

Data User: University of Oxford [Scot Wheeler (SW)]

4.1.2 Asset and Service Description

For both trials, the flexibility service requested from the DSO was a -30 kW shift in power, equivalent to reduced demand (or increased export if large enough) for 1 hour. This was to be provided by the two 24 kW, 90 kWh on-site batteries. For MVS A1.1.1, control was planned to be undertaken manually by the battery operator Off Grid Energy, while for MVS A1.2.1, the batteries were to be operated remotely, also by Off Grid Energy.

4.1.3 Data

All data generated as part of these trials were shared through the Project LEO Data Log and can be accessed by project partners through the Project LEO Data Catalogue. Instructions for accessing this data for project partners can be found in the Project LEO Data Sharing Guide available on the Project LEO SharePoint.

4.1.4 Risks

The following risks were identified and mitigated against as part of the trial.

Table 3: MVS A1.2.1 Risks

Risk	Associated step	Partner responsible	Impact	Likelihood	Total	Mitigation
Loss of remote comms.	9	LCH	Inability to deliver service	Low	Low	All trial participants will be notified and the trial postponed.

4.2 Trial MVS A1.1.1

Prior to the trials running at OBC, it was discovered that the battery wasn't able to function in the desired way. As the battery's original design didn't require power to be exported back to the grid, the installed operating software didn't have this as an option. Instead, the battery was setup as a buffer such that it would only discharge if the power drawn from its charging output was greater than the import capacity of the site. The manufacturer, Off Grid Energy, were consulted to re-engineer the assets to enable the desired functionality which was successfully completed prior to the trial's beginning. However, this software upgrade is a temporary fix which is required for each trial; after the trial is complete, the battery software is reverted to its original design spec.

This section recaps the trial implementation based on the 14-step service delivery procedure (discussed further in the MVS A Procedural Learnings Phase 1 document).

1. The artificial constraint was defined as requiring a -30 kW power shift, equivalent to reducing demand or increasing generation. For the battery asset, this means discharging the battery back to the grid.
2. SSEN registered the constraint competition on the Piclo platform through upload of the relevant excel spreadsheet. There was an issue regarding the latitude and longitude coordinates for creating a bounding box for the service area. The start and end coordinates needed to be the same in order to close the bounding box. This was amended by SSEN.

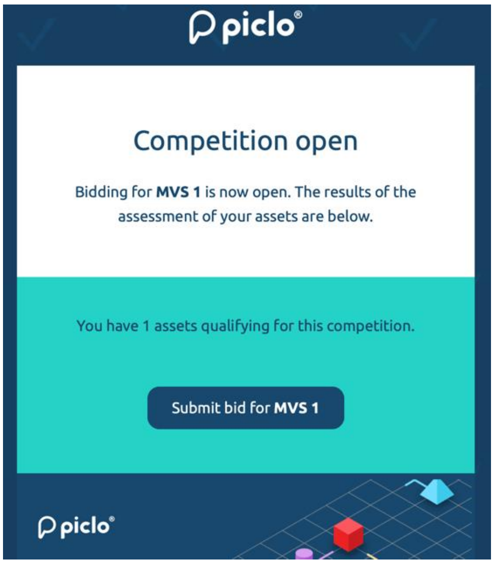

Figure 3: Screenshot showing the competition open on the Piclo LEO platform for MVS A1.1.1

3. The LCH registered the OBC battery as a flexibility resource on the Piclo platform via the Piclo asset spreadsheet (which is available through the Project LEO data portal) with some key fields presented in Table 4.

Table 4: Some key asset parameters uploaded to the Piclo LEO platform when registering the asset.

Asset Characteristic	Value used in trial
Active Power (Export) (MW)	0.03
Active Power (Import) (MW)	0.03
Maximum Import Capacity (MVA)	0.22
Maximum Export Capacity (MVA)	0.14
Technical Response Time (HH:MM:SS)	12:00:00
Maximum Run Time (HH:MM:SS)	01:00:00
Minimum Run Time (HH:MM:SS)	00:10:00
Recovery Time (HH:MM:SS)	01:00:00

4. The LCH were assumed to be registered with SSEN as a flexibility service provider.
5. The LCH updated the asset status on the Piclo LEO platform to 'Operation' by uploading an updated version of the Piclo asset spreadsheet.
6. A proxy bid of £1 was submitted by the LCH through the Piclo platform. It was the only bid entered as part of the competition. There was an issue raised whereby the service provider could not enter the bid as 0.03 MW, instead the platform would only allow 0.02999 to be entered. This was quickly remedied by Piclo during the trial.
7. The bid was accepted by SSEN through the Piclo web interface.
8. SSEN sent the dispatch request at 12:00 on Monday 18th November 2019 requesting the service to be delivered 1 hour later. This was in the form of a text message sent from BW at SSEN to AF at LCH and can be seen in Figure 4.

Figure 4: Screenshot showing the MVS A1.1.1 dispatch request from SSEN to LCH.

9. Following receipt of the dispatch request message, the battery was controlled manually on site, delivering the agreed -30 kW flex for a period of 1 hour between 13:00 and 14:00 on Monday 18th November. Following the service delivery, the batteries immediately started recharging at 10 kW each (20 kW combined).
10. On-site monitoring consists of half hourly metering on the PV generation, and a site import and export meter. However, this data cannot be accessed in real time so monitoring the delivery at time of trial wouldn't be possible. This data was made available in May 2020 following signature of the data sharing agreement. Temporary on-site monitoring was installed at the site boundary. A FLUKE 1735 instrument was installed, with 5-second recording, sampling at 200ms. Data were recorded for 1 hour before and after the scheduled event.
11. Temporary monitoring was also installed on the feeder of Bridge View Watlington Road secondary substation which OBC depot is connected. OBC is the only customer connected to this feeder. A FLUKE 435-II instrument was used, recording at 1-second intervals, sampling at 200ms. Data were available for analysis in April 2020 following signature of the LEO Data Sharing Agreement.
12. Settlement was made with Brian Wann (SSEN) handing over £1 to Adriano Figueiredo (LCH) for the service delivered as part of MVS A1.1.1 as seen in Figure 5.

Figure 5: Settlement between Brian Wann (SSEN)(left) and Adriano Figueiredo (LCH)(right) for MVS A1.1.1. Photo credit: Malcolm McCulloch.

13. The research evaluation is presented in the following sections.
14. The procedural learnings and feedback have already been evaluated and are presented in the MVS Procedural Learnings Phase 1 (Jan 2020) LEO report.

4.3 Trial MVS A1.2.1

The second trial run at the OBC site was MVS A1.2.1 and with the service being delivered on Thursday 5th December 2019. The adaption being tested as part of this second trial was the ability to remote control the battery asset.

1. The artificial constraint was defined as requiring a -30 kW power shift, equivalent to reducing demand or increasing generation, between 11:00 and 12:00 on Thursday 5th December 2019. For the battery asset, this means discharging the battery back to the grid.
2. SSEN registered the constraint competition on the Piclo platform through upload of the relevant excel spreadsheet. There was ambiguity around the meaning of deficit and surplus which led to the wrong constraint being registered initially, however, this was clarified and amended. The old competition was still visible to service providers; logging out and back into the platform fixed this.
3. The OBC battery is already registered as a flexibility resource on the Piclo platform and the asset parameters remained unchanged from MVS A1.1.1.

4. The LCH were assumed to be registered with SSEN as a flexibility service provider.
5. As with step 3, the OBC battery was already marked as operation on the Piclo platform. No additional actions were required here.
6. A bid was entered for both power availability and energy utilisation at rates of £33.00 /MW/h and £33.00/MWh respectively, which corresponds to £1 in total for the service. This can be seen in Figure 6.

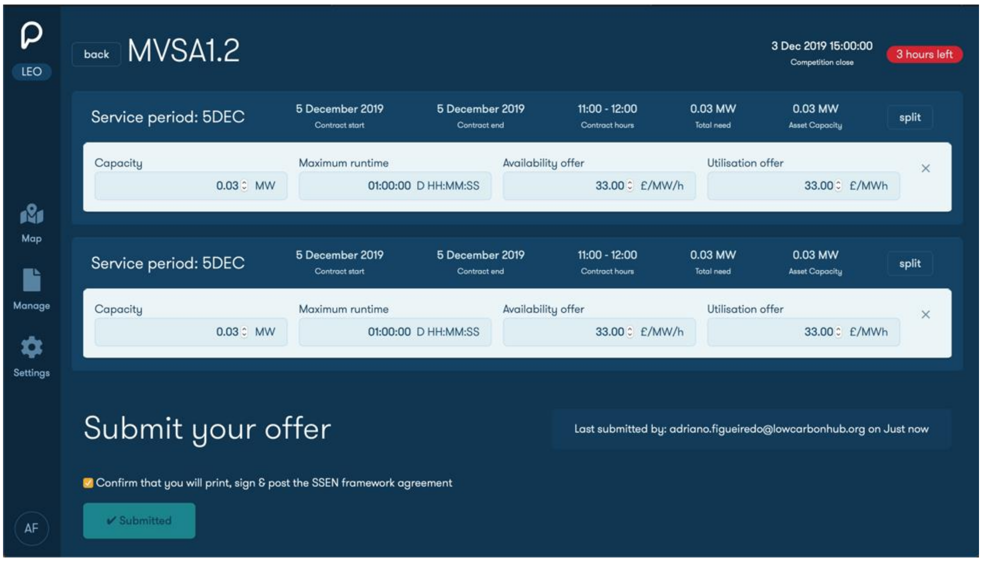

Figure 6: Screenshot of the LCH bid submission through the Piclo market platform for MVS A1.2.1

7. The bid was accepted by SSEN through the Piclo web interface. There were two identical bids showing for an unknown reason. Piclo advised SSEN to accept one and reject the other as seen in Figure 7.

Figure 7: Screenshot of SSEN bid acceptance through the Piclo market platform for MVS A1.2.1

8. SSEN sent the dispatch request at 15:53 on Tuesday 3rd December 2019 requesting the service be delivered on 5th December 2019 at 11:00 for a period of 1 hour later. This was in the form of a text message sent from AW at SSEN to AF at LCH and can be seen in Figure 8.

Figure 8: Screenshot showing the MVS A1.2.1 dispatch request from SSEN to LCH.

9. At the scheduled time for service delivery, the LCH notified Off Grid Energy to remotely dispatch the battery, successfully delivering the agreed -30 kW flex for a period of 1 hour at the scheduled time.

10. There was no additional on-site monitoring than the half hourly metering on the PV generation, and the site import and export meter. Data were made available in May 2020 following signature of the Data Sharing Agreement.
11. There was no monitoring at the secondary substation.
12. No settlement was made following this MVS trial.
13. The research evaluation is presented in the following sections.
14. The procedural learnings and feedback have already been evaluated and are presenting in the MVS Procedural Learnings Phase 1 (Jan 2020) LEO report.

4.4 Discussion of results

4.4.1 Procedural Learnings

The key procedural learnings arising from MVS A1.1.1 and MVS A1.2.1 were largely around internal MVS tracking. As MVS A1.1.1 was the first trial to be run as part of LEO, changes were made to how trial progress was monitored through the procedure documents. This required better definition of coordination roles, sign off when procedural steps had been completed and collection of data throughout the process (not just network monitoring) which confirms procedure steps had been completed.

Some minor bugs were highlighted with the Piclo marketplace which are mentioned in the previous sections, and these were remedied as part of the trial. Questions remain regarding metering requirements to allow for validation to be complete. In the case of MVS A1.1.1, temporary monitoring equipment was installed on-site and on the feeder at the local secondary substation. Permanent metering is required to ensure future trials can be monitored in near-real time to validate service delivery.

Within the LEO MVSs, 'Process Maturity' is used as a metric to quantify the evolution of an MVS; five categories of operation are identified: 'Unknown', 'Proxy', 'Manual', 'Partial Automation' and 'Full Automation'. Further details on the assignment of these categories can be found in the MVS A Procedural Learnings Phase 1 document. Table 5 and Table 6 below give the specific details of the process maturity of MVS A1.1.1 and MVS A1.2.1 respectively.

Table 5: Process Maturity report for MVS A1.1.1. Process Maturity Stage scores range from 1 (Red) to 5 (Green).

Procedure Step	PMS	PMS score	Reason	To reach next stage
1	Unknown	1	There is no established methodology for identifying flexibility services as part of the MVS process.	DSO driven trial service criteria.
2	Manual	3	Spreadsheet is filled out manually and uploaded to the Piclo LEO platform.	Constraint registered through API interface.
3	Manual	3	Spreadsheet is completed manually for each asset and asset update, and uploaded to the Piclo LEO platform.	Asset managed through browser and API interface.
4	Unknown	1	DSO is yet to define requirements or process for registering as a commercial supplier of flexibility	The requirements and process for registering as a commercial supplier of flexibility. A contract.
5	Manual	3	Asset status updated to 'Operation' by uploading new version of Piclo asset spreadsheet.	Asset managed through browser and API interface.
6	Manual	3	Manual determination of bid, input through Piclo LEO browser interface.	Asset modelling informs bid price, input through API.
7	Manual	3	A manual selection of the winning bids by DSO personnel.	Aided decision making based on optimum financial option, delivery risk and system impact modelling.

8	Proxy	2	Dispatch signal is a text message between DSO MVS coordinator and service provider coordinator private phone.	Dispatch signal sent via the Piclo LEO platform, or official facilitator route.
9	Manual	3	Off grid energy dispatched asset through on-site operation.	Remote operation of asset.
10	Manual	3	Temporary monitoring equipment was installed at substation, with data collected on an SD card which requires manual collection and processing.	Monitoring data accessible remotely.
11	Manual	3	Temporary monitoring equipment was installed at the common connection point by Off Grid energy, data require manual collection and processing.	Permanent monitoring with data accessible remotely.
12	Proxy	2	A token £1 coin was handed over at the following LEO MO meeting.	Commercial transfer of the agreed bid amount.
13	Unknown	1	Yet to occur, awaiting data.	Data
14	Manual	3	MVS procedure feedback is provided through the live learnings document and digested in the generic MVS learnings report.	
Average		2.4		

The average process maturity for MVS A1.1.1 was rated at 2.4. As no step scored above a 3 (‘Manual’ operation), there is scope to increase automation across all procedural steps. Particular focus should be made to the steps currently marked as 2, ‘Proxy’, or below. This includes how service requirements are identified on the network by the DSO, how flex providers are registered with the DSO, how the dispatch signal is sent between the DSO and flexibility provider, and how financial settlement is undertaken between the DSO and flex provider.

Table 6: Process Maturity report for MVS A1.2.1. PMS scores range from 1 (Red) to 5 (Green).

Procedure Step	PMS	PMS score	Reason	To reach next stage
1	Unknown	1	There is no established methodology for identifying flexibility services as part of the MVS process.	DSO driven trial service criteria.
2	Manual	3	Spreadsheet is filled out manually and uploaded to the Piclo LEO platform.	Constraint registered through API interface.
3	Manual	3	Spreadsheet is completed manually for each asset and asset update, and uploaded to the Piclo LEO platform.	Asset managed through browser and API interface.
4	Unknown	1	DSO is yet to define requirements or process for registering as a commercial supplier of flexibility	The requirements and process for registering as a commercial supplier of flexibility. A contract.
5	Manual	3	Asset status updated to 'Operation' by uploading new version of Piclo asset spreadsheet.	Asset managed through browser and API interface.
6	Manual	3	Manual determination of bid, input through Piclo LEO browser interface.	Asset modelling informs bid price, input through API.
7	Manual	3	A manual selection of the winning bids by DSO personnel.	Aided decision making based on optimum financial option, delivery risk and system impact modelling.
8	Proxy	2	Dispatch signal is a text message between DSO MVS coordinator and service provider coordinator private phone.	Dispatch signal sent via the Piclo LEO platform, or official facilitator route.
9	Partial Automation	4	Asset dispatched by service operator remotely.	API to allow M2M communication with asset

10	Unknown	1	No monitoring was installed at the local secondary substation.	Monitoring required at local secondary substation with near-real time access.
11	Proxy	2	Standard half hourly metering is present at the site.	Greater than half hourly resolution, real-time monitoring required
12	Unknown	1	No settlement has been made.	Proxy form of settlement.
13	Unknown	1	Yet to occur, awaiting data.	Data
14	Manual	3	MVS procedure feedback is provided through the live learnings document and digested in the generic MVS learnings report.	
Average		2.2		

The second iteration of the OBC MVS saw a decrease in process maturity despite an increase in automation through the remote control of the asset. This decrease was a result of no longer having any monitoring equipment installed at either the substation or the site. There was also no settlement made by SSEN to the LCH.

