Northern Powergrid / FNC / NGESO

Fractal Flow – SIF Discovery Phase Project

FNC 023283 - 144388V

Final Release – 29/05/24

SYSTEMS · ENGINEERING · TECHNOLOGY

Contents

Purpose of this Document

This slide pack is a consolidation of the work performed as part of three work packages for the SIF Discovery Phase project Fractal Flow:

1. WP1: Feasibility Assessment.
    - Requirements capture and feasibility study.
2. WP2: Cost Benefit Analysis.
    - Benefits capture and cost assessment.
3. WP3: Technology Roadmap.
    - Gap analysis and technology roadmap.

The slide deck intends to capture these findings in support of progressing to Alpha Phase.

Fractal Flow has been funded through SIF to address:
Challenge 1: Whole System Planning for faster Asset Rollout
Theme 2: Leveraging data, digital tools, and novel commercial arrangements to maximise existing network capacity

Abbreviations (1)

Abbreviation	Definition
ANM	Active Network Management
API	Application Programming Interface
AWS	Amazon Web Services
BaU	Business as Usual
BM	Balancing Mechanism / Measure
BMU	Balancing Mechanism Units
BR	Balancing Reserve
BSP	Bulk Supply Point
CBA	Cost Benefit Analysis
CCGT	Combined Cycle Gas Turbine
CER	Customer Energy Resources
CVA	Central Volume Allocation
DC	Dynamic Containment
DER	Distributed Energy Resource
DERMS	Distributed Energy Resource Management System
DM	Dynamic Moderation
DMS	Distribution Management System
DNO	Distribution Network Operator

Abbreviations (2)

Abbreviation	Definition
DR	Dynamic Regulation
DSO	Distribution System Operator
EAC	Enduring Auction Capability
ENCC	Electricity National Control Centre
ESO (equivalent to NGESO)	Electricity System Operator
FF	Fractal Flow
Flexr	A DNO data provision and standardisation service to facilitate the energy market transition.
FSO	Future Systems Operator
GC	Grid Code
GIS	Geographic Information System
GSP	Grid Supply Point
ICCP	Inter-Control Center Communications Protocol
IEC	International Electrotechnical Commission
IT	Information Technology
kV	Kilovolt
LCT	Low Carbon Technology
MARI	Manually Activated Reserve Initiative
MBSS	Monthly Balancing Services Summary

Abbreviations (3)

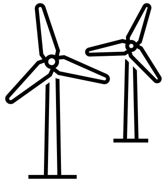
Abbreviation	Definition
mFRR	Manually Activated Frequency Restoration Reserves
MW	Megawatt
MWh	Megawatt-hour
NCER	EU Network Code Electricity Emergency and Restoration Code
NCMS	Network Control and Management Software
NeRDA	Near Real-time Data Access –Scottish & Southern Electricity Networks innovation project.
NGC	National Grid Company (former name now updated to: National Grid Electricity Transmission)
NGESO (equivalent to ESO)	National Grid Electricity System Operator
NGET	National Grid Electricity Transmission
NIC	Network Innovation Competition
NMS	Network Management System
NPg	Northern Powergrid
MFR	Mandatory Frequency Response
OBP	Open Balancing Platform
OCGT	Open Cycle Gas Turbine
ONP	Open Networks Panel
OT	Operational Technology
PoC	Point of Contact

Abbreviations (4)

Abbreviation	Definition
PS	Primary Substation
QR	Quick Reserve
SCADA	Supervisory Control and Data Acquisition
SFFR	Static Firm Frequency Response
SO	System Operator
SO-SO	System Operator to System Operator
SOGL	System Operation Guideline
SR	Static Reserve
SSEN-D	Scottish and Southern Electricity Networks – Distribution
STOR	Short-Term Operating Reserve
SVA	Supplier Volume Allocation
UI	User Interface
UX	User Experience
TERRE	European platform for trading reserve electricity
TSO	Transmission System Operators
VLP	Virtual Lead Party
WPD	Western Power Distribution

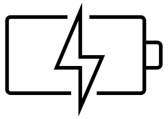
Project Drivers

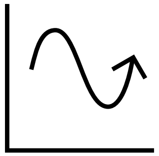
- Distributed Energy Resources (DERs) are a vital part of the solution to help the UK meet its net zero targets.
- Optimal real-time control of DERs will require visibility of power flow across the network, both horizontally, at a transmission level, and vertically, at a distribution level. Vertically, this includes constrained Active Network Management (ANM) schemes, which can introduce operational conflicts.
- Increased visibility will prevent conflicting system dynamics and be an enabler for greater volumes of low carbon generation.



There is a pressing need to:

1. Share real-time demand, service availability and constraint information at the GSP-level between DNO's and NGESO to enable optimal control of DERs.
2. Have the analytic capabilities to understand and forecast changes in demand, service availability and constraint evolution to ensure reliable procurement of services and the reduction of conflicts.





Note: 'Real-time' performance requirements must be defined in later stages of the project. Current understanding indicates that 'real-time' may be less than 30 minutes.

Why Fractal Flow?

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- UK grid operations have historically been dominated by carbon intensive thermal power plants.
- As dependency on such systems reduces, new challenges have emerged to ensure the security of the UK grid.
- Significant investment has been deployed into innovation activities and network reinforcement to support the UK's NetZero transition.
- Fractal Flow is being developed to leverage these investments and innovations, particularly within the technical disciplines of Real-Time Data and Network Visibility, which are fundamental obstacles for achieving a dynamic and low carbon grid.
- At its core, Fractal Flow will be an analytics engine that leverages the intrinsic graphical representation of the grid through Graph Network theory.
- This will require the on-ramping of data sources, such as DNOs NMS and NGESO Market Platforms to provide a holistic view of system behaviour, within operational timeframes.
- Once Fractal Flow is in place it will create a unique data platform that can provide insight into volume services at GSP and provide increased visibility of network behaviour to inform operational decision making.
- Due to the complexity and scale of these challenges, Fractal Flow will include machine learning-based forecasts and analytics that provide the information needed to make optimal network control decisions.
- Regen's paper (May 2024) highlights the projected capacity limitations of distribution networks; successful development and deployment of Fractal Flow would provide better visibility of local networks to facilitate increased utilisation of network capacity.
- The Regan paper also notes the advantages of digitising the connection process, which aligns well with the broader objectives of Fractal Flow.

Discovery Phase Work Package Plan

In alignment with the SIF development process, Fractal Flow has been separated in the following Work Packages:

WP1: Feasibility Assessment	• Requirements Capture • Feasibility Study
WP2: Cost Benefit Analysis	• Evaluate the benefits provided by Fractal Flow • Assess the cost of delivering Fractal Flow
WP3: Technology Roadmap	• GAP Analysis • Technology Roadmap

Discovery Phase Work Package Plan

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WP1: Feasibility Assessment

- Requirements Capture
- Feasibility Study

WP2: Cost Benefit Analysis

WP3: Technology Roadmap

WP1 - Feasibility Assessment

Objectives:

1. A capture of the problem definition that Fractal Flow is solving, an outline of the use cases and requirements identified from workshops and discussion with NPg and NGESO.
    - Note the requirements capture slides are an update on the draft deliverable.

2. A feasibility study outlining:
    - The enabling technologies from the requirements capture.
    - Technical, commercial and regulator enablers and barriers.
    - Data integration tools and initial development.
    - Data analytics and machine learning use cases, along with data requirements.
    - An initial system architecture.

Problem Definition

The drive to Net Zero by 2050 [1] means having more DERs connected to the network, particularly at the distribution-level. This challenges the traditional operating principles of the grid where energy flowed from generators at a transmission level to consumers at a distribution level. ESO and DNOs need to know the direction of net power flows across the GSP to accurately parameterise supporting stability services and identify service conflicts that may impact system security for customers and industry.

The projected uptake in DERs, active networks, and virtual power plants will only exacerbate the issues of characterising power flow and service availability across the network. This characterisation challenge arises from a lack of sub-network visibility, metering data resolution below the primary substation level, and network data sharing. ESO needs to have visibility of what assets are available, where they can be utilised and when they can be reliably deployed at any point in time, including any sudden or planned constraints at the distribution level.

DNOs need to centralise their data to help gain greater visibility and understanding of how DERs behave on their network and the associated changes in local demand. The increase in network visibility will help inform future investment decisions and be an enabler for the transition to a DSO.

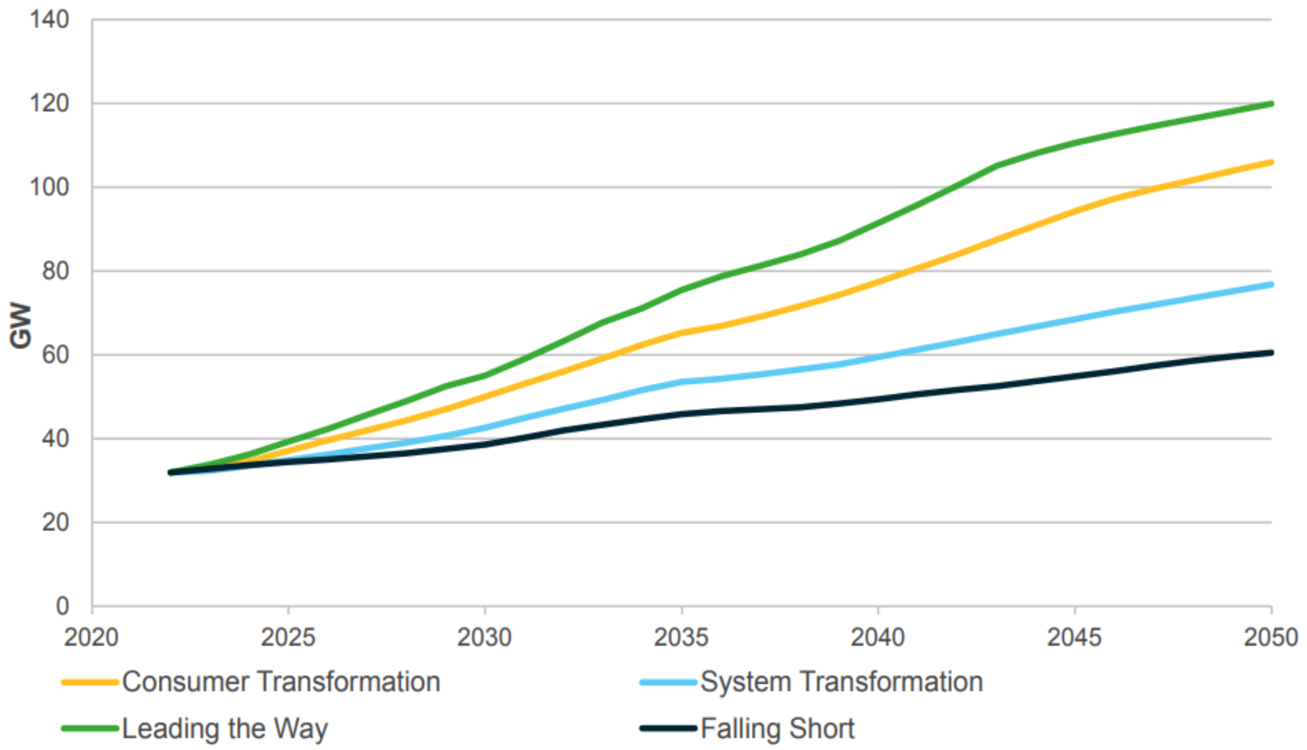
Data and communication infrastructure is not centrally accessible across network operators and is typically siloed based on legacy ownership and security reasons. ESO and DNOs need a shared data platform, with appropriate permissions, and tailored analytic capabilities to address these challenges and provide insights into the optimal control of DERs.

[1] Department for Energy Security and Net Zero and Department for Business Energy & Industrial Strategy, 2021, 'Net Zero Strategy: Build Back Greener', www.gov.uk/government/publications/net-zero-strategy

Future Energy Scenarios (FES)

FES estimates that at a minimum distributed generation doubles by 2050 (Falling Short) and could even increase four-fold (Leading the Way) which will continue to exacerbate the current operational challenges associated with DERs.

Figure ES.22: Distribution connection generation



Improved planning and operational visibility for NPg through Fractal Flow's analysis engine would help consider different operational scenarios for an increasingly interconnected network.

[1] NGESO, 2023, 'Future Energy Scenarios', https://www.nationalgrideso.com/document/283101/download, pg. 142

Fractal Flow – High-level Drivers

Fractal Flow is driven by two high-level aims:

Network Visibility and **Real-Time Control Decisions with DERs.**

1. Network Visibility

Pains	Wants
• Information about the network is siloed and difficult to access due to historic security and transparency issues. • At lower network layers, metering data is less integrated or does not provide enough information to extract supply and demand behaviour. • NGESO and DNOs don't have visibility of each other's network beyond a forecasted snapshot. • Power demand profiles change dynamically (with measurements stored half-hourly).	• NPg want to enhance internal capabilities to provide visibility of supply and demand throughout their network. • NPg want to utilise existing asset and power flow information to aid future investment decisions. • NGESO want to know Power Take-off Demand and Volume Services at GSP. • NGESO want increased resolution of Power Take-off Demand and Volume Services to provide confidence in procured services.

Fractal Flow – High-level Drivers

Fractal Flow is driven by two high-level aims:

Network Visibility and **Real-Time Control Decisions with DERs.**

2. Real-Time Control Decisions with DERs

Pains	Wants
• Difficult to make optimal real-time control decisions when demand and service availability data is not visible to NGESO/DNO teams at required time resolution. • Without visibility of the current state of the network it is difficult to know where constraints may impact the availability of services. • Operational Technology (OT) data is siloed (teams/companies/systems) making it difficult to gather the information needed. • Most data exchanges are manual and not suitable for real-time control with DERs (i.e., on a 30mins basis). • Balancing Units may be aggregated across parts of the network that aren't visible to NGESO/DNO teams making it difficult to forecast supply and demand.	• The ability to see real-time demand and availability of services data at select locations on the grid. • A centralised platform for viewing these datasets. • Asset and power flow data to be combined with market information to understand how customers may choose to operate. • To be able to forecast demand and service availability in 1hr/6hr/24hr forecasting windows to optimally prepare the network for flexibility services. • The ability to access data directly or through faster, secure, and well-established communication channels.

Stakeholder Drivers

NGESO

"I need resolution at the GSP-level of demand and service availability as it evolves in real-time, with an analytics engine that can forecast this information into the future, so that I can reliably instruct services in a timely manner given dynamic changes to the grid."

DNO/DSOs

"I need visibility of demand and service availability across the network so that I can better optimise the utilisation of the network and gain advantages from using local resources to overcome distribution (and transmission) constraints."

Connection-level customer

"I want insight into how I can optimally connect to the distribution-level and perform route finding analysis so that I can help to navigate constraint management."

Requirements Overview

The requirements capture is the result of discussion with NPg and ESO both at workshops and throughout the project.

In general, requirements can be categorised as ‘Must’, ‘Should’, or ‘Could’ which indicates the level of priority.

For Fractal Flow:

- ‘Must’ requirements are those that contribute to aiding the real-time control of DERs and the associated required visibility of assets at a distribution level.
- Any requirements and use cases identified during discussion which do not contribute to this focus area have been categorised as ‘Should’ or ‘Could’, e.g. new connection planning.

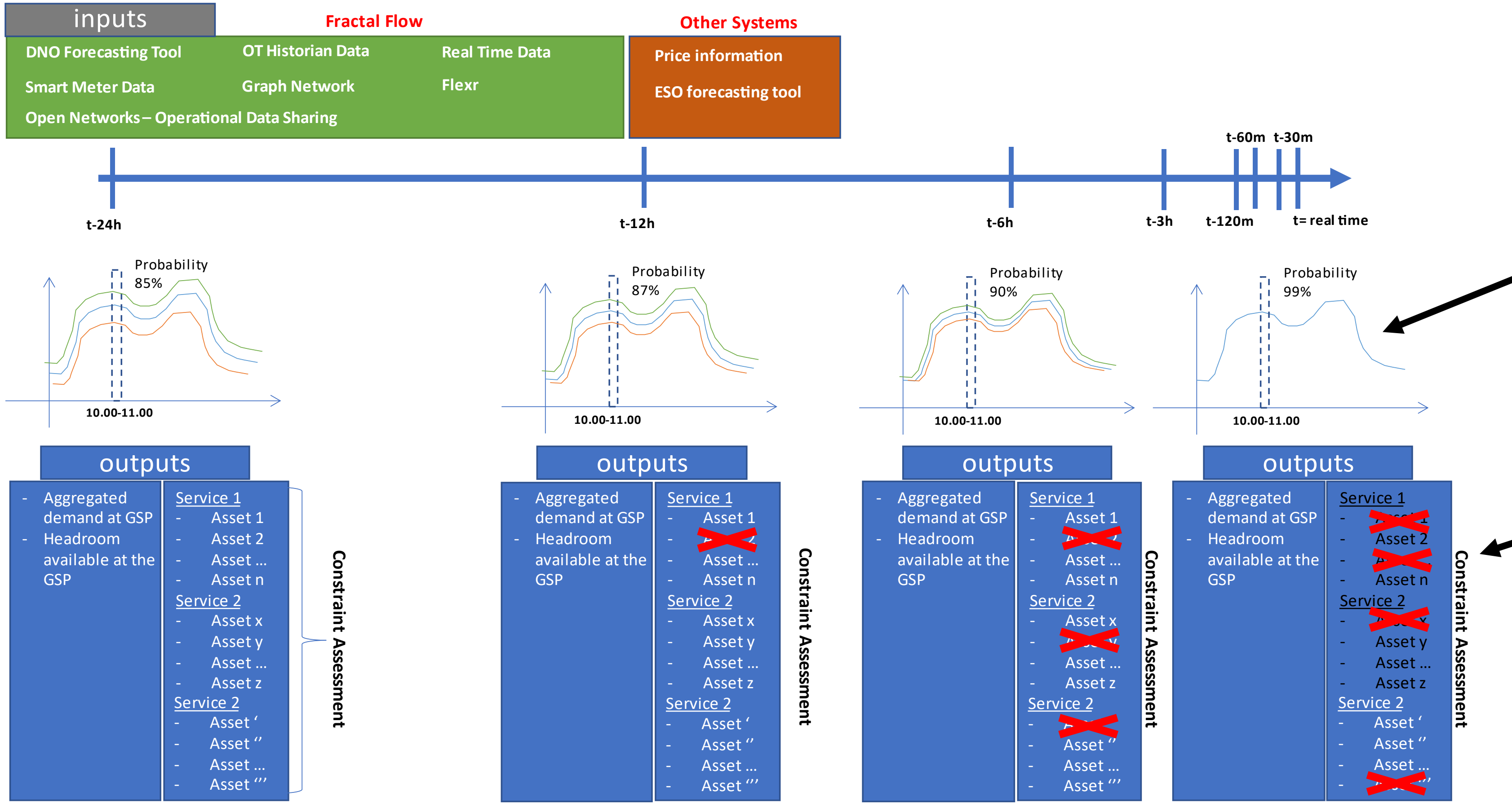
The following slides outline the methodology used to define the requirements and associated use cases and user stories. *Note these are high-level requirements and not software requirements*.

For each use case, some indicative visualisations have been provided to demonstrate a high-level visualisation of how Fractal Flow may meet these requirements. *Note these are not prototypes or wireframes of the user interface (UI).*

Note: ‘Real-time’ performance requirements must be defined in later stages of the project. Current understanding indicates that ‘Real-time’ may be less than 30 minutes.

Fractal Flow - Scope Overview

This slide captures the operational scope of Fractal Flow. The scope includes a range of inputs (below in green) that will be used to reduce the uncertainty in forecasts of demand and service availability, integrating these with other systems (below in orange). As predictions approach real-time the confidence in the forecasts will increase. The tool therefore needs to capture constraint evolution to ensure it accurately identifies available services.

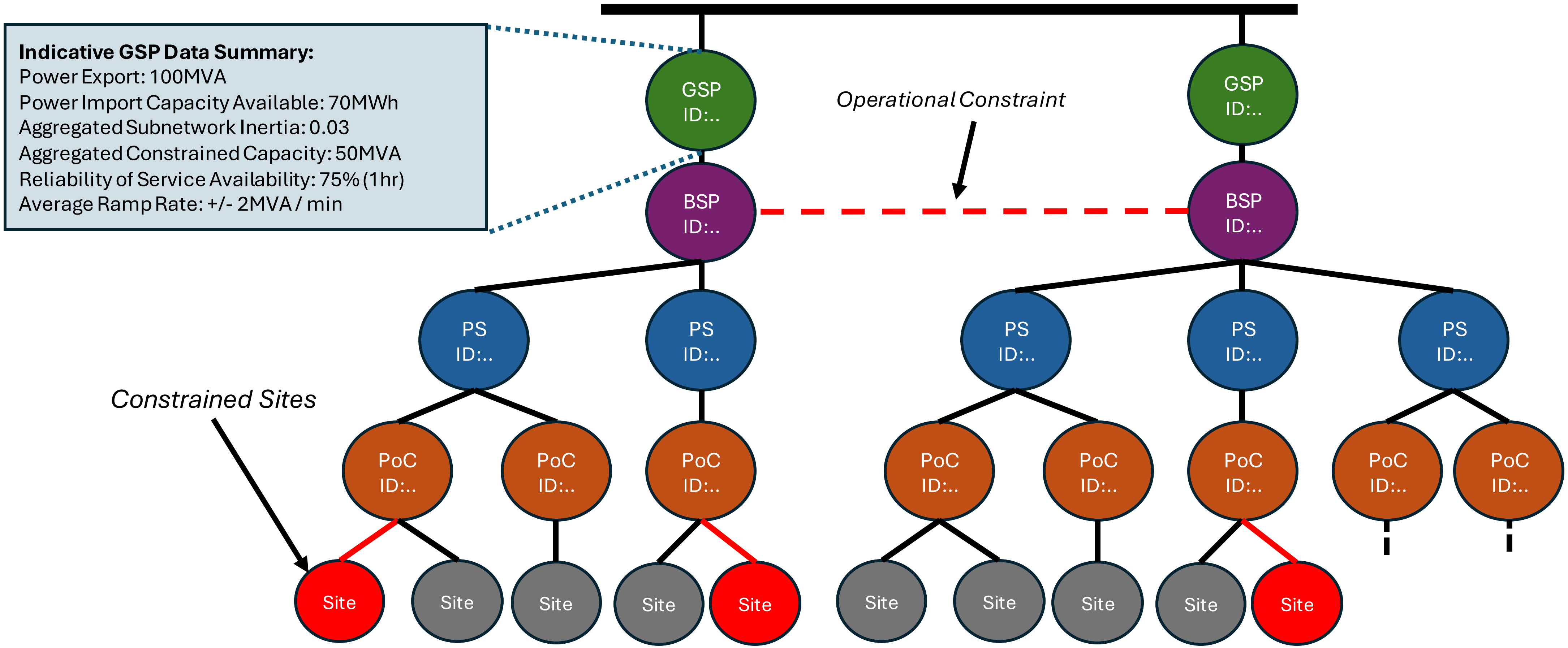


Increased network visibility and service availability will facilitate more accurate procurement of services.

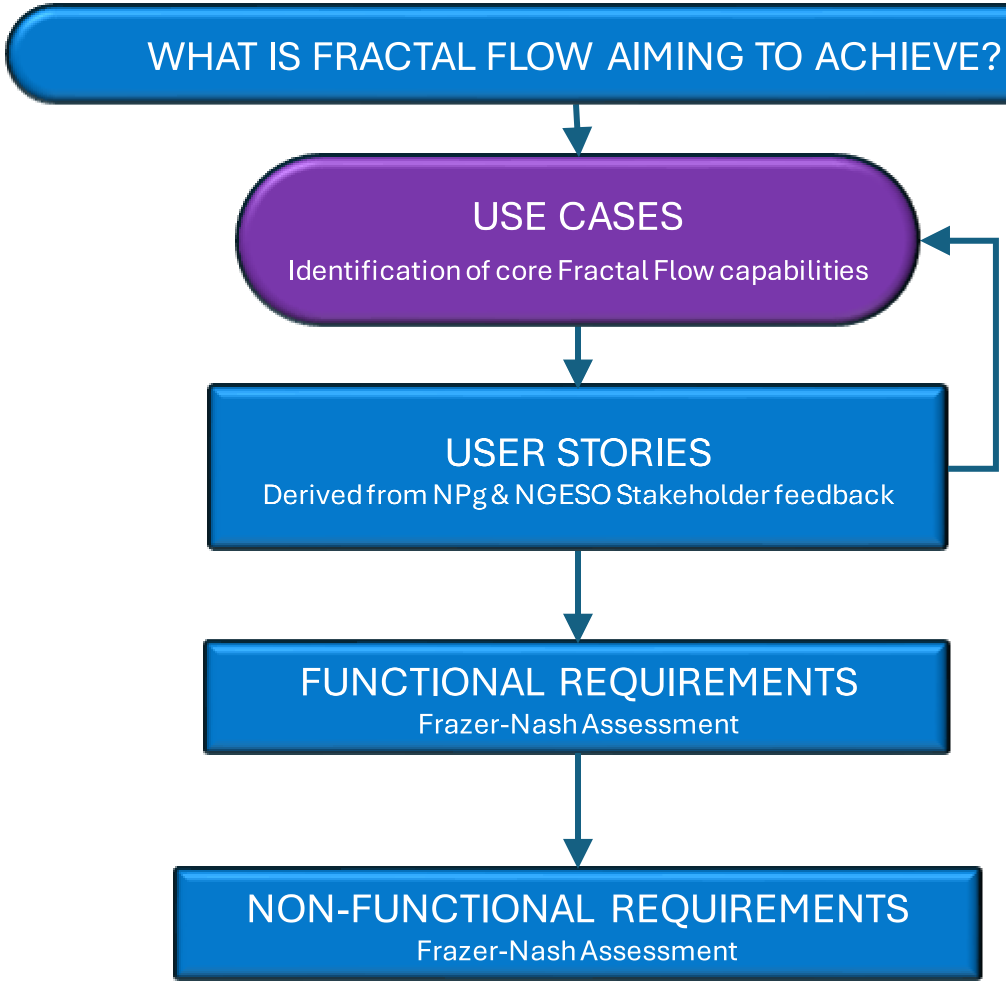
As system forecast windows approach deployment, Fractal Flow will capture an accurate ‘real-time’ view of service availability below the GSP.

Fractal Flow - Scope Overview

For DNO system users, Fractal Flow will provide an intuitive and dynamic view of available capacity, local generator and ANM statuses and provide analytic capabilities to identify operational impact for taking parts of the network offline.



Use Case and User Requirement Workflow



This figure illustrates the process that was used to capture and refine the Use Cases and User Stories.

This is a top-down approach often utilised for software development projects. It allows User Requirements to be captured by assessing their interaction with the system.

This approach was also complimented by a traditional systems approach to review Functionality and gain a deeper understanding of core Non-Functional Requirements

(e.g. The Performance Requirements of 'Real-Time Data').

Example Use Case Workflow

USER STORIES

[20] - As a DNO member, I want to be able to interrogate assets at each level of the network (GSP, BSP, primary, etc.), so that I can identify asset characteristics and view real-time and historic power flow data.

FUNCTIONAL REQUIREMENTS

1. Access real-time network data
2. Access historic network data
3. Analyse all network data

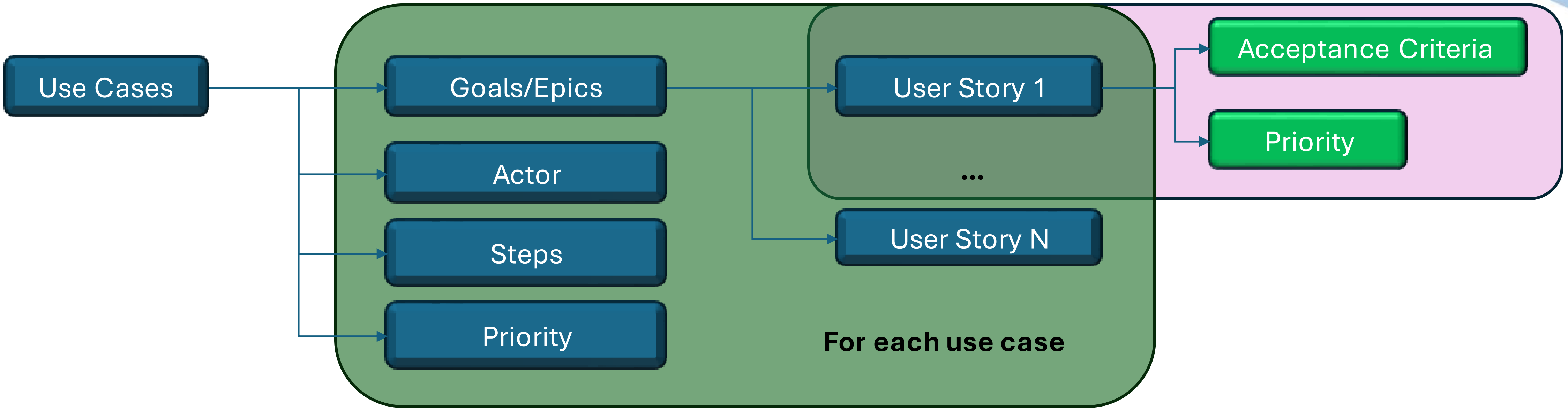
NON-FUNCTIONAL REQUIREMENTS

1. Stakeholder access to Fractal Flow
2. OT Historian Mirror Data Available

ACCEPTANCE CRITERIA

1. Effective real-time queries available at all network layers
2. Effective historic queries available at all network layers

Use Case & User Requirement Workflow

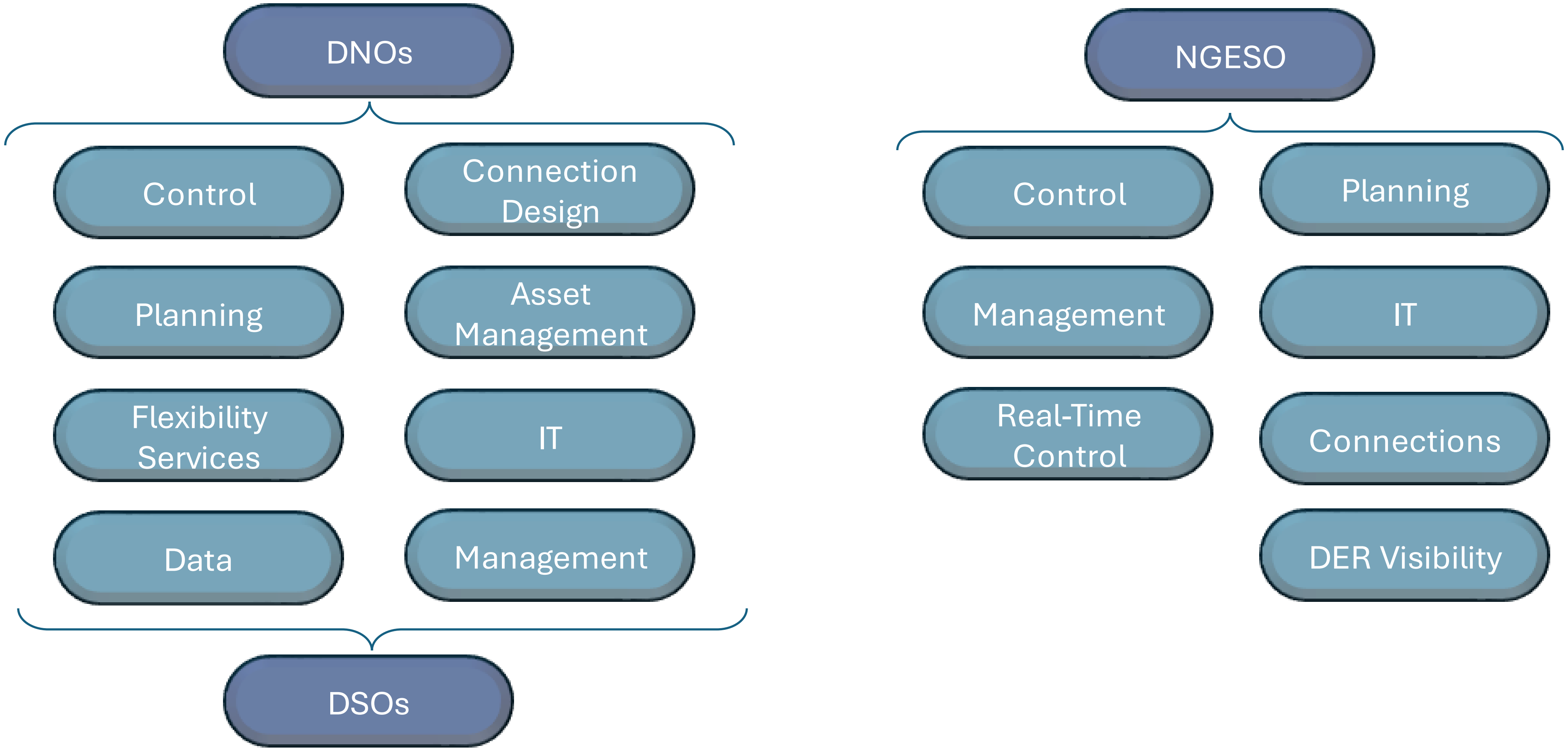


This process captures the core use cases and associated user stories to derive the necessary functionality of Fractal Flow from a Stakeholder/User perspective

Priority will be defined as: MUST | SHOULD | COULD
This document focuses primarily on MUST, with a capture of high-level SHOULD and COULD requirements.

User Groups

This slide provides an overview of the Stakeholder Groups within DNOs and NGESO that may interact with Fractal Flow once fully developed.



DNO User Definitions

User	Description
DNO Control Room Operator	A DNO member working in the control room
DNO Connection Planner	A DNO member working in connection planning
DNO Member	A member of a DNO is anyone working for that DNO
DNO Data Team	A member of a DNO data team
DNO Flexibility Services	A DNO member co-ordinating Flexibility Services
DNO Smart Grid Team	A DNO member working on Smart Grid applications
DNO Asset Management	A DNO member working on Asset Management
DNO Connection Designer	A DNO member working on Connections and Design
DNO System Planner	A DNO member working on Long term Network Planning
DNO IT	A DNO member working on Internet Technology
DNO Management	A DNO member working in the management team

NGESO User Definitions

User	Description
NGESO Connections / Planning	An NGESO member working in connections / planning team
NGESO Member	A member of NGESO is anyone working for the NGESO
NGESO Real-Time Operator	A member of the NGESO Real-Time Operations Team
NGESO ENCC Member	An NGESO member working in the Electricity National Control Centre
NGESO IT	An NGESO member working in Internet Technology
NGESO DER Visibility	An NGESO member working in DER Visibility
NGESO Management	An NGESO member working in the management team
NGESO Strategy	An NGESO member working in Strategy Team
Energy Insights and Market	An NGESO member working in Energy Insights and Market Team

DNO Use Case 1: Network Visibility – MUST (1)

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EPIC: As a DNO Member, I want to be able to view the assets and connections on my network from the GSP-level down, so that I have a better understanding of supply and demand as well as constraints on my network.

ID	User Story	Acceptance Criteria	Priority
4	As a DNO Member, I want legacy assets to be included in Fractal Flow, so that I have a complete view of my network.	1. A graph network that includes legacy assets as nodes and edges.	MUST
5	As a DNO Member, I want visibility of the assets and power flow data across the network, so that I can assess supply and demand across the network and identify constraints.	1. Full network visibility OT data available within operation timescales.	MUST
13	As a DNO Member, I want Fractal Flow to be integrated into the current systems and processes that I use for effective BaU, so that it aligns with existing initiatives.	1. The Fractal Flow tool is deployed and integrated into DNO's existing system and environment for the required users. 2. Fractal Flow can be used by the required users for BaU tasks.	MUST
14	As a DNO Member, I want to identify and fill gaps in the datasets, so that I can identify and resolve missing information and conflicts in the data.	1. A tool that visualises all network data.	MUST
16	As a DNO Member, I want to know the power flow direction below the 'primary' level, so that I can improve network understanding, utilisation, and planning.	1. Power flow direction is visualised in the graph.	MUST
20	As a DNO Member, I want to be able to interrogate assets at each level of the network (GSP, BSP, primary, etc.), so that I can identify asset characteristics and view real-time and historic power flow data.	1. Effective real-time queries available at all network layers. 2. Effective historic queries available at all network layers.	MUST

DNO Use Case 1: Network Visibility – MUST (2)

EPIC: As a DNO Member, I want to be able to view the assets and connections on my network from the GSP-level down, so that I have a better understanding of supply and demand as well as constraints on my network.

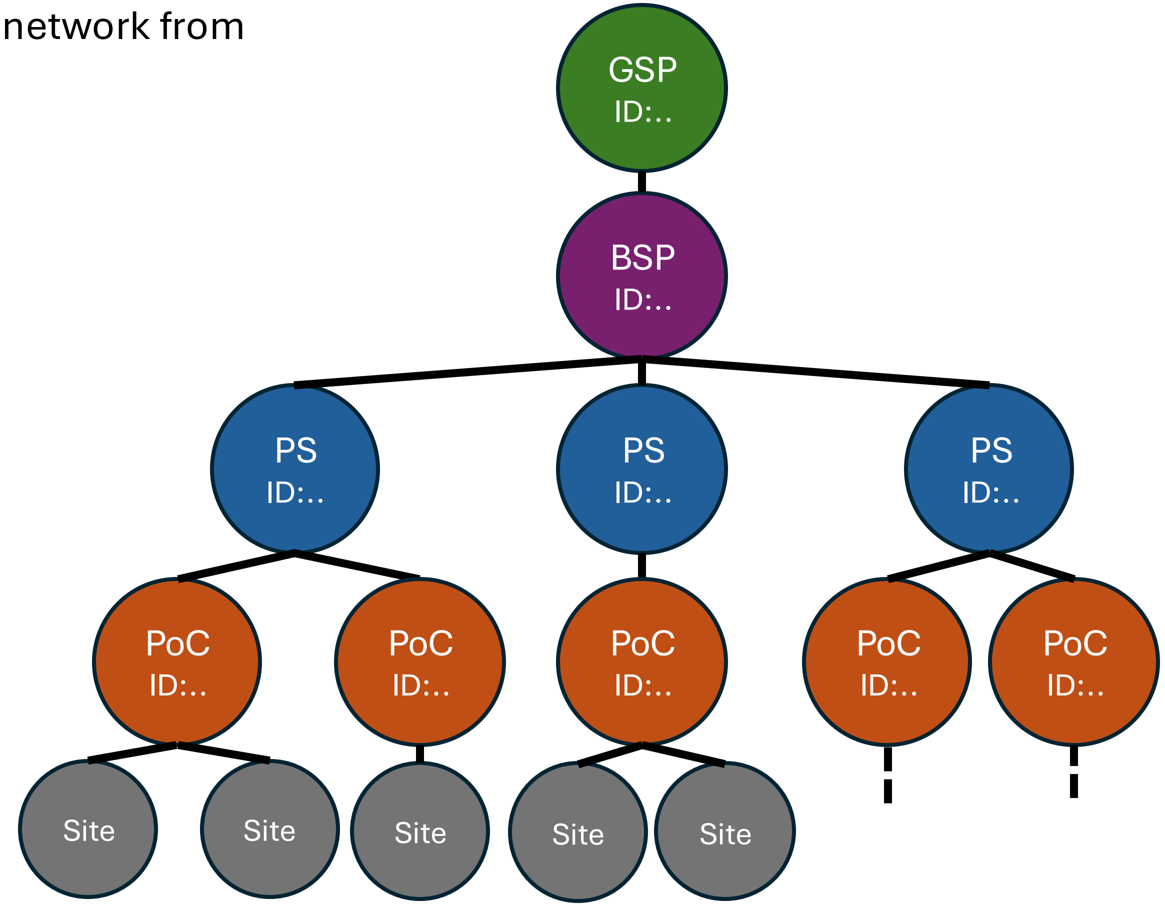
ID	User Story	Acceptance Criteria	Priority
30	As a DNO Member I want a tool that is jointly owned and maintained with DNOs so that I can build trust in the tool and use it effectively.	1. Joint ownership defined and agreed between NGESO and DNOs. 2. Maintained jointly.	MUST
31	As a DNO Member I want a tool that is jointly accessible with DNOs so that it can be used effectively to support BaU decision making.	1. Accessible by NGESO and DNO users.	MUST
32	As a DNO Member I want a tool that is secure to protect my data and wider IT/OT infrastructure.	1. Secured to hold UK Protect Data. 2. Securely accessible by NGESO and DNO users.	MUST
33	As a DNO Member I want a tool that can recieves data from multiple sources and data owners so that it can be used effectively to support BaU decision making.	1. Intakes data from NGESO, DNOs, and third parties.	MUST
34	As a DNO Member I want a tool that is scalable so that it is capable of meeting future data requirements as the volume, resolution, and timescales change.	1. Designed in a way that facilitates future scalability. 2. Deployed on a system, platform, and environment that facilitates future scalability.	MUST

DNO Use Case 1: Network Visibility – MUST (3)

The visualisations are indicative of how Fractal Flow may meet these requirements.

EPIC: As a DNO Member, I want to be able to view the assets and connections on my network from the GSP-level down, so that I have a better understanding of supply and demand as well as constraints on my network.

Fractal Flow presents a graphical view of the network from the GSP-level down.

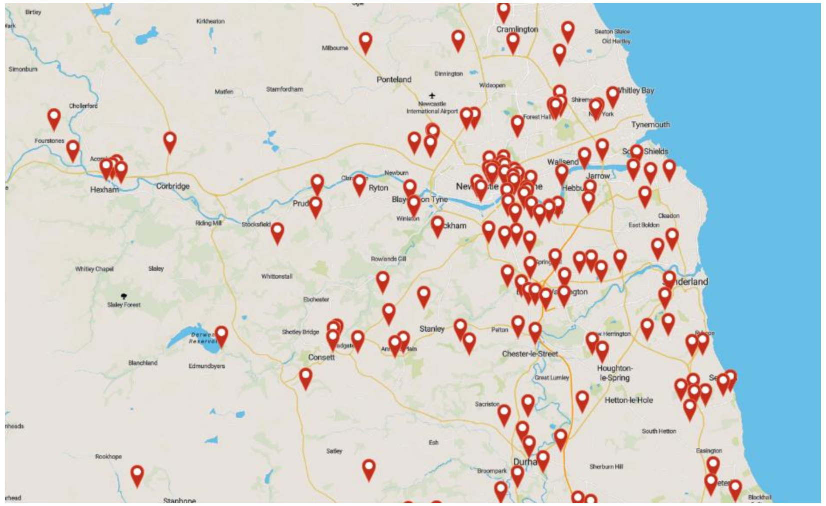


DNO Use Case 1: Network Visibility – MUST (4)

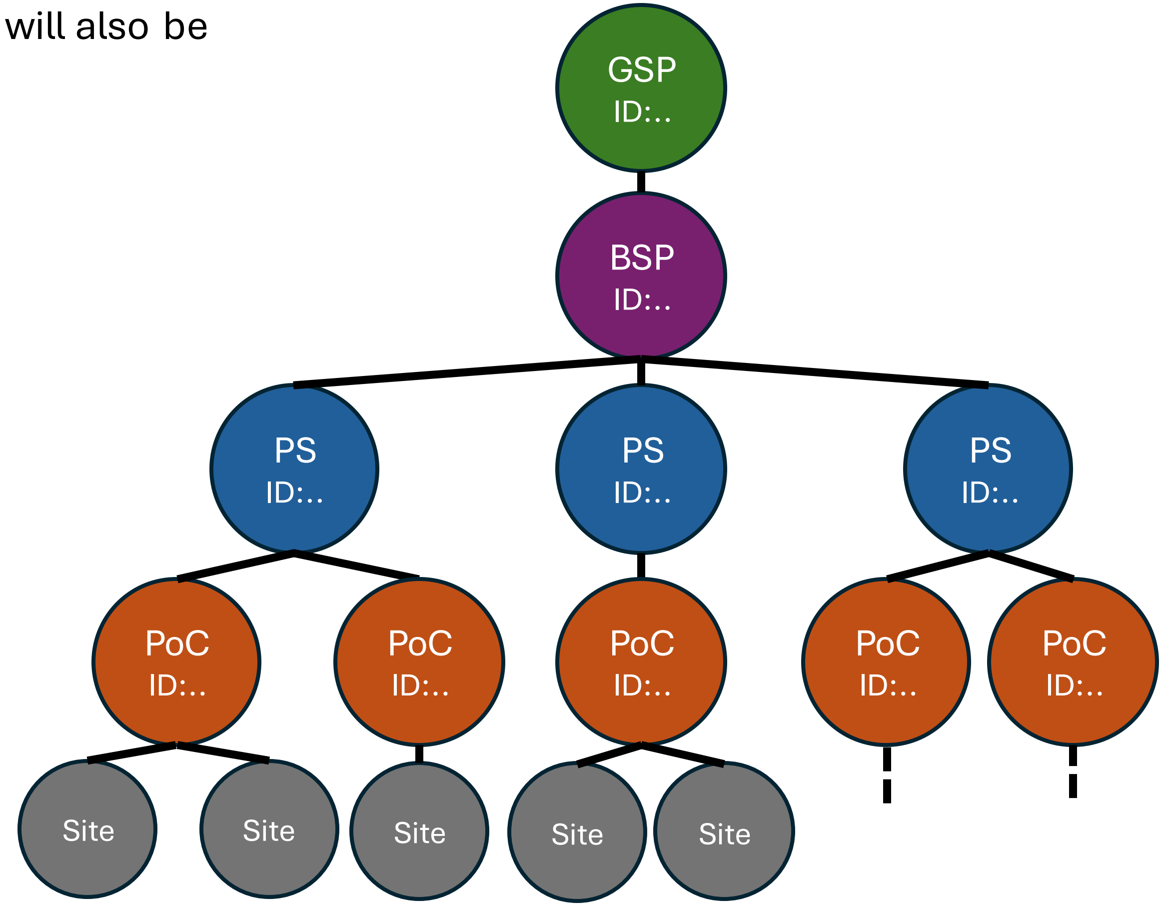
The visualisations are indicative of how Fractal Flow may meet these requirements.

EPIC: As a DNO Member, I want to be able to view the assets and connections on my network from the GSP-level down, so that I have a better understanding of supply and demand as well as constraints on my network.

By linking GIS data, the nodes in the network will also be viewable on a map.



Northern Powergrid Open Data Portal



DNO Use Case 1: Network Visibility – MUST (5)

The visualisations are indicative of how Fractal Flow may meet these requirements.

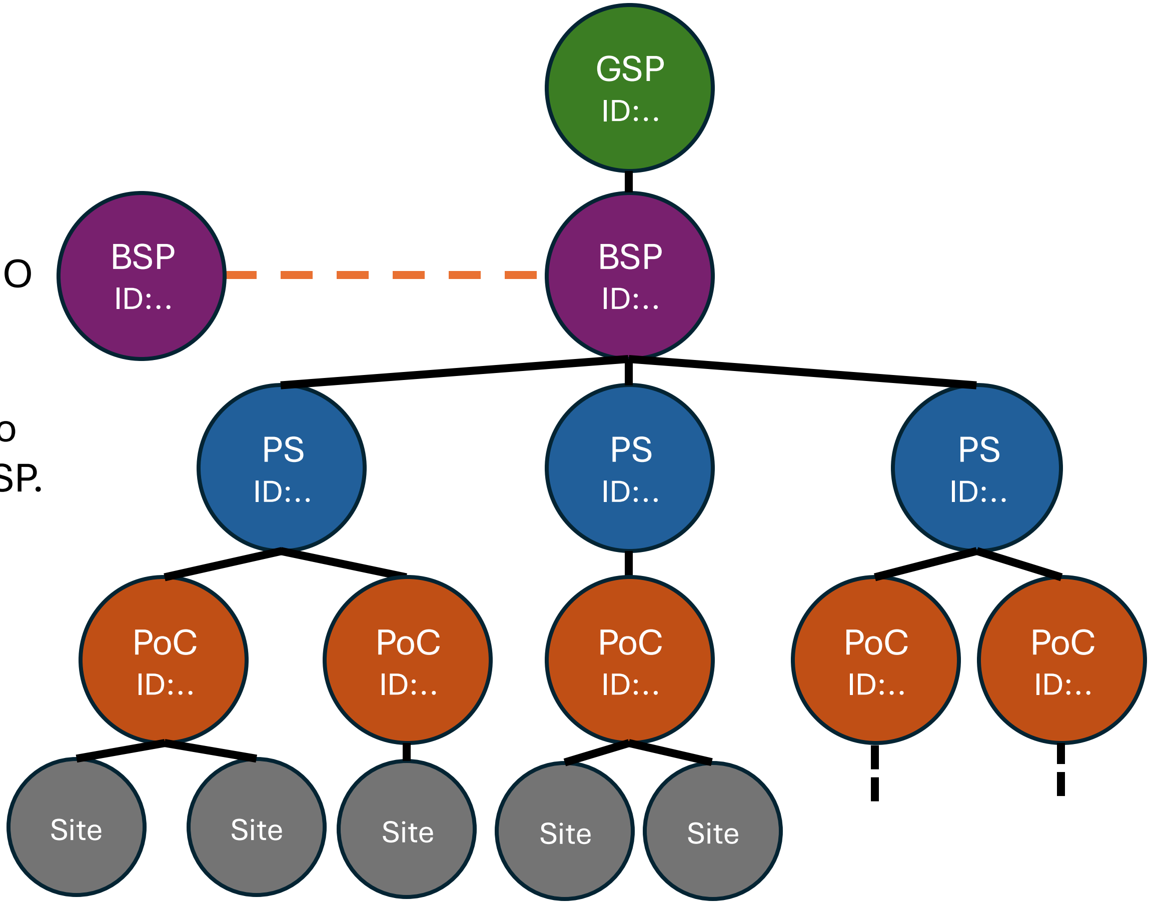
EPIC: As a DNO Member, I want to be able to view the assets and connections on my network from the GSP-level down, so that I have a better understanding of supply and demand as well as constraints on my network.

Interconnections between DNOs could represent a data boundary (see dashed orange line).

This can be managed via inference analysis, as the net power flow can still be determined from the available DNO data, i.e. Net power flow at a node = 0.

The ontology of the system will be defined during Alpha to address topics such as multiple data sources within a GSP. The granularity of the ontology will be determined by the asset data from DNOs.

Switching configurations will be captured across the network to identify operational systems (e.g. ANM schemes).



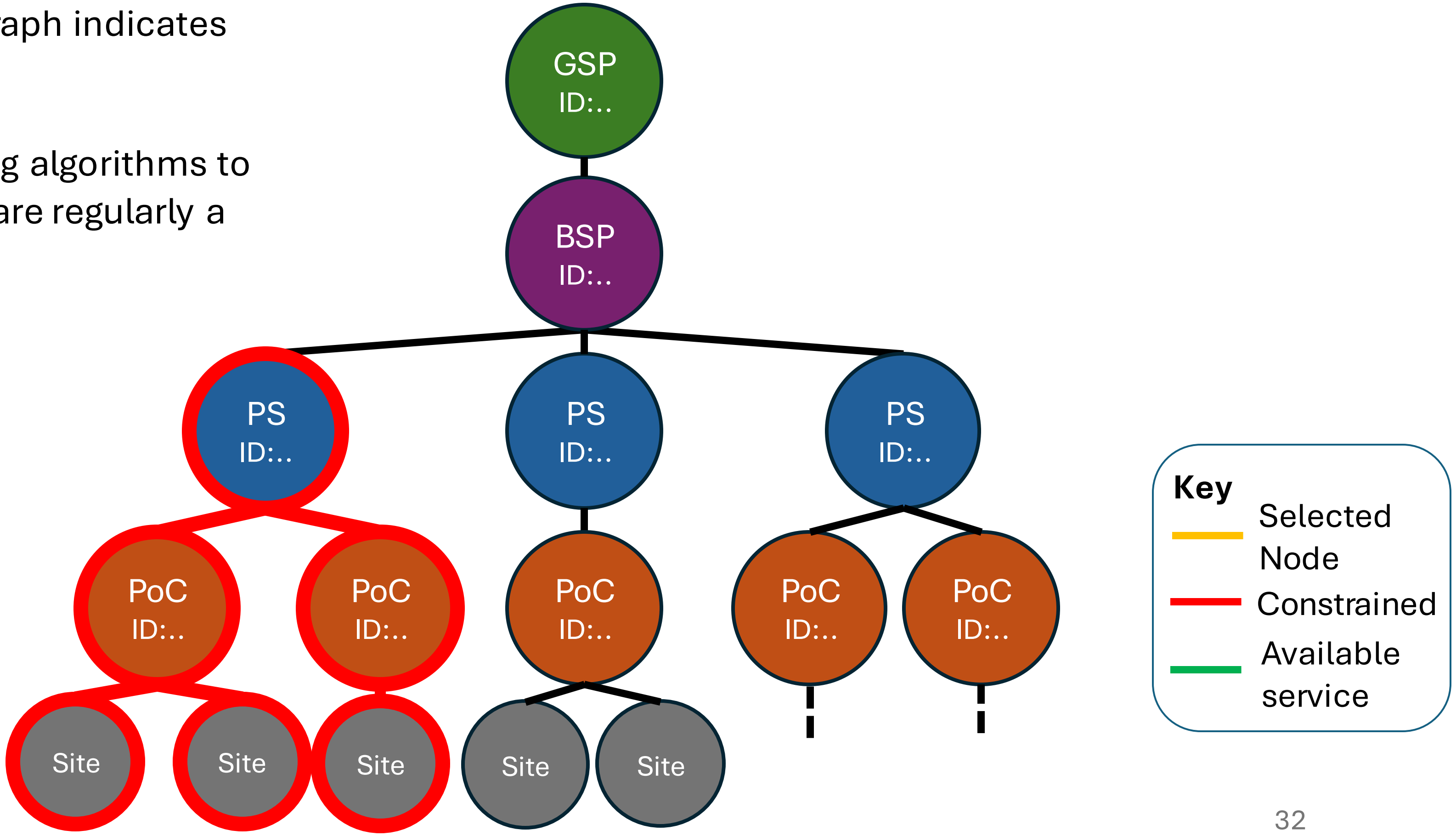
DNO Use Case 1: Network Visibility – MUST (6)

The visualisations are indicative of how Fractal Flow may meet these requirements.

EPIC: As a DNO Member, I want to be able to view the assets and connections on my network from the GSP-level down, so that I have a better understanding of supply and demand as well as constraints on my network.

By querying constraints below the GSP, the graph indicates constrained parts of the network.

The graphical representation allows clustering algorithms to show groupings of assets where constraints are regularly a problem, providing additional insights.

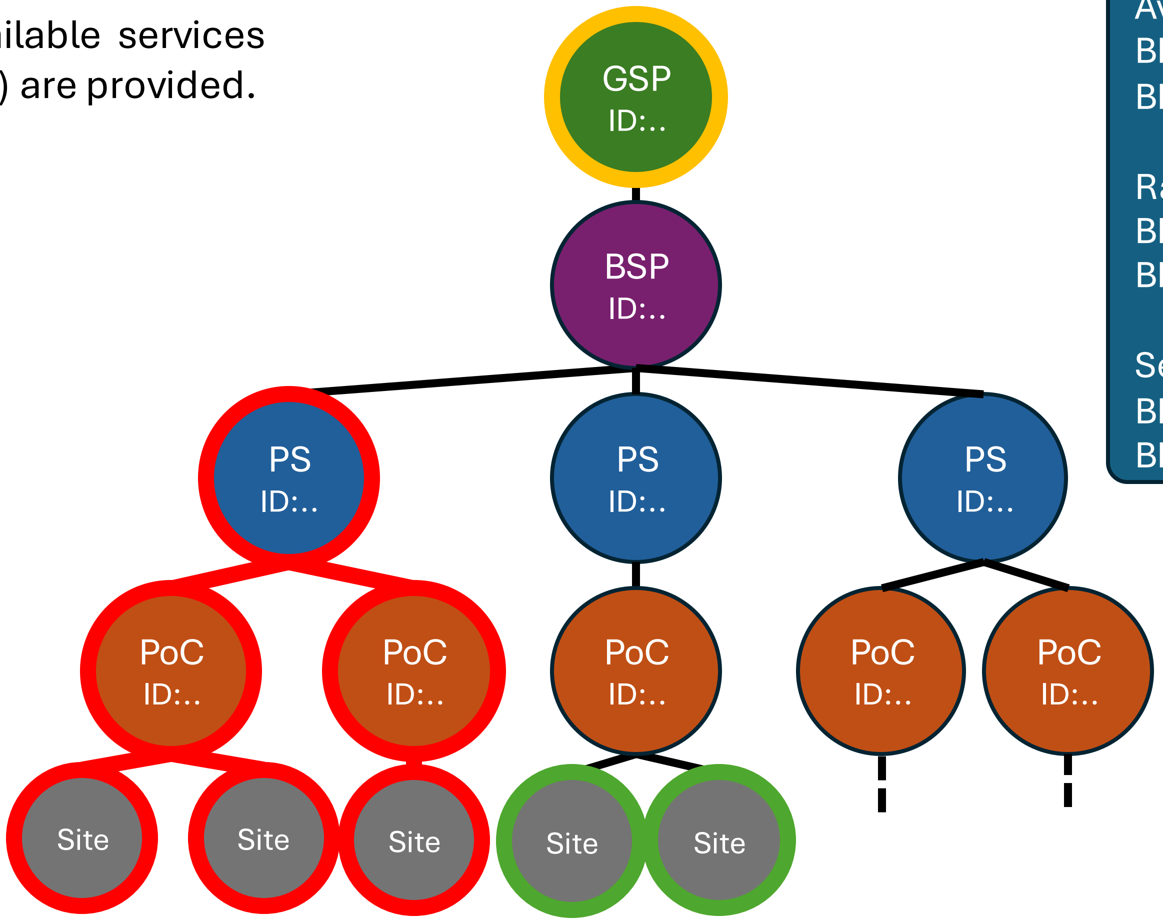


DNO Use Case 1: Network Visibility – MUST (7)

The visualisations are indicative of how Fractal Flow may meet these requirements.

EPIC: As a DNO Member, I want to be able to view the assets and connections on my network from the GSP-level down, so that I have a better understanding of supply and demand as well as constraints on my network.

By querying a GSP node, the demand and available services (given the current constraints on the network) are provided.



GSP ID:..

Demand:
XX MW

Available Services:
BMU X : 10MVA
BMU Y : 20MVA

Ramp Rate:
BMU X: 1MVA/min
BMU Y: 5 MVA/min

Service Reliability:
BMU X: 100%
BMU Y: 80%

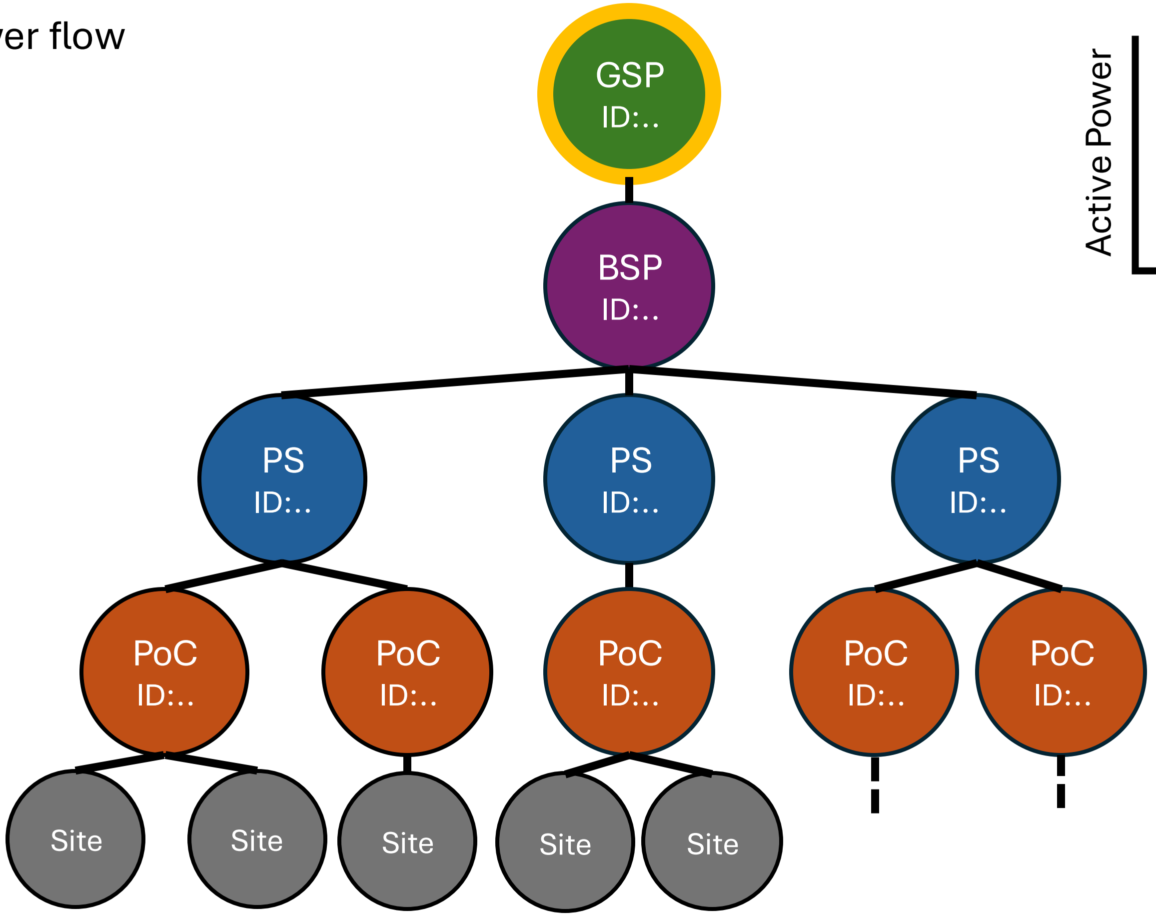
Key
- Selected Node
- Constrained
- Available service

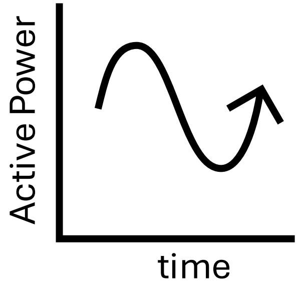
DNO Use Case 1: Network Visibility – MUST (8)

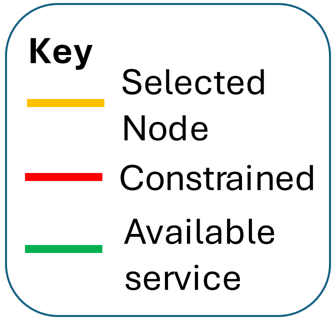
The visualisations are indicative of how Fractal Flow may meet these requirements.

EPIC: As a DNO Member, I want to be able to view the assets and connections on my network from the GSP-level down, so that I have a better understanding of supply and demand as well as constraints on my network.

By querying a GSP node, 30min averaged power flow information is available.





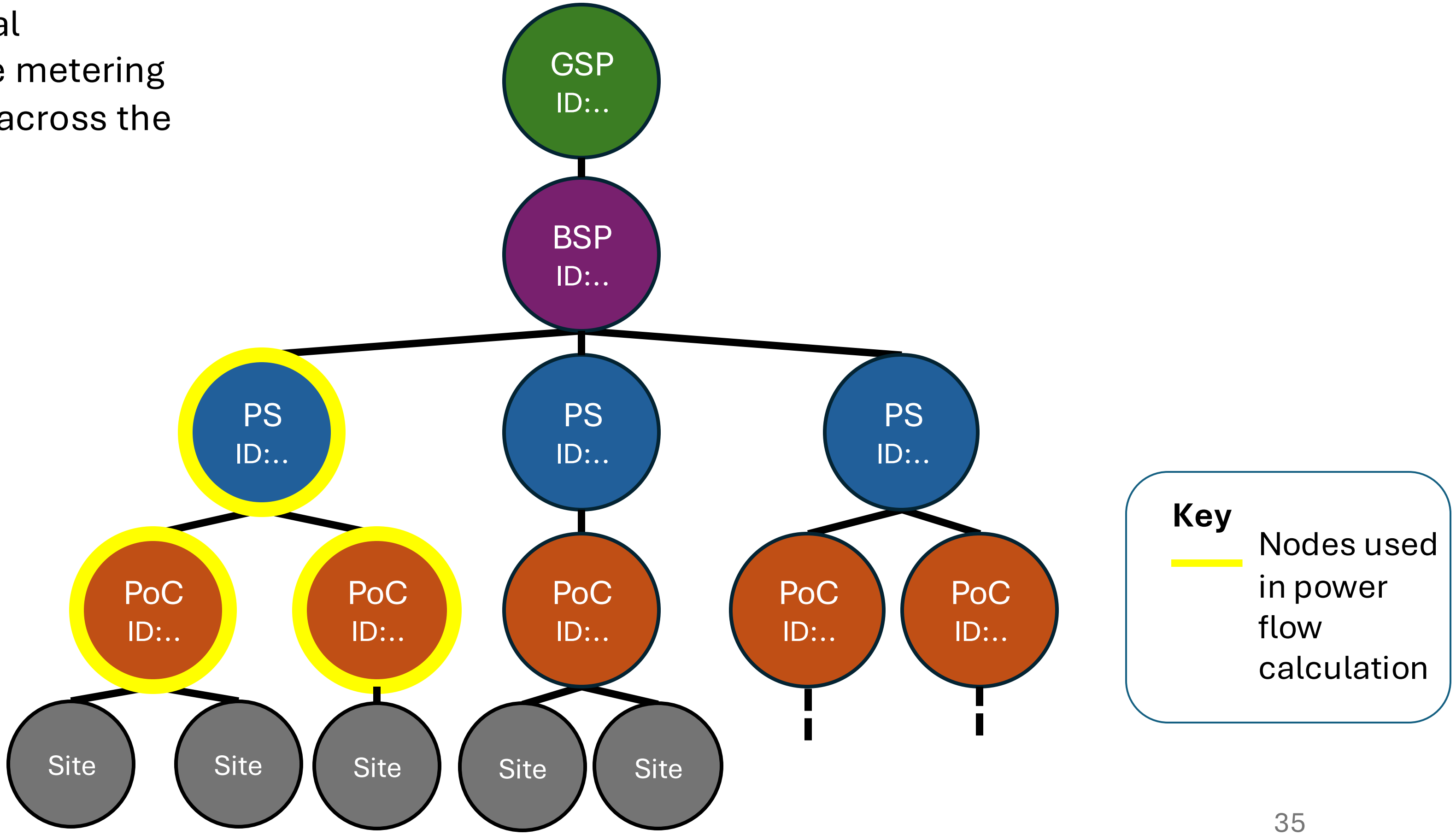


DNO Use Case 1: Network Visibility – MUST (9)

The visualisations are indicative of how Fractal Flow may meet these requirements.

EPIC: As a DNO Member, I want to be able to view the assets and connections on my network from the GSP-level down, so that I have a better understanding of supply and demand as well as constraints on my network.

Power flow calculations are performed in local neighbourhoods of the graph where complete metering dataset are unavailable to obtain power flow across the network.



DNO Use Case 1: Network Visibility – MUST (10)

The visualisations are indicative of how Fractal Flow may meet these requirements.

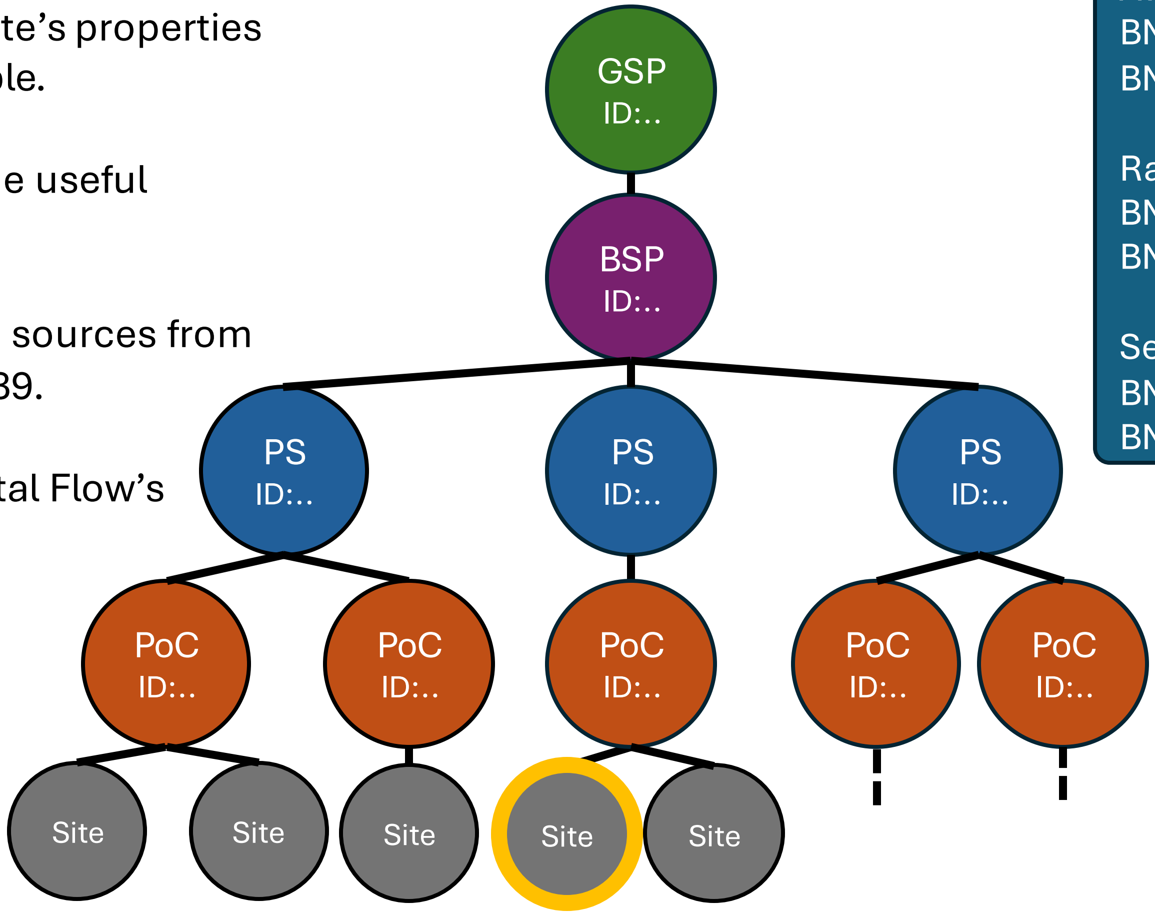
EPIC: As a DNO Member, I want to be able to view the assets and connections on my network from the GSP-level down, so that I have a better understanding of supply and demand as well as constraints on my network.

By querying a customer asset's site node, a site's properties and a forecast of service availability is available.

Existing G99 connected assets already provide useful metadata that can help characterise nodes.

Alpha will aim to explore additional metadata sources from such as CIM, Open Network Panel and GC0139.

Further information that would enhance Fractal Flow's metadata will also be investigated.



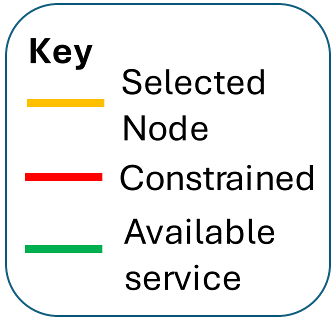
GSP ID:..

Demand:
XX MW

Available Services:
BMU X : 10MVA
BMU Y : 20MVA

Ramp Rate:
BMU X: 1MVA/min
BMU Y: 5 MVA/min

Service Reliability:
BMU X: 100%
BMU Y: 80%



DNO Use Case 2: Future Flexibility Services – MUST (1)

FRAZER-NASH CONSULTANCY — A KBR COMPANY

EPIC: As a DNO Member, I want to have the infrastructure in place to support a system operator model and provide NGESO with the information they need for real-time control, so that I can optimise operations on my network and meet future grid requirements.

ID	User Story	Acceptance Criteria	Priority
6	As a DNO Member, I want to monitor the network in real-time, so that I can understand changes to the network in real-time and inform NGESO.	1. Visualise the network in real-time.	MUST
13	As a DNO Member, I want Fractal Flow to be integrated into the current systems and processes that I use for effective BaU, so that it aligns with existing initiatives.	1. The Fractal Flow tool is deployed and integrated into DNO's existing and expected systems and environment for the required users. 2. Fractal Flow can be accessed by the required users.	MUST
23	As a DNO Control Room Operator, I want to improve communication with NGESO beyond 'slow time' emails and calls, so that I can enhance interoperability and respond faster to changes in supply and demand and any faults that may occur.	1. Fractal Flow data is provided to stakeholders within operational timescales.	MUST
24	As a DNO Member, I want the ability to integrate third party data from customers or other third parties, so that I can increase visibility on the network and more accurately capture power flow on the network.	1. Network data is on-ramped to the tool. 2. Visualise percentage utilisation.	MUST
27	As a DNO Control Room Operator, I want to coordinate BM between NGESO actions and ANMs on my network, so that BM are optimal and capture value within the network for customers where possible.	1. Real-time visibility of sub-network demand. 2. Real-time visibility of sub-network Volume Services.	MUST
28	As a DNO Control Room Operator, I want to query available services in Fractal Flow, so that I can optimise power dispatch requests from NGESO.	1. Fractal Flow can be accessed by the required users. 2. Performs optimisation sub-routines.	MUST

DNO Use Case 2: Future Flexibility Services – MUST (2)

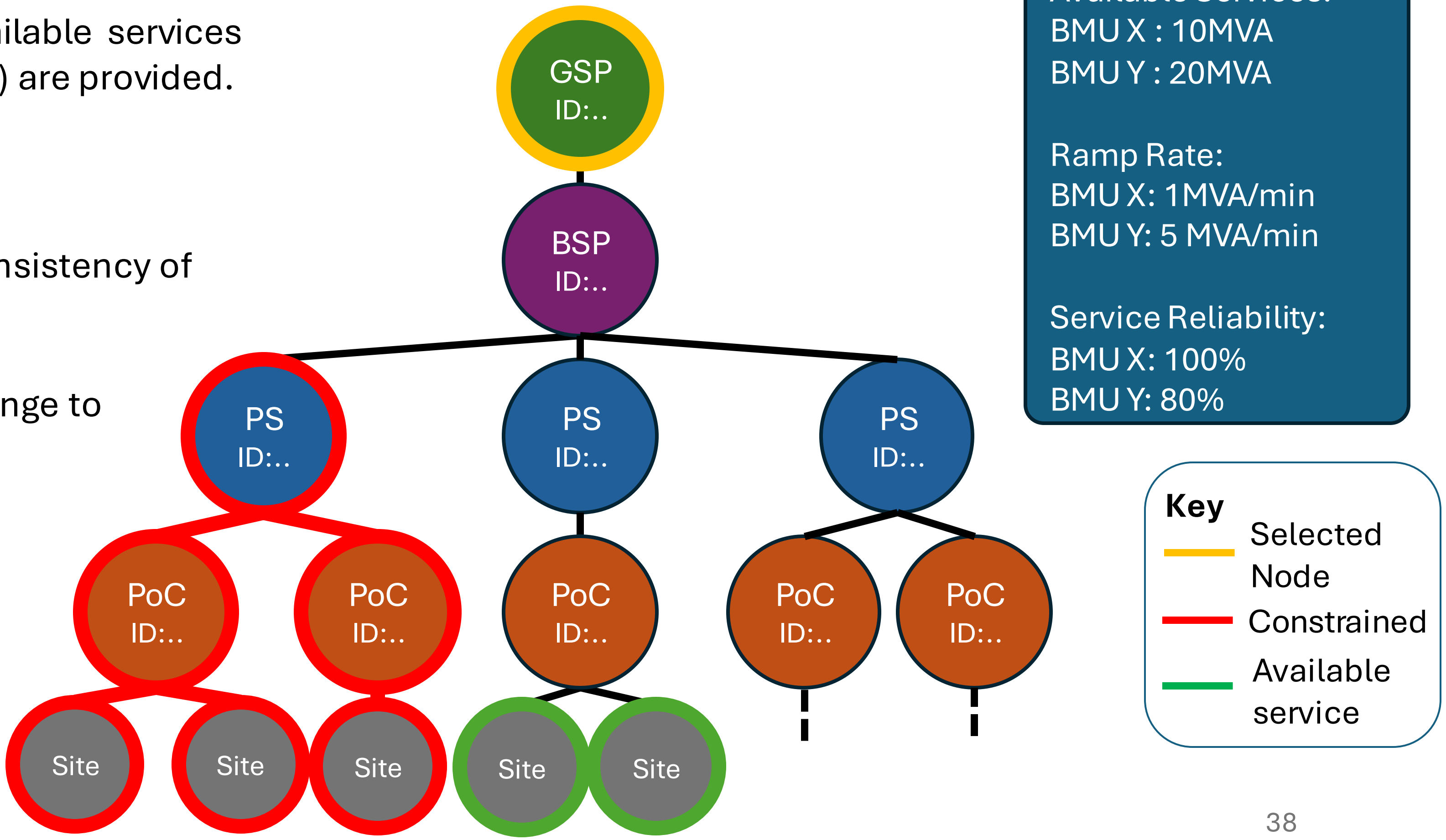
The visualisations are indicative of how Fractal Flow may meet these requirements.

EPIC: As a DNO Member, I want to have the infrastructure in place to support a system operator model and provide NGESO with the information they need for real-time control, so that I can optimise operations on my network and meet future grid requirements.

By querying a GSP node, the demand and available services (given the current constraints on the network) are provided.

This information will support grid codes, e.g.:

- GC0117 - Improving transparency and consistency of access arrangements
- GC0139 - Enhanced Planning-Data Exchange to Facilitate Whole System Planning



NGESO Use Case 1: Real-time Network Monitoring and Control – MUST (1)

EPIC: As an NGESO Member, I want to have access to demand and availability of services at the GSP-level, so that I can make real-time control decisions within a specific region of the network.

ID	User Story	Acceptance Criteria	Priority
1	As an NGESO Real-Time Operator, I want a view of the sudden potential MW volume increase when constraints blocking flexible generators are no longer active, so that I can accurately control the frequency/balancing of the system.	1. Displays real-time visibility of MW volume increase. 2. Displays blocked flexible generators that are constrained.	MUST
2	As an NGESO Real-Time Operator, I want to identify and resolve any critical conflicts in operation between ESO and DNO, so that any consequential conflicts arising between ESO and DSO requirements can be mitigated.	1. Identifies critical conflicts between ESO and DNO operations. 2. Displays the identified conflicts.	MUST
3	As an NGESO ENCC Member, I want visibility of DER behaviour so that during instances of asking DER to cease active power, I can see the effects of it in terms of managing congestion.	1. Displays the DER network and information about its behaviour. 2. Displays the active power consumption in AC circuits.	MUST
4	As an NGESO ENCC Member, I want visibility of post-curtailment DER output so that I can account for any potential sudden MW volume increase seen on the network.	1. Displays the DER network output post-curtailment. 2. Detects and displays MW volume increases. 3. Calculates the potential power available based on generator data. 4. Displays the potential output of curtailed sites post-constraint.	MUST

NGESO Use Case 1: Real-time Network Monitoring and Control – MUST (2)

EPIC: As an NGESO Member, I want to have access to demand and availability of services at the GSP-level, so that I can make real-time control decisions within a specific region of the network.

ID	User Story	Acceptance Criteria	Priority
5	As an NGESO ENCC Member, I want to understand the nature of the DER asset, how it will behave, and any DNO dispatch instructions sent to the specific asset(s), when returning a section of network from outage so that I can safely restore power to customers without causing any further damage to the network or the DER asset.	1. Displays information about DER assets. 2. Displays information about DNO dispatch instructions to DER assets. 3. Displays Flexr data. 4. Displays true demand profiles and assets, including wind variability. 5. Displays fault level information for network sections that are returning from outage.	MUST
6	As an NGESO ENCC Member, I want to manage volts, inertia, contingency, and frequency requirements so that I can ensure there are no unplanned network outages and that there is a reliable and secure electricity supply for all customers.	1. Calculates the system inertia based on demand on a half-hourly basis. 2. Displays system inertia value (calculated/estimated within the timeframe (-24h, -12h, -6h, -4, -1.5h, -1h, -.5h, real-time) or as per snapshot request by the final user). 3. Displays aggregated views at the 400kV, 275kV, 132kV, 33kV, and 11kV voltage levels. 4. Displays losses and reactive power levels at the 400kV, 275kV, 132kV, 33kV, and 11kV voltage level aggregated views.	MUST
7	As an NGESO Real-Time Operator, I want visibility of DNO network status to see which parts of the distribution network contain DERs and also understand network connectivity so that I am aware of which DERs fall in the category of Low Frequency Demand Disconnection category in case of fall in grid frequency in extreme events.	1. Displays the DER network locations and connectivity between assets. 2. Displays connectivity below the GSP level for the 11kV and 33kV networks. 3. Identifies 'Low Frequency Demand Disconnection'.	MUST

NGESO Use Case 1: Real-time Network Monitoring and Control – MUST (3)

EPIC: As an NGESO Member, I want to have access to demand and availability of services at the GSP-level, so that I can make real-time control decisions within a specific region of the network.

ID	User Story	Acceptance Criteria	Priority
11	As an NGESO Member I want a tool that is jointly owned and maintained with DNOs so that I can build trust in the tool and use it effectively.	1. Joint ownership defined and agreed between NGESO and DNOs. 2. Maintained jointly.	MUST
12	As an NGESO Member I want a tool that is jointly accessible with DNOs so that it can be used effectively to support BaU decision making.	1. Accessible by NGESO and DNO users.	MUST
13	As an NGESO Member I want a tool that is secure to protect my data and wider IT/OT infrastructure.	1. Secured to hold UK Protect Data. 2. Securely accessible by NGESO and DNO users.	MUST
14	As an NGESO Member I want a tool that can intake data from multiple sources and data owners so that it can be used effectively to support BaU decision making.	1. Intakes data from NGESO, DNOs, and third parties.	MUST

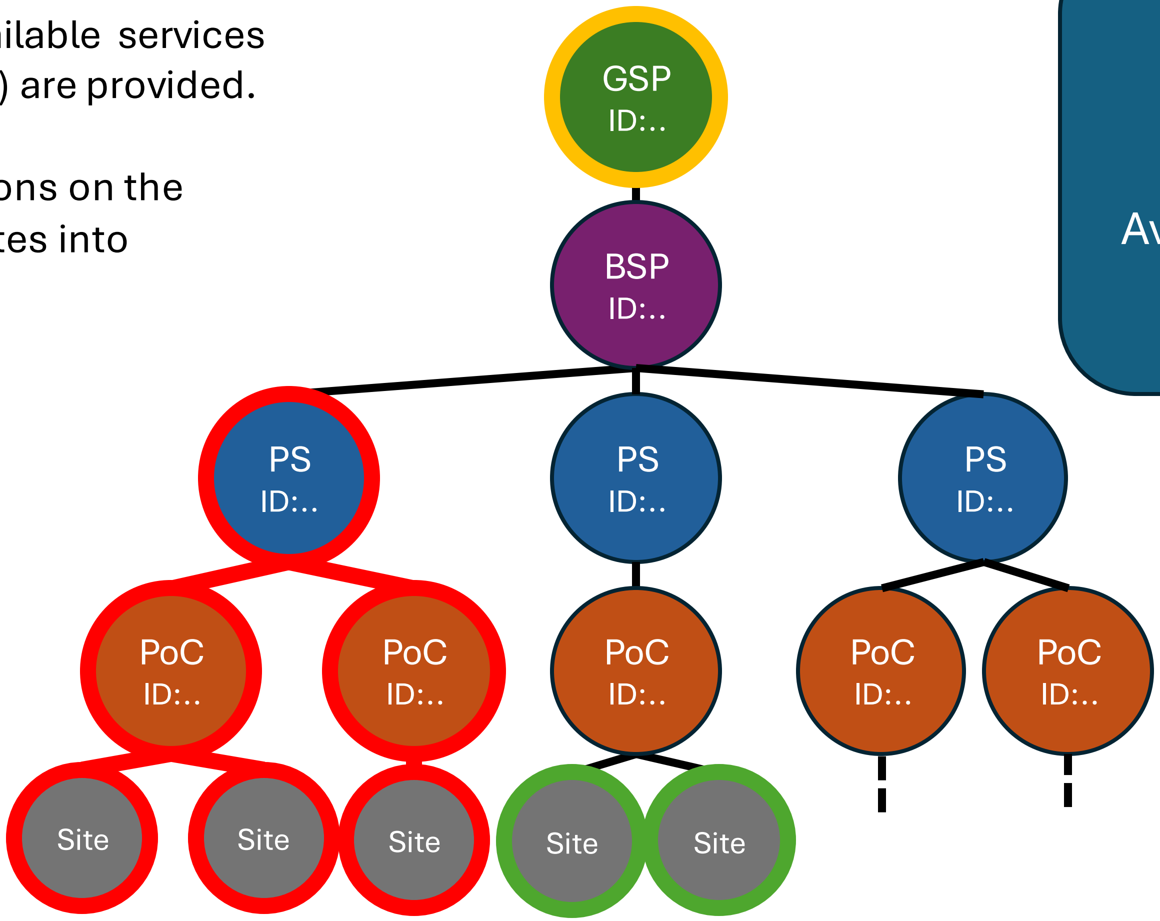
NGESO Use Case 1: Real-time Network Monitoring and Control – MUST (4)

The visualisations are indicative of how Fractal Flow may meet these requirements.

EPIC: As an NGESO Member, I want to have access to demand and availability of services at the GSP-level, so that I can make real-time control decisions within a specific region of the network.

By querying a GSP node, the demand and available services (given the current constraints on the network) are provided.

The graph highlights all DERs and their locations on the DNO's network as well as any groupings of sites into aggregated services.



GSP ID:..

Demand:
XX W

Available Services:
BMU X
BMU Y

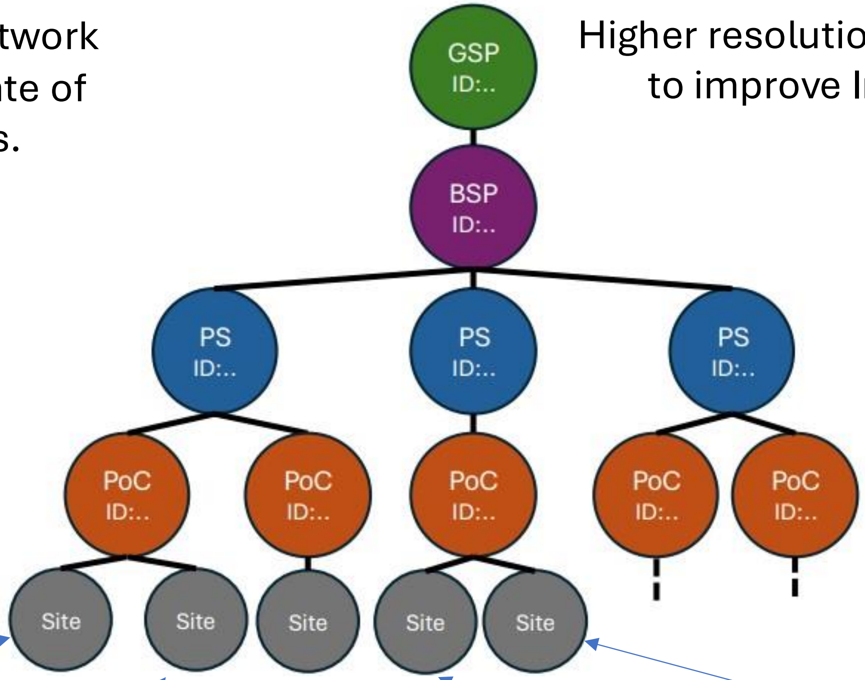
Key
- Selected Node
- Constrained
- Available service

NGESO Use Case 1 – [ID 6] - Inertia Calculations

Metadata and connection statuses can be aggregated up through the network to provide a more precise estimate of Distribution Inertia contributions.

Higher resolution GSP data can also be utilised to improve Inertia forecasting analytics.

Asset	Inertia Contribution generation	Inertia Contribution demand
Asset x	0.005	0.0001
Asset y	0.0001	0.005
Asset …	0	0.0001
Asset z	0.03	0
Σ_PoC 1	,,,	,,,,



Asset	Inertia Contribution generation	Inertia Contribution demand
Asset x’’’’’	0.005	0.0001
Asset y’’’’’	0.0001	0.005
Asset …’’’’’	0	0.0001
Asset z’’’’’	0.03	0
Σ_PoC 5	,,,	,,,,

Aggregated PoC Inertia contributions

Asset	Inertia Contribution generation	Inertia Contribution demand
Asset 1	0.005	0.0001

Asset	Inertia Contribution generation	Inertia Contribution demand
Asset 2	0.02	0

Asset	Inertia Contribution generation	Inertia Contribution demand
Asset 3	0.005	0.0001

Asset	Inertia Contribution generation	Inertia Contribution demand
Asset 4	0.005	0.0001

Asset	Inertia Contribution generation	Inertia Contribution demand
Asset 5	0.005	0.0001

Individual Site Inertia contribution estimates

NGESO Use Case 2: Dynamic Data Exchange for Balancing Services – MUST (1)

FRAZER-NASH CONSULTANCY
A KBR COMPANY

EPIC: As an NGESO Real-Time Operator, I want to have a 30-minute resolution of demand and service availability information at the GSP-level, so that I can coordinate and maintain system stability.

ID	User Story	Acceptance Criteria	Priority
8	As an NGESO Real-Time Operator, I want visibility of DNO network status to see which parts of the distribution network contain DERs and also understand network connectivity so that I am aware of which DERs fall in the category of Low Frequency Demand Disconnection category in case of fall in grid frequency in extreme events.	1. Displays the real-time status of the DNO network, including locations of DERs. 2. Displays DERs for 'Low Frequency Demand Disconnection' during grid frequency fails. 3. Display DER and CER connectivity for the 11kV and 33kV networks.	MUST
10	As an NGESO Member, I want DNOs to receive dynamic BMU data so that where NGESO Balancing Services are procured from distributed assets that are behind network constraints managed by ANM schemes, there aren't any conflicts of instruction between NGESO and DNO ANM, e.g. generation increase instruction by NGESO is counteracted by a curtailment instruction sent by the ANM scheme which presents a risk to security of supply whilst increasing costs to consumers.	1. Transfers dynamic BMU data from NGESO to DNOs. 2. Identifies conflicts between NGESO and DNO ANM instructions.	MUST

NGESO Use Case 2: Dynamic Data Exchange for Balancing Services – MUST (2)

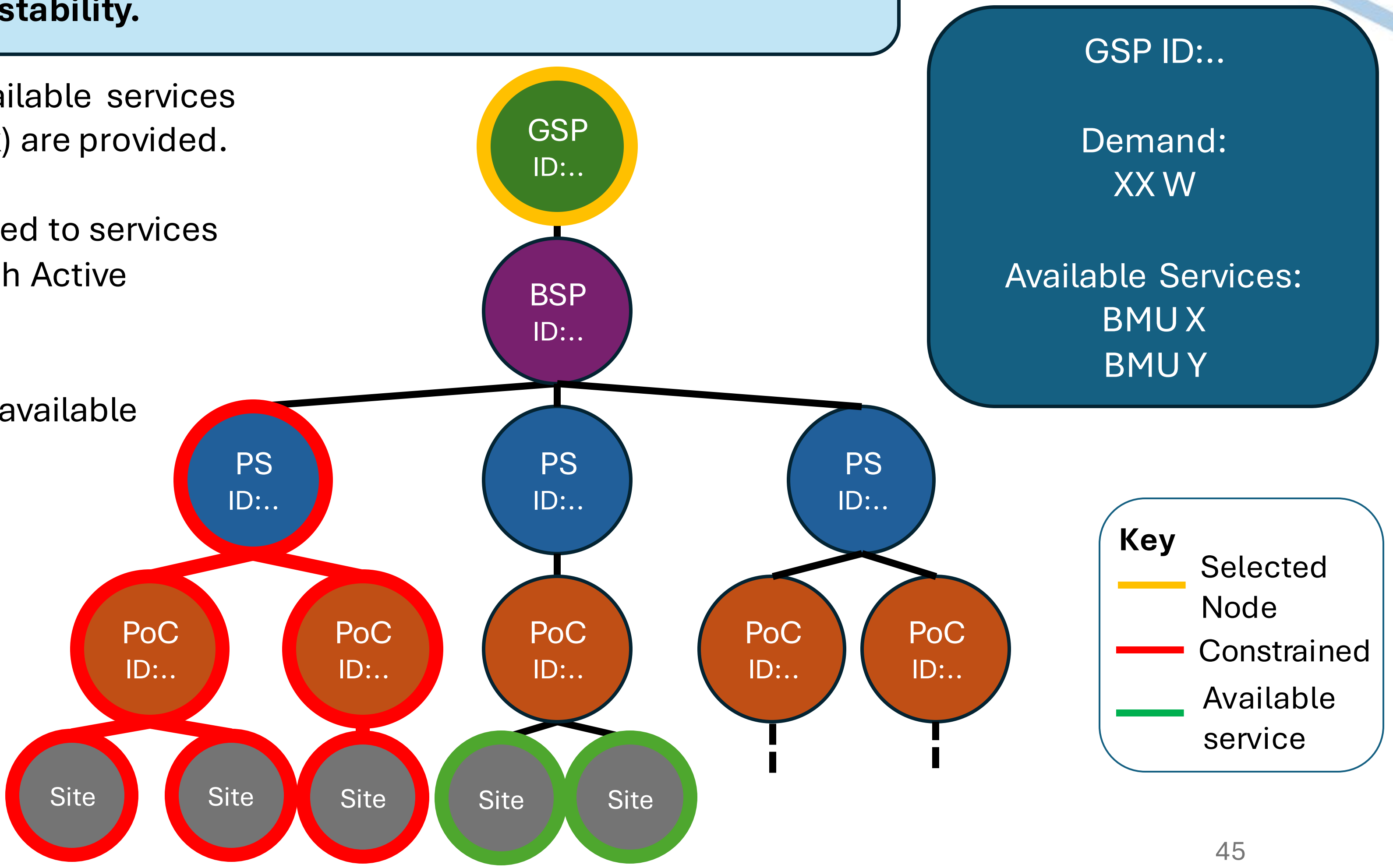
The visualisations are indicative of how Fractal Flow may meet these requirements.

EPIC: As an NGESO Real-Time Operator, I want to have a 30-minute resolution of demand and service availability information at the GSP-level, so that I can coordinate and maintain system stability.

By querying a GSP node, the demand and available services (given the current constraints on the network) are provided.

BM data (capacity and service cost) is attached to services so that conflicts are minimised. This links with Active Network Management scheme visibility.

The utilisation of a BMU can be derived from available network data.



NGESO Use Case 3: Anticipating Future Trends and Consumer Behaviour – MUST (1)

FRAZER-NASH CONSULTANCY A KBR COMPANY

EPIC: As an NGESO Real-Time Operator, I want to view future tariff trends and smart meter data, so that I can anticipate consumer behaviour and market dynamics and the corresponding implications on the network in real-time.

ID	User Story	Acceptance Criteria	Priority
9	As an NGESO Real-Time Operator, I want to understand future trends with tariffs (e.g. time of use tariffs) and implementation of smart meters, as aggregation of renewable energy becomes more commonplace in the energy market, so that I can understand consumer behaviour and anticipate what will happen on the network in real-time.	1. Displays real-time information about future tariff trends and smart meter data. (Note 1: that this data is part of Flexr and would require external partnership during Alpha phase to further explore the latency of this data; Flexr had a 72h data latency which, through machine learning, could support real-time forecast insights; Note 2: Crowd Flex addresses data availability challenges that will be explored in the Alpha phase.) 2. Predicts network impacts based on renewable energy aggregation. 3. Calculates and displays energy consumption patterns.	COULD
15	As an NGESO Member I want a tool that is scalable so that it is capable of meeting future data requirements as the volume, resolution, and timescales change.	1. Designed in a way that facilitates future scalability. 2. Deployed on a system, platform, and environment that facilitates future scalability.	MUST

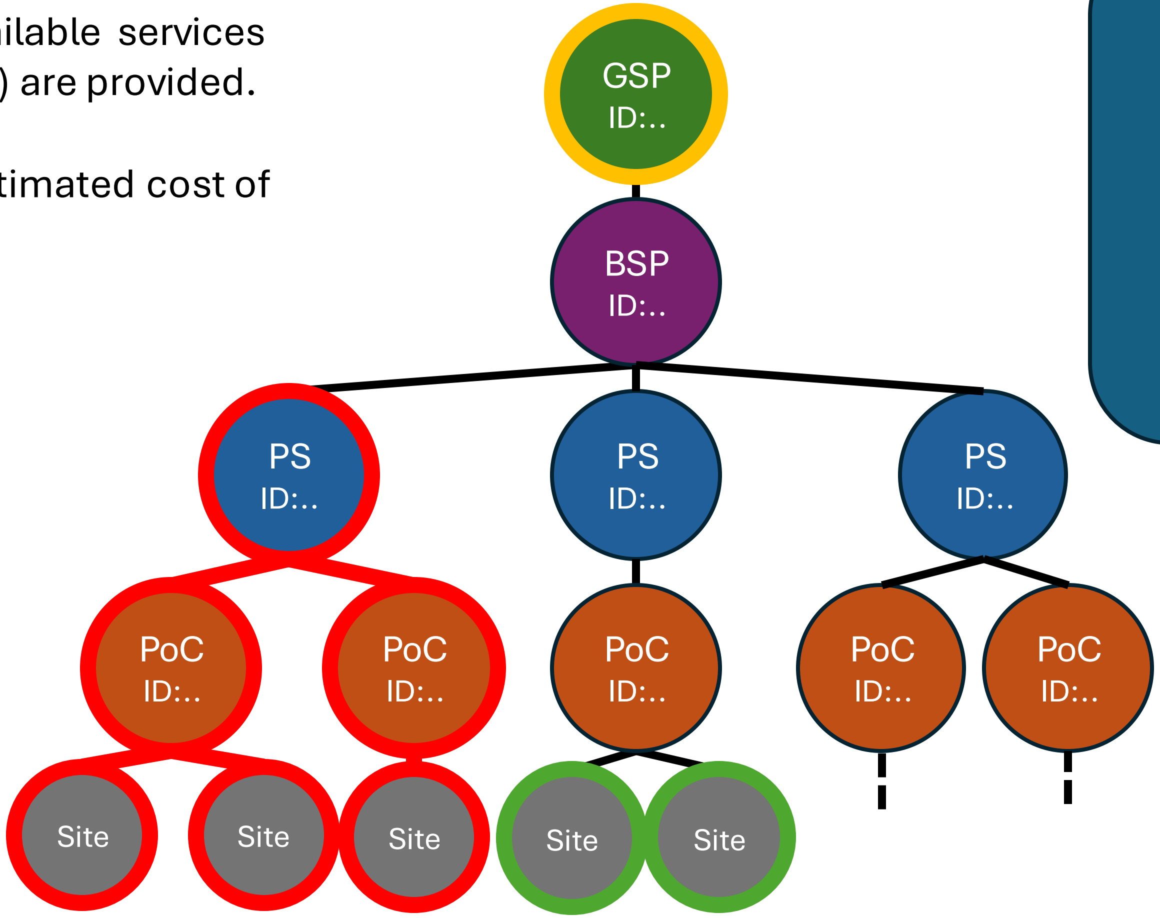
NGESO Use Case 3: Anticipating Future Trends and Consumer Behaviour – MUST (2)

The visualisations are indicative of how Fractal Flow may meet these requirements.

EPIC: As an NGESO Real-Time Operator, I want to view future tariff trends and smart meter data, so that I can anticipate consumer behaviour and market dynamics and the corresponding implications on the network in real-time.

By querying a GSP node, the demand and available services (given the current constraints on the network) are provided.

Live market data is available including the estimated cost of available service.



GSP ID:..

Demand:
XX W

Available Services:
BMU X at £X/MWh
BMU Y at £Y/MWh

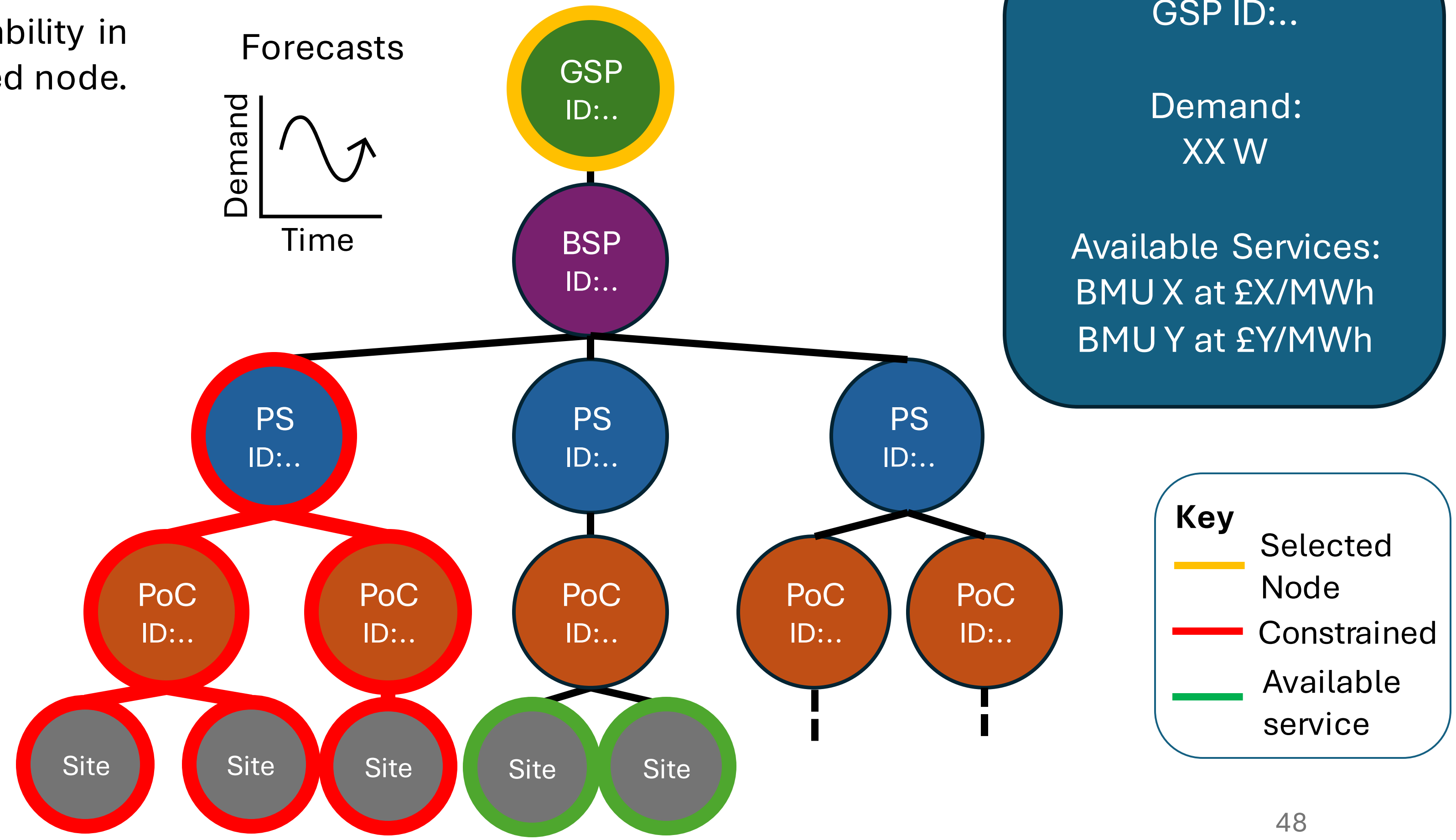
Key
- Selected Node
- Constrained
- Available service

NGESO Use Case 3: Anticipating Future Trends and Consumer Behaviour – MUST (3)

The visualisations are indicative of how Fractal Flow may meet these requirements.

EPIC: As an NGESO Real-Time Operator, I want to view future tariff trends and smart meter data, so that I can anticipate consumer behaviour and market dynamics and the corresponding implications on the network in real-time.

Ability to forecast demand and service availability in 1hr/4hr/24hr ahead predictions at the queried node.



Additional SHOULD and COULD Use Cases

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As the project has progressed, the hierarchy of Use Cases has been refined to provide a clearer view of the minimum viable product (MVP) for Fractal Flow (i.e. the 'Must' Use Cases).

Following the requirements capture, we have defined the MVP for Fractal Flow which has removed the need to have three tiers of Use Cases. Hence, the residual Use Cases which are not 'Must' are now downgraded to 'Could'.

The following table outlines the 'Could' Use Cases identified during the requirements capture activity. These 'Could' Use Cases can be considered after Alpha has concluded, when Fractal Flow has met its core Use Cases.

The functionality required for these use cases will not be designed out at Alpha but added in future design stages. This will provide additional clarity to support the delivery of Alpha.

Use Case ID	Use Case	Priority
DNO Use Case 3	As a DNO Member, I want to be able to understand the financial impacts of network optioneering, so that I have the information needed to make investment decisions.	COULD
DNO Use Case 4	As a DNO Control Room Operator, I want to be able to identify and assess different maintenance planning options, so that I can identify where I can switch or reroute power flow to minimise the number of customers affected.	COULD
DNO Use Case 5	As a DNO Connection Planner, I want to be able to identify whether a new asset can be connected to the network and the optimal connection strategy, so that connection decisions can be made quickly and cost-effectively.	COULD

Feasibility Study

Following the requirements capture, key enabling technologies were identified. Research was conducted into current and future technologies, identifying key enablers and barriers to Fractal Flow. Enablers and barriers were also identified through the workshops and subsequent meetings with NPg and NGESO. Meetings with key stakeholders at NPg and NGESO were used to produce an indicative system architecture.

The feasibility study identifies:

- The enabling technologies from the requirements capture.
- Technical, commercial, and regulator enablers and barriers.
- Data integration tools and initial development.
- Data analytics and machine learning use cases, along with data requirements.
- An indicative system architecture.
- Synergies with existing internal development activities.

Enabling Technologies

Real-time data access

- Data must be accessible within Fractal Flow to enable real-time analytics capabilities.

Standard data format and protocol

- A standard data format and protocol across DNOs and NGESO will enable data to be transferred efficiently without missing information.

Graph theory algorithms

- Graph theory algorithms are required to perform and aid the analytics problems, e.g. identifying clusters of constrained assets.

Data analytics and machine learning

- Data analytics and machine learning algorithms are required to forecast demand, service availability and constraints into the future.

Graph database

- Fractal Flow leverages a graphical database of network assets to simplify analytics problems and to provide insights via graph theory algorithms.

Visualisation platform / User experience (UX) / User interface (UI)

- A data visualisation platform as part of a UI is required to visualise the data and analyse as well as actioning different analytics.

Data link

- Data link technologies are required to transmit the asset and real-time datasets to Fractal Flow.

Hosting infrastructure

- A cloud hosted platform is required to decentralise, share data as well as provide the compute resource to perform real-time analytics.

Constraints, Barriers, and Enablers (1)

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ID	Summary	Description	Mitigation/Exploitation Action(s)	Type	Constraint / Barrier / Enabler
1	**Integration with control room technologies**	There are several software tools that are used in the control room. Fractal Flow must integrate within control room operators' workflows or software where appropriate.	Develop Fractal Flow alongside network and solution architects at NGESO and DNOs.	Commercial/ Technical	Constraint
2	**Reliability and trust in Fractal Flow data streams**	Fractal Flow is dependent on several data streams for its analytics capabilities. These datasets must be regularly pushed to Fractal Flow. If there are errors or these updates are not performed this could lead to NGESO or DNOs making suboptimal (e.g. conflicting) control actions or lead to actions that damage infrastructure or cause faults.	Joint ownership and responsibility for Fractal Flow between DNOs and NGESO will promote trust and reliability of data streams. A legal framework will need to be designed with the responsibilities clearly defined.	Commerical	Barrier
3	**Availability of Data and Hardware limitations**	There are multiple owners of data and numerous parasitic latencies within the management of the information which may create limitations for Fractal Flow.	Develop suitable partnerships to access data. Assess limitations of data during Alpha. Inject clean data into Alpha prototype leveraging techniques defined in previous innovation works e.g. CIM, NeDRA and MW Dispatch. Investigate hardware improvements for Beta e.g additional measurements.	Technical	Barrier
4	**Data communication latency**	Real-time data is being produced by OT devices, however there will latencies introduced by metering resolution, computational digitisation, transmission and storage. <30mins data resolution is expected to be achievable based on current trajectory of technology and system architectures.	Investigate limitations of systems and identify opportunities for improvement (e.g. dedicated fibre-optics or alterative data communication protocols).	Technical	Barrier

Constraints, Barriers, and Enablers (2)

FRAZER-NASH CONSULTANCY
A KBR COMPANY

ID	Summary	Description	Mitigation/Exploitation Action(s)	Type	Constraint / Barrier / Enabler
5	**Data link**	Existing data link initiatives, such as ICCP, many not meet the requirements in terms of throughput, security, and latency.	There are other innovation projects looking into data links for real-time data such as Near Real-time Data Access (NeRDA). Fractal Flow is to be designed to be interoperable with these data protocols.	Technical	Barrier
6	**Inertia requirements**	NGESO have requested that Inertia is estimated at specific timeframes. Calculating inertia requires identifying step changes over small time periods and will therefore require a high sample rate. Currently NMS systems at the DNO level typically store data in 30min averages meaning higher sample rate data is not currently stored and available.	Sub-system Inertia Characteristics can be estimated from connected assets and then aggregated up through the system as illustrated here. More advanced analysis would require access to high-resolution GSP data. This will be explored during Alpha to determine if such can be integrated into FF to compliment the baseline analytic approach.	Technical	Barrier
7	**Cloud storage**	Fractal Flow will have a large amount of data, both asset information and real-time data streams. Storing large amounts of data in the cloud is expensive.	The solution architecture for Fractal Flow will need to be designed around the minimal information that is required for historic analysis. Compressive sensing could be used to reduce this data storage where practicable.	Technical	Barrier
8	**Protecting Sensitive Site Information**	Certain sites may contain sensitive information, for example MoD sites.	Fractal Flow will be designed from a security perspective to have the capability to redact sensitive information from users. Approaches already exist to do this within the GB network.	Security	Barrier

Constraints, Barriers, and Enablers (3)

ID	Summary	Description	Mitigation/Exploitation Action(s)	Type	Constraint / Barrier / Enabler
9	**Unforeseen transmission issues**	By leveraging distribution level assets to provide supply locally, there may be impacts on in situ transmission level generation as demand reduces across all DNOs/DSOs. There is an upwards trajectory for the capacity of DERs in the Future Energy Scenarios for the GB network [1].	Fractal Flow will create a more dynamic and competitive market, where cost and low carbon generation can be prioritised to meet energy needs. Transmission can be used to provide low carbon power to areas where embedded generation is not achievable.	Commercial / Regulatory	Barrier (implication from Fractal Flow)
10	**Access to Smart Meter Data**	Access to smart meter data would require compliance with the Smart Energy Code and data access from the Data Communications Company.	Initiatives such as Flexr data have already overcome these challenges albeit with a 72h data latency and Fractal Flow will seek to work with the system developer of that project to reinforce Alpha. Other innovation projects such as Crowd Flex have improved on the data availability challenges and will be investigated further during Alpha.	Commercial, Regulator	Barrier
11	**Data access and sharing across DNOs and ESO**	Data is available for assets, and there are potentially commercial barriers to sharing all the datasets on Fractal Flow with all users (e.g., a DNO may not want to share their full network with the ESO).	Fractal Flow will have different user interfaces and permissions. For example, an ESO user will only see a summary of the data aggregated at a GSP-level, whereas a DNO user will be able to access information across their network. Initiatives such as Virtual Energy System (a digital twin of the GB network) are also developing solutions to these issues, and we have also investigated the use of data brokers as a potential solution.	Commercial	Barrier

[1] NGESO, 2023, ‘Future Energy Scenarios’, https://www.nationalgrideso.com/document/283101/download

Constraints, Barriers, and Enablers (4)

ID	Summary	Description	Mitigation/Exploitation Action(s)	Type	Constraint / Barrier / Enabler
12	**Open Network Panel [1]**	The Open Network Panel are seeking to overcome issues associated with data sharing governance. Historically DNO information has been locked down and secured as a protected asset with limited sharing internally at DNOs, and this panel is seeking to understand and remove these barriers.	Our partners are already involved in the Open Network Panel – Operational Data Sharing governance, and we have used and continue to use this learning in developing Fractal Flow to prevent duplicated effort.	Technical	Enabler
13	**DNO market opportunities**	Fractal Flow will offer insights to DNOs that could be used to offer commercial services internally on their own networks and to NGESO to help resolve constraints at a transmission level through local services.	Fractal Flow should integrate information from NGESO to help DNOs provide services for NGESO.	Commercial	Enabler
14	**Open data sharing**	There is a regulatory drive towards data sharing across network operators and systems operators.	Leverage any Grid Codes or regulatory initiatives, (e.g. G99, GC0139 and the Ofgem data sharing infrastructure working group [2]) that requires data sharing and visibility, to encourage wider DNO engagement and collaboration with Fractal Flow. We will investigate data sharing initiatives, such as Digital Spine [3] feasibility studies, and the Open Network Panel – Operational Data Sharing Working Group.	Regulatory	Enabler

[1] Open Network Panel, 2022, 'Proposal for Operational Data to be shared by DNOs Open Networks', ON22-WS1B-P7 Proposal for Operational Data to be shared by DNOs (23 Feb 2022).pdf (energynetworks.org)
[2] Ofgem, 2023, 'A roadmap to an energy data sharing infrastructure by 2028', https://www.ofgem.gov.uk/sites/default/files/2023-10/FSNR%20workstream%205%20consultant%20recommendations.pdf
[3] Energy Digitalisation Taskforce, 2021, 'Delivering a Digitalised Energy System', https://esc-production-2021.s3.eu-west-2.amazonaws.com/2022/01/ESC-Energy-Digitalisation-Taskforce-Report-2021-web.pdf

Constraints, Barriers, and Enablers (5)

ID	Summary	Description	Mitigation/Exploitation Action(s)	Type	Constraint / Barrier / Enabler
15	**DSO transition**	The move from the DNO model to a DSO model will require the use of data to provide insights on demand and service availability across the distribution grid.	The regulatory drive toward DSOs will help provide an environment where DNOs require a solution like Fractal Flow. Fractal Flow will be disseminated to DNOs to ensure they are aware of its capabilities and how it will help this transition.	Regulatory	Enabler
16	**Standard data formats**	Standard data formats are being developed by wider initiatives. An example of this is the Common Information Model (CIM) which has been adopted by most of the GB network and has been adopted by the International Electrotechnical Commission (IEC).	Fractal Flow will leverage existing standard data models to ensure interoperability with data streams for DNOs, NGESO, and third parties.	Technical	Enabler
17	**Digital twin / Virtual Energy System**	There is a drive across the industry to create a shared data platform and a digital twin of the GB network.	The NGESO Virtual Energy System framework will help provide useful insights and learning into interoperability, security, and available metadata for developing Fractal Flow.	Technical	Enabler
18	**BM platforms**	There are currently developments to create improved BM platforms to help procure and dispatch services, such as the NGESO's Open Balancing Platform (OBP).	Fractal Flow should integrate with the BM platforms being developed such that its capabilities help inform decision making.	Technical	Enabler
19	**Graph databases**	Graph databases have been developed at scale (i.e., millions of nodes) in commercial solutions such as Neo4j.	Fractal Flow will leverage industry standard graph databases.	Technical	Enabler
20	**UK Protect cloud solutions**	There are existing cloud-host data platforms that contain GB network data.	Ensure that lessons learned from UK Protect cloud solutions, such as Flexr are used to inform the design of Fractal Flow.	Technical	Enabler

On-going Support and Maintenance

On-going support and maintenance will need to be paid for in the long term as part of BaU. The current licencing terms for SIF funded projects means an alternative mechanism needs to be used to pay for these services.

Discussions have begun between NGESO and NPg about future funding and support and these will need to be widened to include any additional technology partners and other DNOs.

Fractal Flow will be a jointly owned solution which will help promote a collaborative commercial arrangement.

To fully realise Fractal Flow's potential, the solution will need to be rolled out across all DNOs. We will continue to disseminate and engage with DNOs, ensuring that they have opportunities to shape and guide how the solution will be supported.

Data Integration Tools

The requirements capture process identified two data integration tools that are central to Fractal Flow meeting the use cases successfully:

1. Cloud hosting - Supports the requirements for a Fractal Flow tool that must be:
    - Jointly owned and maintained by NGESO and DNO.
    - Accessible by NGESO and DNO users.
    - Secured for UK Protect data.
    - Capable of data intake from multiple sources and data owners.
    - Scalable for future data and platform integration.

2. Graph databases – Supports the requirements for network visibility and analysis because they can:
    - Handle complex relationships.
    - Flexibly update the data schema.
    - Leverage graph query performance for node operations.
    - Scale as data volume and throughput increases.
    - Analyse and visualise the data using modelling and ML for advanced insights, forecasting, and understanding.
    - Assure usability and readability of data.
    - Provide fast data query responses.

Data Integration Tools: Cloud Hosting Infrastructure

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Cloud hosting Fractal Flow allows it to meet user requirements for ownership and maintenance, accessibility, security, data, and scalability.

Ownership and Maintenance

- A third party can host Fractal Flow in a cloud platform (e.g. AWS/Azure) to remove sole-ownership and maintenance from a single stakeholder.

Accessibility

- The tool can be accessed by users from multiple stakeholders.

Security

- ‘UK Protect’ secured cloud platforms are available and already host other tools.

Data

- The tool can recieve data from multiple sources and data owners.

Scalability

- The tool can scale its storage and compute as the volume of data increases. It can leverage powerful computing resource from cloud providers to run data analytics.

Graph

- Using a cloud-based enterprise graph database management system is secure, computationally powerful, and well-established in other domains.

Example

- An example of tools running in the cloud with UK Protect data are ElectraLink’s hosting of NeRDA and Flexr.

Data Integration Tools: Graph Databases

Using a graph database at the core of Fractal Flow allows it to handle complex relationships, schema updates, leverage graph query performance, scalability, analysis and visualisation.

Topology Representation

- A graph is a natural reflection of the topology of the power system network. It supports user understanding and visualisation of the physical network.

Handling Complex Relationships

- Data that has many relationships (power system assets) can be efficiently modelled for visualisation, querying, and analysis. Multiple relationships between assets can be defined.

Schema

- Graphs have flexible schemas that can be easily updated when new data is generated or becomes available. New relationships ca n be mapped without requiring a whole-of-schema update.

Performance

- Traversing the node and edge lists is fast by using graph algorithms. Querying big datasets is efficient by traversing only the necessary data, not the entire dataset.

Scalability

- Graphs combine the benefits of flexible schema updates and query performance so new data connections can be added as datasets scale while remaining performant in querying and analysis.

Analytics

- Analytics and machine learning can provide insights into data relationships and trends, forecast metrics, cluster assets, and infer missing data.

Visualisation

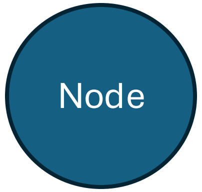
- Graphs can be visualised to the user to develop understanding of the network and provide an interface for querying.

Schema and Ontology Requirements

The next slides outline an initial view of the schema and ontology design of the graph database. The ontology of the graph is not fixed, and its development will be considered as part of the Alpha phase depending on the information that needs to be queried efficiently.

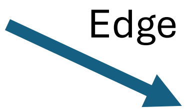
What constitutes a node?

- Nodes represent entities or instances. They are things you have information about.
- The guiding principle of what should be a node is anything that requires additional metadata and is not a relationship.
- At a minimum, each asset type in the distribution level of the network will be a node, e.g., grid supply point, bulk supply point, primary substation, point of connection, site.
- Transmission lines will likely be represented as a node to capture associated metadata in the schema.



What constitutes an edge?

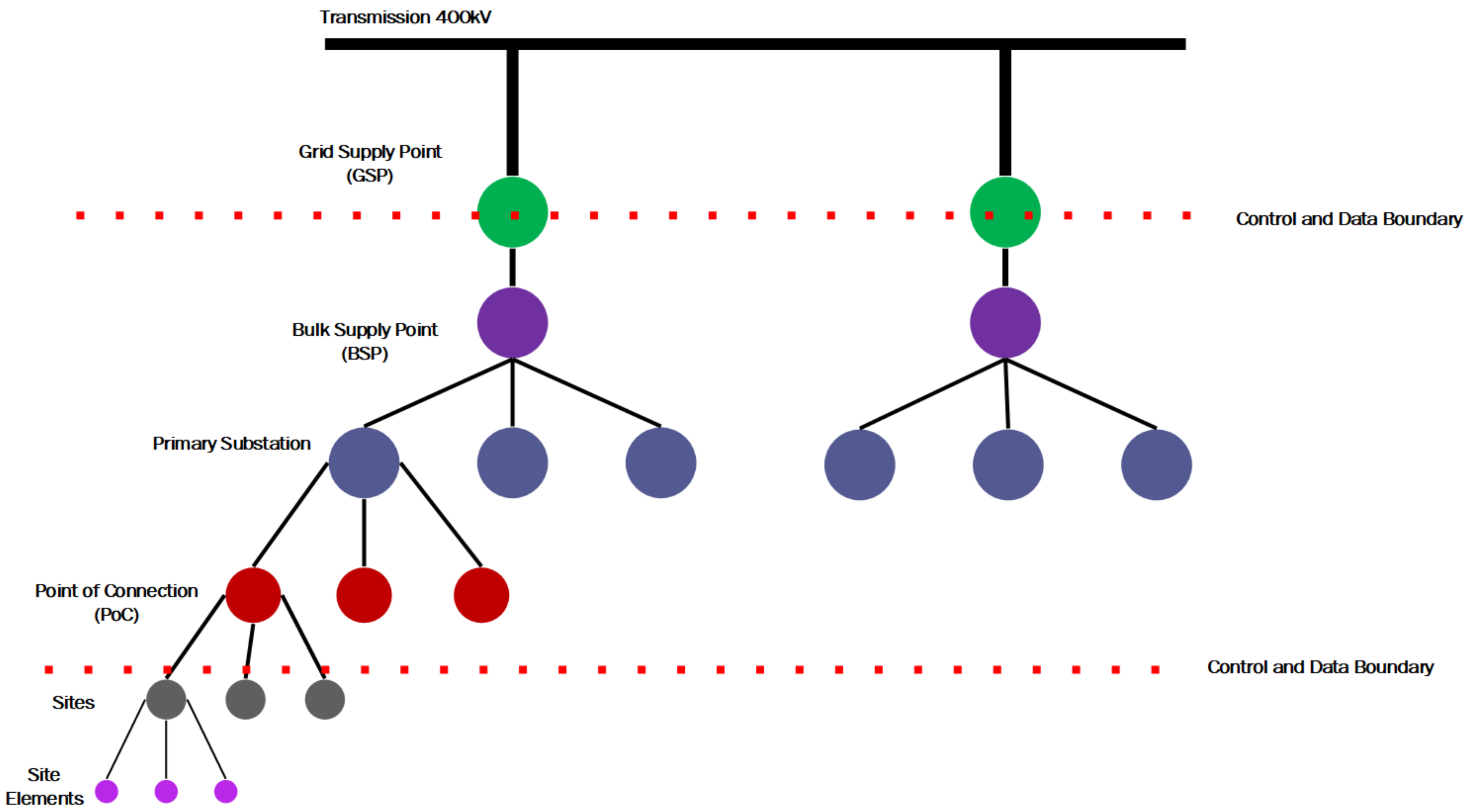
- Edges are relationships between nodes.
- Edges link parent-child relationships with a type and direction.
- At a minimum, edges will define how asset nodes are 'connected to' each other.
- Other relationships will also be important, e.g., BMU or ownership relationships.



The ‘Network Node Representation’ diagram on the next slide shows assets that constitute the minimum set of nodes in Fractal Flow.

- The nodes and edges in the graph can be expanded using this distribution layer as a basis.

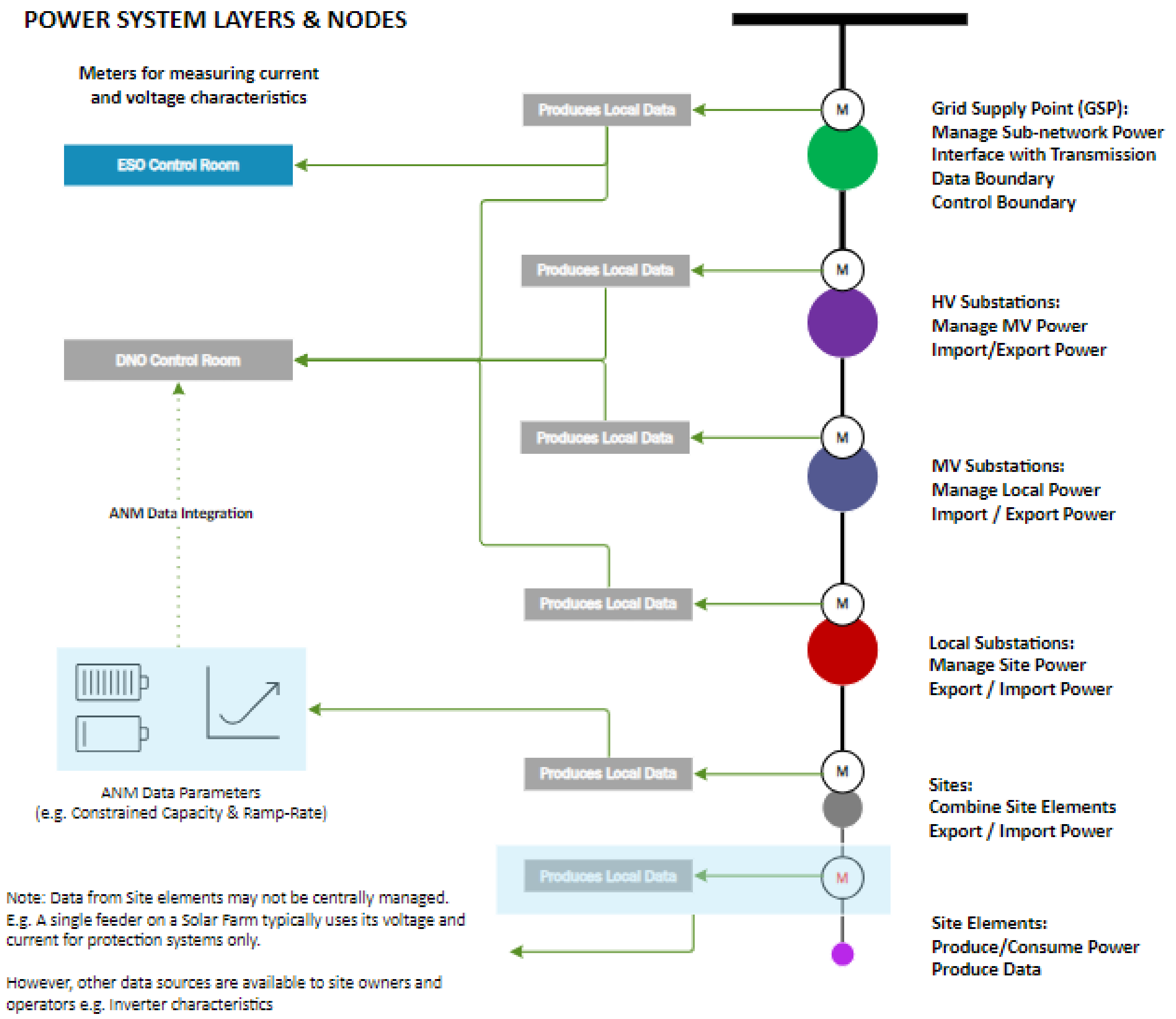
Network Node Representation



The red dashed lines define the DNO boundary. Fractal Flow will include information below the GSP-level within this boundary as a minimum viable product.

It may be benefitable to integrate other customer data (e.g., asset, power flow etc.) to enhance Fractal Flow's capabilities, but this would require further partnership beyond the DNOs and ESO.

Node Data Sources



This figure lists the main asset nodes within the DNO and ESO data boundaries (GSP, BSP, PS, PoC) and shows where that data is currently accessible, i.e. either in the ESO control room (at GSP-level) or DNO control room (GSP, BSP, PS, PoC). It is noted that although this data is available in the control room, not all DNOs have data links to make this data accessible outside of their secure NMS systems.

It is noted that although ESO have access to power flow at the GSP, they don't have information to determine demand and available volume services or lower-level constraints that would impact availability.

Fractal Flow will include asset information and the data sources available to accurately define the behaviour and layout of the network. This includes relationships between the nodes, as well as the current and voltage data to establish power flow, provided via data collection devices and/or metering infrastructure.

Fractal Flow will enable a user to query assets nodes and access the real-time datasets that sit below the graph database layer. All the available information will be captured within Fractal Flow using data links.

The figure also provides an overview of the functionality associated with each node to give an insight into the type of data that can be provided at each network layer.

Integration of Active Network Management (ANM) schemes is an important consideration and will be investigated further during the beta project. It is noted that currently, DNOs have differing levels of ANM data integration.

Data Analytics and Machine Learning Use Cases

This section outlines the data analytics and ML steps that Fractal Flow can complete to meet the use case requirements (which is an additional SIF requirement for Fractal Flow).

Each use case includes the analytical steps required to meet the requirement and the benefits this will provide to the user.

The analysis is separated into two parts:

1. Modelling based on known engineering calculations (e.g. power flow).
2. Analysis that combines understanding of physical modelling with ML techniques to gain new insights into the data (physics-informed ML models).

Following this, the required data and the identified data sources are provided for each use case.

Data Analytics and Machine Learning Use Cases

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The graph database of Fractal Flow enables powerful analytics and machine learning to solve problems and provide insight, optimisation, prediction, and inference.

This allows the user to make more informed decisions for maximising metrics including cost, speed, and reducing carbon emissions.

The diagram below shows a typical data analytics and machine learning workflow in Fractal Flow.

1. Create graph database relationships between nodes and edges
2. Add metadata to nodes (e.g., type of asset, thermal capacity, geographical location)
3. Calculate power flow at nodes
4. Run analytics/ML algorithm on a set of nodes, queried in the graph
5. Return useful result to the user
6. User makes a more informed decision

Data Analytics and ML for DNO Use Case 1: Network Visibility

Data Analytics and ML	Benefit
• Infer the direction of power flow at nodes below the primary substation network level. This will leverage the graph to solve local-neighbourhood power flow problems *[ML1, ML2, ML7, ML9]*.	• Improves network visibility for assets that have limited data or sensor availability, and speed of local calculation on a large network with real-time power flow data.
• Identify constrained edges in the graph and forecast constraint clusters *[ML1, ML2, ML7, ML9]*.	• Improves decision making and forecasting of supply and demand. • Availability status would be metadata on a node allowing route finding problems to resolve outages or maintenance activities where a particular distribution or transmission asset is not available.
• Identify and fill gaps in the datasets. • Identify bad data *[ML3]*.	• Addresses missing data, data conflicts, and bad data. • Allows querying of nodes for real-time and historical statuses.
• Classify nodes to identify those which have generators attached *[ML4, ML8, ML9]*.	• Improves network visibility to understand sources of power flow error.
• Cluster nodes by characteristics *[ML4, ML9]*.	• Improves understanding of types of nodes and trends in node groups. • Adds capability to forecast on expected behaviour of clustered nodes.
• Infer information at nodes and edges including type of asset, voltage, and thermal capacity *[ML3, ML4, ML5, ML6, ML7, ML8, ML9, ML10]*.	• Increases metadata information across all levels of nodes in the network. • Improves decision making through network visibility by estimating missing data.

References to academic literature are denoted by [MLx]. Follow the hyperlink to a slide containing complete references.

Data Analytics and ML for DNO Use Case 2: Future Flexibility Services

Data Analytics and ML	Benefit
• Notify users of changes in the network at defined thresholds *[ML4, ML5, ML7, ML8, ML9, ML10]*.	• Supports dynamic understanding of the network in real-time to improve decision making and flexibility.
• Notify users of faults through anomaly detection *[ML4, ML6, ML8, ML9]*.	• Allows a faster response time to faults to improve customer outage metrics. • Supports a safer, more secure, power system network.
• Notify users of conflicts between DNO and NGESO instructions.	• Improves communication and coordination between DNO and NGESO. • Increases efficiency in curtailment and balancing actions.
• Provide options for mitigating conflicting instructions *[ML9]*.	• Increases efficiency in curtailment and balancing actions. • Cost savings by avoiding redundant instructions.
• Forecast supply and demand at nodes *[ML4, ML5, ML9, ML10]*.	• Provides a clearer view of sub-network behaviour which opens the market to new groups (SVA, VLP) by reducing uncertainty.
• Calculate available headroom at nodes *[ML5, ML9]*.	• Contributes to constraint forecasting, optimising power dispatch requests. • Optimises new connections planning for various metrics (e.g., least cost, soonest availability, thermal capacity).
• Optimise power dispatch requests over specific sets of nodes for various scenarios *[ML9]*.	• Improves decision making for metrics such as overall efficiency, cost, carbon emissions, ramp-up time.

Data Analytics and ML for NGESO Use Case 1: Real-time Network Monitoring and Control

Data Analytics and ML	Benefit
• Analyse power flow at nodes for real-time network monitoring and control *[ML1, ML2, ML7, ML9]*.	• Adds visibility over the network below the GSP-level.
• Identify constrained edges and blocked flexible generators *[ML1, ML2, ML7, ML9]*.	• Forecasts constraint for improved decision making. • Provides insight into where to reinforce the network.
• Predict the impact of NGESO and DNO network instructions *[ML9]*.	• Reduces conflicting instructions, saving costs on superfluous actions. • Identifies mitigations for conflicts. • Improves efficiency in curtailment and balancing actions. • Improves communication and coordination between NGESO and DNO.
• Predict the impact of requests to DERs to cease active power *[ML9]*.	• Reduces network congestion through forecasting. • Adds capability to forecast post-curtailment power output, improving decision making. • Improves ability to handle more DERs connecting to the network (supporting UK net zero goal).
• Forecast the outcome of a section of the network returning from outage *[ML5, ML9]*.	• Improves decision making by forecasting post-outage power output.
• Calculate volts, inertia, contingency, and frequency at nodes for user to query *[ML3, ML4, ML6, ML7, ML8, ML9, ML10]*.	• Maximises network efficiency through anomaly detection and forecasting of metrics. • Reduces network congestion for existing infrastructure. • Improves network stability and security.
• Identify DER nodes and edges that are in the 'Low Frequency Demand Disconnection' category *[ML4, ML8, ML9]*.	• Improves network visibility for decision making.

Data Analytics and ML for NGESO Use Case 2: Dynamic Data Exchange for Balancing Services

Data Analytics and ML	Benefit
• Identify DER nodes and edges that are in the 'Low Frequency Demand Disconnection' category *[ML4, ML8, ML9]*.	• Improves network visibility for decision making.
• Identify conflicting BMU/curtailment instructions between NGESO and DNO and provide mitigation options by analysing other node instruction combinations *[ML9]*.	• Improves communication and coordination between NGESO and DNO. • Increases efficiency in curtailment and balancing actions. • Improves understanding of decisions in various scenario contexts (e.g., cost, carbon emissions, and ramp-up time of generators).

Data Analytics and ML for NGESO Use Case 3: Anticipating Future Trends and Consumer Behaviour

Data Analytics and ML	Benefit
• Forecast future trends in tariffs *[ML5, ML9, ML10]*. *Note: Forecasting tariff data has not been investigated during Discovery and will not be the focus of Alpha. However, this is a possible application of Fractal Flow in the future, where it could be used to provide a better understanding to inform regional pricing and customer demand as EV penetration grows.*	• Improves decision making for the power system network, reducing costs. • Improves network efficiency. • Identifies optimal targets for network adjustments and investment.
• Identify smart meters on the network. • Analyse smart meter data. • Cluster customer behaviour into groups *[ML4, ML9]*. *Note: Real-time access of smart meter data may not be possible based on previous innovation activities. In such cases historic data will be used for forecast prediction. Crowd Flex , NeDRA and Community DSO are understood to be leading innovation projects in this area.*	• Groups customers to better understand behaviour. • Provides insights into patterns among customer groupings. • Identifies trends and hidden relationships in the data.
• Predict power flow and other metrics at nodes using expected customer behaviour *[ML3, ML4, ML5, ML9]*.	• Adds capability to forecast power flow across specific node sets and at specific times based on behaviour.

Data Requirements for DNO Use Cases

Use Case	Data Requirement	Source
DNO Use Case 1: Network Visibility	Power flow data	Provided by metering data or calculated using standard power flow analysis from voltage and current [1]
	Asset data	Provided by DNO (e.g. open data portal, Flexr)
	Transmission connectivity data and associated metadata	Provided by DNO
	Demand data (e.g. smart meter data and metering data)	Provided by DNO and third parties, (e.g. Flexr data)
DNO Use Case 2: Future Flexibility Services	Power flow data (at a real-time rate and historical)	Provided by metering data or calculated using standard power flow analysis from voltage and current [1]
	Asset data and associated metadata (type of generator, cost, ramp-up time, maximum headroom)	Provided by DNO (e.g. open data portal, Flexr)
	Inertia (the fastest data requirement)	Provided by DNO (frequency load step and power step) [2]
	Demand data (e.g. smart meter data and metering data), historical	Provided by DNO and third parties, (e.g. Flexr data)
	Customer data (e.g. subsystem monitoring platform data)	Provided by customer
	BMU data	Provided by ESO (e.g., OBP, EAC, or Elexon)
	DNO/ANM curtailment instruction data	Provided by DNO ANM teams

[1] Power can be calculated using, as a minimum, root mean square current and voltage and some analysis could help resolve power flow queries.
[2] Data sampling rate requirement limited by ICCP capabilities. Inertia requires data of a high sample rate (in the order of ~100Hz).

Data Requirements for NGESO Use Cases

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Use Case	Data Requirement	Source
NGESO Use Case 1: Real-time Network Monitoring and Control	Power flow data (including reactive power, Q)	Provided by metering data or calculated using standard power flow analysis from voltage and current [1]
	Constraint data (e.g., rating and limits for the systems)	Provided by DNO (e.g. open data portal, Flexr)
	Asset metadata, (e.g., steady state ratings of systems, network/node capacity data)	Provided by DNO (e.g. open data portal, Flexr)
	Node maximum power output data	Provided by DNO
	Relay information (e.g., thermal protection)	Provided by DNO
	Relay pick-up time at 110% load	Provided by NGESO and DNO
	Request to cease active power data / curtailment data	Provided by DNO
	Outage data	Provided by DNO
	Inertia data	Provided by DNO (frequency load step and power step) [2]
NGESO Use Case 2: Dynamic Data Exchange for Balancing Services	Power flow data	Provided by metering data or calculated using standard power flow analysis from voltage and current [1]
	Asset metadata (e.g., connection point, head room capacity, speed of power response)	Provided by DNO (e.g. open data portal, Flexr)
	DNO/ANM curtailment instruction data	Provided by DNO ANM team
	NGESO BMU data (e.g., physical notification)	Provided by NGESO

[1] Power flow can be calculated using, as a minimum, root mean square current and voltage.

[2] Data sampling rate requirement limited by ICCP capabilities. Inertia requires data of a high sample rate (in the order of ~100Hz).

Data Requirements for NGESO Use Cases

Use Case	Data Requirement	Source
NGESO Use Case 3: Anticipating Future Trends and Consumer Behaviour	Power flow data	Provided by metering data or calculated using standard [1] power flow analysis from voltage and current
	Asset metadata	Provided by DNO (e.g. open data portal, Flexr)
	DER register	Provided by DNO
	Tariff data	Provided by Flexr
	Smart meter data	Provided by DNO and third parties

[1] Power flow can be calculated using, as a minimum, root mean square current and voltage.
[2] Data sampling rate requirement limited by ICCP capabilities. Inertia requires data of a high sample rate (100hz).

Data Requirements - Weather Data

To allow Fractal Flow to develop accurate and reliable power forecasts for weather dependant renewable sources, it will be necessary to integrate atmospheric data that is being collected at regional ground stations across the UK.

The MET Office Weather DataHub [1] provides a potential source of data via API which could be utilised as one such source. In addition, the MET Office also has UK Climate Projection models that could be used for future developments of Fractal Flow [2], but the latter shall not be considered within the core scope of Alpha due to its peripheral use case.

There are numerous research institutions which also collect Atmospheric Measurements, that could provide valuable partnerships and collaboration opportunities [3]. Furthermore, there are several innovation projects that have approached such forecasting problems, such as SolarPV Nowcasting, Predict4Resilience and WARN, which are discussed in a later section of this slide deck. Alpha will seek to build on this work and develop meaningful approaches to leverage the knowledge gained through this work and implement it within the context of Fractal Flow. Such integration will likely be evaluated during Alpha but developed during Beta.

Modern measurement technologies could also be leveraged to provide higher fidelity predictions, given the advancements in deployed LIDAR monitoring [4].

By integrating various data sources, it is possible to improve the forecast accuracy and reliability of renewable energy sources. Aggregating this over a network provides a clearer understanding of network dynamics and will improve the accuracy of supply/demand characteristics.

[1] Met Office, 'Met Office Weather DataHub', Met Office Weather DataHub - Met Office
[2] Met Office, 'UKCP data', https://www.metoffice.gov.uk/research/approach/collaboration/ukcp/data/index
[3] University of Reading, 'The Chilbolton Facility for Atmospheric and Radio Research', https://research.reading.ac.uk/met-radargroup/chilbolton/
[4] HALO Photonics By Lumibird, 'Streamline VS+', https://halo-photonics.com/lidar-systems/streamline-vs/

Fractal Flow at an Enterprise Level and Indicative Solution Architecture

For Fractal Flow to be a feasible product it must integrate with current and future enterprise architecture at DNOs and NGESO.

Fractal Flow will be a jointly owned and developed tool that will primarily be used in the control rooms of both DNOs and NGESO.

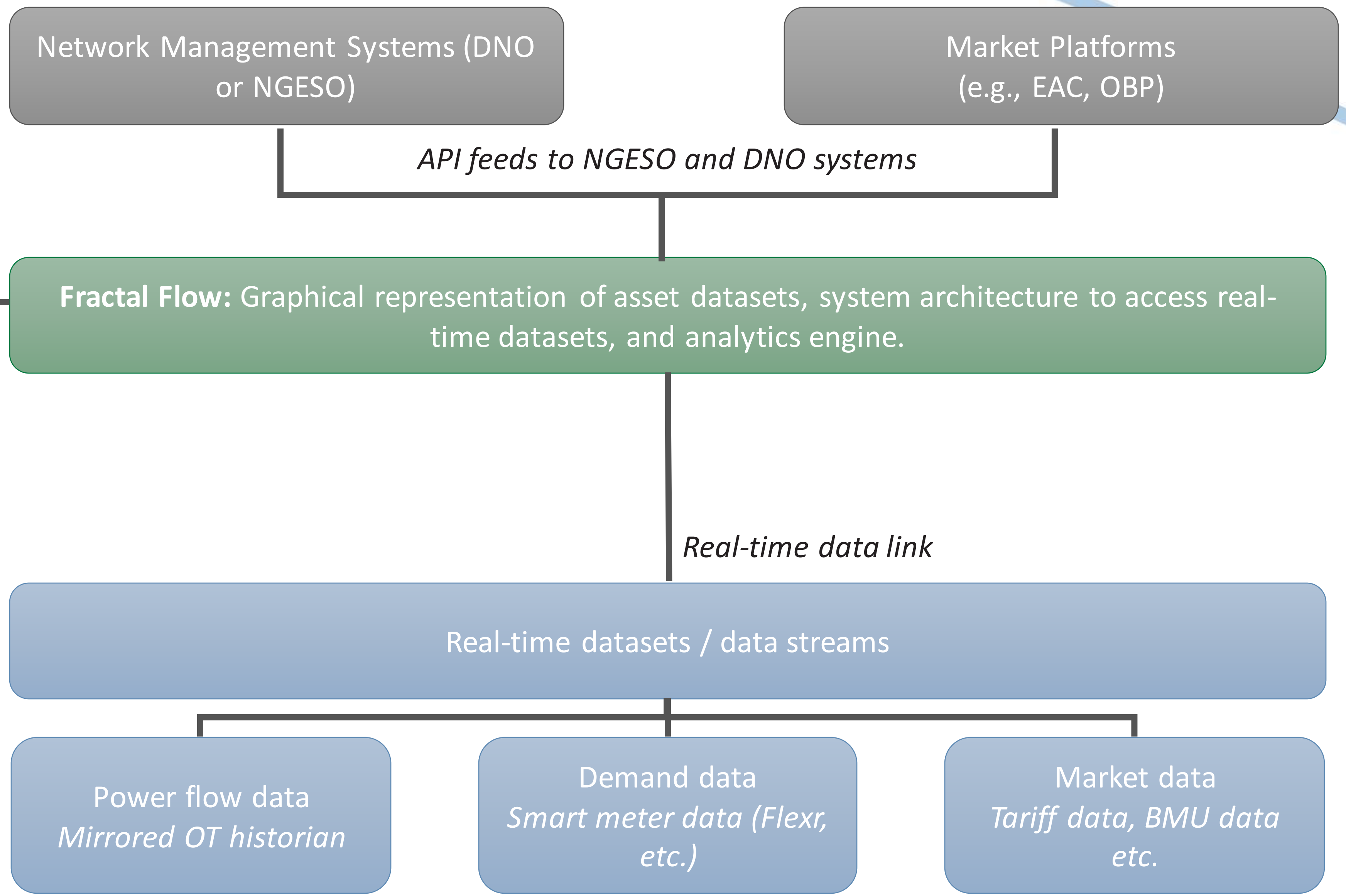
The following slides seek to:

- Outline where Fractal Flow sits between different data streams and control room software.
- Provide an initial, indicative solution architecture for Fractal Flow.
- Summarise initial discussions with NGESO stakeholders about future interoperability.

Where will Fractal Flow sit?

Asset data

Periodic data link (as DNO network topology changes)



Fractal Flow will integrate with network and market platforms.

It is intended that the datasets in blue are de-centralised and Fractal Flow accesses these as required, e.g., via technologies like Digital Spine which have been tested in Australia.

Indicative System Architecture

We have developed an initial indicative system architecture that is presented on the following slide.

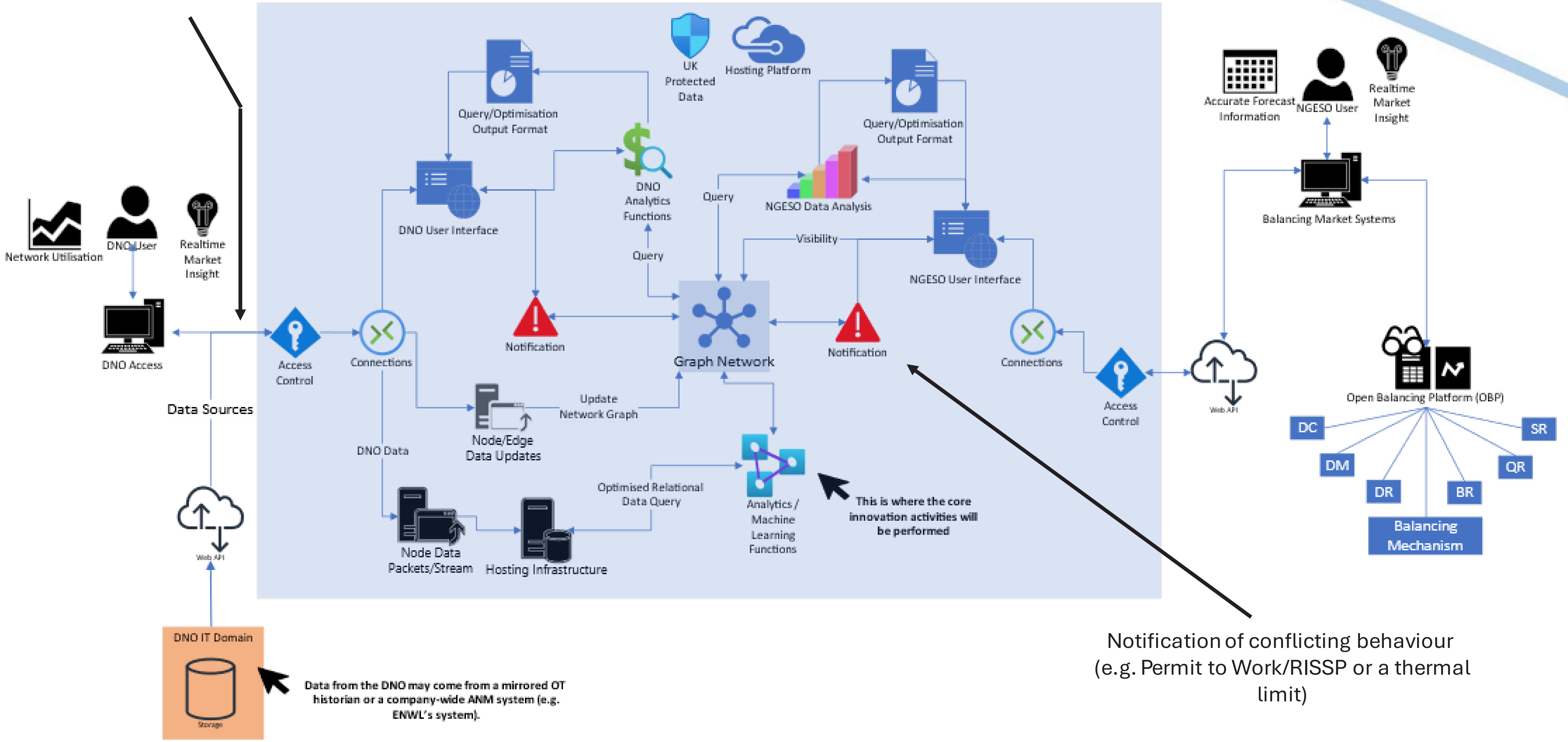
At a high-level, Fractal Flow will receive data from DNO sources via a data link, embed that information within a graphical database and provide a central analytics platform to facilitate User specific queries, optimisation and constraint management for both NGESO and DNOs.

It is noted that:

- The wider system architecture will be considered early for design, deployment, integration compatibility and scalability.
    - Solutions like GRID-OS (a GE platform) could be used but will need to be balanced against a vendor agnostic solution.
- Fractal Flow's Alpha phase does not aim to resolve all system architecture challenges but identify and begin the design process.
- The Alpha phase will develop a standalone tool to demonstrate how the use cases can be achieved to support BaU.
- Existing initiatives at NPg, broader network governance and previous innovation projects will be leveraged to help develop a viable solution – addressing topics like data format and latency.
- See existing initiatives for Fractal Flow synergies, where previous insights can be leveraged to accelerate development.

FRACTAL FLOW – INDICATIVE SYSTEM ARCHITECTURE

Data streams and DNO user interface access point



Notification of conflicting behaviour (e.g. Permit to Work/RISSP or a thermal limit)

Initial Feedback and Considerations

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NGESO

- There are changes in how NGESO are managing their network and the processes for different data links and communication protocols are being updated.
- Fractal Flow is likely to be part of their virtual desktop infrastructure (VDI) for control room software alongside their Network Control and Management Software (NCMS) and their market platforms such as OBP.
- It is crucial to design the architecture of Fractal Flow to ensure it integrates and is interoperable with NGESO's network infrastructure and protocols.

NPg

- Community DSO [1] is an active project at NPg that aims to understand, and to provide initial estimates of the magnitude of the technical, social and economic issues that are important in determining whether Smart local energy systems are a viable future option and to identify barriers to implementation. Fractal Flow aims to provide complimentary capabilities for this existing innovation initiative in later phases.
- NPg are have plans in place to develop their capabilities in: Advanced DMS, Network Operations, Automation & AI, LV Management Technology, DERMS, ESO ICCP Link, Microgrid Management, Flexibility Services and Network Operations. Fractal Flow would form a crucial layer higher level supervisory layer to collate and analyse data associated with each of these topics whilst also providing a centralised means to co-ordinate their services.
- Real Time Data has existing limitations due to data transmission and channel spacing of Free-space Cellular (Radio) vs Fiber Optic data links, this is presented in the Roadmap, Technology Readiness Levels for Real Time Data. Progressing access to real-time data is a crucial enabler for Fractal Flow. Fractal Flow will be developed in parallel with other initiatives that are targeting real time data access to provide an optimised SIF workflow and will give an end user experience that extracts the maximum operational value from the data when it becomes available.
- NPg have expressed interest in where Fractal Flow aligns, conflicts or enhances existing company initiatives.
  - Digital Spine
  - Data Sharing Infrastructure

[1] Energy Networks Association, 2022, 'Community DSO', https://smarter.energynetworks.org/projects/npg_nia_039/

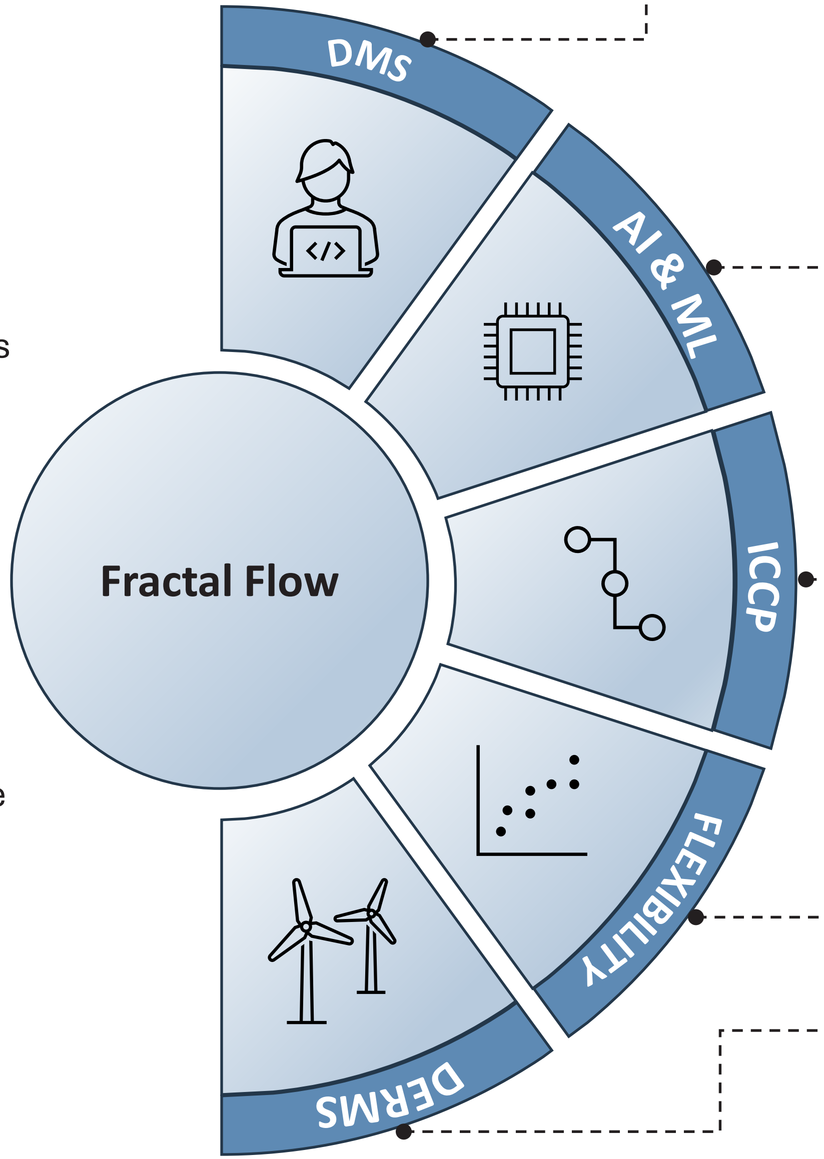
NPG Initiatives & Fractal Flow

Fractal Flow will provide NPg with an accelerated development programme for targeted internal development initiatives.

During visits to NPg, the data pathways were discussed, which has helped to identify the performance requirement for 30min data availability.

Additionally, at lower network layers current measurements are non-directional resulting in uncertainty when aggregated across the network.

Data collection barriers will need to be evaluated in detail during Alpha and Beta.



DMS
Enhanced features to improve grid operations.

AI & ML
Accelerated development time for NPg deployment.

ICCP
Alignment the ONP – Operational Data Sharing directives + better understanding of use cases.

Flexibility
Enhanced analytics for operational insight and network utilisation.

DERMS
Development of required infrastructure to optimise DERs

Data Analytics and ML References

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ID	Reference
ML1	Nellikkath, R. and Chatzivasileiadis, S. (2022) 'Physics-Informed Neural Networks for AC Optimal Power Flow', *Electric Power Systems Research,* 212, https://doi.org/10.1016/j.epsr.2022.108412
ML2	Van Hentenryck, P. (2021) 'Machine Learning for Optimal Power Flows', *INFORMS TutORials in Operations Research,* https://doi.org/10.1287/educ.2021.0234
ML3	Primadianto, A. and Lu, C. (2017) 'A Review on Distribution System State Estimation', *IEEE Transactions on Power Systems,* 32(5), https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7779155
ML4	Jafari, M. et al. (2022) 'A Survey on Deep Learning Role in Distribution Automation System: A New Collaborative Learning-to-Learning (L2L) Concept', *IEEE Access,* 10, https://doi.org/10.1109/ACCESS.2022.3195053
ML5	Aslam, S. et al. (2021) 'A survey on deep learning methods for power load and renewable energy forecasting in smart microgrids', *Renewable and Sustainable Energy Reviews*, 144, https://doi.org/10.1016/j.rser.2021.110992
ML6	Alimi, O. A., Ouahada, K. and Abu-Mahfouz, A. M. (2020) 'A Review of Machine Learning Approaches to Power System Security and Stability', *IEEE Access,* 8, https://doi.org/10.1109/ACCESS.2020.3003568
ML7	Zufferey, T., Renggli, S. and Hug, G. (2020) 'Probabilistic State Forecasting and Optimal Voltage Control in Distribution Grids under Uncertainty', *Electric Power Systems Research*, 188, https://doi.org/10.1016/j.epsr.2020.106562
ML8	Zhang, Y. et al. (2022) 'Review on deep learning applications in frequency analysis and control of modern power system', *International Journal of Electrical Power & Energy Systems,* 136, https://doi.org/10.1016/j.ijepes.2021.107744
ML9	Marković, M., Bossart, M. and Hodge, B. (2023) 'Machine learning for modern power distribution systems: Progress and perspectives', *Journal of Renewable and Sustainable Energy,* 15(3), https://doi.org/10.1063/5.0147592
ML10	Zhang, Z., Zhang, D. and Qiu, R. C. (2020) 'Deep Reinforcement Learning for Power System Applications: An Overview', *CSEE Journal of Power and Energy Systems,* 6(1), https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8859593

Discovery Phase Work Package Plan

WP1: Feasibility Assessment

WP2: Cost Benefit Analysis

- Evaluate the benefits provided by Fractal Flow
- Assess the cost of delivering Fractal Flow

WP3: Technology Roadmap

WP2: Cost Benefit Analysis

Objectives:

1. **Evaluate the benefits provided by Fractal Flow**
    - Note: this includes both quantitative and qualitative benefits of a BaU version of Fractal Flow assuming buy-in from all DNOs and NGESO.

2. **Assess the cost of delivering Fractal Flow**
    - This cost includes development costs for a BaU product and ongoing support and maintenance.

Note: the results here are also captured in the Ofgem CBA tool spreadsheet.

These slides expand on the benefits capture and then discuss the cost estimates for developing Fractal Flow.

Cost Benefit Analysis Structure

The CBA is presented within the following sections.

1. Methodology
2. Benefits capture:
   i. Establish the context for the CBA analysis, BM services and future trends
   ii. Define the services the study applies to, linking with broader network operations
   iii. Evaluate the potential impact Fractal Flow will have on these services
   iv. Outline the methodology for data extraction
   v. High-level summary of benefits capture
   vi. Sensitivity analysis from CBA
   vii. Discussion of impact on constraints
   viii. Derived CO_2 saving if services are offset with LCTs
   ix. Data source references
   x. Key Assumptions
   xi. How these benefits link to ML use cases
3. Cost estimate

Cost Benefit Analysis Methodology Overview

Step 1: Define data inputs

1. Define use cases for Fractal Flow.
2. Determine baseline scenario.

Step 2: Determine cost of developing and operating Fractal Flow

1. Use benchmark data platform costs as basis of cost estimation.
2. Refine based on subject-matter expertise.

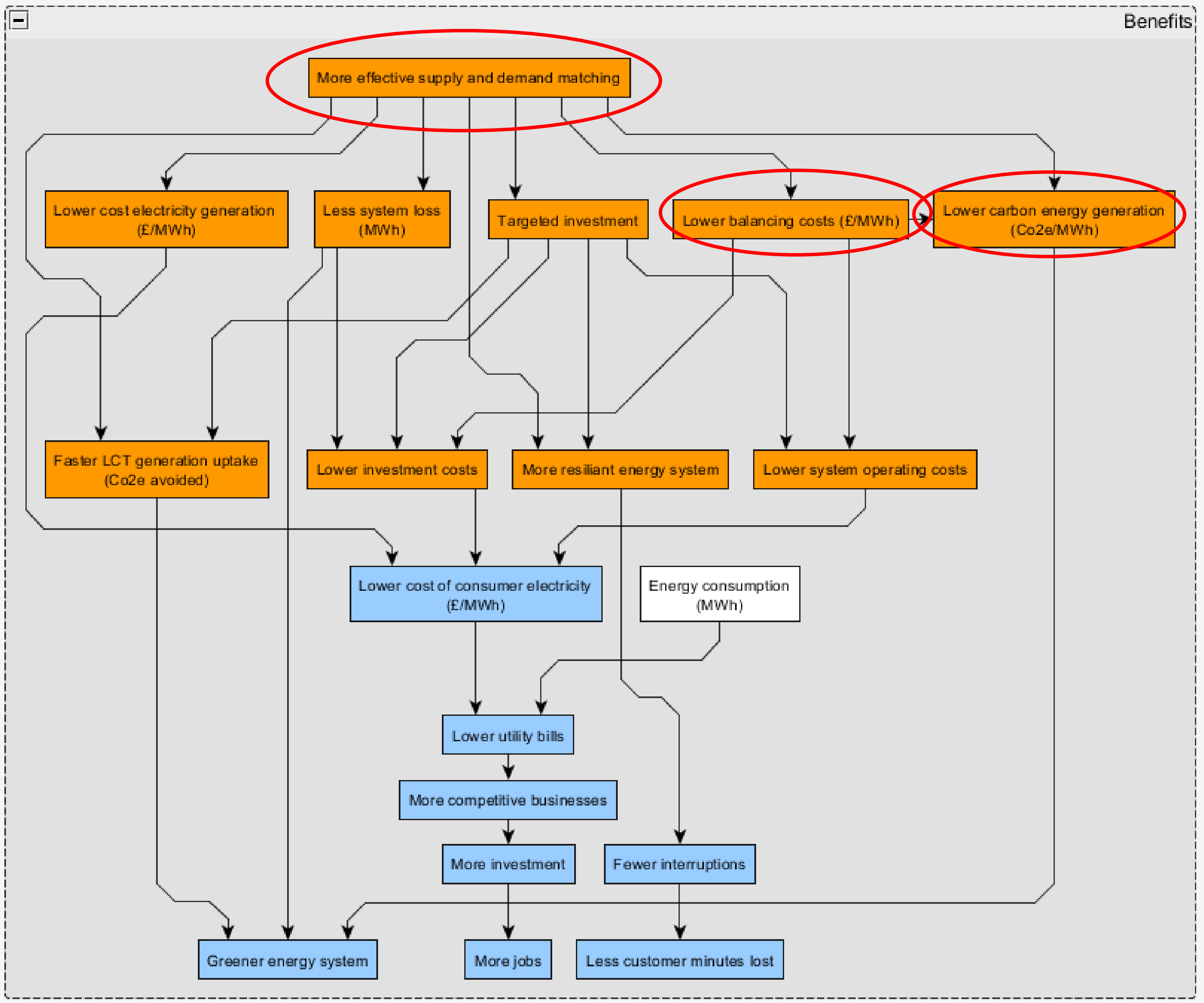
Step 3: Determine expected benefits of Fractal Flow

1. Identify and define all expected benefits (see next slide).
2. Focus on high-impact benefit stream (balancing mechanism).
3. Quantify expected benefits from Fractal Flow using three-point estimates and triangulation.
4. Take a conservative 1st percentile (p1) estimate from the estimated benefits distribution.

Step 4: Compare costs vs benefits

1. Compare cost vs benefits based on comparison between baseline (business as usual) and option 1 (Fractal Flow exists).

Cost-Benefit Analysis – Defining Benefits



Consumer benefits

System benefits

The diagram shows all the expected benefits that could result from Fractal Flow. The CBA focuses on the impact on system-level balancing mechanism costs avoided, and the associated carbon emission savings, resulting from more effective supply and demand matching and visibility of DERs from Fractal Flow.

Benefit Capture – Background Context

- Fractal Flow will receive data at a ½ hourly resolution making the solution optimal for providing benefits associated with a reduction in uncertainty in Balancing Mechanism (BM) procurement due to operational time scales of this network security measure.
- Historically, the BM has been dominated by large thermal plants, which are mandatory participants in the service as defined by their license condition.
- This contribution is also underpinned by a high level of fidelity within the monitoring and communication infrastructure associated with central volume allocation (CVA).
- For NGESO, utilisation of such systems for BM have been preferable due to the efficiency of their dispatch.
    - i.e. only a single instruction to a single plant.
- Thermal plant also represents security for the system through its intrinsic inertial contribution, helping to stabilise voltage fluctuations during the sudden load steps associated with faults.
- With increasing uptake of renewables, supplier volume allocation (SVA) and virtual lead party (VLP) are presenting new opportunities and challenges for the system operators.
- In response to these changes, NGESO have developed the open balancing platform (OBP).

Benefit Capture – Service Overview

Ancillary services – monopolised by batteries because of fast response time:

- Dynamic regulation (DR) | dynamic moderation (DM) – pre-fault services
- Dynamic containment (DC) – post fault services

Reserve services

- Linked with the largest potential step change on the network
  - Power Plant trip, interconnector trip etc.
  - Service Auctions allow NGESO to select cost effective availability prices (e.g. market platforms such as EAC, OBP)
- If additional services are procured outside of this auction, they can be expensive because the cheapest services will have already been selected via the auction.

Fractal Flow will improve the forecasting accuracy for NGESO and hence improve the precision of the required services acquired through auctioning.

Our cost-benefit analysis (CBA) has focused on the balancing mechanism as the operational timescales of balancing actions are well aligned with the real-time performance expectations of Fractal Flow. However, it is expected that Fractal Flow will also impact fast-acting ancillary services providing an additional cost saving. The increase in data availability and visibility will help reduce uncertainty, and the resulting conservatism in procured ancillary services, to reduce the need for higher-cost post-auction procurement.

Reserve
BM
STOR
BR/QR/SR

Response
DC/DM/DR
SFFR
MFR

Stability
inertia
reactive power

Constraints
network capacity
voltage
thermal

Balancing Services Development Timeline

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2023

BM Wider Access and Open Balancing Platform

Virtual Lead Parties as small as 1 MW will be able to participate. Ability to dispatch multiple smaller BMU.

Local Constraint Market Launch

Q1 2024

Balancing Reserve Go Live (Replacing Operating Reserve)

Decision to keep D-1 Reactive Market

MW Dispatch Product UKPN launch

EC5 CMIS interim service start

Q3 2024

Quick Reserve Phase 1 Go Live (Replacing Fast Reserve)

Stacking response and reserve services on the EAC

Q2 2025

Quick Reserve Phase 2 Go Live

Slow Reserve Go Live (Replacing STOR)

EC5 CMIS Enduring service start

Q1 2026

Short Term (D-1) Stability Market Targeted Go Live

Q4 2026

B6 CMIS Enduring service start

Comparison of Legacy and New Reserve Services

Operating Reserve

- Procured through the BM, trades, or system operator to system operator (SO-SO)
- Spilt into negative (Negative Reserve) and positive product (Operating Reserve)
- Procured in operational timescales (between real-time to 4 hours ahead)

Balancing Reserve

- Secures headroom and footroom for regulating reserve
- Procured day ahead
- Spilt into negative and positive products
- 1 MW minimum entry requirement
- Must be a BM unit
- 30-minute Service Window (10-minute ramp)
- Expect service requirement of 500 to 2,500 MW

Fast Reserve

- Pre-fault rapid delivery of reserve for changes in demand or generation
- Procured intraday
- Suspended in 2020
- Ramp in 2 minutes
- 50 MW minimum entry (225 MWh/min)

Quick Reserve

- Pre-fault disturbances
- Procured day ahead
- Spilt into negative and positive products
- 1 MW minimum entry requirement
- Availability and utilisation payments
- Activation 5 to 15 minutes (1 minute ramp)
- Expect service requirement of 300 to 1,400 MW

Short Term Operating Reserve (STOR)

- Post-fault to recover system frequency from large loss
- Procured day ahead
- 3 MW minimum entry requirement
- Availability and utilisation payments

Slow Reserve

- Post-fault to recover system frequency from large loss
- Procured day ahead
- Spilt into negative and positive products
- 1 MW minimum entry requirement
- Availability and utilisation payments
- Expect service requirement of 1,400 MW

Balancing Mechanism Updates

There are updates to balancing mechanism that will affect the benefits captured in this CBA.

- The first phase of the OBP enabled bulk dispatch.
  - This provides the ability to optimise more bids/offers from batteries and small BMUs more quickly, and issue bulk instructions to hundreds of units simultaneously in real-time.
- Commitment to add 300 MW of aggregated assets.
- Removal of the ‘15 minute’ rule for storage assets enabling NGESO to see the state of energy for these assets.
- Procuring Balancing Reserve (BR) at a day ahead will save money because it prevents having to trade capacity or hold reserve in the BM closer to real-time as is the case with Operating Reserve.
- Fractal Flow will support these projected system updates.

Balancing Services Changes

There are balancing service changes that will affect the benefits captured in this CBA.

- The BM regularly must redispatch a significant proportion of scheduled generation, owing primarily to the fact that constraints on the system are not reflected in wholesale market trading.
- Improved forecasting (including National Demand forecasts) via Fractal Flow will reduce the volume of these redispatches.
- Improved understanding of smaller assets and aggregated assets will improve their utilisation in the BM and complement ongoing updates.
- It is unlikely to affect procurement of day ahead reserve services although it should reduce utilisation payments and may provide the confidence to reduce availability procurement
- Improved forecasting should reduce the actions in constraint markets because of a decrease in reactive actions.

Congestion Challenges – High Wind Conditions

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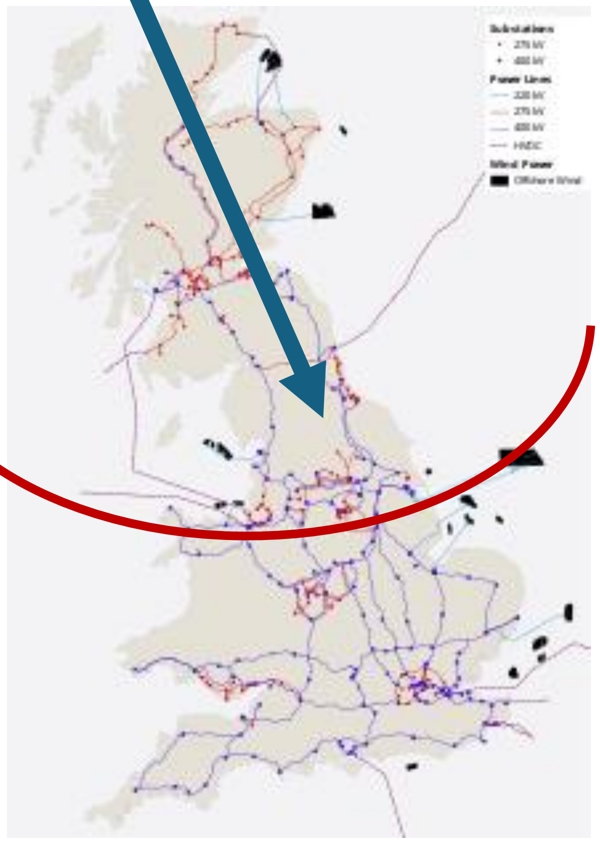
- During Discovery NGESO have identified the risks posed by congestion conflicts. These are associated with high wind production instances and the need to transmit power from the North to the South of the UK.
- If southernly net power demand is being addressed by embedded assets within local regions, which were previously reliant on wind, the need for wind power would be reduced and result in further curtailment.
- While this may present opportunities for northern industrial consumers and battery systems, the broader point of conflicting renewable curtailment is noted for further consideration during Alpha.
- For example, transmission level generation assets may be curtailed due to demand reduction met by DNO/DSO level DERs. Noting there may be a greater cost associated with curtailing transmission level generation assets (e.g. large wind farms), when compared to the local equivalent at a DNO level.

High wind production increasing southernly power flow.



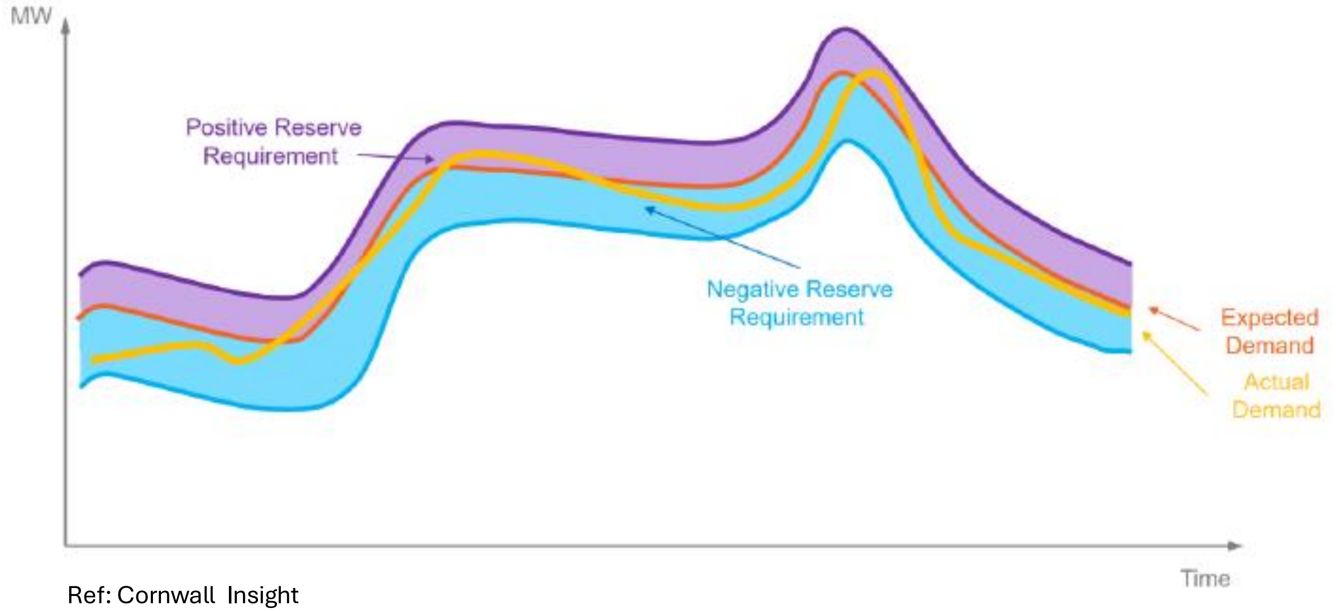
Active constraints triggered resulting in lower line capacity to manage fault scenarios. I.e., lines are not run at maximum capacity in case of a Transmission Fault, which would result in the power demand being picked up by the remaining lines.

Benefit Capture – Balancing Mechanisms Savings

Fractal Flow will improve the forecasting accuracy of Expected Demand (orange) compared with Actual Demand (yellow).

Improved forecasting precision will lead to a reduction in conservatism during the procurement of positive and negative reserve (purple and blue respectively), leading to Balancing Mechanism Savings.

This CBA is focused on demonstrating the potential extent that Fractal Flow can impact this sub-section of the energy market.



Ref: Cornwall Insight

Benefits Capture – Assumed BM Impact Assessment

This table captures the percentage reduction of Fractal Flow on the respective BM Categories.

Balancing Volume - Balancing Categories	Description	Fractal Flow Impact	Capability Score	Percentage Impact (%)	Comments/Justification
Minor Components	These are small adjustments made to electricity generation or consumption to maintain balance on the grid. They typically involve minor changes to power output or consumption levels.	Medium	High	30-50	Better network visibility and real time data would allow these scenarios to be identified more clearly.
Response (Absolute - BM Only)	This refers to a specific type of response provided by certain balancing mechanisms (BM). It involves an immediate and absolute adjustment to electricity supply or demand in response to grid imbalances.	Low	Medium	2-5	More co-ordination. More data for holistic optimisation. Impact minimisation.
Fast Reserve (BM Only)	This is a type of reserve capacity that is quickly available to respond to sudden changes in electricity demand or supply. It is typically activated within seconds to address rapid fluctuations on the grid.	Low	Low	0-1	Too fast acting to be responded to directly. Could be visible with real-time data but Fractal Flow would not action this.
Negative Reserve	Negative reserve refers to the capacity available to reduce electricity supply or increase demand in response to an excess of generation on the grid. It helps prevent grid instability by adjusting supply to match demand.	Medium	High	30-50	Improved data and network visibility, along with additional analytics from including weather API forecasting and customer data, is expected to provide insights that would reduce the volume of negative reserve.
Constraints [1]	Constraints are limitations or restrictions on the operation of the electricity grid, often due to factors like transmission capacity or grid configuration. Managing constraints involves ensuring that electricity flows within safe and efficient limits.	Medium	Low	10-15	Capturing constraints within a graph network will allow for large improvements when combined with analytics.
STOR (Short-Term Operating Reserve)	STOR refers to reserve capacity that can be deployed quickly to address short-term imbalances between electricity supply and demand. It provides additional flexibility to the grid operator in managing fluctuations.	Low	Medium	2-5	Fast acting services are typically due to unforeseen circumstances, and likely to be covered by Ancillary Services.
Operating Reserve	Operating reserve is the capacity held in reserve to address unexpected changes in electricity supply or demand. It provides a buffer to ensure grid stability and reliability, particularly during times of high demand or unexpected outages.	Medium	Medium	15-30	Fast acting services are typically due to unforeseen circumstances, and likely to be covered by Ancillary Services.
Energy Imbalance	Energy imbalance occurs when the amount of electricity generated does not match the amount consumed on the grid. Balancing mechanisms and reserves are used to address energy imbalances and maintain grid stability.	Medium	High	30-50	Understanding energy imbalance is core to Fractal Flow. Combined with machine learning and AI it is expected to have a high impact.

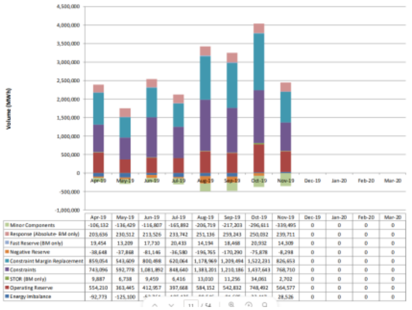
[1] Note that 'Constraints' is an aggregation of 'Constraints' and 'Constraint Margin Replacement'

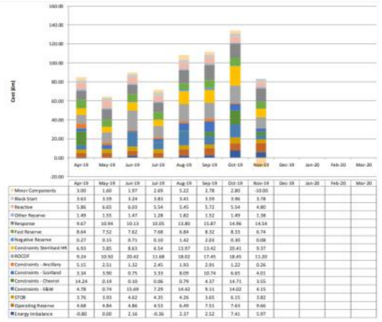
Fractal Flow Impact is a qualitative measure of how much Fractal Flow might reduce this service.

Capability Score is a qualitative measure of how likely it is that Fractal Flow will contain that capability.

The two categories have been mapped into a **Percentage Impact** that reflects the current understanding at discovery.

Benefits Capture – BM CBA Process





Step 1: Collated balancing cost data from MBSS, for the previous 5 years

Step 2: Extracted total balancing volume broken down by categories from MBSS summaries.

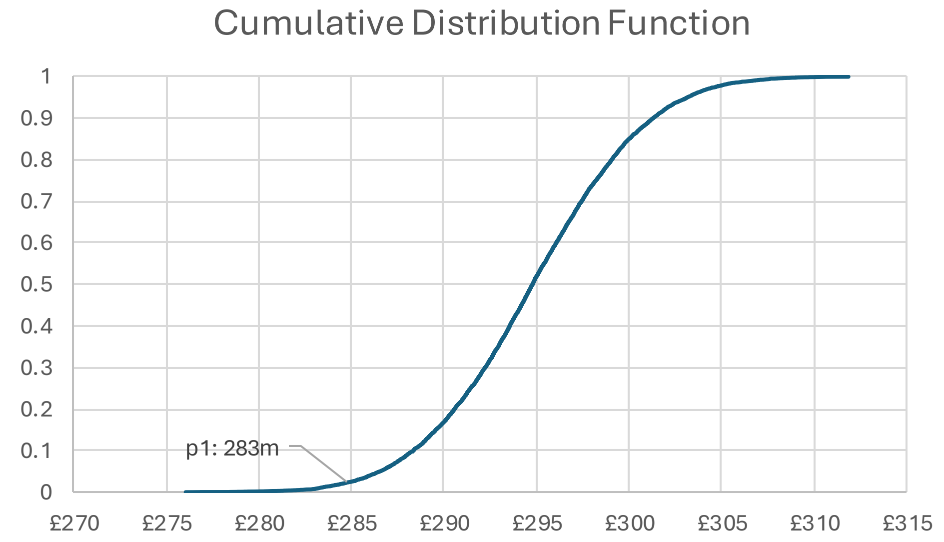
Step 3: Extract total cost of balancing in £m.

Step 4: Aggregate data

Step 5: Apply percentage impact scores

Step 6: Forecast results

Following this process the potential percentage reductions in BM services have been propagated through using Monte Carlo analysis to obtain a distribution of benefits per annum. The 1st percentile of this distribution is a value of £283M in benefits per annum.



Based on this distribution there is a wide range of benefits that Fractal Flow has the potential to unlock. However, this CBA assumes a conservative 1st percentile to initially parametrise benefits.

BM CBA Process Methods

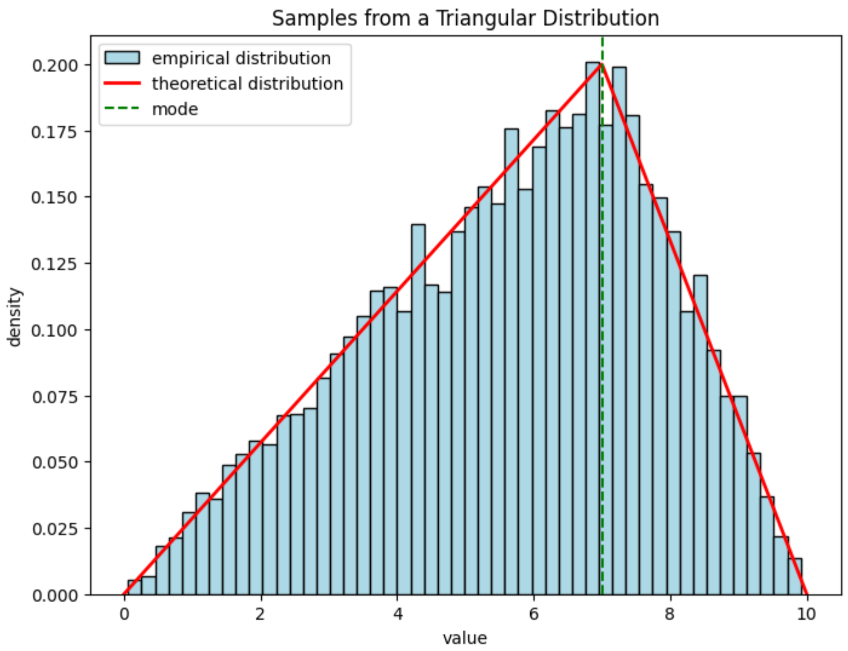
The BM CBA process used the triangular distribution with Monte Carlo simulation to provide estimates that account for uncertainty in the data and inputs.

Triangular distribution:

- This distribution uses a three-point estimate that includes the most optimistic (maximum), most pessimistic (minimum), and most likely (mode) scenario point estimates.
- The benefit of this distribution is in cases where the shape of the distribution is uncertain, but the maximum and minimum are known.
- The modal point estimate is a ‘best guess’ using prior expert knowledge.
- The triangular distribution is commonly used when estimating cost from historical data.

Monte Carlo simulation:

- Inputs are drawn randomly (thousands of iterations) from the triangular distribution and outputs computed.
- The simulated outputs are aggregated to provide an estimate which accounts for uncertainty in the inputs.



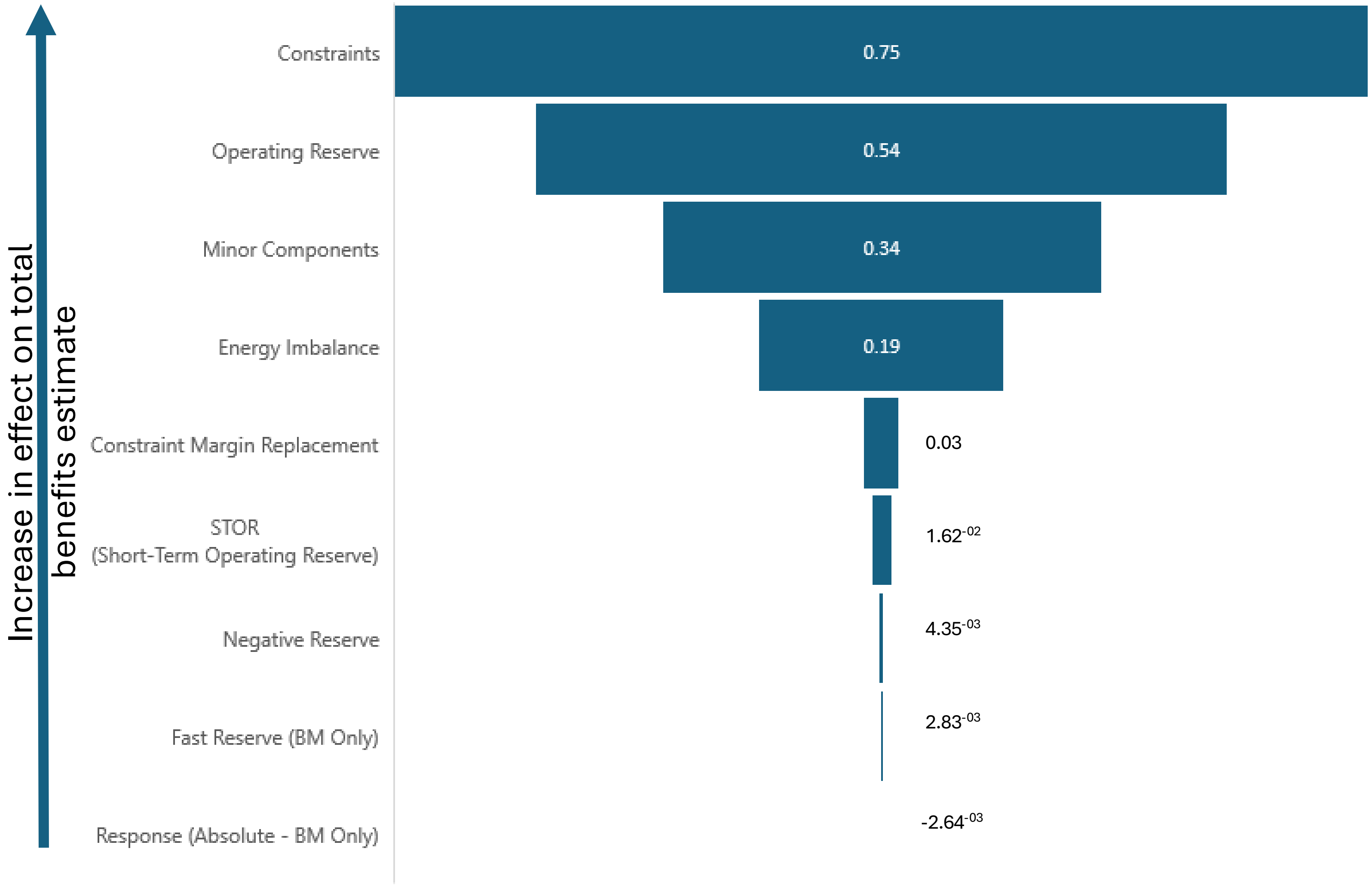
An example triangular distribution where the minimum = 0, maximum = 10, and mode = 7.

High-Level Cost Benefit Summary

- Fractal Flow provides a range of benefits, those that we have identified are:
  1. Balancing mechanism cost saving
  2. Decreased carbon dioxide emissions
  3. Ancillary services cost saving [1]
  4. Increased system security [1]
  5. Improved DNO investment decisions [2]
  6. Reduction in conservatism in new connections [2]
- From these benefits, we estimate that Fractal Flow will provide £283M cost per annum of potential saving through the reduction of procurement of balancing mechanism services. This equates to a potential carbon saving of 1.07 Megatons of CO2 per annum if these services were provided by a low carbon technology (LCT) service. Both the financial and CO2 savings are based on the 1st percentile of their respective distributions following a Monte Carlo Analysis, which represents a conservative lower range boundary.
- Future work will quantify the broader impact of Fractal Flow on markets such as ancillary services. It is assumed that the impact will not be negligible as ancillary services represent a similar order of magnitude of operating expense.
- We estimate the total development costs of Fractal Flow to reach BaU is within the order of £15M. We anticipate annual operations, maintenance, and support to be £1.5M per annum.

[1] We have focused on quantifying the benefits for the balancing mechanism services because we consider this to be a significant target area of benefit for Fractal Flow due to the time horizon provided by the system. There are also qualitative benefits associated with establishing a greater understanding of system security, which will provide value to customers.
[2] Note these benefits are covered by requirements given a COULD priority and therefore have not been the focus during discovery.

Benefits Capture - Probabilistic Sensitivity Analysis



The Pearson correlation coefficient is calculated to measure the association between each input parameter (the balancing measure impacted by Fractal Flow) and the output (total) benefit estimates. This provides a measure of the variance in benefits that arises from the variance in each input parameter.

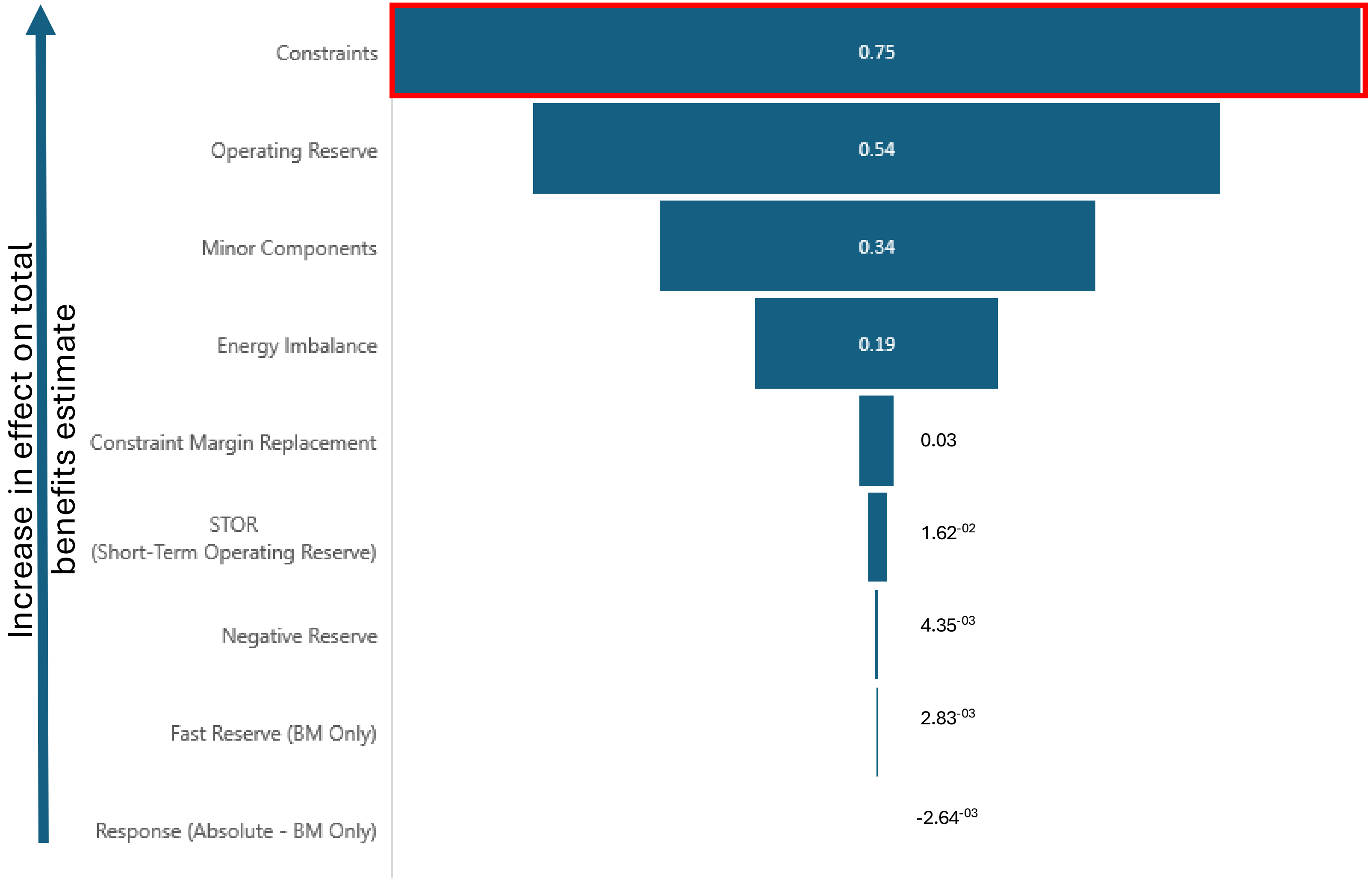
These results mean that Fractal Flow impact on constraints has the largest effect on the total benefits estimate, with its effect on response providing the least contribution to the total benefit estimate.

To maximise the benefit of Fractal Flow, capabilities should focus on impacting the following balancing mechanism services:

1. Constraints
2. Operating reserve
3. Minor components
4. Energy imbalance

Benefits Capture - Probabilistic Sensitivity Analysis

Use Cases – Constraints



CBA Key Findings

The CBA has highlighted that Fractal Flow can provide considerable benefits by reducing BM constraints. As a result, Fractal Flow at a minimum should develop ML use cases that target BM constraints at Alpha.

An example of such constraints is discussed within this section. The example identified is associated with excess wind power production in Northern Scotland resulting in net power flow Transmission capacity limitations.

How can Fractal Flow target BM constraints?

Fractal Flow will enable a better understanding of net power flow at GSPs across the country. This information will provide a strategic, national view of how best to utilise regional distribution networks to reduce transmission level constraints. This would allow the UK grid to improve utilisation of resource availability as the system evolves dynamically based on hourly, daily, seasonal and future weather conditions. For example, currently offshore wind connected in Scotland can be curtailed. This curtailment is associated with transmission constraints that could be alleviated by precuring more negative reserve in northern distribution networks.

This would provide opportunities to access additional revenue stacks at a DNO-level. This could also benefit future connections planning.

CBA Process - Carbon Dioxide Savings

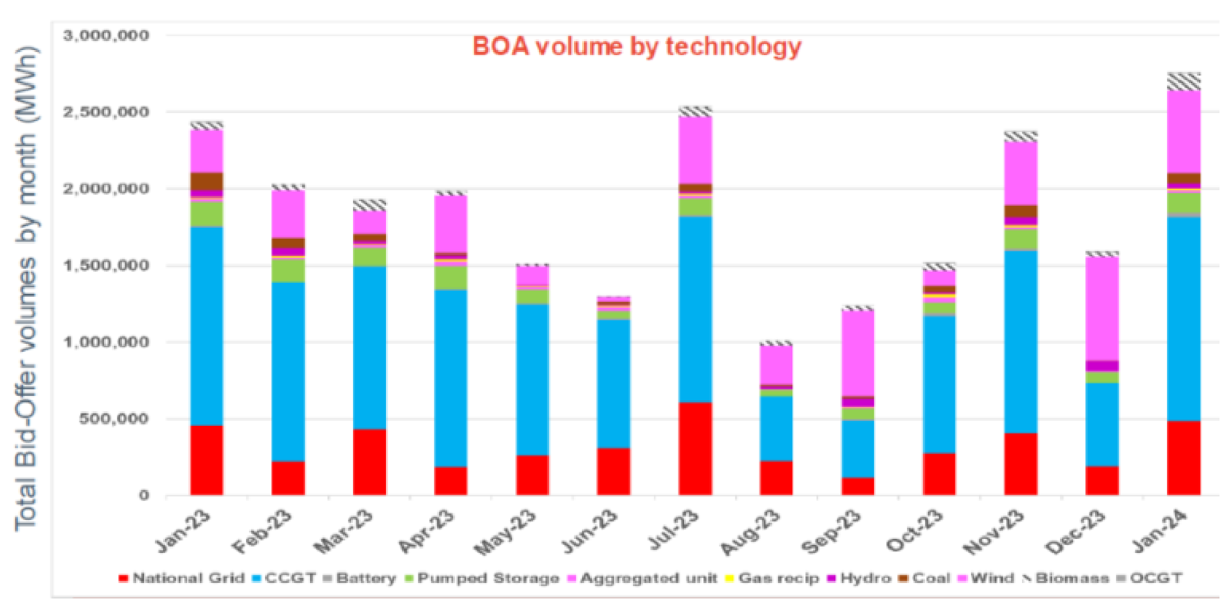
Based on the distribution of bid offer acceptance across different technologies, it was possible to correlate the utilisation of generation in MWh with an estimate of the associated CO2 production per month, when cross referenced with the corresponding MBSS.

For this assessment, data from Jan-23 to Jan-24 was used as a baseline, focusing on the dominant BM contributions provided by CCGT, OCGT, and coal power stations.

Summing these contributions per month per technology and taking a conservative saving at the 1st percentile from the annual benefits CO2 distribution, indicates 1.07 megatons of CO2 per year could be saved by Fractal Flow.

Using a carbon price between £40.64 and £43.49 per tonne (2024 prices[1]) equates to between £43.5k and £46.5k in benefits from carbon emission avoided per year.

Using the UK Government greenhouse gas emission central value for policy appraisal in 2024 prices (£256 per tonne[2]) the total cost avoided from carbon savings is £274k per annum.



Ref: Cornwall Insight & Elexon Data Sources

[1] Ofgem RIIO-ED2 Cost Benefit Analysis template – Fixed Data
[2] Department for Business, Energy & Industrial Strategy and Department for Energy Security & Net Zero, https://www.gov.uk/government/publications/valuing-greenhouse-gas-emissions-in-policy-appraisal/valuation-of-greenhouse-gas-emissions-for-policy-appraisal-and-evaluation#introduction

CBA Process – Data References

Dataset	Description	Use in CBA	Reference
Monthly Balancing Services Summary (MBSS)	MBSS gives the cost and volumes of balancing services used by NGESO.	We have used approximately five years of MBSS data (April 2019 to February 2024[1]) to obtain the total cost of balancing in £M per category of service.	https://www.nationalgrideso.com/data-portal/mbss
CCGT cost of CO2 Equivalent	A reference cost for CCGT CO2 equivalent.	Use to estimate carbon savings from substituting CCGT BM services with LCTs.	https://consult.environment-agency.gov.uk/psc/ng11-0ee-uniper-uk-limited/supporting_documents/Greenhouse%20Gas%20Assessment.pdf
OCGT cost of CO2 Equivalent	A reference cost for OCGT CO2 equivalent.	Use to estimate carbon savings from substituting OCGT BM services with LCTs.	https://www.ipieca.org/resources/energy-efficiency-database/open-cycle-gas-turbines-2022#:~:text=Typical%20carbon%20dioxide%20(CO2,500%20kg%20CO2%2FMWh
Coal cost of CO2 Equivalent	A reference cost for Coal CO2 equivalent.	Use to estimate carbon savings from substituting coal BM services with LCTs.	https://www.epa.gov/sites/default/files/2020-12/documents/power_plants_2017_industrial_profile_updated_2020.pdf

[1] At the time of study, data is only available up to the end of February 2024.

Benefits Capture - Assumptions

The following assumptions have been made during the CBA activity:

- The CBA does not account for new and future services that will come onto the market as the available data only captures historic services. We discuss future service trends here.
- The CBA focuses on balancing mechanism savings and does not quantify the benefits associated with ancillary services, increased system security, improved DNO investment decisions, nor reduction in conservatism in new connections. This can be investigated further during Alpha.
- CO_2/MWh has been derived from averaged data from a single reference.
- CO_2 impacts have only been considered for the major BM technology categories: CCGT, OCGT and coal.
- Fractal Flow has been fully adopted across the GB network and is a BaU product and service.
- Fractal Flow is based on historic data and therefore does not consider future energy scenarios.
- Uncertainty in cost has been represented by triangular distributions and conservatively the first percentile benefit value reported.
- The cost of atmospheric weather data APIs has not been evaluated during Discovery.
- It is assumed that the revenue stack from the BM will be distributed to sub-network assets operating below the GSP, which provide access to LCTs. This is expected to have a positive impact on DNO and customer revenue stacks by enabling access to the market.

Benefits and Data Analytics and ML

The benefits identified in the CBA are supported by Fractal Flow's use of data analytics and ML.

Fractal Flow Use Case Benefit	Data Analytics and ML Benefit
Balancing Mechanism Cost Saving	1. Improves forecasts of demand, service availability, and constraints. 2. Improves visibility of BMU. 3. Adds capability to optimise power dispatches for various scenarios (e.g., cost, carbon emissions, ramp-up time).
Decreased Carbon Dioxide Emissions	1. Adds capability to optimise power dispatches that prioritise low carbon emissions.
Ancillary Services Cost Saving	1. Optimises procurement of ancillary services through increased precision and reduced uncertainty of forecasts.
Increased System Security	1. The graph database provides enhanced visibility of the network. Users can query nodes to return their information to support decision making. 2. Improves forecasting and procurement from balancing and ancillary services. 3. Increases the stability of the system. 4. Reduces outages through fault prediction and reduced uncertainty of demand and generation.

Fractal Flow Costs

- There are several initiatives that have developed data platforms with analytics capabilities (albeit these do not have the functionality proposed within Fractal Flow):
  - **Near real-time data access (NeRDA)** – Developed a near real-time data link for power flow data, IT infrastructure and analytics for a small section of SSEN-D's network in Oxford.
    - Phase one (2020-2024) cost £1M and focused on creating an API link and setting up the IT infrastructure [1].
    - Phase two (2023-2025) cost £495k and developed the analytics capabilities [2].
  - **Flexr** – Developed a central data platform for smart meter data, DNO data, and a DER register. The solution is cloud-hosted and UK Protect classified.
    - ElectraLink spent £3.5M in initial funding for a minimum viable product (MVP) of Flexr [3].
    - Obtained £10M in NIC funding (2021-2022) to develop Flexr into a BaU product [3].
- Based on these projects we estimate Fractal Flow would cost £10M-£15M to develop.
- Ongoing maintenance and support costs are estimated at 10% of development costs, e.g. £1M-£1.5M per annum.
- The uncertainty in this estimate will reduce during Alpha where software requirements are defined.
- **The key innovation and value of Fractal Flow (as well as differentiator with projects such as NeRDA and Flexr) is the analytics capabilities to be integrated with the data platform as well as the interoperability of the platform to interface with other DNO NMS.**

[1] Energy Networks Association, 2020, 'Near Real-time Data Access (NeRDA)', https://smarter.energynetworks.org/projects/nia_ssen_0050/

[2] Energy Networks Association, 2023, 'Near Real-time Data Access 2 (NeRDA 2)', https://smarter.energynetworks.org/projects/nia_ssen_0070/

[3] Ofgem, 2020, 'Network Innovation Competition Screening Submission Pro forma', 'Flexr', https://www.ofgem.gov.uk/sites/default/files/docs/2020/05/flexr_npg_0.pdf

Discovery Phase Work Package Plan

WP1: Feasibility Assessment

WP2: Cost Benefit Analysis

WP3: Technology Roadmap

- GAP analysis
- Technology Roadmap

WP3: Technology Roadmap Overview

Objectives:

1. **Establish Technology Readiness Levels for Component Technologies**
    - Note this is from the point-of-view of Fractal Flow rather than the technologies' maturity. Some of the component technologies by themselves are already at mid-high TRL levels, however further development is required for them to be ready for Fractal Flow as a solution..
2. **Define High-Level Fractal Flow Workflow**
    - Note this provides the understanding at the time of writing and is subject to change as project definition matures.
3. **Capture Funding Gates High-Level Fractal Flow Workflow**
    - Note these are pre-defined by the SIF funding process
    - See Roadmap row 'Funding' in relation to the vertical development gates.
4. **Identify Supporting Initiatives:**
    - Innovation Projects
    - Regional Development Programmes
    - Open Network Panel
5. **Review Current Regulations:**
    - Grid Codes

Technology Readiness Level for Fractal Flow

Technical Readiness Level (TRL) Definitions

1	Basic Technology Research
2	Basic Technology Research | Research to Prove Feasibility
3	Research to Prove Feasibility | Technology Development
4	Technology Development
5	Technology Development | Technology Demonstration
6	Technology Demonstration | System/Sub-system Development
7	System/Sub-system Development
8	System/Sub-system Development | System Test, Launch & Operations
9	System Test, Launch & Operations

The reader should note that the Technical Readiness Levels of the Technology are assessed from the point-of-view of Fractal Flow.

It is understood that several component technologies which are anticipated to facilitate Fractal Flow are already established at varying degrees of Technical Readiness.

Discovery has focused on building this understanding and identifying the key enablers and barriers which are required to deliver a system which can meet the User Requirements that have been defined by NGESO and NPg.

This approach has allowed Fractal Flow to identify the core innovation elements to focus on during Alpha.

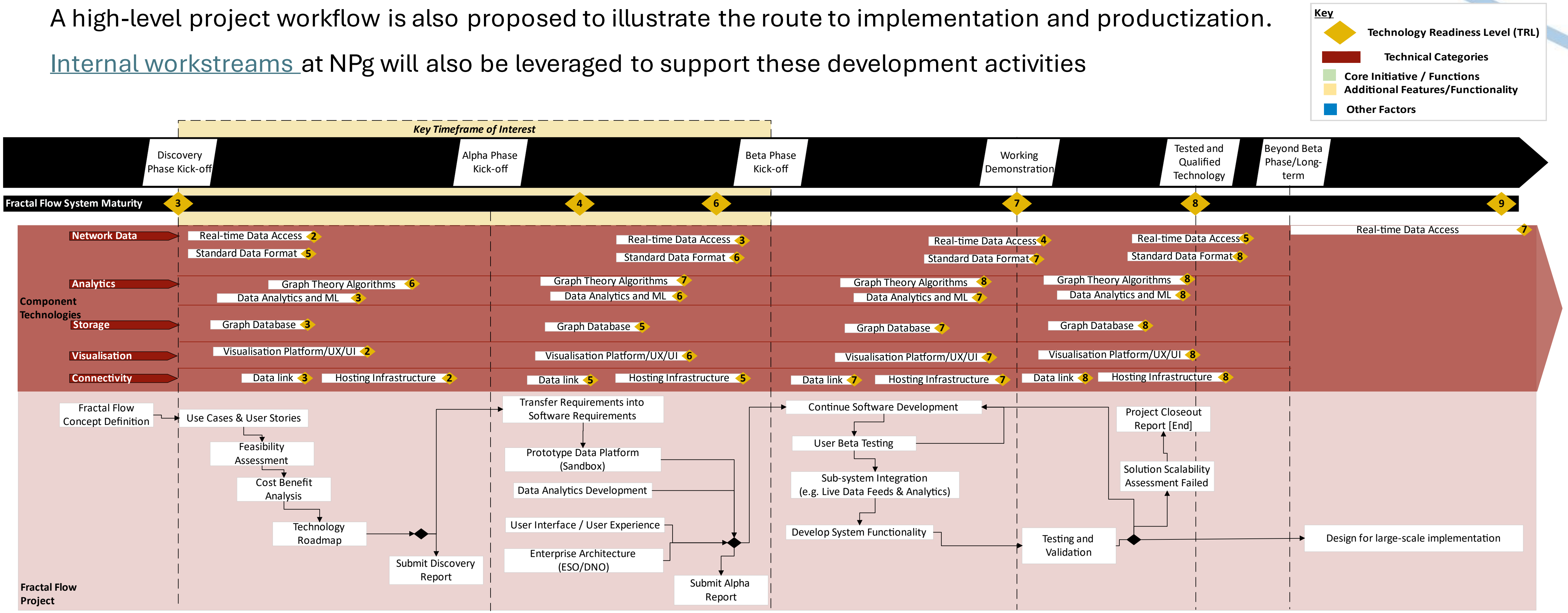
Technology Roadmap

The figure below captures the component technologies required to deliver Fractal Flow as a system.

It also provides an indication of the TRL levels for the component technologies in relation to the SIF development phases.

A high-level project workflow is also proposed to illustrate the route to implementation and productization.

Internal workstreams at NPg will also be leveraged to support these development activities



GAP Analysis (1)

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No.	Component Technology	Current State	Desired Future State	GAP	Actions
1	Real-time data access	**TRL 2**: 1. Real-time data is available at network management system (NMS) level at 30min averages. 2. OT/IT systems are not in place across all DNOs that would enable data sharing. 3. Data links are not available for transmitting data from secure NMS systems into Fractal Flow for every DNO (some DNOs are more advanced). 4. Smart meter data currently has a latency of around 72hrs to be processed and stored on the cloud.	**TRL 7**: 1. The identified real-time datasets need to continuously stream to Fractal Flow every 30mins. 2. A mirrored OT historian needs to be available at each DNO that could be shared with Fractal Flow 3. Latency in storage and processing of data need to be within the real-time window.	1. 'Real-time' power flow data is not currently shared between DNOs and ESO, but in discussion with Open Network Panel. 2. Latency in current data link and storage. Some data uses networks which have channel spacing limitations. 3. Data link that can share the required volume of data in real-time does not exist and is key enabler for Fractal Flow at NPg.	1. Initiatives such as NeRDA and Flexr are working on developing technologies for real-time access to power flow and smart meter data. Key insights and conclusions will be leveraged and used in Fractal Flow at Alpha. 2. Data collection barriers will need to be evaluated in detail during Alpha to further understand the limitations of existing systems and identify opportunities for improvement (e.g. dedicated fibre-optics or alterative data communication protocols).
2	Standard Data Format	**TRL 5**: 1. There are initiatives that have defined standard data formats for datasets such as asset data, power flow data, and smart meter data. 2. These data formats may not meet all the requirements for Fractal Flow.	**TRL 8**: 1. A standard data format for the required datasets that provides all the information required for Fractal Flow.	1. The standard data formats that exist may not meet all the requirements for Fractal Flow.	1. Capture the data requirements from the data analytics processes and identify any modification required to standard data formats, e.g. CIM. 2. Establish suitable data format for data links.
3	Graph Theory Algorithms	**TRL 6**: 1. Graph theory is understood as a technology but its application within Fractal Flow is at concept stage.	**TRL 8**: 1. Graph algorithms will be fully developed and tested.	1. Graph theory algorithms for Fractal Flow need to be developed.	1. Develop graph algorithms for Fractal Flows through Alpha.

GAP Analysis (2)

No.	Component Technology	Current State	Desired Future State	GAP	Actions
4	Data Analytics and ML	**TRL 3:** 1. There are several initiatives and in-house developments at DNOs and NGESO to create the required ML and analytics models 2. Not all the required data analytics and ML algorithms exist to meet the use cases and user requirements.	**TRL 8**: 1. Core Data Analytics and ML applications will be fully developed and tested for BaU.	1. The data analytics and ML algorithms required for Fractal Flow either do not currently exist or are themselves at a low TRL levels (either innovation projects or research papers) and will need testing and validating in live environments.	1. Ensure data analytics and ML capabilities being developed through other initiatives and within DNOs and NGESO are incorporated as modules in Fractal Flow. 2. Identify and develop data analytics and ML capabilities not covered by existing programmes of work.
5	Graph Database	**TRL 3:** 1. An optimal ontology design for GB network assets is not defined. 2. Limit on the efficiency of querying graph databases as the number of nodes approaches the 10's of millions.	**TRL 8:** 1. An optimal ontology design that includes all useful relationship edges for analytics. 2. An efficient graphical database and associated infrastructure to enable queries and analytics within a 30min window.	1. Ontology design for GB network assets needs to be developed. 2. There may be a GAP in that graphical database infrastructure design and querying efficiency may need improvement if the ontology design includes additional node types beyond assets.	1. We will design an ontology as part of Alpha. 2. Commercial graph database providers are improving performance and capacity of graphical database solutions.
6	Visualisation Platform/UX/UI	**TRL 2**: 1. A bespoke UX/UI has not been designed or built for Fractal Flow and was not a focus during Discovery.	**TRL 8**: 1. Operational visualisation platform/UI/UX, allowing interaction with Fractal Flow data in accordance with User Requirements.	1. UX/UI for Fractal Flow needs to be developed	1. UX/UI user and software requirements 2. Wire framing and workshopping design 3. Front-end build/test/deployment.

GAP Analysis (3)

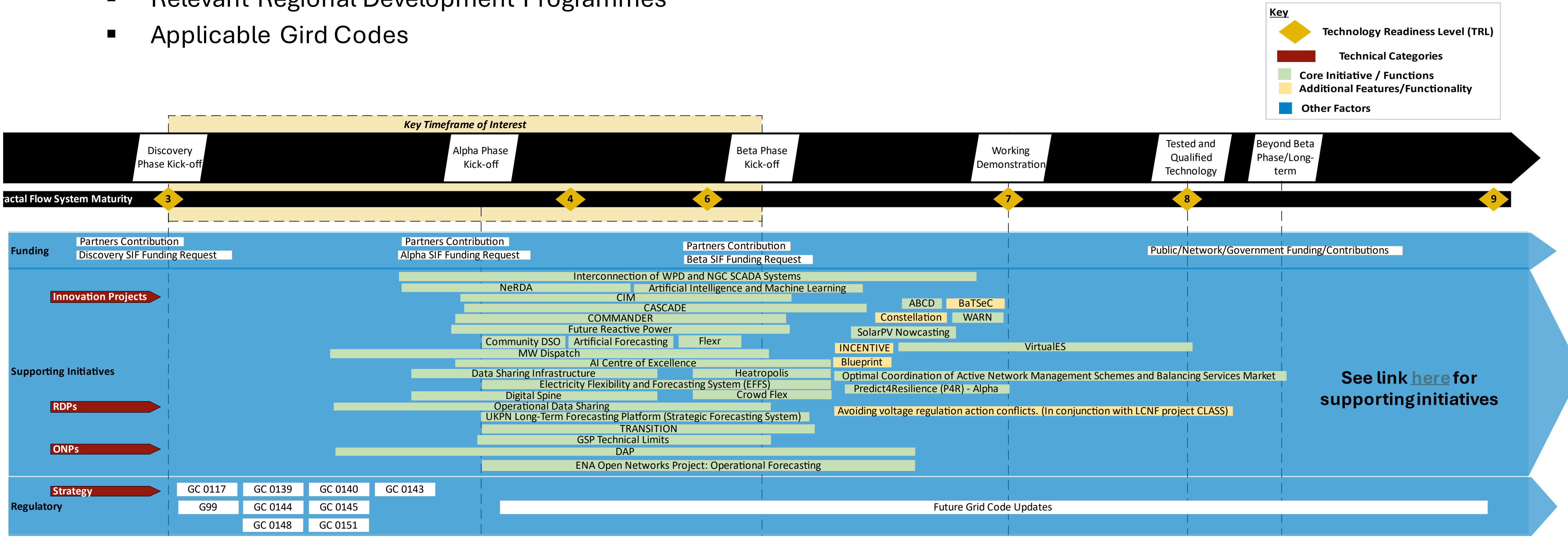
No.	Component Technology	Current State	Desired Future State	GAP	Actions
7	Data link	**TRL 3:** 1. TCP/IP based ICCP links have been developed but ONP governance has established that this is not suitable for all data types. See Wider Project Synergies for more details.	**TRL 8**: 1. A data link per identified dataset that is scalable for use with Fractal Flow (e.g. optimal interfaces, can handle throughput of data, not constrained by latency etc.) 2. Existing initiatives leveraged to determine optimal data link interfaces.	1. Data link solution used in GB networks needs improving to meet requirements for Fractal Flow.	1. Quantify the performance requirements necessary for Fractal Flow. 2. Monitor existing initiative and ensure continued engagement, feeding lessons learnt into system definition. 3. Understand data throughput and format limitations of existing initiatives and leverage technologies where applicable. 4. Develop and test Fractal Flow to verify the necessary performance requirements of the system.
8	Hosting Infrastructure	**TRL 2:** 1. Initiatives such as NeRDA have trialled approaches to collect and store data in conjunction with DNOs. 2. No hosting infrastructure has been developed for Fractal Flow during Discovery.	**TRL 8:** 1. A secure cloud-hosted platform that is accessible for all users given a set of permissions. 2. Storage and compute resource to store the identified datasets and run a range of data analytics and machine learning modules.	1. A secure cloud-hosted platform that is accessible for all users given their permissions. 2. A scalable cloud solution with the required storage and compute resource.	1. Potential Alpha partners with experience building UK Protect classified cloud-hosted data platforms for the GB networks have already been engaged with initial positive response. 2. Leverage previous innovation initiatives to develop a suitable hosting infrastructure. 3. Build/test/deployment of platform to collect, store, and access network data for Fractal Flow applications.

Initiatives – Introduction

- Following the gap analysis conclusions, we examined existing initiatives.
- The goal was to identify areas where work has been done or is actively being explored in relation to Fractal Flow's core themes and gaps.
- The subsequent section outlines these initiatives, highlighting their alignment with Fractal Flow.
- While included in the timeline, these initiatives are extracted to explicitly showcase their relevance to Fractal Flow for clarity.
- The primary objective is to ensure Fractal Flow identifies Component Technologies requiring further development to achieve the identified use cases, which can be individually focused on during Alpha.
- Additionally, the aim is to capitalise on previous or ongoing workstreams to enhance development focus and value.

Initiatives – Roadmap

- The figure below captures the existing initiatives that have been investigated during Discovery.
- Focus is given to :
  - Open Network Panel Directives (Operational Data Sharing)
  - Innovation projects which have technical elements that can be leveraged at system Technical Readiness Levels
  - Relevant Regional Development Programmes
  - Applicable Gird Codes



Supporting Initiatives (1)

See Roadmap: Innovation Projects | RDPs | ONPs | Strategy

Category	Initiative	Description	Synergy with Fractal Flow
Innovation	Future of Reactive Power	1. Exploring a reactive power market to address challenges posed by the shift from conventional to renewable and decentralised sources. 2. Aims to improve voltage control on the electricity system by accessing more reactive power in the right location and incentivising efficient technologies.	1. Monitoring reactive power is a core NGESO BaU function which FF can support. 2. This may require resolution higher than 30 mins which Fractal Flow would need to address.
Innovation	COMMANDER: Coordinated Operational Methodology for Managing and Accessing Network Distributed Energy Resources	1. Addresses uncertainties in the roles of NGESO and DSOs in the evolving energy landscape. 2. Aims to create flexibility market opportunities and deliver whole systems benefits through coordination schemes. 3. Deliverables include reports on trends, feasibility assessments, impact assessments, and a roadmap for coordination scheme deployment.	1. Contextualisation for service trajectory to inform FF development.
Innovation	CASCADE: Communication Adaptive Systems for Coordinated Architecture and Data Exchange	1. Develops software linking NGESO control room with DNO data, focusing on ANM schemes. 2. Enhances interoperability between NGESO and DSO centres, improves communication, and reduces conflicting balancing measures. 3. