Cornwall Local Energy Market

LEM Flexibility Market Platform Design and Trials Report

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Author	Organisation	Revision	Description	Date
James Atkinson	Centrica	-	1st draft	08/10/2020
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The Cornwall Local Energy Market is part-funded by the European Regional Development Fund under the European Structural and Investment Funds Programme 2014-2020.

Contents

1 Executive Summary

The Cornwall Local Energy Market is an energy market innovation jointly funded by the European Regional Development Fund and Centrica. The project is led by Centrica in association with project partners Western Power Distribution (WPD), National Grid ESO, N-SIDE, Imperial College London and the University of Exeter (UoE). This paper focuses on the design and trials of the flexibility market platform, which is one component of the wider Cornwall LEM Programme.

The Cornwall LEM Platform ("the Platform") is a first-of-its-kind auction-based flexibility market which allows both the Distribution System Operator (DSO) and the Transmission System Operator (TSO) to procure flexibility simultaneously through regular closed-gate, pay-as-clear auctions. The Platform coordinates DSO and TSO flexibility procurement to maximise efficiency by ensuring conflicting resources are not simultaneously dispatched and ensuring contracts for national services do not increase or create congestions at the local level.

Combining procurement into a single market platform allows both parties to contract with a wider range of flexibility providers and simplifies the process for flexibility resources to be utilised by both parties, increasing system efficiency. While there is a strong desire for local, flexible energy markets that maximise whole-system value, there has never been a market or product that has sought to implement this in practice.

The Cornwall LEM Platform covers the full end-to-end process for flexibility procurement, including resource registration, commercial optimisation of available offers, contract creation, performance assessment, and settlement after the event.

Reserve and utilisation procurement have been split in order to comply with European Electricity Balancing Guideline ("EB GL") regulations. Reserve capacity is procured in the long-term (M-3, M-1, W-1), and a reserve capacity contract requires the provider to be available in the subsequent Day-Ahead and Intraday utilisation auctions for the time and volume contracted.

There is no requirement for the buyer to utilise the reserved capacity, and if a buyer does place a utilisation bid, there is no guarantee that a reserved asset will win the utilisation contract if there is a cheaper utilisation only offer from an unreserved asset. This ensures the lowest cost of dispatch is obtained and that the clearing price reflects the real-time value of the service.

Short-term utilisation procurement allows a wider range of flexibility to providers to participate including, renewables and intermittent generation, Demand-Side-Response, and, in the future, electric vehicles and domestic heat technologies. By increasing the range of participants and reducing the need for long-term capacity contracts with low utilisation rates, short-term flexibility procurement will provide savings to the end consumer and will be a key enabler of smart energy systems.

An optimisation algorithm has been developed by N-SIDE and integrated into the Platform to solve the commercial optimisation problem by identifying the solution which maximises whole-system value for each auction. The algorithm accounts for the technical parameters of the participating assets and the network topology including forecast available capacity at each node of the network. The algorithm then generates contracts between buyers and sellers that are compliant with any asset constraints and which are grid-secure, meaning they do not violate distribution network limits. Due to the effect of network congestions, the Locational Marginal Price is calculated for each node of the network per settlement period.

Based on a defined set of market rules, the optimisation algorithm coordinates DSO and TSO procurement and ensures that no conflicting contracts are generated. When the DSO submits a flexibility request, the line downstream of the request is blocked in the opposing direction, ensuring that contracts to meet the TSO requirement won't worsen a congestion.

The Platform has been developed using a Minimum Viable Product (MVP) approach and an agile development process based on SAFe and SCRUM frameworks. It has been built based on a micro service architecture, designed to be modular and composed of "loosely coupled" components to cover different market locations, market requirements and adaptable based on future development in regulations surrounding flexibility markets.

The Cornwall LEM Platform trials saw Western Power Distribution (WPD) participating as the DSO, and National Grid ESO participating as the TSO. The Phase 2 trials, on which this document focuses, ran from August 2019 to March 2020, with a total of 77 reserve contracts and 49 utilisation contracts, equating to 210MWh of reserve and 99MWh of utilisation contracted. The use cases covered included; DSO pre-fault constraint management (both winter peak demand and summer peak generation scenarios); DSO post-fault constraint management; TSO constraint management; and the calculation of grid-secure flexibility to be entered into the existing Balancing Mechanism following the LEM Intraday auction gate closure.

2 Introduction

2.1 Background

The UK electricity industry faces many significant challenges due to the urgent need to decarbonise electricity supply to meet climate change objectives.

1) With the increase in intermittent renewables and the decrease in traditional fossil fuel generators, the UK electricity system needs to become more responsive to changes in supply and more tolerant of renewable generation assets.

2) There is an expectation of dramatically rising electricity demand in the next decade as consumers switch away from fossil fuel usage for heating and transportation. Continued digitalisation across all sectors will also add to increasing electricity demand.

3) Much of this increased demand and new generation sources are distributed by nature and often connected to the low voltage networks. We are rapidly moving away from the traditional model of large power plants connected to the transmission network supplying electricity in a top down fashion, and the types of customers that network operators need to be able to contract with to provide flexibility are changing.

These challenges have been recognised by Ofgem, the UK government, and the Electricity Network Association (ENA). Ofgem and the UK Department for Business, Energy & Industrial Strategy (BEIS) published a joint document in 2017[1], on enabling a smarter, more flexible energy system. As set out in the document, key components of the transition are for network operators to "open up new markets for flexibility, including as alternatives to network reinforcement", improve coordination between National Grid ESO and UK DSO's, and lower the barriers to entry for participants. Ofgem has further described the importance and value of flexibility for the energy system in its position paper on Distribution System Operation[2].

The Cornwall LEM Platform focuses on these challenges and is a first-of-kind market platform that can coordinate TSO and DSO flexibility procurement, allowing both parties to contract with a wider range of flexibility providers while lowering the barriers to entry for participants.

There have been a number of studies aimed at assessing the quantitative benefits of deploying and utilising more flexible resources. The Carbon Trust and Imperial College London estimated the net benefits of utilising flexibility (compared to current network operation strategies) to be in the range of £1.4-2.4 bn/year in 2030[3]. The Committee on Climate Change study[4] found the gross benefits to be £3-3.8 bn/year in 2030. A study by National Infrastructure Commission[5] states that gross benefits could range from £2.9 - £8.1 bn/year in 2030 (a lower target grid carbon intensity of 50g CO_{2e}/kWh in 2030 produced the high end of the range compared to a target 100g CO_{2e}/kWh by 2030 in the other studies).

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[1] https://www.ofgem.gov.uk/publications-and-updates/upgrading-our-energy-system-smart-systems-and-flexibility-plan - Initial Plan (2017)

[2] Ofgem position paper on Distribution System Operation. https://www.ofgem.gov.uk/publications-and-updates/ofgem-position-paper-distribution-system-operation-our-approach-and-regulatory-priorities

[3] Carbon Trust and Imperial College London. An analysis of electricity system flexibility for Great Britain, 2016

[4] Imperial College and NERA Consulting, Value of flexibility in a decarbonised grid and system externalities of low-carbon generation technologies, report for the Committee on Climate Change (CCC), 2015.

[5] National Infrastructure Commission, Smart Power, 2016.

2.2 Context

2.2.1 DSO Services

The term DSO has been used throughout this document to distinguish between the newer activities carried out by the DNO to actively operate the distribution network and the traditional activities conducted by the DNO as part of the historically passive operation of the network. As DSO activities are currently undertaken by Britain's 6 DNO's, these terms refer to different functions by the same entities.

A DSO has a number of options available to ensure the safe and efficient operation of the network. These include; switching/topology changes, tap changes, utilising network equipment such as capacitor banks and, increasingly, the use of flexibility.

Traditionally, DSOs have mostly obtained flexibility through the use of alternative connections (including export limitation, timed connections, soft intertrip, and generator curtailment via Active Network Management ("ANM")). However, since the beginning of this project, DSO's have begun to procure flexibility as business as usual to help alleviate network congestions and defer network reinforcement costs.

In December 2018, Britain's 6 DNO's signed the Flexibility First Commitment, co-ordinated by the Energy Network Association (ENA), and have committed to assess the use of flexibility as the first option when reviewing requirements for building significant new electricity network infrastructure. A Common Evaluation Methodology[6], developed by Baringa for the ENA, has been used to create a common cost-benefit analysis tool DNOs will use to assess flexible vs non-flexible options to meet network needs. This aims to provide transparency on how DNOs make decisions in the pre-procurement stage to choose the most suitable solution from options such as ANM schemes, flexibility services, or physical reinforcement.

Due to the increase in DSO flexibility services, the ENA Open Network project has standardised four DSO flexibility products, shown in Table 1 below.

Table 1: DSO flexibility product descriptions: Source, ENA [7]

Product	Use-case	Description
Sustain	Scheduled Constraint Management	The DSO procures, ahead of time, a pre-agreed change in input or output over a defined time period to prevent a network going beyond its firm capacity. (Utilisation Only)
Secure	Pre-Fault Constraint Management	The DSO procures, ahead of time, the ability to access a pre-agreed change in Service Provider output based on network conditions close to real-time. Utilisation is then delivered by different mechanisms, depending on whether the DSO wishes to manage network risk manually, or automatically.
Dynamic	Post-fault Constraint Management	The DSO procures, ahead of time, the ability of a Service Provider to deliver an agreed change in output following a network fault. Utilisation is then instructed when the fault occurs on the network.

[6] Common evaluation methodology and tool: Baringa on behalf of the ENA https://www.energynetworks.org/assets/files/ENA%20Common%20Evaluation%20Methodology-publishedpdf.pdf

[7] Open Networks Project DSO Service Requirements: Definitions https://www.energynetworks.org/ assets/files/ON-WS1-P2%20DSO%20Service%20Requirements%20-%20Definitions%20-%20PUBLISHED.pdf

Restore	Restoration Support	Following a loss of supply, the DSO instructs a provider to either remain off supply, or to reconnect with lower demand, to support increased and faster load restoration under depleted network conditions

The following figure shows the volume of flexibility which has been procured, or is predicted to be procured, by the UK DNO's up to the end of 2020. Currently, the majority of flexibility procured by WPD has been done using their proprietary Flexible Power platform, whilst UKPN has used the Piclo platform for participants to register interest and collect offers.

Figure 1: UK DSO flexibility procurement 2018 - 2020. Source: ENA [8]

Last updated: April 2020

DNO Flexibility Tenders		Sustain (MW)	Secure (MW)	Dynamic (MW)	Restore (MW)	Reactive Power (MVAr) (if applicable)
ENWL	End of 2018			0	3	
	End of 2019			0	3	
	Projections for 2020			11	2	
NPg	End of 2018				0	
	End of 2019				0	
	Projections for 2020				100	
SPEN	End of 2018	0	0	0	0	0
	End of 2019	0	0	0	0	0
	Projections for 2020	125	125	125	125	30
SSEN	End of 2018	0	0	0	0	0
	End of 2019	0	2	2	2	0
	Projections for 2020	20	150	150	150	30
UKPN	End of 2018		0.3			
	End of 2019		19.29			
	Projections for 2020	20	150			
WPD	End of 2018		23.5	33.8	58.5	
	End of 2019		7.3	115.8	123.1	
	Projections for 2020		47.52	286.05	333.57	
Industry Total - End of 2018		**0.0**	**23.8**	**33.8**	**61.5**	**0.0**
Industry Total - End of 2019		**0.0**	**28.6**	**117.8**	**128.1**	**0.0**
Projections for 2020		**165.0**	**472.5**	**572.1**	**710.6**	**60.0**

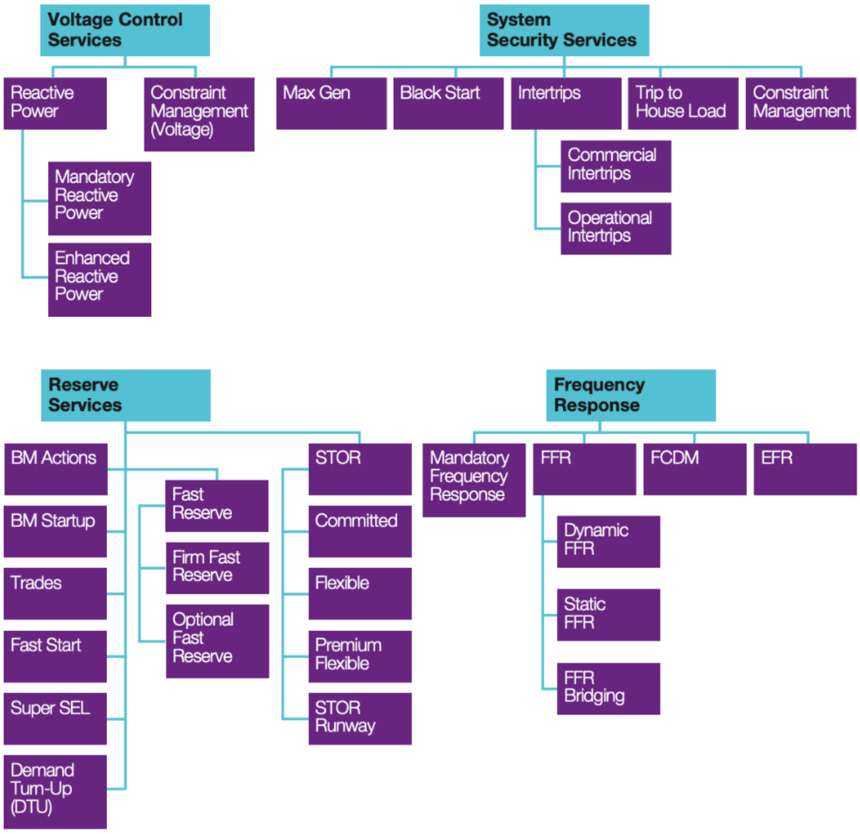
DSO flexibility procurement so far has taken place on an annual or bi-annual timeline, with tender rounds running for long periods and the awarding of contracts taking several months. However, to allow a wider range of flexible generators, renewables, and demand response to take part, markets for short-term flexibility procurement are required. By increasing the range of participants and reducing the need for long-term capacity contracts with low utilisation rates, short-term flexibility procurement will provide savings to the end consumer and will be a key enabler of smart energy systems.

[8] Energy Network Association, Flexibility in Great Britain https://www.energynetworks.org/electricity/futures/flexibility-in-great-britain.html

2.2.2 National Grid ESO Services

National Grid ESO have a suite of existing services which they use to ensure the UK transmission network operates within defined limits ensuring safe operation. These include; frequency response services, reserve services, system security services and reactive power services[9]. These products are procured in a variety of methods, but primarily through monthly or seasonal tenders.

Figure 2: National Grid ESO ancillary services. Source, National Grid ESO[10]



National Grid ESOs primary tool for balancing the network after gate closure is the Balancing Mechanism. However, only large participants are obligated to register in the Balancing Mechanism; if their Generation or Demand Capacity is at or above 50MW in England and Wales, 30MW in South Scotland or 10MW in North Scotland. It is optional below these limits, but the operational and implementation costs have often been prohibitive for smaller participants to enter. The introduction of Secondary BM Units which can be registered by Virtual Lead Parties (VLPs) has looked to address this as part of the Wider Access to the Balancing Mechanism. Secondary BM Units must be at least 1MW and can be individual units or a collection of units aggregated across a GSP Group. This process also distinguishes between Balance Responsible Parties and Balance Service Providers, which means a VLP can now provide a balancing action without effecting the original suppliers balancing position.

The total spent by National Grid ESO running these services is over £1billion per year[11], Figure 3 below shows the monthly costs per service from National Grid ESO's "Monthly Balancing Services Summary 2019/20, January 2020".

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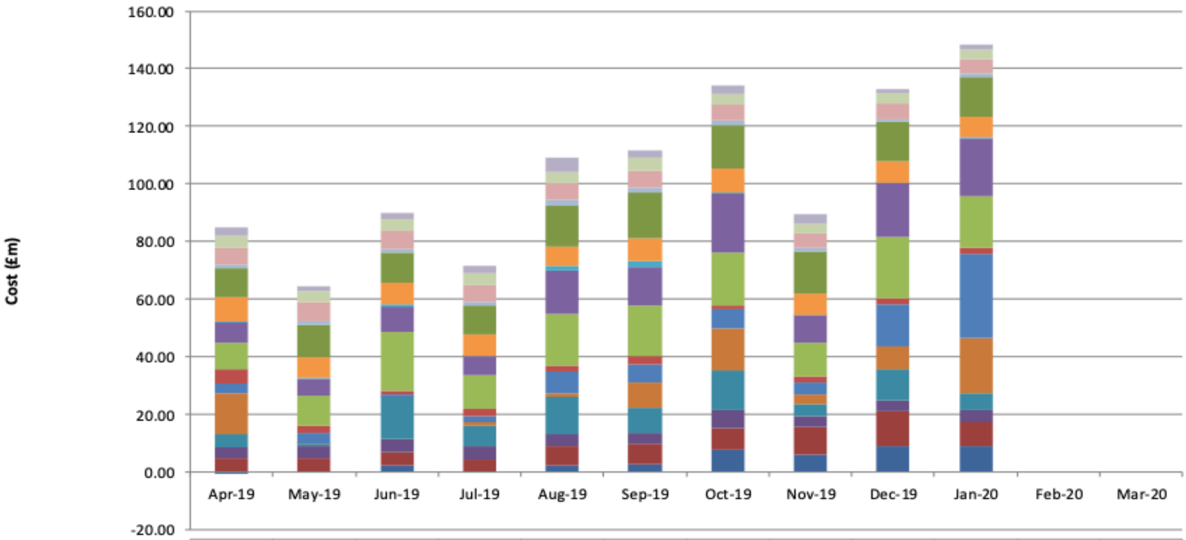
[9] https://www.nationalgrideso.com/industry-information/balancing-services

[10] National Grid: System Needs and Product Strategy 2017 https://www.nationalgrideso.com/document/84261/download

[11] https://www.nationalgrideso.com/document/165056/download

Figure 3: National Grid Monthly Balancing Services costs January 2020 [11]



	Apr-19	May-19	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19	Jan-20	Feb-20	Mar-20
Minor Components	3.01	1.62	2.08	2.79	5.21	2.86	2.81	3.30	1.50	1.46		
Black Start	3.92	3.62	4.54	4.12	3.86	4.40	3.70	3.49	3.65	3.66		
Reactive	5.91	6.70	6.08	5.66	5.68	5.84	5.54	4.86	5.37	4.87		
Other Reserve	1.46	1.51	1.44	1.25	2.15	1.50	1.40	1.34	1.12	1.21		
Response	9.69	10.99	10.29	10.14	13.98	15.93	15.11	14.56	13.78	13.76		
Fast Reserve	8.64	7.38	7.62	7.62	6.91	8.24	8.42	7.73	7.25	7.26		
Negative Reserve	0.27	0.15	0.71	0.10	1.42	2.03	0.30	0.08	0.17	0.43		
Constraints Sterilised HR	6.93	5.85	8.63	6.54	15.30	13.42	20.41	9.42	18.82	19.73		
ROCOF	9.24	10.50	20.42	11.68	18.02	17.45	18.45	11.51	21.12	18.07		
Constraints - Ancillary	5.23	2.42	1.35	2.45	1.93	2.91	1.22	2.32	2.29	2.09		
Constraints - Scotland	3.29	3.90	0.94	2.20	7.57	6.28	6.65	4.01	14.43	29.36		
Constraints - Cheviot	14.24	0.19	0.10	1.19	1.31	8.83	14.71	3.55	7.93	19.04		
Constraints - E&W	4.54	0.72	14.43	7.15	12.88	8.42	13.97	3.86	10.79	5.88		
STOR	3.76	3.95	4.63	4.38	4.35	3.75	6.27	3.88	3.89	4.13		
Operating Reserve	4.68	4.84	4.64	4.39	6.30	7.37	7.60	9.66	12.21	8.49		
Energy Imbalance	-0.80	0.00	2.16	-0.36	2.36	2.52	7.41	5.97	8.76	8.83		

As the penetration of intermittent renewables and non-traditional generation increase, the costs to operate the transmission network continue to increase. In July 2020, National Grid ESO published their updated Future Energy Scenarios which predict a decrease in dispatchable thermal generation from approximately 45GW in 2020 to 19GW in 2050. This will be replaced by new types of flexibility, much of which will come for new distributed resources (including industrial and commercial DSR, electric vehicles, domestic heating systems and large-scale battery storage). As the type of flexibility providers change, National Grid ESO need new and innovative ways to access these distributed assets.

The period of lower electricity demand caused by the COVID-19 pandemic exaggerated the existing problem of making sure there is enough demand on the system during the summer months and may represent a future energy system where renewables make up the dominant share of generation. As such, the need for flexibility on the grid has never been more pressing, and this has been evident by the quick implementation of National Grid ESO’s Optional Downward Flexibility Management (ODFM) service.

The ODFM service allows National Grid ESO to contract directly with generation assets connected to the distribution network that they do not have access too through the Balancing Mechanism. Due to the quick implementation of this service National Grid ESO coordinates and procures this service via email.

2.2.3 Energy Network Association - Future Worlds

The Energy Network Association's (ENA) Open Networks project, and specifically the Future Worlds consultation it produced, developed five models which represent the potential structures which could "best deliver flexibility markets providing services from DER for both national and regional (transmission and distribution) requirements."[12] At the moment, no recommendations have been made as to which Future World should be adapted, but the models represent the different possibilities. Figure 4 below has been taken from the ENA Open Networks Future Worlds consultation document and describes the five models at a high level.

Figure 4: ENA Future Worlds descriptions[4]

World A
DSO Coordinates – a World where the DSO acts as the neutral market facilitator for all DER and provides services on a locational basis to National Grid in its role as the Electricity System Operator (ESO).

World B
Coordinated DSO-ESO procurement and dispatch – a World where the DSO and ESO work together to efficiently manage networks through coordinated procurement and dispatch of flexibility resource.

World C
Price-Driven Flexibility – a World where changes developed through Ofgem's reform of electricity network access and forward-looking charges have improved access arrangements and forward-looking signals for Customers.

World D
ESO Coordinate(s) – a World where the ESO is the counterparty for DER with DSO's informing the ESO of their requirements.

World E
Flexibility Coordinator(s) – a World where a new national (or potentially regional) third-party acts as the neutral market facilitator for DER providing efficient services to the ESO and/or DSO as required.

The Cornwall LEM design approach has been, as far as possible, agonistic to which Future World may underpin UK flexibility markets. Our services have been designed to be modular and can be split up between different entities in the future if required.

[12] https://www.energynetworks.org/assets/files/14969_ENA_FutureWorlds_AW06_INT.pdf

2.3 Scope

2.3.1 Cornwall LEM Platform Use Cases

Due to the increased procurement of flexibility services by DSO's, and the updating of National Grid ESO's existing ancillary services to reach new distributed resources, the Cornwall LEM Platform has been designed to coordinate both TSO and DSO procurement of upward and downward flexibility over varying time horizons. Only active power services have been considered throughout the trials.

The Cornwall LEM Platform supports the following use cases:

- DSO seasonal constraint management, via long- and short-term procurement:
  - Using flexibility to manage demand constraints, primarily during peak hours in the winter months.
  - Managing reverse power flow constraints, primarily caused by excessive generation in the summer months during periods of high solar and wind output.
- DSO post-fault constraint management. Using the Intraday auctions to procure flexibility to help manage a network fault.
- TSO constraint management, via long- and short-term procurement.

2.3.2 Objectives

The project objectives sought to:

1) Demonstrate the use of a flexibility market platform to improve the efficiency of the UK Electricity Network (11kV – 400kV), as per the Cornwall LEM Platform use cases.
2) Demonstrate the use of a third-party market platform to coordinate TSO and DSO flexibility procurement through a transparent auction process.
3) Improve the visibility of, and allow access to, Distributed Energy Resources (DER) by the TSO.
4) Create a network-validation process to optimise the remaining flexibility which can be offered to the TSO through existing Balancing Mechanism without violating distribution network limits, whilst ensuring optimal allocation of distribution network capacity.
5) Reduce barriers to entry for participation and provision of flexibility services, notably to increase the range of participants who can provide demand-side response.

2.3.3 Out of Scope

The following issues were out of the scope for the project:

- Congestion forecasting by the DSO to update available network capacity at varying timeframes.
- Assessing impact of temporary network running arrangements due to switching or topology changes on a customer's ability to provide a contracted flexibility service.
- Conducting a full power-flow analysis or the calculation and use of Power Transfer Distribution Factors and Sensitivity Matrices.
- Addressing the impact of providing a local service on the providers balancing position. Throughout the trials it was the responsibility of the provider to ensure that their balancing position reflected any changes to their consumption or generation due to an action contracted through the Platform.

2.3.4 Document Scope

The scope of this document is to detail the design choices of Cornwall LEM Platform and examine the events and transactions undertaken as part of the Cornwall LEM Platform trials.

2.4 Project Background

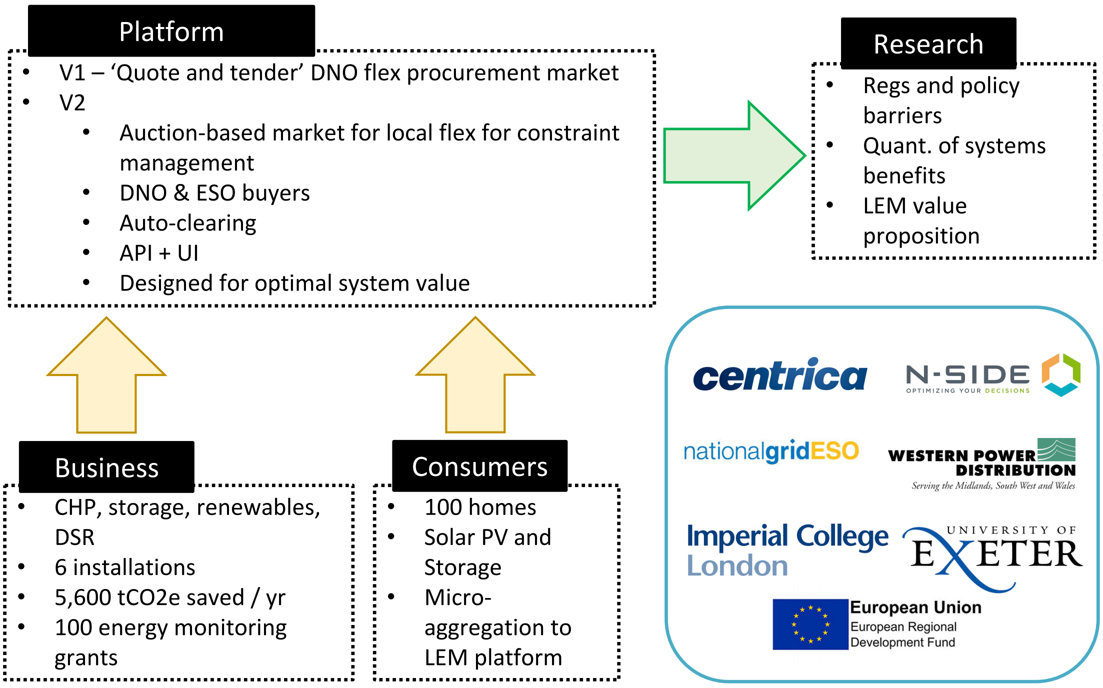
The Cornwall Local Energy Market (LEM) Programme is a three-year trial from 2017 to 2020 jointly funded through the European Regional Development Fund and Centrica. The project is led by Centrica in association with project partners Western Power Distribution (WPD), National Grid ESO, N-SIDE, Imperial College London and the University of Exeter (UoE).

The Cornwall LEM Programme comprises of five key work packages:

- WP1. Development of the LEM flexibility trading platform, and trials (the Work Package on which this paper focuses).
- WP2. Residential battery storage installation and trials.
- WP3. Industrial & Commercial engagement, installations and support.
- WP4. Project management, communications and compliance.
- WP5. Research and reporting.

A high-level summary of each project within the LEM programme is as follows:

Figure 5: Cornwall LEM Programme workstreams



2.4.1 Development Timeline

The first, proof-of-concept platform developed as part of the Cornwall LEM Programme was a quote and tender platform. This "Version 1" platform was manual, with the DSO placing bids, sellers responding to bids, and the DSO then manually downloading and selecting specific offers using their own optimisation tool developed using Excel's Solver. Following this, the more advanced "Version 2" was developed, which is the Cornwall LEM Platform referenced throughout this document. The Version 2 Platform was delivered using the Scaled Agile Framework (SAFe), with initial design beginning in mid-2018, development beginning in Q3 2018, and the platform trials running from September 2019, to March 2020. More information on the first phase of development is contained within WPD's Visibility Plugs and Sockets Closedown Report.

2.5 Related Documents

This document forms part of a series of research reports related to the LEM Programme. The table below details the related reports created by Centrica and project partners.

Table 2: Cornwall LEM research reports

Organisation	Paper	Author(s)	Available (at time of writing)
WPD	Visibility Plugs and Sockets - Phase 1 Interim Learning Report	Woodruff J.	Yes
	Visibility Plugs & Socket – Closedown Report	Woodruff J.	Yes
National Grid ESO	Testing Coordinated DSO-ESO Procurement and Dispatch	Sellar A.	Ongoing
Imperial College	Business Case for Flexibility Providers	Moreira R. & Strbac G.	Yes
	Review of Electricity Market Design Challenges and Recommendations	Papadaskalopoulos D., Ye Y., Qiu D., Li J., & Strbac G.	Yes
	Validation of the LEM Clearing Engine	Papadaskalopoulos D., Ye Y., Qiu D., Li J., & Strbac G.	Ongoing
Exeter University	Policy and Regulatory Barriers to Local Energy Markets in Great Britain	Bray R., Woodman B. & Connor P.	Yes
	Unlocking Local Energy Markets	Bray R., Woodman B.	Yes
	Barriers to Independent Aggregators in Europe	Bray R., Woodman B.	Yes
	Cornwall Local Energy Market - Householder Survey Report	Bray R., Woodman B.	Yes
Centrica	Industrial & Commercial Workstream: Summary Report	Parish D.	Yes
	Cornwall LEM: Research Umbrella Report, the Rise and Definition of Flexibility	Parish D.	Ongoing

All completed research documents associated with the Cornwall LEM Programme can be found using the following link:

https://www.centrica.com/what-we-do/centrica-innovations/cornwall-local-energy-market-research-reports-and-papers/

3 Platform Design and Configuration

3.1 Overview

The primary goal when designing an effective flexibility market is to ensure the lowest-cost solution is obtained whilst respecting both the technical constraints of the participating assets and any network constraints. It is also critical that future markets are structured in a way that maximises transparency, competition, and incentives to invest, whilst reducing the potential for gaming or bidding strategies which may distort the results. If such key characteristics are missing from markets, consumers may lose out on the potential £17-50 billion in savings predicted to flow from a smart, flexible energy system by 2050.[13] Market designs which coordinate flexibility procurement will be crucial in the transition towards a smarter, decentralised energy supply.

The Cornwall LEM market rules were designed based on a few high-level objectives:

1. Fairness: Allowing any participant regardless of size and sophistication to participate in the market.
2. Simplicity: Reducing barriers to entry and increasing competition and liquidity.
3. Transparency: A transparent auction allows participants to easily adjust behaviours based on auction results and converge at an accurate price for the services.
4. Cooperability: A new market must interact with, and complement, existing national and wholesale markets.
5. Configurability: Optimum market design will change in different geographical areas based on existing markets, regulatory frameworks and network requirements. Therefore, it is crucial that parameters such as auction timings can be easily configured.

The Cornwall LEM Platform is an auction-based flexibility market platform which allows both the DSO and the TSO to procure flexibility simultaneously through regular closed-gate, pay-as-clear auctions. The Platform covers the full end-to-end process for flexibility procurement from resource registration, through to baselining and settlement after the event as shown in Figure 6 below.

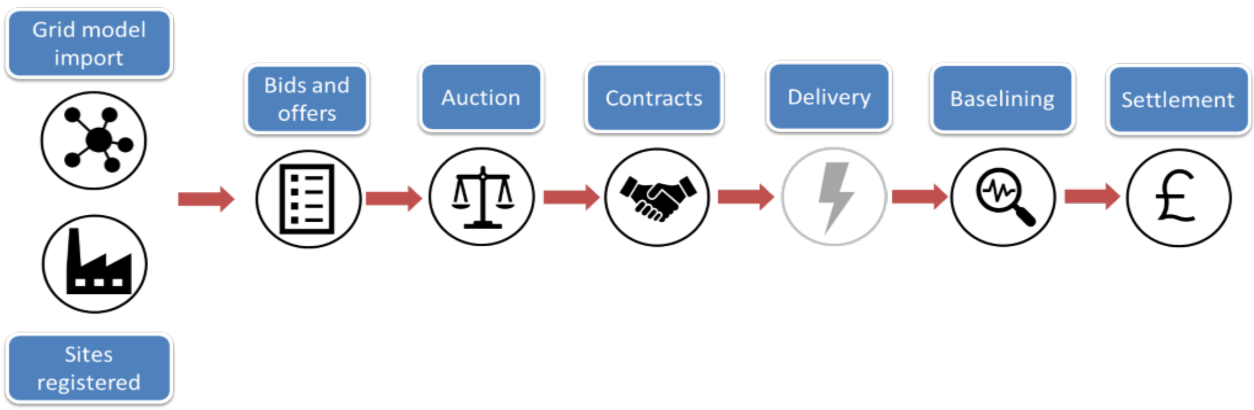


Figure 6: End-to-end flexibility procurement process.

The Cornwall LEM Platform functionality can be summarised as follows:

1. A grid model is imported representing a static view of WPD's network topology and both the demand and generation constraints at each substation.
2. Flexibility providers register their Distributed Energy Resources, which are any assets that can modulate their demand or generation when required.

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[13] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/568982/An_analysis_of_electricity_flexibility_for_Great_Britain.pdf

3. Buy orders ("Bids") and sell orders ("Offers") for flexibility are placed on the Platform detailing the time, volume and location of the flexibility order. Additional optional parameters can be used to define block orders or asset constraints. Buyers and sellers can create either reserve capacity or utilisation orders.
4. The Cornwall LEM Platform runs regularly scheduled, closed-gate auctions for both reserve and utilisation contracts.
5. Reserve auctions are run 3 months ahead, 1 month ahead and 1 week ahead of delivery. A reserve capacity contract requires the seller to be available in subsequent utilisation auctions for the time and volume contracted.
6. Utilisation auctions are run the day-ahead of delivery and intraday until 2 hours before delivery. Utilisation auctions allow the buyers to specify how much reserve they wish to activate and/or participants can create utilisation only orders.
7. A Clearing Engine developed by N-Side matches the bids and offers in each auction to create contracts which are compliant with any network constraints and the technical constraints of the participating assets. The Clearing Engine is designed to find the solution which maximises the social welfare (otherwise known as global welfare) for each auction.
8. Users are automatically notified of any contracts following an auction, currently via email.
9. If a seller wins a utilisation contract, they must deliver the flexibility as per their contract. The Cornwall LEM Platform does not control the end assets or send a subsequent dispatch notification.
10. After the event, sellers provide half-hourly site-level metering data covering one month prior to the event until the end of the event window.
11. The Platform calculates a baseline for the site using the historic metering data and conducts a performance assessment per event.
12. The Platform then runs a monthly settlement process, issuing consolidated invoices to buyers and dispersing the payments to the sellers.

A simple web-based user interface and API's have been designed and built to reduce the barriers to entry for smaller and less sophisticated participants. Simple product parameters and a minimum clip size of 50kW, which can be met by aggregating smaller units, were also implemented to increase the range of potential participants and increase future competition.

This section details the high-level design for the key functions of the Cornwall LEM Platform.

3.2 Auction-Based vs Continuous Markets

There are two main types of market design which are used throughout energy markets, continuous trading and auction-based models. The continuous model allows buyers and sellers to contract directly with each other through Bi-lateral contracts, where a different price will be agreed for each individual trade. The auction-based model has an intermediary which will clear the market and identify a uniform price for all participants at the intersection of the supply and demand curves.

Both models have their advantages, but the case for centralised auction design is strongest when there is a strong need for optimisation and coordination. An auction-based model was chosen for the Cornwall LEM Platform as there are a limited number of buyers but multiple sellers, therefore the optimisation problem can become very complex for the buyers. The auction-based approach allows all offers to be considered at the same time and it is, therefore, possible to account for the technical constraints of the available assets within the optimisation problem to identify the lowest-cost combination of offers. A buyer can allow the market to optimise the available flexibility and return a single solution which represents the most economical option.

The auction-based model also allows for consideration of network constraints within the optimisation problem and allows for the optimum allocation of network capacity within a given auction. This also allows the Cornwall LEM Platform to conduct a grid validation check on the remaining flexibility which can be offered to the TSO through existing markets, meaning that the flexibility offered will not violate any distribution network limits. Examples of this are shown in Section 0.

3.3 Network Model

3.3.1 Network Connectivity

To ensure that a flexibility resource can be used to mitigate a constraint, the market must be able to locate the resources on the network to determine what impact a change in consumption or generation will have on the target (constrained) location.

There is much discussion around whether the market should do the customer-to-network mapping, and therefore what data the DSO should provide to markets, or whether the DSO should conduct the customer-to-network mapping. For the purposes of the trials, the network location of an asset was determined in the first instance by the Cornwall LEM Platform using a postcode-to-substation mapping provided by WPD, and there was then a secondary validation of this mapping by WPD using the Meter Point Administration Numbers (MPANs) provided by the participants.

The customer-to-network mapping was initiated when a new site was registered onto the Platform, but the connectivity was then fixed for the duration of the trials. It was therefore not updated based on temporary running arrangements or dynamic management of the network; this issue is explored in more detail in Section 5.1.

3.3.2 Topology

For the Cornwall LEM Platform trials, a radial network was assumed. WPD provided the hierarchical mapping between the Primary substations, Bulk Supply Points (BSP's) and Grid Supply Points (GSP's), including the parent/child relationships between the substations. An asset was therefore assumed to be able to either fully meet a bid at a target substation, or not. I.e. there was a 0 or 1 relationship between the increase/decrease of power at one grid node with the increase/decrease of power noticed at another node. A subsection of the Cornwall network is shown in Figure 7.

It would be possible to embed a Sensitivity Matrix within the Platform and the Clearing Engine which represents the impact of an action at one location on other areas of the network as a ratio between 0 to 1. However, this information was not available and was outside the scope of the trial.

The network hierarchy was fixed for the duration of the trials and not updated based on temporary running arrangements or dynamic management of the network; this issue is explored in more detail in Section 5.1.

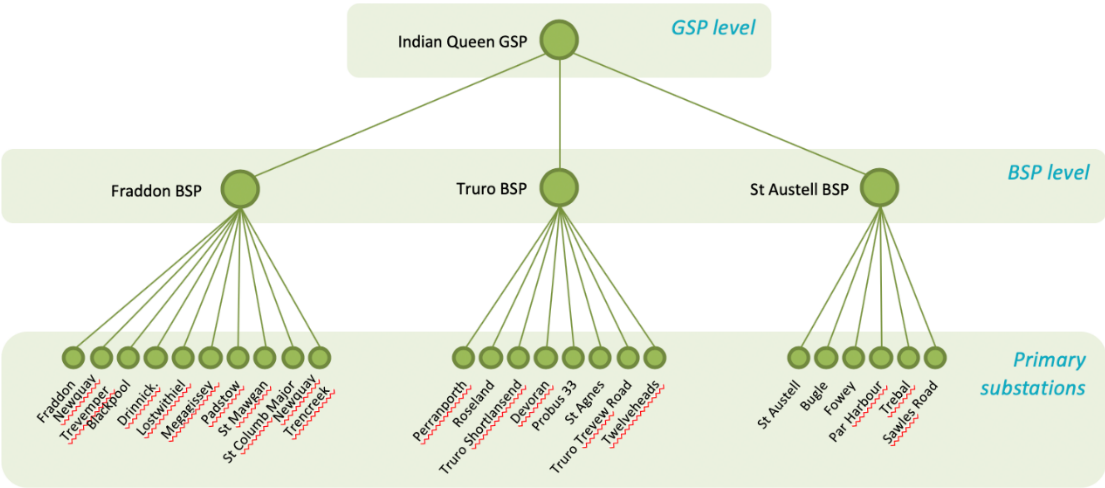


Figure 7: A subsection of the Cornwall distribution network, represented as a radial network

3.3.3 Congestion Modelling

A key innovation of the Cornwall LEM Platform is the inclusion of distribution network capacity within the optimisation algorithm. The Clearing Engine accepts both demand headroom and reverse power headroom for every settlement period at each grid node. However, as congestion forecasting was outside the scope of WPD's involvement in the project, the measured peak demand and peak generation values available from WPD's network capacity map were used to calculate the available headroom at each substation.

Two fixed headroom values were created for each substation which represented the available demand capacity during a winter constraint scenario and the available generation capacity during a summer constraint scenario. These headroom values were then used throughout the trials if a particular use case was being tested.

The tables below show a sample of the headroom values used throughout the trials.

Substation Name	Asset Type	Firm Capacity of Substation (MVA)	Measured Peak Demand (MVA)	Demand Headroom (MVA)
St Austell Bsp	BSP	68.59	61.62	6.97
Blackpool	Primary	22.86	3.71	19.15
Fowey	Primary	6.29	3.69	2.6
Trebal	Primary	14	3.55	10.45

Table 3: Sample demand headroom values

Substation Name	Asset Type	Reverse Power Capability (MVA)	Generation Connected (MVA)	Generation Headroom (MVA)
St Austell Bsp	BSP	68.59	47.305	21.285
Blackpool	Primary	17.25	11.058	6.192
Padstow	Primary	5.28	6.406	-1.126
Fraddon	Primary	17.25	14.128	3.122

Table 4: Sample generation headroom values

The headroom values are considered by the optimisation algorithm and used to ensure that contracts for flexibility services procured by the TSO at GSP level won't violate network limits on the distribution network. Although the headroom values were static estimations for the purposes of the trial, the optimisation algorithm has been designed to handle headroom values per settlement period, and the Platform could be easily adapted in the future to allow the DSO to update the headroom values dynamically following their load/generation forecasting when these systems have been further developed.

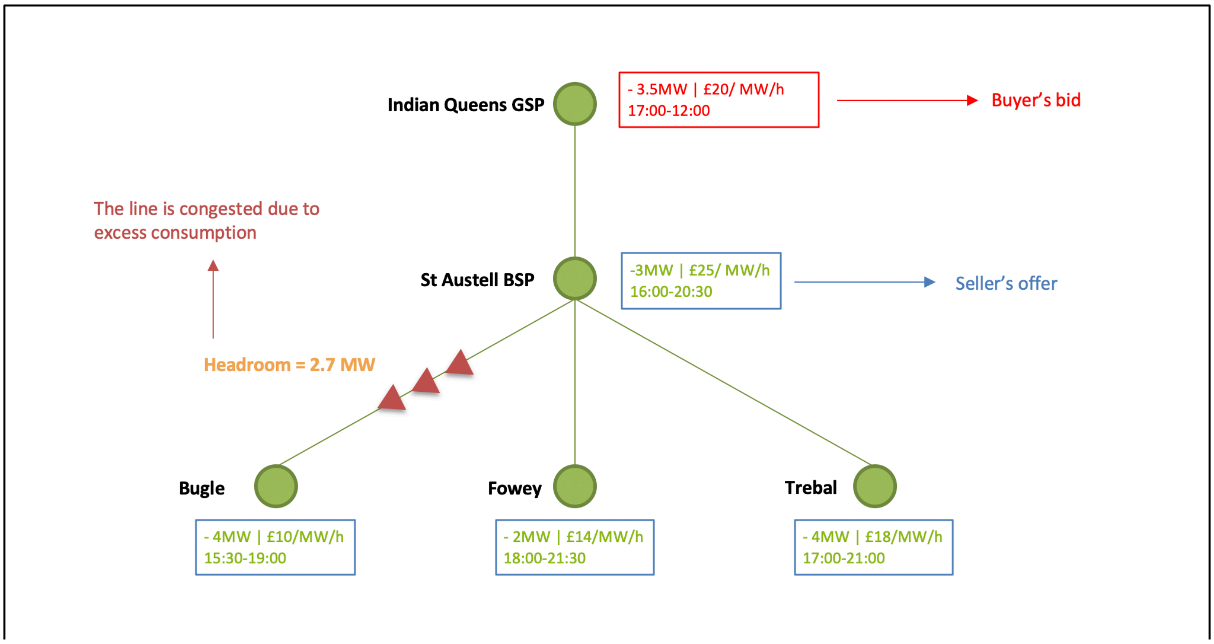


Figure 8: Distribution network capacity limits in optimisation algorithm

In the example shown in Figure 8 above, the TSO requests 3.5MW of downward reserve at Indian Queens GSP. The cheapest bid is at Bugle Primary at a price of £10/MW/hr and has the capacity to meet the TSO requirement. However, due to the headroom limitation, the service is only partially met from the offer at Bugle, and the remaining requirement is fulfilled from the offer at Fowey Primary substation, the next cheapest option.

3.4 TSO / DSO Co-ordination

As the need for local flexibility increases, and the DSO becomes more active in flexibility markets, the interaction between the DSO and TSO will become increasingly more important. It is essential that both parties coordinate their procurement to maximise efficiency by ensuring conflicting resources are not simultaneously dispatched, and to ensure contracts for national services do not increase or create congestions at the local level. By creating a market where both the DSO and TSO are procuring flexibility concurrently, it is possible for the optimisation algorithm to coordinate procurement.

If the TSO and DSO are procuring flexibility in the same direction, then the optimisation algorithm will give priority to the entity which values the flexibility the highest, I.e. which buyer sets the highest bid price. This is consistent with the markets rules as it will provide the solution which maximises social welfare.

When a DSO places a bid on the platform, the line downstream of the bid node is locked in the opposite direction to ensure that a separate contract can't be created that would exacerbate the congestion. Therefore, by definition, if the DSO and TSO are procuring flexibility in opposing directions, priority will be given to the DSO. In this scenario, the flexibility available in unconstrained areas of the network will instead be contracted to meet the TSO requirements, as shown in Figure 9.

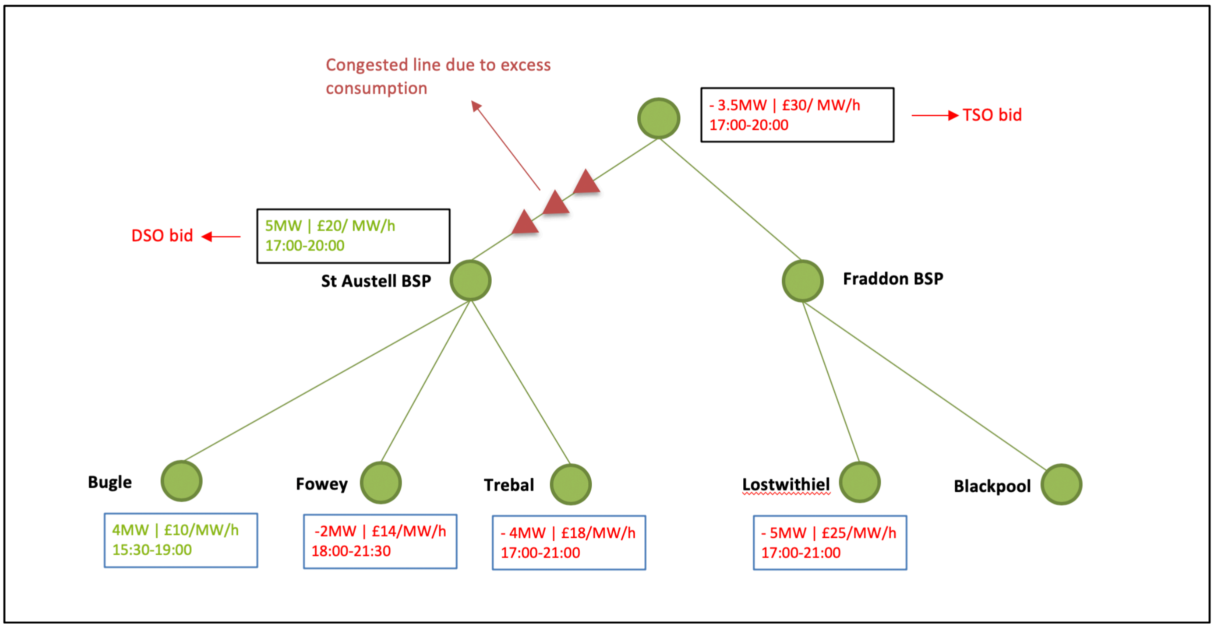


Figure 9: Scenario showing DSO bid in opposing direction to the TSO requirement

In the above example, despite cheaper offers downstream of St Austell BSP being available which could meet the TSO requirement, the offer located at Lostwithiel Primary will be cleared as this offer is located in an uncongested area of the network.

The Platform also provides an informational dashboard to the system operators which shows all bids and contracts related to other network operators (with pricing information redacted), and any conflicting bids or contracts are clearly highlighted. A conflict is defined as any bids or contracts for different system operators which overlap in time and location. This allows parties to view and alleviate conflicts before an auction, although this cross-party communication was outside the scope of the trials.

3.5 Auctions

Reserve and utilisation procurement have been split to comply with Electricity Balancing Guideline (EB GL) regulations which states; "The price of balancing energy shall not be pre-determined in contracts for balancing capacity,".[14] This choice ensures the Cornwall LEM market design can efficiently integrate with TSO balancing markets throughout Europe and safeguards the procurement of flexibility by a TSO through the Cornwall LEM platform.

Reserve capacity is procured in the long-term and a reserve capacity contract requires the provider to be available in the relevant subsequent Day Ahead and Intraday utilisation auctions for the time and

[14] Regulation (EU) 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity: Article 6

volume contracted. There is no requirement for the buyer to utilise the reserved capacity, and if a buyer does place a utilisation bid, there is no guarantee that a reserved asset will win the utilisation contract if there is a cheaper utilisation only offer available from an unreserved asset. This ensures the lowest cost of dispatch is obtained and that the clearing price reflects the real-time value of the service. Consequently, there is no consideration of the utilisation price during a reserve auction. Therefore, buyers and sellers can set and adjust their utilisation prices at any time before the utilisation auctions.

Figure 10 below shows the auction schedule used for the Cornwall LEM Platform trials. As aforementioned, it is crucial that auction timings can be easily configured depending on different requirements in different geographical areas. The design of the Platforms market management service allows the below timings to be easily configured.

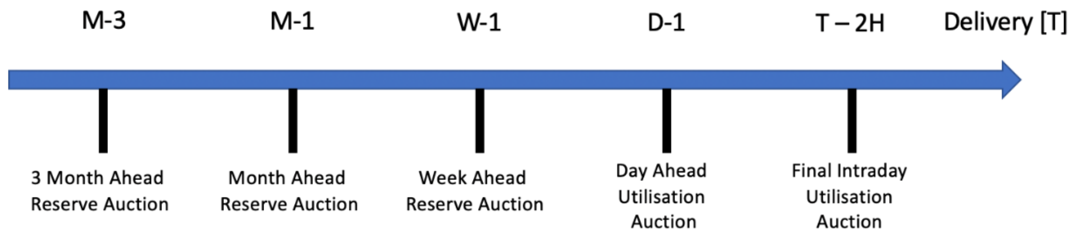


Figure 10: Auction timeline

Auction	Type	Timings	Example		
			Auction Runtime	Delivery Start Date	Delivery End Date
M-3	Reserve	Runs at 12:00 (midday), 1st of the Month. Covering the month 3 months ahead	12:00, Monday 1st June 2020	1st September	30th September 2020
M-1	Reserve	Runs at 12:00 (midday), 1st of the Month. Covering the following month	12:00, Monday 1st June 2020	1st July 2020	31st July 2020
W-1	Reserve	Runs at 12:00 (midday), every Wednesday for the following Monday to Sunday	12:00, Wednesday 17th June	Monday 22nd June	Sunday 28th June
D-1	Utilisation	Runs at 16:00, the Day before delivery	16:00, Tuesday 23rd June	00:00 Wednesday 24th June	00:00 Thursday 25th June
Intraday	Utilisation	Runs every 30 minutes until two hours before delivery. Covering the remainder of the day.	02:00, Wednesday 23rd June	04:00, Wednesday 23rd June	00:00, Thursday 24th June

Table 5: Auction timings and examples

For the purposes of the trial, reserved capacity was only made available to buyers during the Day Ahead utilisation auctions and did not carry over into the Intraday auctions. This was because not all participants in the trials could respond within the timeframes required for participation in the Intraday auctions.

3.6 Resource Registration

Flexibility providers were able to navigate to Cornwall LEM Platform and register their organisation by providing some simple details. For the trials, participants were walked through the process, and no additional pre-qualification process was required. Once a seller has registered an account, they can register sites and assets either through the UI or via API.

Site registration requires sellers to provide the following details:

- Site name and owner
- Site location
- Site MPAN number(s)
- Site import/export capacity
- Contact details

Sites registered on the LEM are automatically tagged to a network location based on their postcode in the first instance and then verified through a manual process which was conducted by WPD.

Once a site is registered, sellers can add assets to that site by providing the following details:

- Asset type (e.g. storage, demand, generation)
- Asset name
- What the asset is used for (this is for informational purposes only)
- Power output (MW)
- Usable capacity (MWh) [optional field]
- 1-minute metering (Yes/No)
- 30-minute metering (Yes/No) [Yes is mandatory to continue]
- Minimum and maximum operating durations (Hrs/Mins) [optional field]
- Response time (Mins) [optional field]
- Recovery time (Hrs/Mins) [optional field]
- Ramp rates up and down (kW/min) [optional field]

Sellers can then manage and edit their resources through the Platform as required.

3.7 Bids and Offers

The bid and offer model created is based on ERRP 2 v5r0 implementation guide from ENTSO-E[15]. It was then extended in a generic way to cover the technical characteristics related to the flexible distributed resources and the market products. Bids and offers can be submitted through UI journeys or directly via the API. The UI also supports functionality to create repeating bid and offer patterns.

To reduce complexity and to enable all types of actors, the products have been designed to have few mandatory parameters, whilst allowing a number of optional parameters. The list below shows the parameters available to participants when creating bids and offers through the Platform.

[15] ENTSO-E: Reserve Resource Process (ERRP) Implementation Guide. https://eepublicdownloads.azureedge.net/clean-documents/EDI/Library/depreciated/07%20errp2-guide-v5r0_approved.pdf

LEM Bid (buyers)

- Time
- Volume (MW) – minimum 50kW
- Location (grid node)
- Price (£/MW/h)
- *(optional)* Min acceptance volume (MW)
- *(optional)* Time block (Boolean)

LEM Offer (sellers)

- Time
- Volume (MW) – minimum 50kW
- Location (either by site, or at grid node level)
- Price (£/MW/h)
- *(optional)* Maximum energy (MWh)
- *(optional)* Maximum energy over a particular time span (MWh)
- *(optional)* Minimum activation time
- *(optional)* Maximum activation time
- *(optional)* Minimum recovery time
- *(optional)* Minimum acceptance volume (MW)
- *(optional)* Time block (Boolean)
- *(optional)* Ramp rate up and down (kW/min)

For the LEM trials, the above parameters were considered for both reserve and utilisation auctions. Therefore, a participant will only win a reserve contract that could be fully utilised based on any technical constraints specified for the associated asset(s). This ensures that buyers do not reserve assets which can't match the required utilisation profiles in the subsequent utilisation auctions. However, it also removes the ability for buyers to reserve assets over large availability windows when utilisation rates are low. This is further discussed in Section 5.2.3.

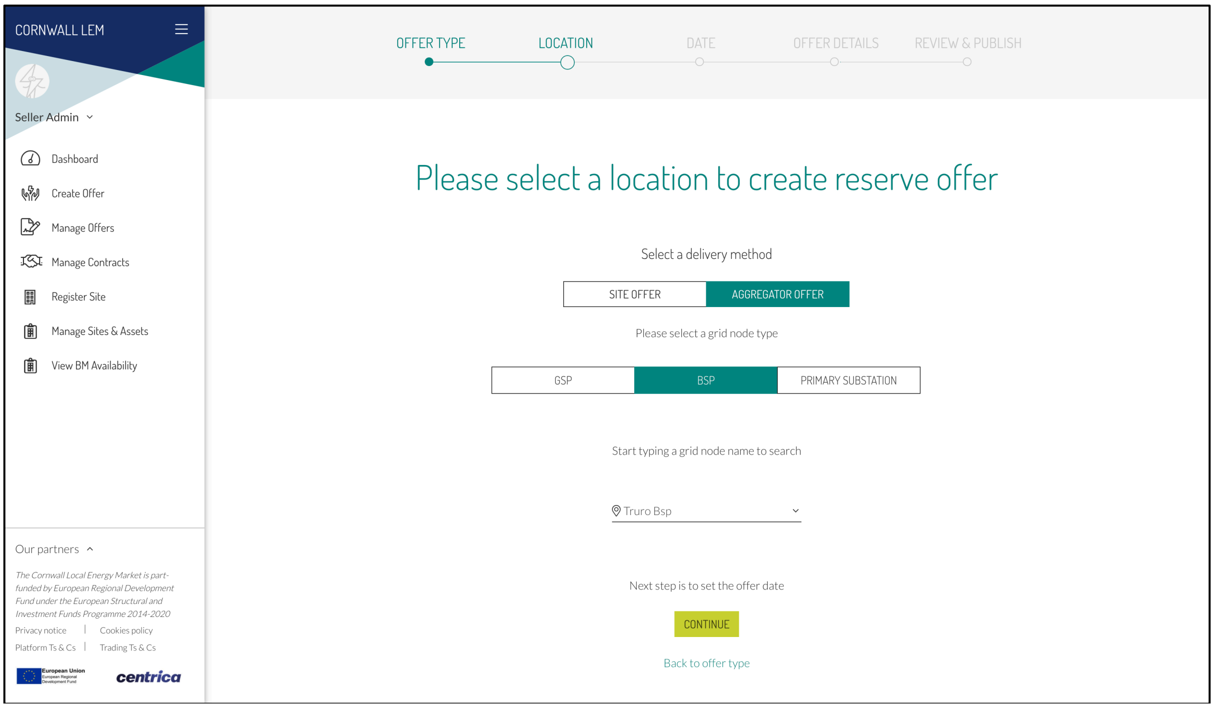
3.7.1 Aggregator Offers

When submitting offers, flexibility providers can choose to create the offer for either, an individual asset registered on the Platform, or, an aggregated pool of flexibility connected downstream of a single grid node.

For example, if a participant has multiple DER connected to various Primary substations all downstream of the same BSP, instead of making separate offers for all the individual assets, the participant can make offers directly at the BSP level. Participants can aggregate their flexibility at any grid level, including at GSP level; however, this would mean their services were only available to the TSO.

When undertaking the performance assessment after the event, aggregated data is provided by the participant representing how the associated pool of flexibility performed collectively.

Figure 11: Grid node selection for aggregated offer through the User Interfaces



3.8 Clearing Engine

As the auction-based model allows for a wide range of conditions and variables to be considered, the optimisation problem can become very complex. Therefore, if market platforms are going to be able to scale up, it is imperative to have a sophisticated solver to clear the market. Throughout this report, the optimisation problem refers to the commercial optimisation only, system operators have further optimisation to do to assess whether flexibility is the most appropriate solution to deal with a constraint against other available options.

The Clearing Engine and the optimisation algorithm has been developed by N-SIDE, an advanced analytics and optimisation company based in Belgium, and is based on the commercial optimisation engine CPLEX. It has capabilities over and above those supported by other options such as Excel's Solver which removes the need to avoid complexity, and the Clearing Engine can therefore support partial matching of services rather than requiring all or nothing selection to simplify the optimisation process. The additional computational abilities are essential in supporting the functions required to manage conflicting services, as described in Section 3.4.

When an auction is triggered by the Platform, the following information is sent to the clearing engine: bids and offers covering the auction period, a view of network topology, the available network capacity at each node of the network and a list of historic contracts. The optimisation algorithm then matches the bids and offers and calculates the Locational Marginal Price for every grid node per settlement period. The solution provided maximises social welfare by maximising the sum of the surplus for the buyers and for the sellers, as illustrated in Figure 12 below.

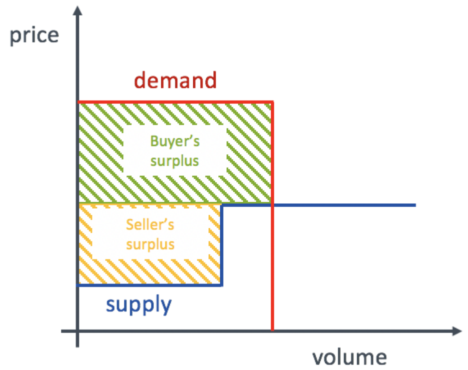


Figure 12: Optimisation algorithm, supply and demand curves

When solving the optimisation problem, offers without specific constraints have to be accepted and/or rejected solely on their price. For each unconstrained offer, there are three possible outcomes:

- The offer is fully accepted, which means the nodal price is greater than or equal to the offer price.
- The offer is fully rejected, which means the nodal price must be less than or equal to the offer price.
- The offer is partially accepted, and based on the two previous outcomes, the nodal price cannot be greater than the offer price (as it is partially rejected) and cannot be less than the offer price (as it is partially accepted). Therefore, the nodal price must equal the offer price.

Two kinds of indeterminacies can be encountered in this kind of optimisation problem.

1. Volume indeterminacy: in this case, the clearing engine will maximise the matched volume as shown in Figure 14.

2. Price indeterminacy: in this case, the clearing price will be the average of the marginal price of the demand curve and of the offer curve, as shown in Figure 15.

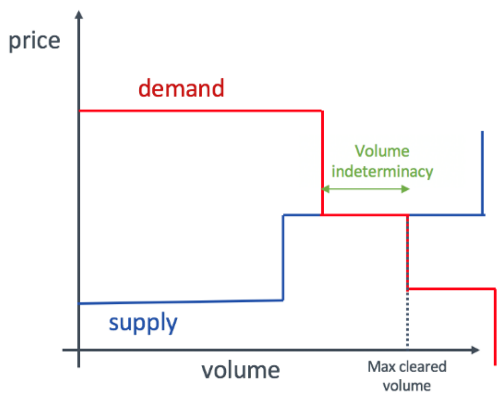


Figure 13: Optimisation algorithm solution for volume indeterminacy

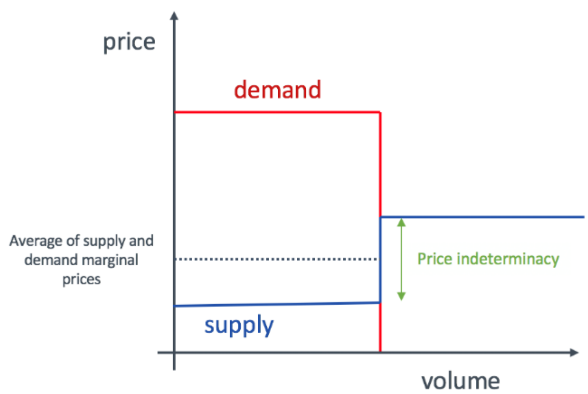


Figure 14: Optimisation algorithm solution for price indeterminacy

When coordinating procurement between the TSO and the DSO, if both parties are procuring flexibility in the same direction, the Clearing engine will prioritise the buyer who values the flexibility the greatest. However, if both parties are procuring flexibility in opposite directions, priority will be given to the DSO to ensure the security of the local network, as detailed in Section 3.4.

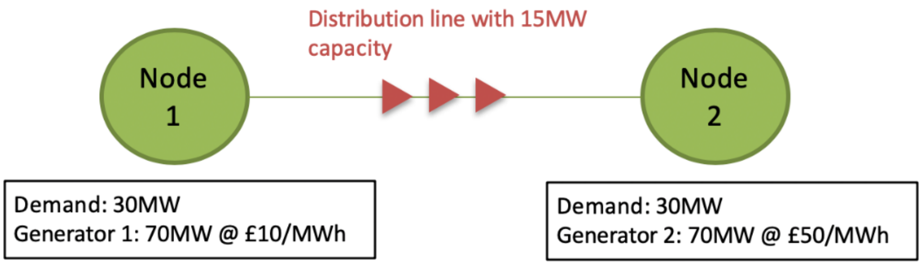
A further review into the design of the Clearing Engine and validation of the technical parameters of the orders has been undertaken by Imperial College and can be found alongside all completed research documents shown in Section 2.5.

3.8.1 Locational Marginal Pricing

The Clearing Engine uses Locational Marginal Pricing ("LMP") to establish the price of flexibility at each node of the network. LMP is used in several energy markets around the world, including the ISO New England and PJM networks in America. Network congestions mean that the price for flexibility at one node may be substantially different to the price of flexibility at another. The following example explains how network congestions cause the LMP to differ at each node.

Assume you have two nodes, both with a flexibility requirement and one available generator over a settlement period. Both generators can increase their output by 70MW, however the line between the nodes can only transfer 15MW.

Figure 15: Simple Locational Marginal Pricing example



In this example, the flexibility requirement at Node 1 can be fully satisfied by the lower cost Generator 1. However, only 15MW of the 30MW requirement at Node 2 can be met by Generator 1, and Generator 2 will also be dispatched for 15MW. Assuming the flexibility requirement at Node 1 increased by 1MW, this would be met by Generator 1. Therefore Node 1 has an LMP of £10/MWh, whilst Node 2 has an LMP of £50/MWh.

3.8.2 Congestion Rent

Locational Marginal Pricing creates scenarios where the flexibility providers may be paid a lower price than is paid by the buyer. In the previous example, Generator 1 would be paid for 15MW of flexibility which was required at Node 2. However, the LMP paid by the buyer at Node 2 was £50/MWh compared with the £10/MWh Generator 1 would receive.

For the purposes of the Cornwall LEM trial, no congestion rent was generated and the contracted price for each event was the LMP at the Bid location. Market rules are required to determine what happens with the congestion rent generated by a flexibility market. This could include being redistributed evenly between all participants on a monthly or annual basis.

3.9 Provision of grid-secure flexibility to the Balancing Mechanism

3.9.1 Overview

An additional process was introduced as part of the optimisation algorithm at the end of each utilisation auction to optimise the remaining, uncontracted, flexibility based on the forecasted available network capacity. This flexibility can then be offered to the TSO through the Balancing Mechanism or other national markets.

This process ensures that all flexibility available to the TSO through the balancing mechanism is grid-secure and will not violate any distribution network limits, whilst ensuring optimal allocation of distribution network capacity for TSO flexibility.

3.9.2 Process

1) Flexibility providers register their DER on the LEM and create offers (detailing the flexibility they can provide and the required cost for doing so).
2) Utilisation auctions are triggered by the LEM Platform at 16:00 at the Day Ahead stage, and every 30 minutes within day (up to two hours before delivery).
3) The LEM auction matches buyers and sellers and creates contracts for the delivery of flexibility.
4) The remaining flexibility which has not been contracted during the first stage of the auction is then limited and optimised based on available network capacity. Ensuring that the level of flexibility is never greater than the available capacity on the network.
5) The grid-secure flexibility for each offer is then displayed through the Platform's UI or queried via API.
6) The offers are entered into each subsequent utilisation auction, ensuring the allocation of distribution network capacity is reoptimised every 30 minutes until the gate closure of the last relevant LEM utilisation auction (2 hours before delivery).
7) Participants update their Bid-Offer data within the Balancing Mechanism based on their grid-secure flexibility.

3.9.3 Grid-secure example

In this example, we will look at a simplified network for one individual settlement period with the following assumptions:

- Three offers have been made from sites connected downstream of Bugle Primary.
- There is 2.7MW of available Generation Headroom forecasted between Bugle Primary and St Austell BSP throughout the settlement period.
- No contracts are created through the LEM utilisation auction.

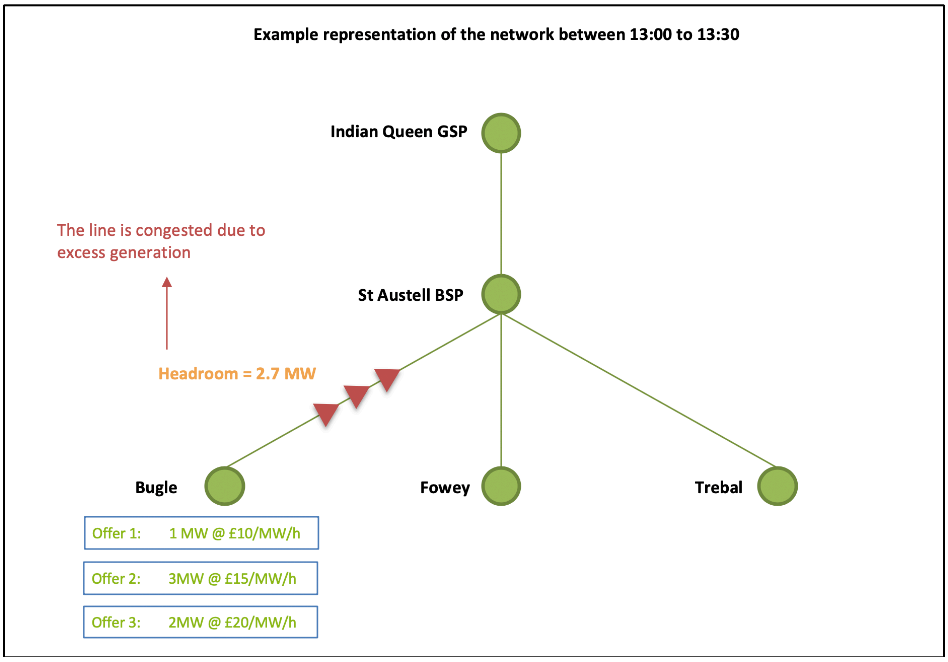


Figure 16: Scenario for the provision of grid secure flexibility to the Balancing Mechanism

During the utilisation auction, the following grid-secure flexibility will be calculated ensuring optimum allocation of distribution network capacity for TSO flexibility.

- Offer 1 will be cleared at 1MW as it is the cheapest offer and therefore, represents the best value to the system.
- Offer 2 will be cleared for 1.7MW
- Offer 3 will not be cleared

The allocation of the available network capacity is reoptimised in each subsequent utilisation auction and participants are able to change their price in order to become more competitive.

This validation process is expected to become more critical as the number of connections which are granted that may exceed traditional network limits increases. This methodology is one potential solution showing how coordinated markets can conduct the grid-secure validation to help efficiently operate both the distribution and transmission networks.

3.10 Performance Assessment

3.10.1 Baselining

A baseline is a short-term forecast of expected energy usage during a given time period. Baselines are typically calculated using time-series meter data using simple and well-defined methodologies. Demand response program administrators use baselines to retrospectively measure the performance of demand-side resources during a flexibility activation (i.e. events) to calculate settlements. Below is an illustration of a baseline for a demand turn down event, showing metered load as the black trace, the baseline as the red trace and the committed capacity, which is the baseline minus the committed curtailment amount.

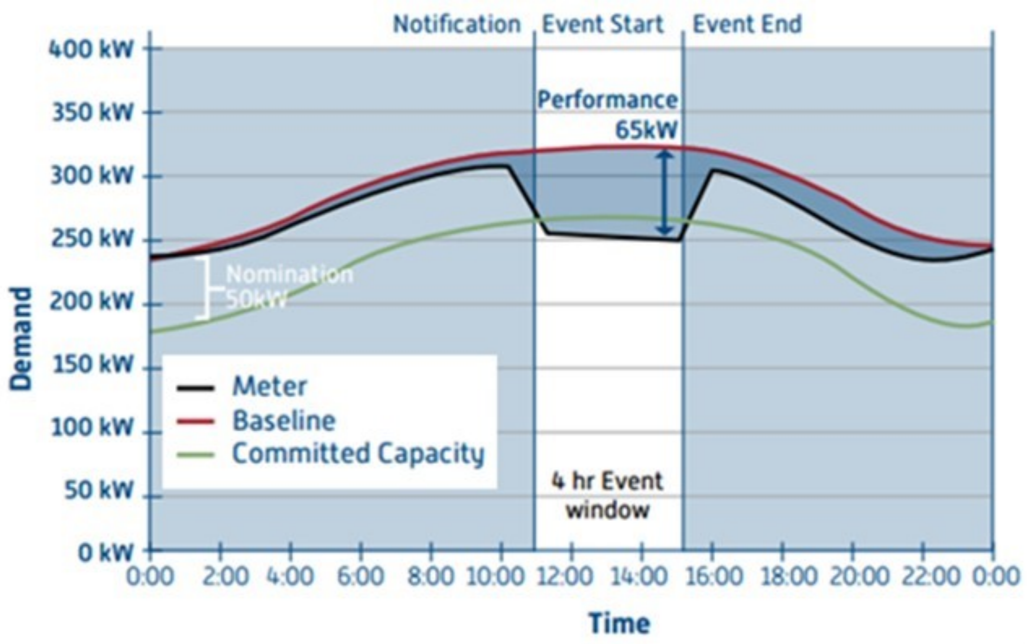


Figure 17: Baseline example

For the Cornwall LEM Platform trials, a baseline using the similar days' methodology was chosen. This methodology is widely accepted and is currently used by ISO New England[16], a large system operator and demand response program administrator in the United States. The methodology was chosen as it performed best for accuracy, bias and variability in a study by PJM which compared these three attributes for 11 different, commonly used, baseline methodologies over a two period[17].

The inputs are:

- A time-series of 30 days of historical meter data of 30-minute interval length up to at least one hour before the event start.
- The past days with a resource dispatch event will be excluded from the baseline calculation, as well as the days where the load can be considered abnormal for specific transparent reasons (i.e. metering communication or equipment issues, site shutdown).
- The event time intervals.

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[16] ISO New England: Manual for Measurement and Verification of Demand Reduction Value from Demand Resources https://www.iso-ne.com/static-assets/documents/2017/02/ mmvdr_measurement-and-verification-demand-reduction_rev6_20140601.pdf

[17] PJM: Empirical Analysis of Demand Response Baseline Methods https://www.pjm.com/-/media/markets-ops/demand-response/pjm-analysis-of-dr-baseline-methods-full-report.ashx?la=en

The following calculation method is then used:

- Select the Y most recent similar days
  - If a weekday, select Y=10 most recent weekdays, excluding holidays or previous event days.
  - If a weekend or holiday, select Y=5 most recent matching weekend days (Saturday = Saturday, Sunday/Holiday = Sunday/Holiday)
- Calculate the average load by interval for the event day, which becomes the "unadjusted baseline".
- Calculate an additive adjustment factor, which is
  - The average metered load from the three 30min intervals, between 2 hours before and 30 minutes before the event. The period immediately preceding the event was excluded from the calculations to ensure the ramping up/down of assets did not affect the calculations.
  - Minus the average unadjusted baseline load from the three most recently completed 30min intervals before the event.
- The adjusted baseline is then equal to the original plus the additive adjustment factor.

All sellers were required to provide energy data from the boundary meter at a minimum of ½ hourly resolution from 30 days prior to the event up to 1 hour after the event.

File format specification

- File type: CSV
- File name: compliant with the pattern below:
  METERING_%SellerId%_%StartTime%_%EndTime%_%Resolution%_%Unit%.csv
  - **SellerId**: Identifier of the seller (shall match the name of the organization entered as part of the registration)
  - **StartTime**: start time of the metering data included in the file
  - **EndTime**: end time of the metering data included in the file
  - **Resolution**: resolution of the metering data included in the file (e.g. "PT30M" for 30min resolution, PT15M for 15min …)
  - **Unit**: "KW" or "KWH"
- File content: CSV columns:
  - **SiteId:** string identifier of the site as registered in the platform
  - **MPAN**: 21 digits
  - **Timestamp**: string following ISO 8601 format "YYYY-MM-DDTHH:MM:SS" local time
  - **Value**: power or energy float value for the time interval (as per the unit specified in the file name)

Figure 18: Required CSV format for metering data

3.10.2 Performance Assessment

Using the baseline and the sites metered data, a delivery proportion is then calculated based on the delivered service against the contracted capacity. To calculate the payment proportion per settlement period a penalisation factor is applied where the delivery proportion is below 0.95.

The ratio of the payment proportion against delivery proportion is shown in the Figure 19 below.

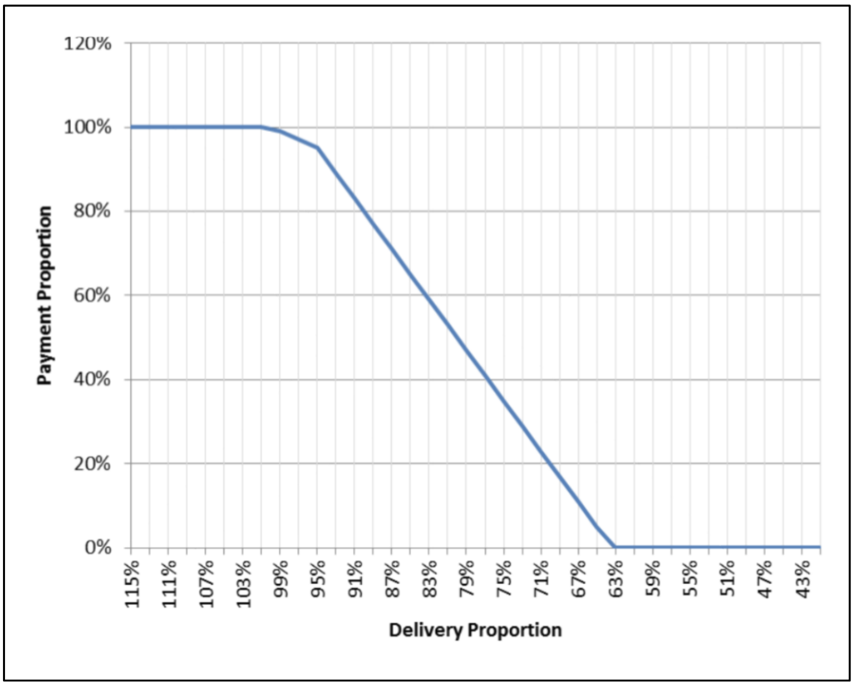

Figure 19: Graph showing the change in payment proportion against delivery proportion

3.10.3 Settlement

Following the performance assessment, a monthly settlement statement is generated by the Platform at the beginning of each month for the preceding months contracts. The buyers and sellers are then invoiced, there is then a dispute period should any participant want to query the results, after which point the payment is issued by the buyer to the market operator and dispersed to the sellers.

3.11 Contractual Structure

In the Cornwall LEM Platform trials, Centrica has acted as the market operator. The Platform itself is not responsible for delivery of flexibility contracted through the platform and, as such, there are two key contracts that sit underneath the LEM platform:

- LEM Platform Ts & Cs: all users agree to these upon registering. These cover basic platform usage issues such as privacy, liability, IP, payment processes. They also make clear that contracts struck on the LEM platform are binding between the parties, but that those contracts are between the seller and buyer.

- LEM Trading Ts & Cs: all users agree to these upon registering. These cover the terms of the flexibility service delivered by the seller to the buyer, the baselining and settlement methodology, and how payments are to be reduced in the event of under-delivery.

3.12 IT Architecture

The Cornwall LEM Platform has been built using a Minimum Viable Product (MVP) approach and an agile development process based on SAFe and SCRUM frameworks. The Platform is based fully on a micro service architecture and can be divided into 2 parts:

a. The set of components supporting the LEM business operation & processes
b. The set of components monitoring the micro services covering the business requirements

The services rely on reusable software layers. Each high-level micro service covers a specific business function, has its own data model and database schema. Horizontal scalability is supported within a Kubernetes cluster by leveraging event driven approach. Each service can expose a set of synchronous REST APIs and can interface an asynchronous messaging system for data exchange between components. The platform is hosted by AWS.

4 Platform Trials

4.1 Methodology

In order to test the Cornwall LEM Platform, trials were conducted from May 2019 until March 2020. The Phase 2 Platform trials, on which this paper focuses, ran from September 2019 to March 2020 and had both Western Power Distribution and National Grid ESO placing bids on the Platform.

The trial events focused around one GSP (Indian Queens) which feeds a large proportion of the distribution network within Cornwall. WPD bid locations were then determined based on the outcome of customer recruitment.

Both WPD and National Grid ESO were operating under a 'shadow' market approach, meaning all activities in the trial were not used to mitigate or resolve real system issues but were done solely for the purposes of testing and trialling the Cornwall LEM Platform. Procurement took place in all available auction formats.

Some trial events were designed to ensure that both WPD and National Grid ESO procured flexibility over the same periods to test the conflict-avoidance and market clearing capabilities of the Platform, as shown in Section 4.6. Other periods of the trials allowed for independent operation and had National Grid ESO and WPD procuring flexibility independently. Both WPD and National Grid ESO were responsible for conducting their own project learnings as part of the two individual projects:

- WPD: Visibility Plugs and Sockets
- National Grid ESO: Testing Coordinated DSO-ESO Procurement and Dispatch

The Platform is designed to match bids and offers, and the intent is that when the market becomes more liquid sellers will submit offers representing their full availability and their true cost for providing flexibility over the given timeframes. However, due to the limited number of events throughout the trials, participants were inclined to directly respond to bids and not submit long-duration offers.

4.2 Flexibility Recruitment

Flexibility recruitment for participation in the trials was conducted by the Cornwall LEM team and saw 30.91MW of flexible capacity register on the Platform. The Platform is technology agnostic and saw the following technology types register:

- Demand-side-response
- Residential battery systems (aggregated at various grid nodes)
- Battery storage
- Gas turbine generators
- Diesel generation

Table 6 shows a list of the sites registered on the Platform. The sites have been anonymised and are referenced according to the Primary substations and BSPs to which the sites are connected.

	Connection Points		**Grid Connection Capacities**	
Site	Primary Substation	Bulk Supply Point	Import Capacity MW	Export Capacity MW
1	Liskeard	St Germans	0.2	n/a
2	Drinnick	Fraddon	7	7

3	Bugle	St Austell	8	8
4	Par Harbour	St Austell	10	10
5	Drinnick	Fraddon	1	1
6		Fraddon	0.05	0.05
7		Truro	0.05	0.05
8	Newlyn	Hayle	0.4	n/a
9	St Columb Major	Fraddon	0.025	0.48
10	Delabole	St Tudy	0.01	n/a
11	Hayle	Hayle	1.5	1.5

Table 6: Sites registered on the platform anonymised by grid node.

The aim of the flexibility recruitment was to ensure a diverse range of technologies and participants registered in order to maximise learnings. To achieve this, the Cornwall LEM team held an aggregator event in 2018 which was attended by 10 of the UK's leading aggregators, as well as hosting events to target Cornish businesses and utilising media coverage. In general, recruitment was more difficult than anticipated. The main barriers faced during customer recruitment are explored in Section 5.4. Whilst some of the barriers were unique to the trials, some are typical barriers which may limit the types of providers and technologies that participate in future flexibility markets.

4.3 Residential Battery Systems

As part of Work Package 2 of the Cornwall LEM Programme, 100 battery systems were installed in 100 homes around Cornwall. The batteries installed ranged from 2kW – 5kW and were aggregated together as part of a Virtual Power Plant. As the minimum clip size for the trials was set at 50kW, the following clusters were created from the 100 battery systems and were used to respond to the trial events.

Grid Node	Total Capacity MW
Fraddon BSP	0.05
Truro BSP	0.05
Indian Queens GSP	0.25

Table 7: Residential battery clusters used for the trials

The clusters downstream of Fraddon BSP and Truro BSP were registered as sites on the Platform and correspond to sites 6 and 7 in Table 6 respectively. The cluster downstream of Indian Queens GSP was used as part of an aggregated offer to meet a National Grid ESO bid.

4.4 Results

In total, there were 381 Bids and 107 Offers created throughout the Cornwall LEM Phase 2 Platform trials. From these, there were 77 reserve contracts and 49 utilisation contracts generated.

This included 37 reserve contracts which were then utilised by the buyer and 40 contracts which had a reserve component but were not utilised during subsequent utilisation auctions. 12 utilisation only contracts were generated.

Table 8 below shows the number of contracts and the volume contracted throughout the trials summarised by buyer.

	Number of Contracts			Volume Contracted [MWh]	
Organisation	Total	Reserve	Utilisation	Reserve	Utilisation
WPD	19	12	19	24	37
National Grid	70	65	30	187	62
Total	89	77	49	210	99

Table 8: Results summarised by buyer

4.4.1 Utilisation Contracts

Table 9 below shows the overall contracted volumes and prices for the 49 utilisation contracts. Each utilisation contract is composed of multiple settlement periods which could each have different contracted volumes and prices. The details displayed in this section are summarised per contract for simplification.

Organisation	**Direction**	**Date**	**Total Cleared Reserve Qty [MWh]**	**Average Cleared Reserve Price [£/MW/h]**	**Total Cleared Utilisation Qty [MWh]**	**Average Cleared Utilisation Price [£/MWh]**
WPD	UP	06/09/2019			4.63	315.00
WPD	UP	10/09/2019	5.12	17.50	3.13	330.00
WPD	UP	13/09/2019	0.13	30.00	0.13	277.50
WPD	UP	20/09/2019	2.25	17.50	2.25	315.00
NG	UP	25/09/2019			1.50	235.00
NG	DOWN	27/09/2019	-1.00	52.50	-1.00	162.50
WPD	UP	27/09/2019			4.20	400.00
WPD	UP	01/10/2019	0.13	16.50	0.13	277.50
WPD	UP	01/10/2019			3.30	325.00
WPD	DOWN	03/10/2019	-0.25	20.00	-0.25	315.00
NG	UP	03/10/2019			2.00	222.50
WPD	UP	22/10/2019	6.00	30.00	6.00	315.00
WPD	DOWN	24/10/2019	-0.15	20.00	-0.15	330.00
NG	UP	31/10/2019	1.00	58.50	1.00	222.50
WPD	UP	03/11/2019	0.08	30.00	0.08	315.00
NG	UP	05/11/2019	2.00	46.00	2.00	260.00
NG	UP	14/11/2019			2.50	260.00
WPD	UP	14/11/2019			0.10	260.00
WPD	UP	15/11/2019			2.75	300.00
NG	UP	15/11/2019			1.00	260.00
NG	UP	21/11/2019	2.00	46.00	2.00	260.00
NG	UP	22/11/2019	3.00	73.00	3.00	260.00
NG	UP	25/11/2019	2.00	46.00	2.00	260.00

WPD	DOWN	25/11/2019	-0.10	10.00	-0.10	220.00
WPD	DOWN	26/11/2019			-0.10	220.00
WPD	DOWN	28/11/2019	-0.10	10.00	-0.10	220.00
WPD	DOWN	29/11/2019			-0.10	200.00
WPD	UP	05/12/2019	4.25	17.50	4.25	345.00
WPD	UP	06/12/2019	5.12	17.50	5.12	345.00
NG	UP	14/01/2020	2.00	46.00	2.00	235.00
NG	UP	15/01/2020	2.00	46.00	2.00	235.00
NG	UP	16/01/2020	2.00	46.00	2.00	235.00
NG	UP	22/01/2020	3.00	46.00	2.00	235.00
NG	UP	23/01/2020	3.50	46.00	2.00	235.00
NG	UP	30/01/2020	2.00	46.00	1.50	260.00
NG	UP	31/01/2020	2.00	46.00	2.00	260.00
NG	UP	04/02/2020	3.00	55.00	1.50	242.50
NG	UP	05/02/2020	3.00	55.00	2.00	242.50
NG	UP	27/02/2020	4.50	55.00	4.50	282.50
NG	UP	02/03/2020	2.50	50.00	2.00	282.50
NG	UP	03/03/2020	2.50	50.00	2.50	282.50
NG	UP	04/03/2020	2.50	48.00	2.50	327.50
NG	UP	05/03/2020			2.50	320.00
NG	UP	11/03/2020	2.50	50.00	2.50	297.50
NG	UP	12/03/2020	3.00	49.00	2.00	355.00
NG	UP	20/03/2020	3.00	50.00	3.00	297.50
NG	UP	27/03/2020	2.50	49.00	2.50	380.00
NG	UP	30/03/2020	2.00	50.00	1.50	367.50
NG	UP	31/03/2020	2.00	48.00	1.50	345.00

Table 9: Utilisation contracts generated throughout the trials

Figure 20 below shows the cleared utilisation prices for the contracts shown in Table 9. The average utilisation price was £280.51/MWh. It is likely that previous DSO flexibility prices, such as prices published by WPD for their Flexible Power tenders of £300/MWh, appear to have strongly influenced the participants valuing of the service.

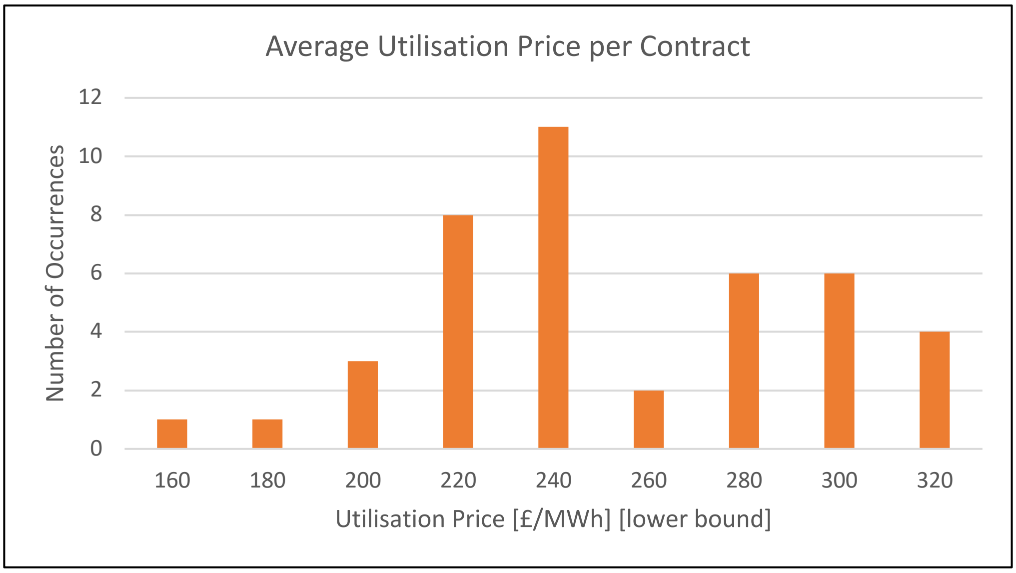

Figure 20: Summary of contracted utilisation prices

4.4.2 Reserve Contracts

Table 10 below shows the overall contracted volumes for the 40 reserve contracts which were not subsequently utilised. Each reserve contract is composed of multiple settlement periods which could each have different contracted volumes and prices. The details displayed in this section are summarised per contract for simplification.

Organisation	Direction	Date	Total Cleared Reserve Qty [MWh]	Av Cleared Reserve Price [£/MW/h]	Total Cleared Utilisation Qty [MWh]	Av Cleared Utilisation Price [£/MWh]
NG	UP	14/10/2019	1	58.5		
NG	UP	21/10/2019	1	58.5		
NG	UP	23/10/2019	2	58.5		
NG	UP	24/10/2019	2	58.5		
NG	UP	30/10/2019	1	58.5		
NG	UP	04/11/2019	3	73		
NG	UP	06/11/2019	2	46		
NG	UP	13/11/2019	5	62.5		
NG	UP	14/11/2019	2.5	73		
NG	UP	15/11/2019	3	73		
NG	UP	29/11/2019	3	75		
NG	UP	02/12/2019	5	75		
NG	UP	03/12/2019	3	75		
NG	UP	04/12/2019	3	75		
NG	UP	05/12/2019	4	75		
NG	UP	06/12/2019	1.5	5		
NG	UP	11/12/2019	5	75		
NG	UP	17/12/2019	3	73		

NG	UP	18/12/2019	3	73		
NG	UP	24/12/2019	3	75		
NG	UP	25/12/2019	5	65		
NG	UP	27/12/2019	5	73		
NG	UP	31/12/2019	5	75		
NG	UP	06/02/2020	5	73		
NG	UP	11/02/2020	5	75		
NG	UP	12/02/2020	3	73		
NG	UP	13/02/2020	3	73		
NG	UP	14/02/2020	3	73		
NG	UP	17/02/2020	3	73		
NG	UP	18/02/2020	3	55		
NG	UP	20/02/2020	3.5	73		
NG	UP	21/02/2020	3.5	75		
NG	UP	24/02/2020	5	65		
NG	UP	28/02/2020	5	73		
NG	UP	05/03/2020	2.5	48		
NG	UP	13/03/2020	3	48		
NG	UP	19/03/2020	2.5	45		
NG	UP	23/03/2020	3	48		
NG	UP	30/03/2020	1	80		
NG	UP	31/03/2020	1	80		

Table 10: Reserve contracts generated throughout the trials which were not subsequently utilised

The figure below shows the average cleared reserve prices for the reserve only contracts shown in Table 10 and the reserve component of the utilisation contracts shown in Table 9.

Figure 21: Summary of reserve prices

The average reserve price was £53.55/MW/hr. Whilst this may seem high, due to the short duration of the contracts and the small number of trial events in total, this represents the opportunity cost to providers for participating in the trial events. However, due to the limited duration of the trial, low liquidity, unknown utilisation rates and no previous market data to analyse and set prices, the results from the trials will not be representative of future, business as usual, flexibility markets. It is not until participants are familiar with market mechanisms in a competitive and liquid market that prices will converge at the true opportunity cost for providers.

4.4.3 Results per grid-node

The following table shows the average prices summarised for each grid node where bids were placed throughout the trials. The higher reserve prices at Indian Queens GSP are due to the different strategies adopted by National Grid ESO and WPD throughout the trials. However, as aforementioned, this is unlikely to be representative of prices in future commercial markets.

Bid Grid Node	Number of bids	Number of Contracts	Reserve Only Contracts	Utilisation Only Contracts	Av. Cleared Reserve Price (£/MW/hr)	Av. Cleared Utilisation Price (£/MWh)
Indian Queens GSP	357	70	40	5	£59.88	£268.10
St Austell Bsp	1	2	0	1	£17.50	£330.00
Fraddon Bsp	10	7	0	5	£21.00	£298.20
Truro Bsp	6	5	0	2	£14.67	£238.50
Newlyn Primary	3	2	0	0	£20.00	£322.50
Drinnick Primary	1	1	0	0	£17.50	£315.00
Bugle Primary	2	2	0	2	N/A	£312.50

Table 11: Trials data summarised by grid node

4.4.4 Bids without Offers

Due to the low number of participants, a large proportion of bids placed on the Platform were not matched during the auctions due to a lack of available offers. This was particularly true for downward reserve bids placed by National Grid ESO due to the barriers which prevented renewable technologies from registering and providing a generation-turn-down service. The figure below shows the percentage of bids that were contracted summarised by bid direction.

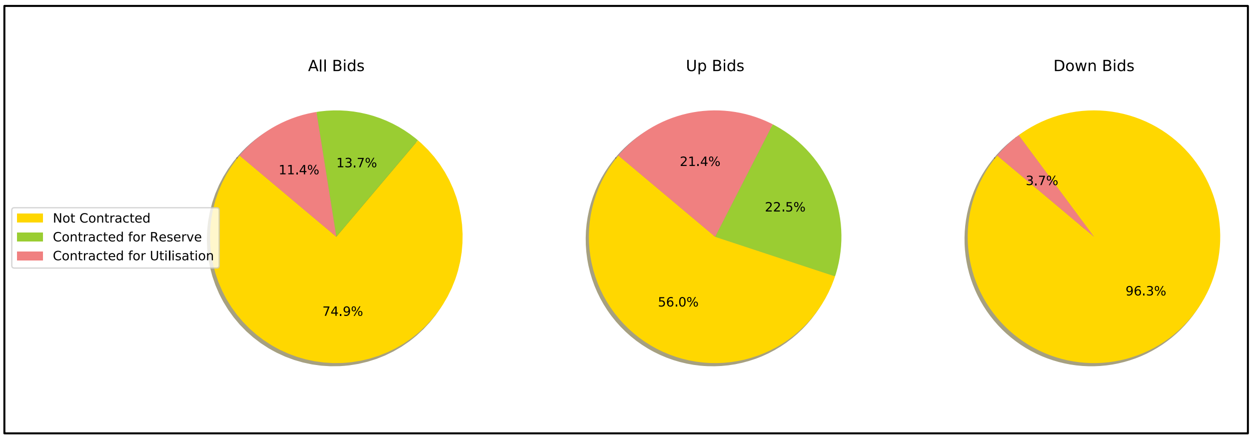

Figure 22: Percentage of bids which won contracts

4.5 Performance Assessment Results

The histogram and table below show the average delivery proportion for each utilisation contract. The delivery proportion has been capped at a minimum of 0, and a maximum of 1.

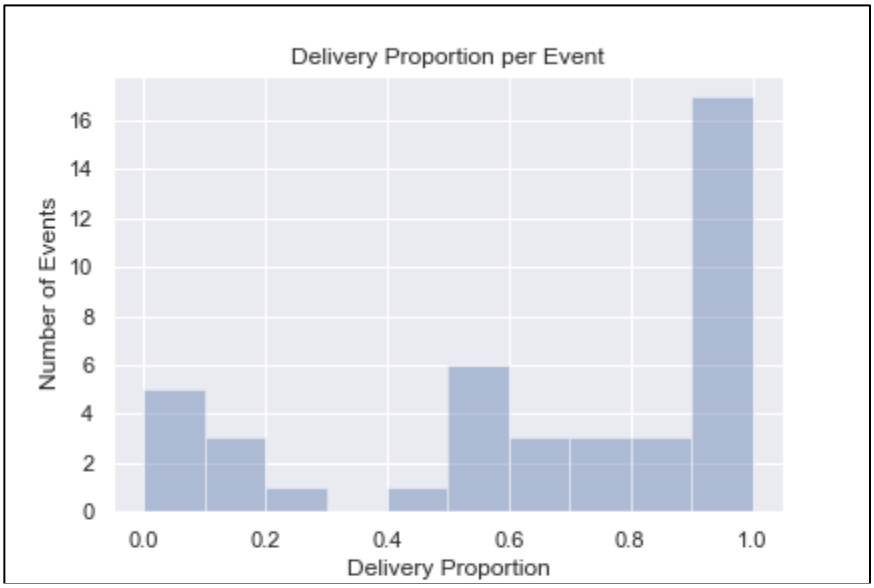

Figure 23: Histogram showing the delivery proportion per event

Delivery Proportion		**Number of Events**
Lower Bound	Upper Bound	
0.8	1	20
0.6	0.8	6
0.4	0.6	7
0.2	0.4	1
0	0.2	15

Table 12: Average delivery proportion per event

The average delivery percentage throughout the trials was 57.3%. This is comparable with a previous WPD innovation project which focused on flexibility services in the East Midlands, called project Entire, where the average delivery proportion was 61%. However, it is considerably lower than the reliability that would be required for DSO's to efficiently rely on flexibility to defer network reinforcements. The main reasons for the low delivery in several events are explored in Section 5.3.1.

4.6 Use Cases

This section focuses on two days throughout the trials which highlight the main use cases of DSO flexibility procurement. These events have been selected as they coincide with TSO flexibility procurement in the opposing direction and demonstrate the Platforms capability for coordinating TSO and DSO procurement.

4.6.1 DSO Demand Constraint

Figure 24 below shows the utilisation volumes procured by WPD and National Grid ESO during the trials on the 27th September. WPD procured flexibility to try and resolve a simulated demand constraint by procuring increased generation or load reduction at Fraddon BSP. At the same time, National Grid ESO procured downward flexibility at Indian Queens GSP.

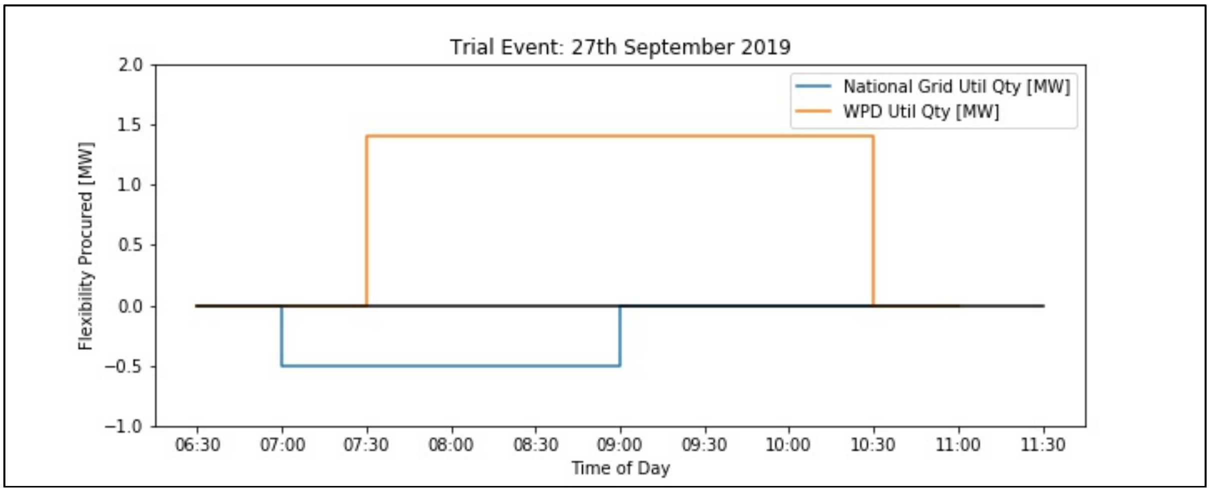

Figure 24: Contracted utilisation volumes on the 27th September 2019

The flexibility required by WPD was provided by a gas generator increasing its output at an industrial site downstream of Fraddon BSP. The flexibility required by National Grid ESO was met from unconstrained areas of the network by an industrial load in Newlyn, and a cluster of residential batteries aggregated at GSP level. The downward offer at Fraddon BSP, which was from a pool of residential batteries, was rejected as it would worsen the local congestion. This proves an important future use case for the Platform to be able to contract flexibility for the TSO whilst ensuring the safe operation of the distribution network.

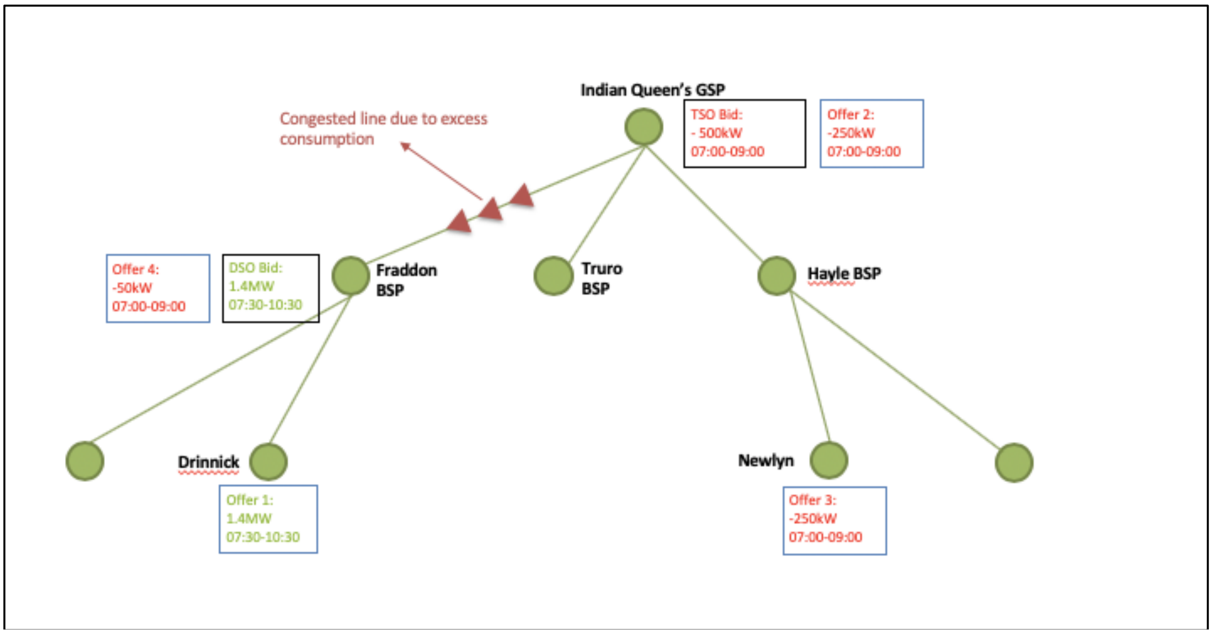

Figure 25: Locations of bids and offers on the 27th September 2019

4.6.2 DSO Generation Constraint

Figure 26 below shows the flexibility volumes procured by WPD and National Grid ESO during the trials on the 3rd October. In this instance, WPD procured downward flexibility to resolve a simulated generation constraint, whilst National Grid ESO simultaneously procured upward flexibility.

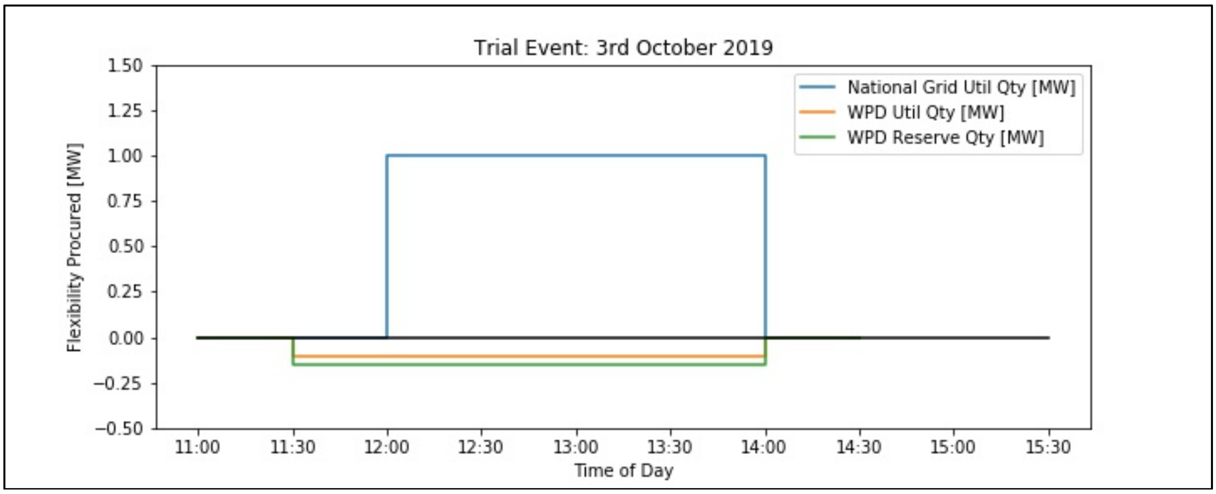

Figure 26: Contracted volumes on the 3rd October 2019

In this simple scenario, National Grid ESO were awarded a contract with a generation asset located downstream of Bugle Primary substation, whilst WPD contracted with a DSR provider at Newlyn. This use case again shows that the Platform can coordinate conflicting flexibility requirements, ensuring that flexibility providers contracted with the TSO are located in unconstrained areas of the network.

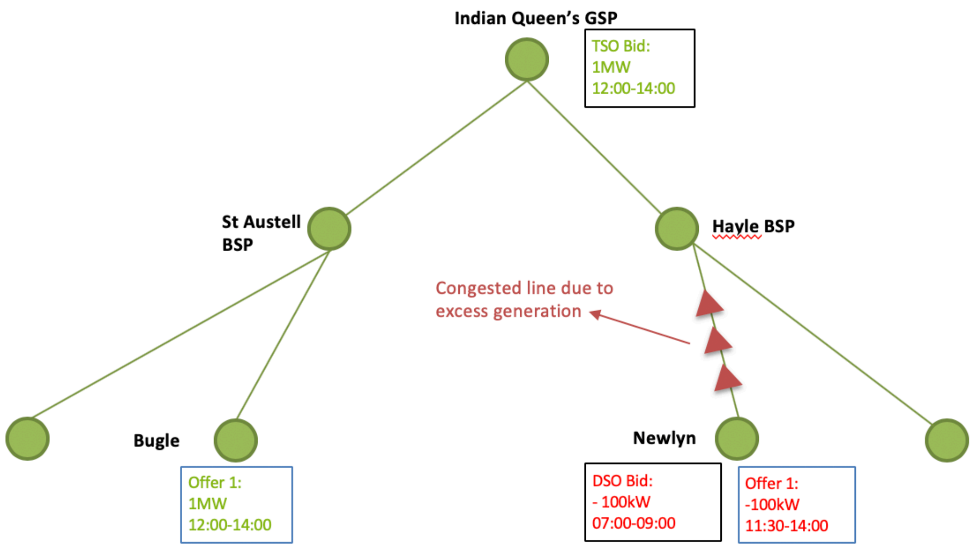

Figure 27: Location of bids and offers on the 3rd October

4.7 Performance Against Objectives

All 5 of the main objectives for the Cornwall LEM Platform have been tested and verified as part of the trial process. The Cornwall LEM Platform allows the DSO and TSO to procure flexibility as per the defined use cases. Going forwards the Platform could enable the TSO to access a wider range of flexibility providers whilst coordinating DSO and TSO flexibility procurement.

Although the objectives have been met, there is also a wide range of future development and learnings from the project which could better enable the use of 3rd party market platforms to coordinate flexibility procurement for both the TSO and DSO as business as usual. These are explored in the following section.

5 Discussion

5.1 Network Data

The scope of future flexibility market platforms is widely debated, and it is unknown which of the ENA Future World scenarios will become the operating model. Whilst the LEM Platform covered a board spectrum of the flexibility procurement process, including a grid security check of the distribution network for flexibility provided to the TSO, these functions may sit outside the scope of future flexibility markets. However, regardless which functions are conducted by the DSO, TSO or by future market platforms, the availability and accuracy of the following data items need to be improved to enable the efficient operation of flexibility markets.

5.1.1 Constraint forecasts

As aforementioned, congestion modelling was outside the scope of WPD's involvement in the project and a single static figure was used to impose network capacity limits when testing specific use cases. However, as distribution network congestions increase in frequency, and gird connections are granted which would overstep network limits[18] without the use of flexibility, the need to accurately calculate constraints and available distribution network capacity will become vital. Without accurate constraint forecasts, efficient procurement of flexibility is not possible and will rely on over significantly over procuring capacity.

Several initiatives are already underway to improve constraint modelling by the DSO's, notably WPD's Electricity Flexibility and Forecasting System (EFFS) project. EFFS aims to "create weather adjusted forecasts for load and generation at different time frames and adjusting these for planned flexibility service despatch in order to determine the nature, duration and frequency of expected constraints".

Whilst the EFFS project will see WPD trigger flexibility requests based on these forecasts, it would also be possible to send details of the constraints to flexibility platforms to enable them to optimise the allocation of distribution network capacity. The Cornwall LEM Platform has already been designed to do this in each auction by considering the available network capacity within the optimisation algorithm and demonstrates one option for how TSO flexibility procurement can be conducted in a grid-secure way.

5.1.2 Network topology under abnormal running arrangements

The default network topology provided by WPD details the nodal parent/child relationships during normal running arrangements. This view of the network was fixed for the duration of the trials as it was thought that abnormal running arrangements were unlikely to occur.

However, during the trials, it became apparent that parts of the network were operating under abnormal running arrangements for long periods of time. This meant that flexibility services which were expected to be delivered downstream of St Austell BSP were instead being delivered downstream of Truro BSP.

This suggests that if DSO's are procuring flexibility, they will need to provide information relating to any switching changes or abnormal running arrangements when, or before, they occur. However, as changes to the network configuration occur primarily due to unplanned outages, this represents a significant problem for DSO's as procuring flexibility ahead of time or in long term capacity contracts may mean that the flexibility purchased does not alleviate the identified network constraint.

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[18] Ofgem: Reform of network access and forward-looking charges
https://www.ofgem.gov.uk/electricity/transmission-networks/charging/reform-network-access-and-forward-looking-charges

One potential solution would be for the DSO to publish other views of the network hierarchy that represent the network under various scenarios and not only under normal running arrangements. These hierarchies could be static, and the DSO could specify which one should be used on a day-to-day basis, or they could be dynamically updated by the DSO to ensure that any changes are immediately known to reduce the inefficient procurement of flexibility.

5.1.3 Customer-to-network mapping

To ensure that a flexibility resource can be used to mitigate a constraint, the market must be able to locate the resources on the network. Discussion regarding the future approach for the customer-to-network mapping required is still ongoing. Whilst a manual validation by WPD was acceptable for the limited number of participants and events during the trials, for flexibility platforms to effectively scale a more robust solution is required. GDPR compliance is also making the use of customer MPAN's more difficult and new solutions are required.

One potential option which was considered during the design phase of the project and is described in detail in WPD's VPAS report[19], is the use of Electricity Supply Areas (ESA's) which specify the geographical area serviced by a BSP or Primary substation. Polygons have been produced which represent the ESA's and are available as ESRI shape files. These polygons were used by the Platform for display purposes on the user dashboards and could be used to conduct the customer-to-network mapping based on the geolocation of the flexibility resources. However, further investigation is required to verify the accuracy of this solution.

5.1.4 Power flow analysis

The Platform does not conduct a power flow analysis to determine whether a capacity level has been breached but instead uses a simplified network hierarchy. Although this is suitable for radial networks, it is not appropriate for meshed networks. However, it is unlikely the required level of data will be available to market platforms to conduct such analysis.

One approach could be the use of sensitivity matrices or power transfer distribution factors. This information removes the need for the market to conduct a full power flow analysis and contains less sensitive grid data. This approach represents the relational power flow between grid nodes as a ratio of 0 – 1. This information can then be used by the Clearing Engine to first, find the optimal combination of offers to meet the DSO flexibility requirement, and second, ensure a capacity level would not be breached for TSO contracts.

[19] WPD: Visibility Plugs & Socket – Closedown Report 2020

5.2 Market Design

5.2.1 Market Coordination

The Clearing Engine can only process the information that is available to it at the time. While the algorithm takes the results of previous auctions through the Cornwall LEM Platform into account, this may not be a complete picture if multiple platforms are trading services in the same area. This could be improved through additional data exchanges which would allow the Platform to better coordinate flexibility procurement and optimise the allocation of distribution network capacity. However, whether these data exchanges occur directly between market platforms or via a central repository will depend on future regulatory guidance.

5.2.2 Aggregated Offers

Participants can choose to submit offers aggregated at a grid node which could be supplied from multiple resources downstream of the selected grid node. However, the Clearing Engine does not have detailed information of the individual assets comprising the aggregated offer and therefore may not be able to accurately validate if the offer would violate any downstream network limits if contracted. Whilst aggregated offers give greater flexibility to the resource provider, not knowing exactly which asset will provide the service in advance is problematic when coordinating TSO-DSO procurement.

The adaptation of Local Flexibility Markets to allow aggregators to optimise their portfolios close to real-time, whilst providing sufficient locational informational to protect the network will be a necessary future adaptation. It could be possible for an aggregator to specify several configurations which could be used to provide information regarding the location of the available assets, whilst specifying the level of flexibility available at each downstream grid-node if certain configurations are selected. Increased automation and integration with flexibility providers could also enable providers to give more granular data without becoming too burdensome.

5.2.3 Short-term reserve capacity contracts

Whilst the Cornwall LEM Platform supports long- and short-term procurement, the product design for the trials factored the same parameters during both the reserve and utilisation auctions. Therefore, limited duration assets would only secure short reserve capacity contracts. This ensures that buyers do not reserve assets which then can't match required utilisation profiles and avoids overpaying for reserve capacity. This approach is well suited to short term markets and products where the utilisation requirements are reasonably well known ahead of time.

However, the main drawback of this approach, is that a participant may win a short duration contract in an auction which runs months ahead of delivery. Therefore, the contracted asset would be unable to enter subsequent monthly or weekly tenders/auctions for other markets as it would be unavailable for this short time period and the opportunity cost for the contract becomes very high.

This problem is more complex to solve than it first seems, as allowing long duration reserve contracts for short duration assets significantly increases the complexity of comparing reserve prices. For example, it is not trivial to compare the reserve price for an asset with a maximum duration of 5 hours against an asset with a maximum duration of 1 hour if utilisation rates are not well known.

A simple approach would be to introduce a new product specifically for long term reserve contracts during the month ahead auctions which specifies the minimum technical requirements of the assets and therefore does not consider asset constraints within the optimisation problem, similar to most existing ancillary services. However, this does not remove the issue of buyers not being guaranteed that future utilisation requirements can be met unless significantly over procuring reserve capacity.

Due to the nascence of local flexibility markets, DSO's need confidence that they will have enough reserve capacity ahead of time, therefore, long seasonal contracts have recently been preferred by the DSO's. However, this does not represent the best value to the end customer as short-term markets improve liquidity and competition by enabling more resources to participate fully in the market[20] whilst limiting the procurement of unnecessary reserve capacity. EB GL requirements for the TSO to procure services no further than the day-ahead also mean long-term markets cannot be coordinated. As flexibility markets mature, we will likely see the move towards closer to real-time procurement in line with the current Cornwall LEM product design. A recent example of this is the evolution of the Frequency Response products procured by National Grid ESO which, since 2015, as liquidity and familiarity increased, have gone from multi-year contracts to monthly tenders and now week/day ahead auctions are being trialled[21].

The prudent approach would be for flexibility markets to support both long and short duration reserve capacity contracts depending on the time horizon of the auction.

5.3 Performance Assessment

5.3.1 Reliability

Reliability will be a key performance metric for DSOs if they are going to have the confidence in using flexibility to defer network reinforcements. The average delivery proportion of 57.3% throughout the trials, whilst in line with similar innovation projects, is considerably lower than the reliability that would be required for cost-effective use of flexibility. However, the main reasons for the low delivery proportions can mostly be attributed to the nature of the trials and are unlikely to occur in a business as usual market. The main reasons for poor delivery in several events are listed below:

- The delivery from the residential batteries was poor. This is because most householders are not on Time-of-use tariffs and the decision was made to rely on the householders PV systems alone to charge the batteries and not to draw additional power from the grid to charge to avoid incurring costs for the householders.
- New market entrants needed to familiarise themselves with the process, including assessing the level of flexibility available from their assets, as they had not participated in similar markets before. This resulted in 2 events where it was not possible for the participants to respond as the assumed level of flexibility was not available.
- There were three events where the contracted provider was unable to deliver the response due to a technical issue.

If the events involving the residential batteries are excluded from the calculations, the average delivery proportion increases to 68.7% and removing the 5 events where the participants did not respond at all increases the delivery proportion to 80.2%.

Changes to the market rules should be implemented to improve reliability further. No penalties were imposed for poor performance or non-delivery throughout the trials, however, in commercial markets, fines and penalties could be used if participants continually under deliver.

[20] Regulation (EU) 2019/943 of the European Parliament

[21] National Grid ESO, Phase 2 Auction Trial https://www.nationalgrideso.com/balancing-services/frequency-response-services/frequency-auction-trial

5.3.2 Site vs Asset Metering

As aforementioned, the baselining methodology used for the trials was chosen as it performed well in statistical analysis by PJM comparing different methodologies[22]. However, for all the trial events flexibility was provided by individual assets behind the site boundary meter, and not by controlling the demand/consumption for the overall site. This meant that the delivered service calculated using site-level data may not accurately represent the service provided by the asset operator.

Asset level data was available for 38 of the 49 utilisation contracts, relating to 170 individual contract periods. This asset-level data has been compared to the performance calculated using the chosen baselining methodology and the site level data.

The histogram and Kernel Density Estimation below shows the difference in the delivery percentage calculated for each settlement period using the two different methodologies. A "Difference" of 0% shows that the two methodologies calculated the same service delivered over a settlement period, a negative Difference value means that the delivery proportion calculated using the site-level data is lower than the delivery evidenced using the asset level metering.

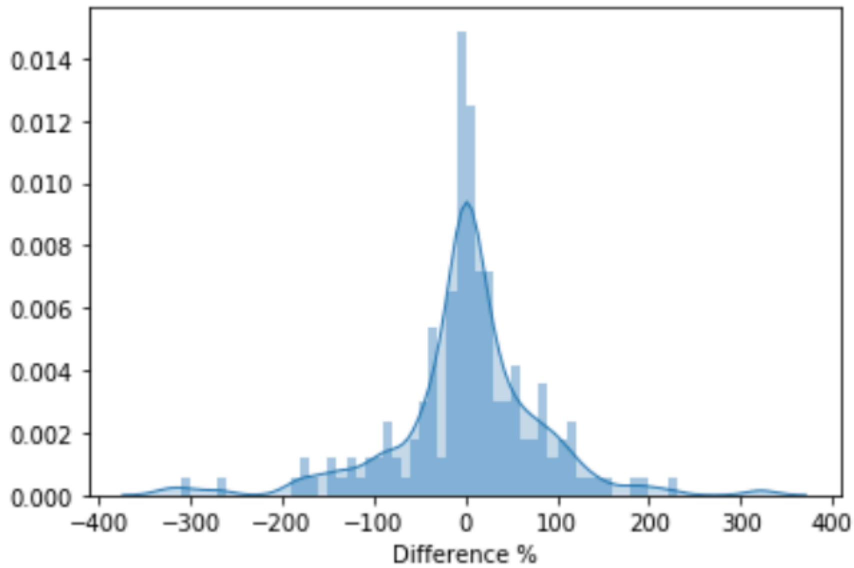

Figure 28: Difference in delivery proportion calculated when using site level or asset metering data

The figure shows that whilst the mean value is approximately 0, there are many occurrences where the service delivered varies significantly depending on whether site or asset level data is used; the standard deviation of the dataset is 82%.

The main factors which increased the difference in the calculated delivery proportions were:

- The ratio of the contracted flexibility volume in comparison to the average site demand. The larger the site demand, the greater the potential for relatively small fluctuations in demand to significantly affect the calculated baseline.

[22] PJM: Empirical Analysis of Demand Response Baseline Methods https://www.pjm.com/-/media/markets-ops/demand-response/pjm-analysis-of-dr-baseline-ethods-full-report.ashx?la=en

- The variability of the site load between consecutive settlement periods. As the standard deviation for the sites metering data increased, the difference between the two methodologies became more varied.

It will be the decision of individual network operators if they choose to accept asset-level metering as well as site-level metering. For the trials, WPD chose to only accept site-level metering as they wanted to validate that the service paid for was the change in consumption or generation noticed at the boundary meter. However, as Figure 28 shows there is a large risk that flexibility providers controlling behind-the-meter assets may not be accurately rewarded for a flexibility action, especially when the assets are situated at large sites with highly variable demand patterns.

Modification P375[23] is introducing the settlement of Secondary BM Units using metering from assets behind the site Boundary Point as part of the Wider Access to the Balancing Mechanism. Similar methodologies could be imagined for future DSO services. The more aggregators and asset operators who control behind the meter assets that participate in local flexibility markets, the stronger the case for accepting asset level metering.

5.3.3 Metering Data Resolution

As part of WPD's VPaS report, they conducted a comparison between the 30-minute resolution data used for the Cornwall LEM Platform trials, and 1-minute resolution data provided by participants for flexibility events as part of a separate WPD led innovation project named project ENTIRE. The comparison concluded that while half-hourly metering can reduce the penalties from under-delivery, it can also have the opposite effect, "for the vast majority of the events examined there was no benefit or only a small value either way".[24]

The analysis found that corrupted data was a significantly larger issue and improving the monitoring and communications systems or applying data cleansing has a greater impact in the performance assessment per event than the resolution of the data used.

5.3.4 Multiple Methodologies

Whilst the current baselining methodology is well suited for the demand response and the behind the meter assets which participated in the trials where site demand and load patterns were repetitive, it will not be the most suitable methodology for all flexibility providers going forwards. For example, technologies such as wind energy will require a significantly different approach and future flexibility markets may need to be able to select different methodologies depending on the technology providing the service.

Three baselining methodologies were proposed to assess the performance of renewables throughout the trials. However, due to a lack of renewables participation no comparison of the methodologies was possible. The three proposed methodologies are included in Appendix 8.1.

Another option is the potential for participants to self-baseline and provide a schedule ahead of time in a similar fashion to the submission of Physical Notifications in the Balancing Mechanism. However, this will be problematic for smaller, less sophisticated, participants who are not equipped to be able to do this.

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[23] Elexon modification P375: https://www.elexon.co.uk/mod-proposal/p375/

[24] WPD: Visibility Plugs & Socket – Closedown Report 2020

5.4 Barriers to Participation

As aforementioned, whilst some of the barriers which stopped potential flexibility providers from participating were unique to the trials, some are typical barriers which may limit the types of providers and technologies that participate in future flexibility markets. The main barriers faced throughout the customer recruitment for the trials are listed below.

- The number of industrial and commercial loads in Cornwall that may be attracted to flexibility offerings is small in comparison to other parts of the country.
- The limited number of trial events, each with a duration of only a few hours, meant that the financial incentive for participation was low. This is particularly true for small sites as the revenue per event is insignificant when compared to the time taken to familiarise themselves with a new market. This may be a barrier to future participation from individuals and SME's without a commercial aggregator.
- Despite the aim of the trials being to help alleviate network constraints, two sites were unable to participate in the trials as the cost to obtain export connections was prohibitive. Therefore, as their on-site generation could not provide a service when demand was low, they could not participate. Future amendments and variations in connection agreements, i.e. timed connections, should allow participants easier access to export agreements which could benefit the network. However, these were not available to the participants during the trials.
- Asset managers who operate wind and solar farms in Cornwall that wanted to participate were unable to do so as modulating their output would have been in breach of their Power Purchase Agreements ("PPA's").

5.5 Imbalance Effect

Currently, an action taken by a flexibility provider for DSO services will expose the Balance Responsible Party for that site to potential imbalance risks. This becomes a significant problem when the two parties are different entities, which is often the case for commercial aggregators and parties controlling distributed assets or demand-side-response assets. National Grid ESO are trying to overcome this through the introduction of Virtual Lead Parties in the Balancing Mechanism by distinguishing between a Balancing Service Provider, and the Balance Responsible Party ("BRP"). The balancing position of a BRP is adjusted after the event to account for actions taken by a Balance Service Provider in response to an instruction by National Grid ESO.

Due to the nascence of commercially procured DSO flexibility services, the relationship between wider wholesale and balancing markets is not yet well defined. Introducing a process which allows parties to provide a DSO service without impacting a BRP's position will require significant development and regulatory oversight. Potential options for overcoming this issue include;

1. The procurement of DSO services concludes sufficiently before the wholesale market gate-closure for Balance Responsible Parties to rebalance their positions. This is the current approach of the Cornwall LEM Platform due to existing regulatory frameworks.
2. If a participant is contracted to provide DSO services, automated transactions are initiated in wholesale markets to balance the BRP's position.
3. Actions taken by flexibility providers to provide DSO services are considered an applicable balancing service and can be considered post-event to rebalance a Balance Responsible Parties ("BRP") position. This could require a similar methodology as National Grid ESO and Elexon have developed for Virtual Lead Parties ("VLP").
4. Flexibility volumes could be traded by a VLP through the wholesale market with the traded volumes used to adjust the original supplier/BRP's position.

5. Future DSO flexibility services are procured through the existing Balancing Mechanism.

5.6 Market Price Caps

The ability for market platforms to limit gaming potential will require the further development of regulatory frameworks and consistent penalties/incentives to participants.

One risk by splitting reserve and utilisation procurement is that participants could secure reserve contracts and then price themselves out of the subsequent utilisation auctions. This could be mitigated in a number of ways, but the easiest solution is to introduce a price-cap by either:

- Defining a utilisation price cap in the market rules, thus prohibiting sellers from setting any offer price over this limit.
- Allowing buyers to set a utilisation price cap per bid. This would then require sellers to set a utilisation price at or below this limit in order to successfully win flexibility contracts.

However, when considering wholesale markets, European regulation expresses the need to avoid price caps when possible as "effective scarcity pricing will encourage market participants to react to market signals and to be available when the market most needs them".[25] Similar considerations should be made for flexibility markets and, although buyers may request stringent price caps, this may create market distortions and mean flexibility is not available during system stress events.

[25] Regulation (EU) 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity: Article 6

6 Conclusion

The Cornwall LEM Platform demonstrates that a 3rd party platform can be used to coordinate the procurement of flexibility services by the DSO's and TSO. As the optimisation problem can become very complex when there are multiple providers with varying asset parameters, a sophisticated market clearing algorithm is required to ensure that platforms will be able to scale in the future.

It has also been demonstrated that a market platform can be used to ensure that flexibility made available to the TSO is grid-secure and will not violate any distribution network limits, whilst also ensuring the optimal allocation of distribution network capacity.

However, although the technologies exist, a significant improvement in the data available from the DSO's is required for the efficient procurement and utilisation of flexibility. Particularly regarding; congestion and constraint forecasting; the modelling of network topology changes; and power transfer distribution factors detailing the power-flow relationship between grid-nodes.

DSO's need to be encouraged to move away from long-term capacity contracts towards short-term procurement in order to allow a wider range of flexibility providers to participate including; renewables and intermittent generation; Demand-Side-Response; and in the future, electric vehicles and domestic heat technologies. By increasing the range of participants and reducing the dependence on long-term capacity contracts with low utilisation rates, short-term flexibility procurement can provide savings to the end consumer.

7 Glossary

Term	Abbreviation	Definition
Application Programming Interface	API	A standard interface which allows for direct software-to-software communication
Bid		A buy order for flexibility through the Platform
Bulk Supply Point	BSP	Typically, a 132kV/ (66kV or 33kV) substation. The active BSP's throughout the trials were 132kV/33kV substations.
Balance Responsible Party	BRP	Balance responsible parties are responsible for maintaining supply and demand within their own portfolio and providing accurate Physical Notifications to National Grid ESO.
Balancing Service Provider		An entity that provides a balancing service through the Balancing Mechanism without being the Balance Responsible Party for the associated site.
Distributed Energy Resource	DER	Small-scale power generation or storage technologies connected to the distribution network. Typically, between 1kW to 20MW.
Downward Flexibility		Corresponds to a decrease in generation or an increase in demand.
Energy Networks Association	ENA	The Energy Networks Association is the industry body funded by UK gas and electricity transmission and distribution licence holders.
Flexibility		The deviation from a normal or predicted profile of generation or consumption of electrical power.
Grid Supply Point	GSP	Typically, a 400kV/132kV substation.
Grid-secure		A contract which is validated against network data to ensure it will not cause local network issues.
Headroom		The available capacity a specified grid node. The platform considers both demand headroom and reverse power headroom, representing the increase in power which can flow through a node without exceeding the designed capacity of the equipment.
Local Flexibility Market	LFM	A platform where buyers and sellers can come together to trade flexibility services.
Meter Point Administration Number	MPAN	A unique identifier for a customer's meter point at the point of connection with the distribution network.
Offer		A sell order for flexibility through the Platform
Primary substation		Typically, a (66kV or 33kV) / 11kV substation. The active Primary substations throughout the trials were 33kV/11kV substations.

Reserve		A capacity mechanism where flexibility providers are required to be available for the volume and time contracted.
Upward Flexibility		Corresponds to an increase in generation or a reduction in demand.
User Interface	UI	The User Interface refers to the web-based Platform which was accessed through www.lemcornwall.com.
Utilisation		The delivery of a flexibility service by modulating demand or generation as required
Virtual Lead Party	VLP	A VLP is a new type of participant defined by the BSC that can register Secondary BMU's to provide balancing services.

8 Appendix

8.1 Proposed baselining methodologies for renewables

8.1.1 Method 1 - Split Site Baseline

This method of baselining renewables is unquestionably valid. A renewables generation facility having multiple metered assets (of the same technology) is able to turn down part of the site whilst leaving another part of the site at full operational output. The generation turn down is then evidenced by reference to the fully operational output from the unaffected part of the site.

Examples:
1. A solar PV farm having more than one inverter, where each inverter has export sub metering.
One or more inverters can be turned down and the output turn down/off can be evidenced after the event, with reference to the concurrent output data from one or more fully operational inverters at the same site. The datasets under scrutiny will include the half hour immediately preceding the flex action. Mean outputs will be derived for both datasets, before and during flex action. The 'control' means will be scaled according to the relative capacity of the two parts of the site. Simple comparisons will then demonstrate the 'like for like' generation before the event and determine the mean turn down capacity achieved during the flex period.

2. A windfarm having multiple turbines, each having export sub metering.
One or more turbines can be turned down and the output turn down/off can be evidenced after the event, with reference to the concurrent output data from one or more fully operational turbines at the same site. The data is then processed as for example 1.

8.1.2 Method 2 – Similar Site Baseline

This method is similar in principle to method 1 but is suited to renewables generation sites with a single metered asset or a cluster of assets without individual sub metering. Instead of using fully operational assets at the same site, data from a nearby site of the same technology is used as the reference.

Examples:
3. A solar PV farm having a single inverter.
In this case, the inverter is turned down/off and concurrent generation data from a similar, nearby solar PV farm is used for reference. The data is then processed as for example 1.

4. A windfarm having a single turbine or single metering point.
As for example 3.

8.1.3 Method 3 – Resource Based Baseline

This method is appropriate where methods 1 and 2 are not possible but where suitable resource measurement is conducted continuously on site.

Examples:
5. A solar PV farm having a single inverter.
In this case, the inverter is turned down/off and concurrent solar insolation data from the site's pyranometer is used for reference. Data from the half hour preceding the flex action is used and a correlation coefficient is derived to represent mean generation output according to mean solar insolation. Data from the flex period is processed and the correlation coefficient is applied to the insolation data to determine the mean 'unaffected' generation that would have occurred.

6. A windfarm having a single turbine or single metering point.
In this case, the windfarm output is turned down/off and concurrent windspeed data from the site's anemometer, or the turbine's anemometer, is used for reference. Data from the half hour preceding the flex action is used and a correlation coefficient is derived to represent the mean generation output in relation to the turbine model power curve, according to the mean windspeed. Data from the flex period is processed and the correlation coefficient is applied to the mean windspeed, in relation to the power curve, to determine the mean 'unaffected' generation that would have occurred.