4.4.2 Technical Learnings

The data collected through the MVS A1 trials, presented below, helped inform the data processing methods being developed as part of Project LEO. These data have had the cleaning methods applied in addition to the pre-processing steps described below. The code alongside documentation is available on the Project LEO Data Bitbucket repository.[3]

4.4.2.1 Data Sources

Description	**Meter**	**Measurement Resolution**	**Start time**	**End time**

[3] Project LEO Database Bitbucket Repository; https://bitbucket.org/projectleodata/project-leo-database; accessed June 2020.

Substation feeder monitoring	FLUKE 435-II	1 second	05/11/2019 10:50:05	05/12/2019 10:50:04
Site monitoring	FLUKE 1735	5 second	18/11/2019 11:45:43	18/11/2019 14:56:53
Import Meter	N/A	30 minutes	01/11/2019 00:00:00	30/04/2020 23:30:00
PV Generation Meter	N/A	30 minutes	01/04/2019 00:00:00	30/04/2020 23:30:00
Export Meter	N/A	30 minutes	01/11/2019 00:00:00	30/11/2019 23:30:00

Due to the various measurement resolutions, data were downsampled before analysis was undertaken. When comparing the substation and site high-resolution monitoring, the substation data were downsampled from 1 second resolution to 5 second resolution using mean values. When making comparisons with half hourly energy data, power was resampled to 30-minute resolution, again using mean values, and then converted to energy where necessary.

4.4.2.2 Time synching

Initial analysis of the metering data collected at both the substation and the site showed a temporal misalignment, seen in Figure 9. This can be a common occurrence if equipment hasn't been calibrated for a long time and the internal clock has drifted, or the calibration was done incorrectly. As both instruments didn't have the ability to self-synchronise their internal clocks (e.g. through a GPS connection), we cannot be sure which, or if both, were incorrect.

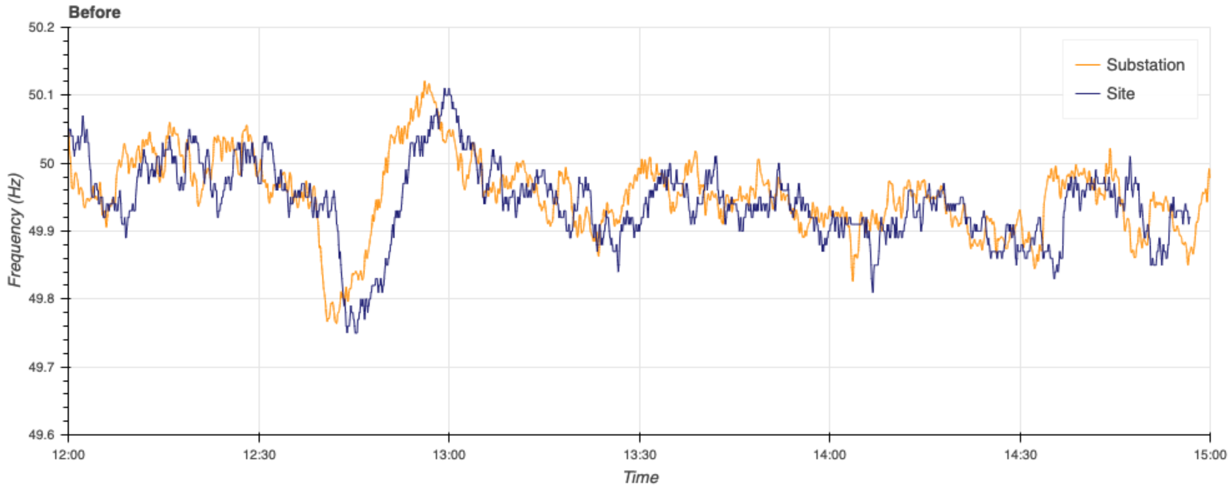

Figure 9: Frequency (Hz) measured by temporary monitoring equipment at the OBC site and secondary substation feeder showing a time shift of 193 seconds due to a difference in internal clock

In the case of this trial, the person that installed the site meter noticed a time discrepancy, so we have assumed that only this meter's clock was incorrect. Before any further analysis was undertaken, a time-synching correction algorithm which minimised the root mean square difference between the datasets was written. A time difference of 193 seconds was determined.

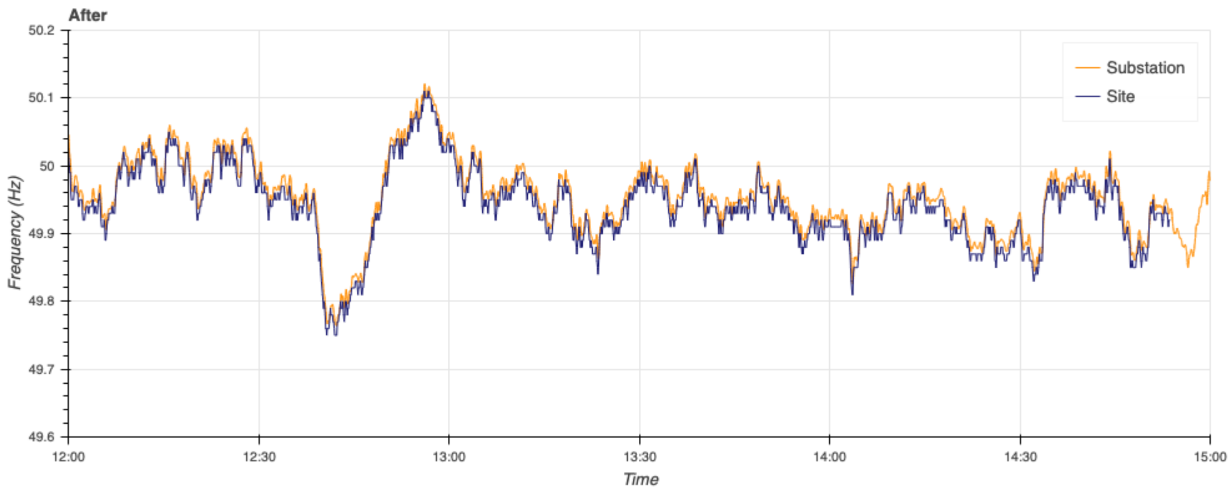

Figure 10: Frequency (Hz) measured by temporary monitoring equipment at the OBC site and secondary substation feeder after a time-synching algorithm has been applied to the site data.

Once the time offset between the two datasets was established, the site data timestamp was shifted by -193 seconds (shifting earlier in time) resulting in the data presented in Figure 10 which clearly shows the datasets aligned.

4.4.2.3 MVS A1.1.1 Service Delivery

Power

The following analysis investigates the service delivery; this was for a -30 kW flex in demand for 1 hour between 13:00 and 14:00. An algorithm was written to automatically identify a step change in the power output with the results shown in **Error! Reference source not found.** below. This u tilized a convolution between the real power measured at the site with a step function; the maximum and minimum of the resulting convolution give the timings of the step change in power output. The code is available through the Project LEO code repository.[4]

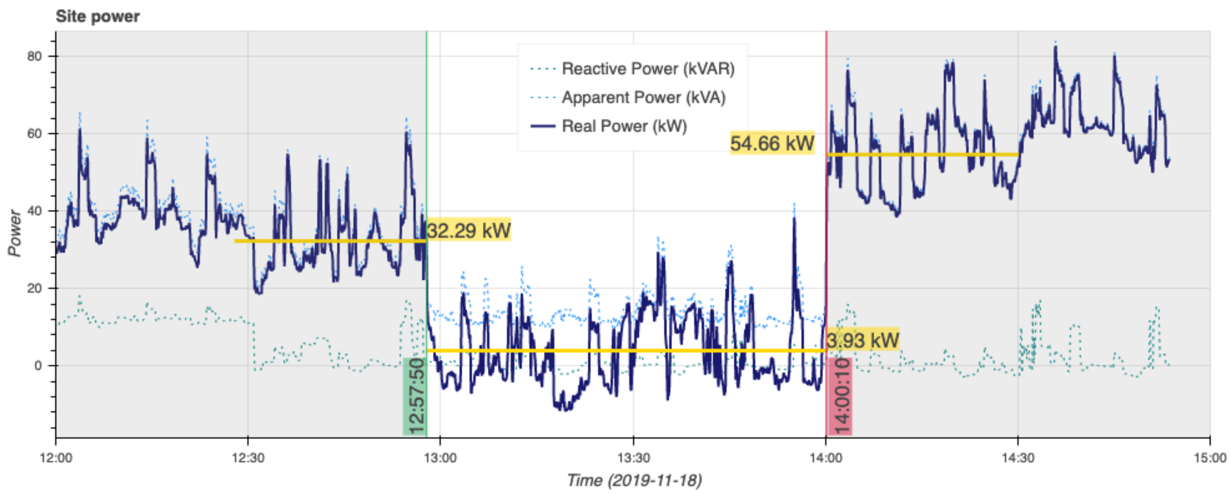

Figure 11: Power traces measured at the OBC site showing the flexibility event. The annotations are determined from a convolution algorithm for step change identification. The algorithm was applied to the real power trace.

The service was determined to have started at 12:57:50 and finished at 14:00:10. The magnitude of the delivered service was determined by using the average power in the half hour period preceding delivery as a baseline and comparing to the average power over the whole service window. This showed a reduction in site demand from 32.3 ± 8.3 kW to 3.9 ± 9.0 kW, a shift of **-28.4 ± 12.3 kW**. Without monitoring directly on the battery, this will include other variations in site load and PV generation which is likely the reason this is slightly below the expected 30 kW. The baselining method will also impact the calculated service, for instance, had the previous hour

[4] Project LEO Database Bitbucket Repository; https://bitbucket.org/projectleodata/project-leo-database; accessed June 2020

before service delivery been used as the reference point, the delivered service would have been measured at -31.5 ± 12.3 kW. However, extending this time means the baseline is more likely to include the effects of long-term changes in load or generation at the site. It is important that the validation methodology including metering requirements and baselining is developed alongside the tolerances of the service delivery. Due to variations in site demand and PV generation, at times the power dropped below 0 kW meaning power was being exported from the site. The peak export was -11.6 kW.

After the service delivery, a shift in power of +50.7 ± 13.1 kW to 54.7 ± 9.5 kW is observed. This is higher than the power before the event by 22.4 ± 12.7 kW. This is a result of the batteries immediately charging following the event at an expected 10 kW each. The power is well outside the site import and export power constraints of 220 kVA and 143 kW respectively.

Voltage

As well as changes in power, there will also be associated changes in voltage as a result of the flexibility service. In fact, voltage management to keep the delivered voltage within regulated tolerances and extend transform lifespan (by avoiding excessive use of tap changers – a mechanical mechanism for controlling the output voltage of a transformer) could be a reason for procuring flexibility services in the first place. Figure 12 displays the voltage trace for each of the three phases as measured at the site. The voltage annotations refer to phase 1 and are averages in the half hour periods before and after the event, and for the hour event. The baseline voltage shows an increase of 0.85 ± 0.4 V from 244.3 ± 0.7 V to 245.1 ± 0.5 V as a result of the -30 kW shift in power. The peak voltage measured during service delivery was 246.5 V.

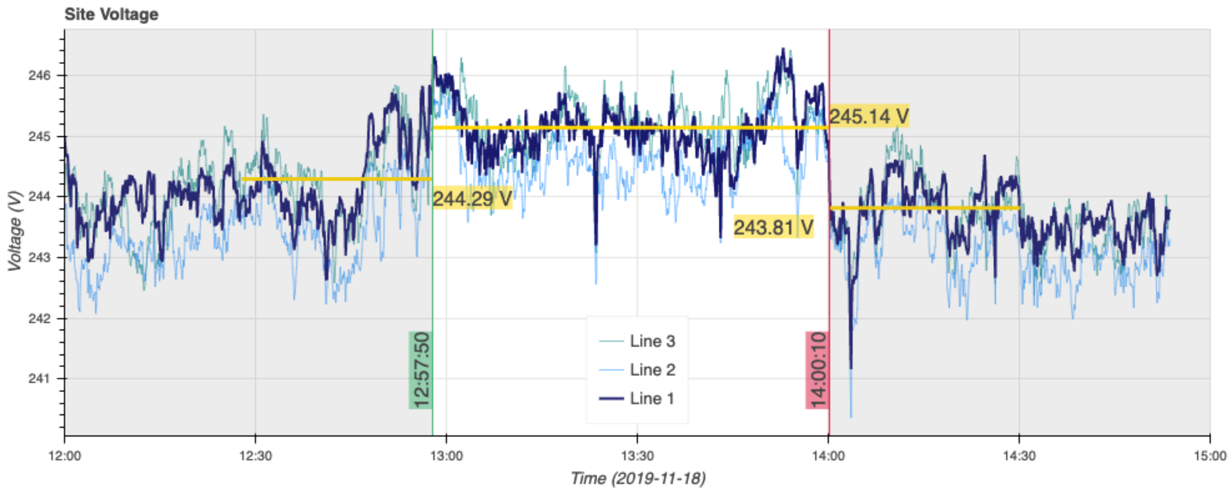

Figure 12: Voltage traces for each phase measured at the OBC site during the flexibility service. Voltage values are for Line 1.

Energy

To compare the high-resolution measurements with that of the standard half hourly metering on site, the net active energy measured by the FLUKE instrument was separated into import (values > 0) and export (values < 0) then resampled to 30-minute data by summing the active energy in each half hour period. Figure 13 below shows the resulting energy data for import (blue bars), export (green bars) and net energy (solid black line) measured on the temporary site instrumentation; the standard half hourly metered net energy (dotted black line) is shown for reference, confirming consistency between the two metering setups.

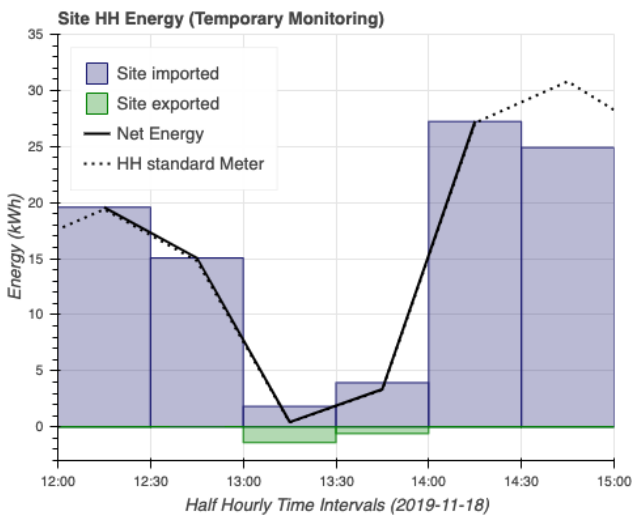

Figure 13: Half hourly energy aggregated from the 5-second on-site monitoring (black solid). Site import (blue) sum of positive values, site export (green) sum of negative values. Standard half hourly import meter (black dotted) shown for comparison.

The presence of the green bars indicates there was a small amount of export from the site during the two half hour periods of service delivery, although this was not large enough to show as average net export during this period. If the half hour period immediately prior to the expected service delivery is used as a baseline, the shift in net power is observed as **26.3 kW** from an average of 30.1 kW for the period 12:30-13:00 and 3.8 kW for the period 13:00 – 14:00; this shift in power is slightly less than that measured above.

In addition to hidden changes in PV generation and site demand presented above, the lower resolution metering doesn't allow for an exact identification of service operation. In this case the service started a couple of minutes before the scheduled time which cannot be identified here, this means that the previous period's energy use is slightly lower than measured with the higher resolution monitoring. When it comes to settlement, this may influence the payment the service provider receives, in this case, the service provider would be paid less for the service. While this is self-inflicted by the service provider for starting the service early, it highlights the lack of visibility to the true service being delivered; perhaps this could be exploited by the service provider. There are also potential technical implications to this as well, it is not possible to tell if the 30 kWh were delivered at a flat rate of 30 kW for the full hour, or if this was delivered within 10 minutes at 180 kW. This difference could have serious implications for network stability.

While this only had a very small impact in the case presented here, when scaling the service up to MW, the impact could be much larger. This highlights the importance of tolerances based on network requirements and that the appropriate metering, baselining and validation methodologies are used to regulate this.

Standard Half Hourly Metering

There are three standard half hourly energy meters on site used for settlement of energy use between OBC and their energy supplier for imported energy, between the LCH and the energy supplier for the PV generation and exported energy, and between the LCH and OBC for self the self-consumption of PV generation on site. From these three meters it's possible to calculate the site demand and net half hourly energy in addition to import, export and PV generation. Calculating site demand will help with baselining and service validation by negating the impact of variable PV output during service delivery.

Generation filling

Unfortunately, there was a loss of data recording for the PV generation for the 18th and 19th November, exactly when the trial took place. As a basic estimate, the gaps in the solar output were filled with predicted power output from the online renewables.ninja PV model (which uses NASA's weather reanalysis data and the open source 'gsee' PV modelling library).[5] A simple linear regression model was used to account for unknown differences between the model PV setup and the actual installation (such as invertor efficiency). Figure 14 shows the two-week period around the trial with the predicted PV output in red which was used to fill the gaps in the measured output (blue). An alternative approach could be to fill missing PV data based on the difference between expected site demand (analysed through a clustering approach) and that measured at the import, export meters. A potential issue to be aware of is that the PV data being cleaned is used to calculate the site demand, so if not careful, an analysis based on this may in fact use erroneous data to correct other erroneous data. Also, the import and export meters may be susceptible to the same communication issues. Such challenges will be addressed with further development of the baselining methodology in future trials.

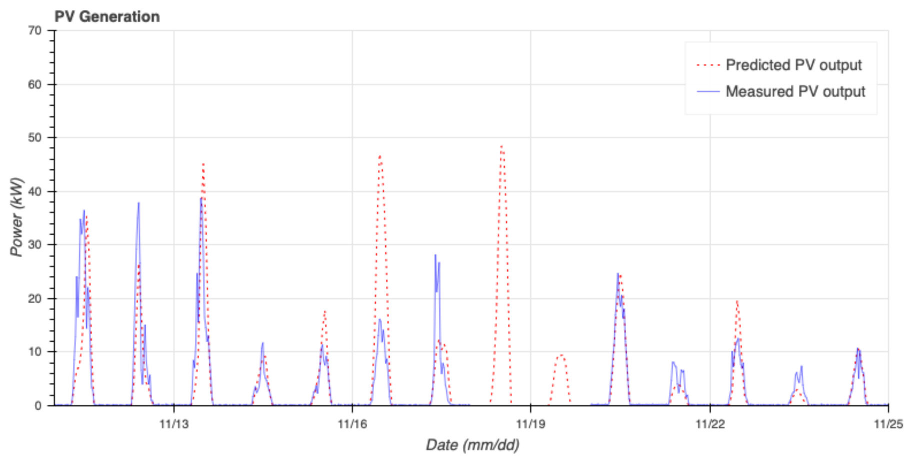

Figure 14: PV generation measured (blue) highlighting missing data and predicted generation (red) using linear regression of weather reanalysis data available via www.renewables.ninja.

The demand of the site (E_{site}) can now be estimated by first calculating the net demand (E_{net}) from the import meter (E_{import}) and export meter (E_{export}, a positive meter value), $E_{net} = E_{import} - E_{export}$ and then adding the generation recorded from the PV meter (E_{PV}), $E_{site} = E_{net} + E_{PV}$. Figure 15 shows the different energy flow at the OBC site during the trial window, site import,

[5] www.reneables.ninja; accessed: 21/05/2020

export and standard HH net are all measured values, PV generation and by extension site demand are estimated values and expected battery use displays the intended battery operation.

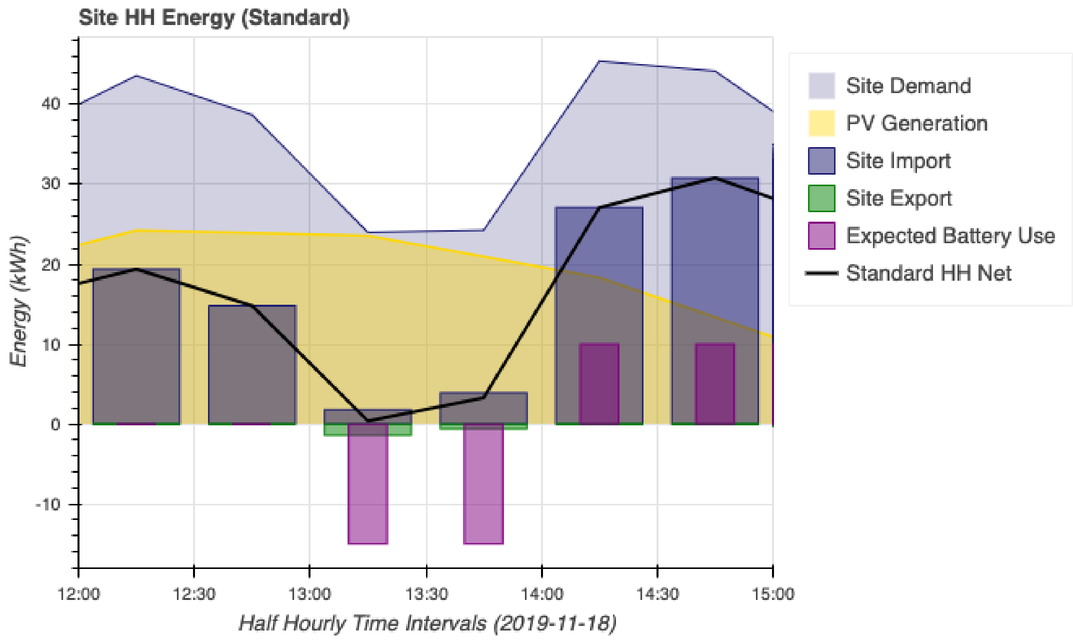

Figure 15: Half hourly energy as measured from the standard half hourly import, export and PV meters.

Using the net demand calculated from standard half hourly import and export meters and the same reference of the previous half hour, the flex event is measured at **25.9kW**, changing from an average 29.6kW in the period 12:30 – 13:00 to an average of 3.7kW in the period 13:00 – 14:00. Lower than both the high-resolution metering and half hourly aggregated high-resolution metering, this is now only 86% of the expected 30kW service dispatched.

Impact at the substation

Due to the presence of high-resolution metering at both the site and the secondary substation feeder (that only has the OBC connected), it's possible to investigate the difference in response between the site and the substation. Such differences which result from line losses may influence the size of service procured by the DSO. Figure 16 below shows the voltage measured for Line 1 at the site (blue) and the substation (orange). As expected, the substation voltage is slightly higher than that observed at the site. The peak voltage measured at the substation during the service delivery was 247.0 V.

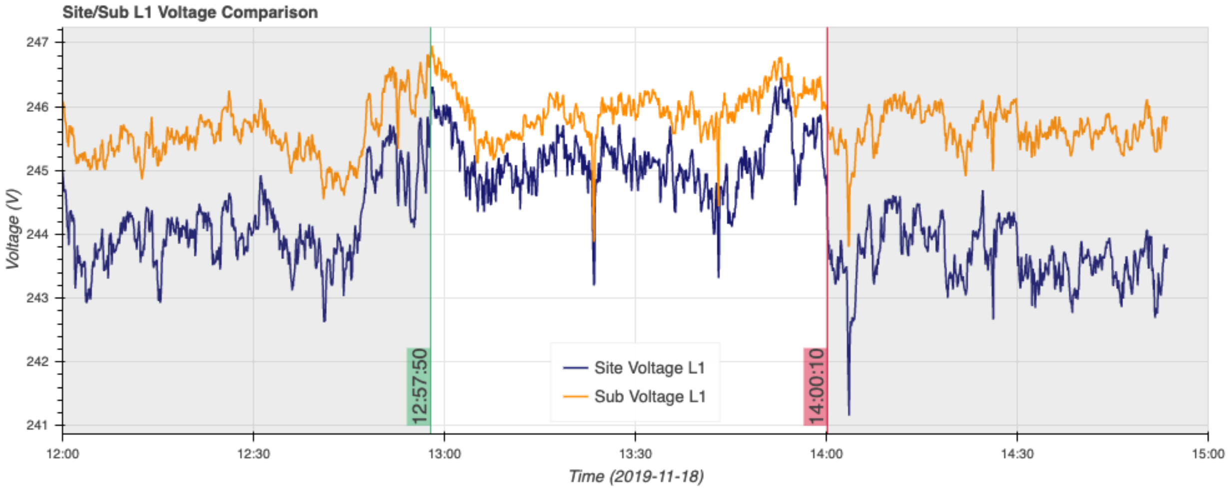

Figure 16: Comparison of voltage measured at the OBC site (blue) and at the secondary substation (orange). Voltage is lower at the site due to the voltage drop across the line to the site. The size of the voltage shift at the substation is lower than at the site due to the same reason.

The OBC site is connected via a 73.7m length of 300 Wavecon cable and 45.3m of 185 Wavecon cable. There is an average voltage drop of **1.32 V** in the 30-minute period before the flex event. This voltage drop is reduced to **0.81 V** during the event due to the reduction of load as part of the flex service. This means that the impact on voltage observed at the substation is smaller than that measured at the site.

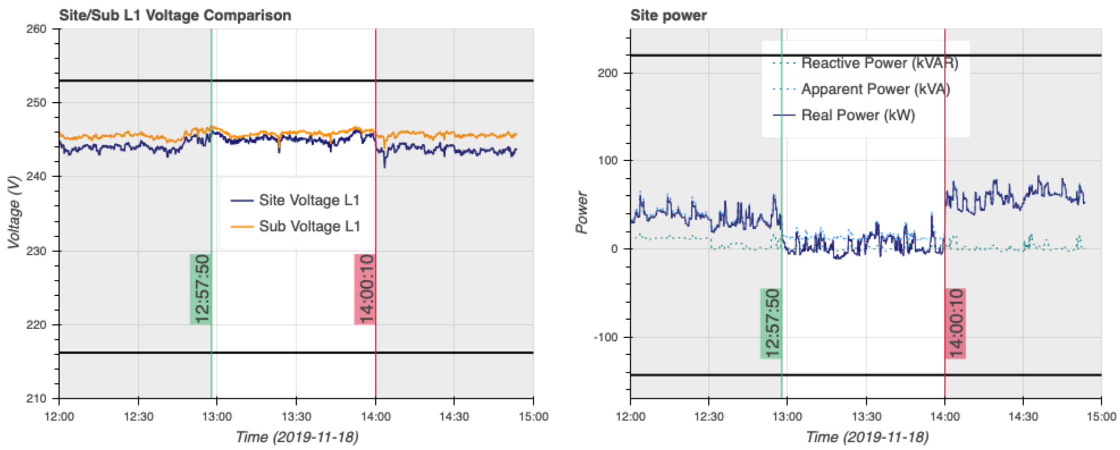

Figure 17: Left – Voltage relative to upper (230 + 10%) and lower (230 - 6%) voltage supply tolerances. Right - Site power relative to maximum import capacity and maximum export capacity (black horizontal lines)

Figure 17 displays the voltage and power traces (previously presented in Figure 16 and **Error! Reference source not found.**) in context with the DNO's supply voltage regulations and the sites import and export capacity constraints respectively. As can be seen from the two traces, both power and voltage remain well within operational constraints.

Further analysis of the difference in service delivered at the site and observed at the substation will be the focus of future MVS trials. The dataset collected at the substation provides a month's worth of data, the value of which has not been fully explored here. Further analysis of this data should be undertaken and be used to inform questions around substation monitoring moving forwards.

4.4.3 Commercial Learnings

The commercial learnings were not the core objective of MVS A1.1.1 or A1.2.1 and as such, only a proxy value of £1 was used to bid into the auction. However, for future reference, a basic financial assessment is presented which may help to inform future trials which focus on finances. As the exact financial arrangements between the LCH, OBC and their energy suppliers are commercially sensitive information, typical rates have been used which reflect the relative importance between rates; that the rate for self-consumption is between that for external import and export. This was presented in Table 1 earlier. The 'No Flexibility Service' baseline was calculated from the actual half hourly energy use presented in Figure 15 with the expected battery use subtracted (i.e. a complete discharge-charge cycle of –30 kW for 1 hour followed by +20 kW for 1.5 hours). A breakdown of costs is shown below.

Table 7: Daily cost breakdown for the site as one entity, OBC and LCH with and without the flexibility service. Positive values indicate expenditure.

Energy Transaction	No Flexibility Service Daily Energy Costs	With Flexibility Service Daily Energy Costs	Difference
Site Import (C_i)	£144.50	£144.74	£0.24
Site Export (C_e)	£0.00	£0.12	£0.12
Self-Consumption (C_{sc})	£18.51	£18.51	£0.00
FiT (C_{FiT})	£27.26	£27.26	£0.00
Flexibility (C_{flex})	£0.00	£1.00	£1.00
Site total (C_{site})	£117.24	£116.36	-£0.88
OBC Total (C_{OBC})	£163.01	£162.25	-£0.76
LCH total (C_{LCH})	-£45.77	-£45.89	-£0.12

The site total represents the general case if all assets were owned by a single organisation, it is simply $C_{site} = C_i - C_e - C_{flex}$. The flexibility service would have cost the site 12p in energy due to the difference between import and export rates, but this is compensated by the £1 flex payment leaving a total difference of **-£0.88** in favour of delivering the flexibility.

OBC total $C_{OBC} = C_i + C_{sc} - C_{flex}$ and LCH total $C_{LCH} = -C_e - C_{sc} - C_{FiT}$ account for the more complex financial arrangement between the LCH, owners of the PV system, and OBC, responsible for site demand and owners of the batteries. OBC see a change of **-£0.76** in favour of delivering the flex event, this is due to the £1 payment for flex offsetting the additional cost of importing energy, while LCH see a change of **-£0.12** in favour of the flex event, a result of the additional export from the site which wouldn't have happened without the flex event.

While for this specific trial, the flex event has benefitted both companies, this is not generally true given the financial arrangement. It will depend on the relative size of site demand to PV output as to how it effects both actors. For instance, if site demand had been slightly higher, or PV generation slightly lower, no export would have happened and the LCH wouldn't see any change. This basic financial assessment also doesn't include the effects of variable pricing from either network charges or variable tariff structures from the supplier. This will be addressed in future MVS trails and modelling and will impact the optimum time for charging the batteries following the flex event.

4.4.4 Social Learnings

Following the running of this first set of trials, a new process was developed by Project LEO for mapping the stakeholders, based on experience and existing generic stakeholder mapping approaches. This process is tailored to be specific for Project LEO MVSs and is intended to be used during the initiation phase of future MVS trials. Firstly, stakeholders are identified and categorised into three core themes: 'Critical to Success', 'Adds Value' and 'Keep Informed'. This process was applied to the OBC system post MVS A1.2.1 and the results are summarised in Table 8 below.

It was realised that planning engagement for different stages of the MVS process and being able to visualise it would be helpful. The second stage of the process is to identify the level of engagement during the different stages of trial development, these are: Inception, Feasibility, Funding, Developing the System, Operation/Testing and Dissemination. Table 9 shows a heat map of how the engagement process could have worked for the OBC trials described herein.

Table 8: Stakeholder mapping

<table>
<tr><td colspan="3"><u>Stakeholder categorisation sheet</u>

What is the objective/activity: Development and testing of MVS A1 – Oxford Bus Company (Cowley Depot) Battery-PV system – developing storage response.</td></tr>
<tr><td>Critical to success - i.e. who has authority and has to say “yes” for things to proceed, and/or is responsible for “doing”.</td><td>Adds value - i.e. who is responsible for “doing” added value tasks and/or needs to be consulted to develop a better outcome.</td><td>Keep informed - i.e. wouldn’t materially alter or impede the achieving the objective, but are necessary to keep informed.</td></tr>
<tr><td>Who has authority?

Oxford Bus Company – as battery owner/building occupier. As owner of data from meters.
Oxford Bus Company Operations Team – impacted by timings of test.
Low Carbon Hub – as owner of PV panels.
LCH investment committee
PiP board – approval of progress
SSEN – simulating grid constraints for testing, installation of monitoring equipment.
Piclo – communication with Piclo LEO platform for testing.

Who is responsible for implementing?
Low Carbon Hub – reprogramming battery management, calculating loads/assessing feasibility
University of Oxford – assisting SSEN in installing monitoring equipment.</td><td>Who needs to be consulted?

University of Oxford – as data users
Off Grid Energy (battery manufacturer) – consulted about capability of batteries

Who is responsible for implementing added value?

Oxford Bus Company have potential to add value in the future if they allow the flexibility in their second battery to be used.</td><td>All groups who are either “critical to success” or “adds value”.
LEO Partners otherwise uninvolved in the MVS.
Local environmental interest groups/local communities (passive interest)
Monitoring Officers
Press</td></tr>
</table>

SSEN – providing simulated grid constraint, verifying flex event as happened?, installing monitoring equipment. Piclo – facilitating the relevant information being registered on the Piclo LEO platform.		

Table 9: Ongoing stakeholder engagement strategy heat map

Stakeholder	Inception	Feasibility	Funding	Developing the system	Operation/testing	Dissemination
Oxford Bus Company - as battery owner/building occupier	Low	Fully	None	Fully	Fully	Fully
Oxford Bus Company - as meter data owner	Low	High	None	Fully	Fully	Fully
Oxford Bus Company Operations Team - impacted by test timing	Low	High	None	Fully	Fully	Fully
Low Carbon Hub - as owner of PV panels	Some	Some	Some	Fully	Some	Fully
Low Carbon Hub - as implementor	Fully	Fully	Fully	Fully	Fully	Fully
Low Carbon Hub - investment committee	Some	None	Fully	None	None	Some
PiP Board - approval of process	Some	Some	Some	Some	Some	Some
SSEN (assisted by University of Oxford) - Installing monitoring	Some	High	Some	Fully	Some	Some
SSEN - simulated grid constraint, verifying flex event occurred	Some	High	None	Fully	Fully	Fully
Piclo - facilitating the LEO Piclo platform	Some	High	None	Fully	Fully	Fully

University of Oxford - as data users	Some	Fully	None	Fully	Fully	Fully
Off Grid Energy - battery manufacturer, consulted on battery capability	None	Some	None	Some	Some	Some

The ability for Project LEO to get a trial up and running in such a short space of time is largely thanks to the ongoing relationship between the LCH and OBC who have worked together for a number of years previous. Understanding the success of this relationship could be important for the fast development of other sources of flexibility like the one trialled here, both within Project LEO and beyond. The success of the trial also hinged on the battery manufactures Off Grid Energy, who were required to adjust the standard operation of the battery, which when installed had not been intended for this usage.

4.4.5 KPIs

Table 10: Specific MVS Key Performance Indicators (KPIs) with values for MVS A1.1.1 Oxford Bus Company where analysis undertaken.

KPI	Value
Capacity under flexible control	30 kW
Impact on network utilisation (constraints)	N/A
Service response time	5 minutes
Levelized cost of flex event (full flex process, cost per kW and cost per kWh)	N/A
Additional generation capacity unlocked	N/A
Number of customers participating in the Project LEO service	1
Number of vulnerable customers / ‘energy poor’ customers participating in the Project LEO service	0

Net benefit to participants	£0.88
Estimation/measurement of CO2 impact of the Project LEO service	N/A
Impact on non-participants	N/A

5 Key Learnings Summary and Future Work

The MVS A1.1.1 and MVS A1.2.1 trials using a 48 kW battery setup at the Oxford Bus Company's Cowley depot represents the first set of trials undertaken as part of Project LEO. As such, the trials have provided the project with the opportunity to gain quick learnings early on and have paved the way for future trial coordination, procedures and progress tracking.

Both trials successfully delivered the –30 kW (reduction in demand) for the scheduled 1-hour period, the first through manual operation on site, the second through remote operation. As part of the trial, some minor bugs were highlighted and fixed on the marketplace platform and the communication of dispatch requests.

Several technical learnings have been gathered from the MVS trial data collected. The data have provided a real-world use-case to develop some of the data collection, cleaning and processing methodologies; the time syncing methods and filling of missing data being examples of these. The presence of both high-resolution monitoring (5 seconds) and low-resolution standard half hourly metering (30 minutes) has allowed comparisons to be made between the two. Having only standard half hourly metering severely limits the ability to identify exact timings and magnitude of the service delivered and decoupling it from other background variations due to site demand and generation. However, high resolution metering will come at a cost and a balance needs to be found. This, along with baselining methodology, should be a high priority learning objective of future MVS trials.

The trial also provided the opportunity to monitor data both at the site and the secondary substation feeder to understand the differences observed and how these impact the requirements of the service. Due to the voltage drop across the line supplying the depot, the shift in voltage resulting from the flexibility dispatch is smaller at the substation than at the site. This along with associated power losses may influence the amount of flex procured by the DSO, or in cases of offsetting and peer-to-peer trading, the ability to track output and settle at the correct price.

A basic financial analysis was undertaken using the standard half hourly for the day of the trial. It showed that the site earned £0.88 from delivering the service which included an additional cost of energy of £0.12 due to the mismatch in import and export prices, compensated by the £1 paid to the site for the delivered service. While these figures are only a basic proxy at this stage and don't include any of the additional non-energy costs associated with operating a flexibility service and participating in the market, it is a starting point to informing future trials centred around cost. Finally, a stakeholder assessment was undertaken as part of the trial.

The MVS trials presented really kickstarted the Project LEO MVS framework and the end-to-end procedure has developed as a result of the learnings here and other MVS trials which have happened in the meantime; future trials at OBC will focus on furthering the development of these procedures. The process maturity tables above touch on some future work identified in order to progress the process maturity and level of automation. These relate to communications methods and protocols between the different actors within the process, along with investigating different monitoring solutions. The Oxford Bus Company continues to be the flagship asset within the prosumer MVS category, and learnings obtained from this site are important in the development of many similar PV + storage sites identified within LEO.

Modelling work will also be carried out by UoO and LCH to investigate optimised battery operation which maximise the additional value both financially and environmentally, for such a site. For example, recharging of the battery occurred immediately after the discharge event in the trials above. A more suitable time might be available based on other site demand requirements, on-site generation, or the presence of time-varying retail prices. Understanding how this battery strategy is integrated with the Project LEO flexibility market will both be the focus of future trials, but also help inform future commercial learning opportunities.

6 Appendix A – Glossary

Best efforts have been made throughout the document to use accepted terminology common to the UK electricity industry and DSO industry. For clarity, some key terms used in this document are defined below.

Term	Definition
Aggregator	An aggregator is a company who acts as an intermediary between electricity end-users, DER owners and the power system participants who wish to serve these end-users or exploit the services provided by these DER. The aggregator groups distinct agents in the electric power system (i.e. consumers, producers, prosumers, or any mix thereof) to act as a single entity when engaging in power system markets (both wholesale and retail) or selling services to system operators.
BMS	Building Management System
BSP	Bulk Supply Point: A node on the distribution network between extra high voltage and high voltage. Typical voltage level (kV): 132/33.
Data User	A party or individual who requires access to some or all of the data generated as part of the MVS trial for analysis, evaluation and/or learning generation.
Delivery	The fulfilment of the flexibility service as per the dispatch instruction.
DER (Asset)	Distributed Energy Resource connected at distribution level.
DER (asset) Owner	The legal owner of a DER (asset).
Dispatch	Instruction sent by the DSO to the Service Provider to initiate the flexibility service.
DNO	Distribution Network Operator.
DSO	Distibution System Operator. A party that takes on the role of system operation. A DSO securely operates and develops an active distribution system comprising networks, demand, generation and other flexible DERs.
DSR	Demand Side Response. Varying the demand of a DER, such as a building, to offer flexibility.
EA	Environment Agency

Flexibility Market	The arena of commercial dealings between buyers and sellers of Flexibility Services.
Flexibility Service	The offer of modifying generation and/or consumption patterns in reaction to an external signal (such as a change in price) to provide a Service within the energy system.
Grid	The electricity distribution network.
GSP	Grid Supply Point: The point where the distribution network connects to the transmission network. Typical voltage level (kV): 400/132.
HVAC	Heating, Ventilation and Air Conditioning
KPI	Key Performance Indicator
LCH	Low Carbon Hub
LEO	Local Energy Oxfordshire
MIC/MEC	Maximum Import Capacity/Maximum Export Capacity
MPAN	Meter Point Administration Number
MVS	Minimum Viable System. A minimum stress set of participants, technology and processes required to trial new system innovation.
MVS Coordinator	A single person taking on the responsibility of 'Project Manager' for the specific MVS trial, they are responsible for coordinating other partner coordinators to ensure the MVS documentation gets completed.
OBC	Oxford Bus Company
OBM	Oxford Behind the Meter: A plug-in project within Project LEO.
OBU	Oxford Brookes University
OCC	Oxfordshire County Council
OCityC	Oxford City Council
Partner Coordinator	The lead person from each organisation involved in the MVS trial that coordinates the activity of that organisation in the trial, and has responsibility for completing the MVS documentation relevant to their organisations role.
Plug-in Project	A flexibility asset or system being developed as part of LEO which is capable of 'plugging-in' to the flexibility market.
PMS	Process Maturity Stages. A metric measuring automation of a process.

PSS	Primary Substation: A node on the distribution network between high voltage and medium voltage. Typical voltage level (kV): 33/11.
Service Provider	Those parties able to offer Flexibility Services. Not necessarily the Asset Owner.
Settlement	A financial transfer to the Service Provider following the successful delivery of the instructed Flexibility Service.
SFN	Smart and Fair Neighbourhood
SSEN	Scottish and Southern Electricity Networks
Technology Platform	A market where user interactions are mediated by an intermediary, the platform provider, and are subject to network effects. As opposed to a marketplace or trading exchange, a platform intermediary must offer inherent value beyond the simple mediation process for the two sides of the market.
UoO	University of Oxford

7 Appendix B - Data

7.1 Trial data package

Data in LEO, particularly as they relate to the MVS trials, are captured through the Data Log and held on a secure repository. The data are automatically parsed, and their metadata are summarized into individual 'Data Certificates' which highlight the key aspects and information relating to a particular dataset. The Project LEO Foreground Data Catalogue, which summarizes the data captured from all of LEO's activities at a high level, can be used to access data for MVS A1 and all associated Data Certificates which describe the data in further detail.

7.2 Substation data

Substation timeseries data from temporary monitoring installed on the Oxford Bus Company feeder at Bridge View, Watlington Road, secondary substation. Measured on a FLUKE 435-II instrument with 1 second resolution.

Value headings:

'Vrms ph-n L1N Min', 'Vrms ph-n L1N Avg', 'Vrms ph-n L1N Max', 'Vrms ph-n L2N Min', 'Vrms ph-n L2N Avg', 'Vrms ph-n L2N Max', 'Vrms ph-n L3N Min', 'Vrms ph-n L3N Avg', 'Vrms ph-n L3N Max', 'Vrms ph-n NG Min', 'Vrms ph-n NG Avg', 'Vrms ph-n NG Max', 'Vrms ph-ph L12 Min', 'Vrms ph-ph L12 Avg', 'Vrms ph-ph L12 Max', 'Vrms ph-ph L23 Min', 'Vrms ph-ph L23 Avg', 'Vrms ph-ph L23 Max', 'Vrms ph-ph L31 Min', 'Vrms ph-ph L31 Avg', 'Vrms ph-ph L31 Max', 'Peak Voltage L1N Min', 'Peak Voltage L1N Avg', 'Peak Voltage L1N Max', 'Peak Voltage L2N Min', 'Peak Voltage L2N Avg', 'Peak Voltage L2N Max', 'Peak Voltage L3N Min', 'Peak Voltage L3N Avg', 'Peak Voltage L3N Max', 'Peak Voltage NG Min', 'Peak Voltage NG Avg', 'Peak Voltage NG Max', 'Current L1 Min', 'Current L1 Avg', 'Current L1 Max', 'Current L2 Min', 'Current L2 Avg', 'Current L2 Max', 'Current L3 Min', 'Current L3 Avg', 'Current L3 Max', 'Current N Min', 'Current N Avg', 'Current N Max', 'Frequency Min', 'Frequency Avg', 'Frequency Max', 'Unbalance Vn Min', 'Unbalance Vn Avg', 'Unbalance Vn Max', 'Unbalance Vz Min', 'Unbalance Vz Avg', 'Unbalance Vz Max', 'Unbalance An Min', 'Unbalance An Avg', 'Unbalance An Max', 'Unbalance Az Min', 'Unbalance Az Avg', 'Unbalance Az Max', 'THD V L1N Min', 'THD V L1N Avg', 'THD V L1N Max', 'THD V L2N Min', 'THD V L2N Avg', 'THD V L2N Max', 'THD V L3N Min', 'THD V L3N Avg', 'THD V L3N Max', 'THD V NG Min', 'THD V NG Avg', 'THD V NG Max', 'THD

A L1 Min', 'THD A L1 Avg', 'THD A L1 Max', 'THD A L2 Min', 'THD A L2 Avg', 'THD A L2 Max', 'THD A L3 Min', 'THD A L3 Avg', 'THD A L3 Max', 'THD A N Min', 'THD A N Avg', 'THD A N Max'.

7.3 Site data

Site high resolution timeseries data from temporary monitoring installed at the Oxford Bus Company main incomer. Measured on a FLUKE 1735 instrument with 5 second resolution.
Values headings:
Voltage L1N Min, Voltage L1N Avg, Voltage L1N Max, Voltage L2N Min, Voltage L2N Avg, Voltage L2N Max, Voltage L3N Min, Voltage L3N Avg, Voltage L3N Max, Current L1 Min, Current L1 Avg, Current L1 Max, Current L2 Min, Current L2 Avg, Current L2 Max, Current L3 Min, Current L3 Avg, Current L3 Max, Current N Min, Current N Avg, Current N Max, Frequency Min, Frequency Avg, Frequency Max, Active Power L1N Min, Active Power L1N Avg, Active Power L1N Max, Active Power L2N Min, Active Power L2N Avg, Active Power L2N Max, Active Power L3N Min, Active Power L3N Avg, Active Power L3N Max, Active Power Total Min, Active Power Total Avg, Active Power Total Max, VA Full Classic L1N Min, VA Full Classic L1N Avg, VA Full Classic L1N Max, VA Full Classic L2N Min, VA Full Classic L2N Avg, VA Full Classic L2N Max, VA Full Classic L3N Min, VA Full Classic L3N Avg, VA Full Classic L3N Max, VA Full Classic Total Min, VA Full Classic Total Avg, VA Full Classic Total Max, VAR Classic L1N Min, VAR Classic L1N Avg, VAR Classic L1N Max, VAR Classic L2N Min, VAR Classic L2N Avg, VAR Classic L2N Max, VAR Classic L3N Min, VAR Classic L3N Avg, VAR Classic L3N Max, VAR Classic Total Min, VAR Classic Total Avg, VAR Classic Total Max, PF Classic L1N Min, PF Classic L1N Avg, PF Classic L1N Max, PF Classic L2N Min, PF Classic L2N Avg, PF Classic L2N Max, PF Classic L3N Min, PF Classic L3N Avg, PF Classic L3N Max, PF Classic Total Min, PF Classic Total Avg, PF Classic Total Max, Cos Phi Classic L1N Min, Cos Phi Classic L1N Avg, Cos Phi Classic L1N Max, Cos Phi Classic L2N Min, Cos Phi Classic L2N Avg, Cos Phi Classic L2N Max, Cos Phi Classic L3N Min, Cos Phi Classic L3N Avg, Cos Phi Classic L3N Max, Cos Phi Classic Total Min, Cos Phi Classic Total Avg, Cos Phi Classic Total Max, Distortion Power L1N Min, Distortion Power L1N Avg, Distortion Power L1N Max, Distortion Power L2N Min, Distortion Power L2N Avg, Distortion Power L2N Max, Distortion Power L3N Min, Distortion Power L3N Avg, Distortion Power L3N Max, Distortion Power Total Min, Distortion Power Total Avg, Distortion Power Total Max, Active Energy L1N Min, Active Energy L1N Avg, Active Energy L1N Max, Active Energy L2N Min, Active Energy L2N Avg, Active Energy L2N Max, Active Energy L3N Min, Active Energy L3N Avg, Active Energy L3N Max, Active Energy Total Min, Active Energy Total Avg, Active Energy Total Max, Reactive Energy L1N Min, Reactive Energy L1N Avg, Reactive Energy

L1N Max, Reactive Energy L2N Min, Reactive Energy L2N Avg, Reactive Energy L2N Max, Reactive Energy L3N Min, Reactive Energy L3N Avg, Reactive Energy L3N Max, Reactive Energy Total Min, Reactive Energy Total Avg, Reactive Energy Total Max, THD V L1N Min, THD V L1N Avg, THD V L1N Max, THD V L2N Min, THD V L2N Avg, THD V L2N Max, THD V L3N Min, THD V L3N Avg, THD V L3N Max, THD A L1 Min, THD A L1 Avg, THD A L1 Max, THD A L2 Min, THD A L2 Avg, THD A L2 Max, THD A L3 Min, THD A L3 Avg, THD A L3 Max, THD A N Min, THD A N Avg, THD A N Max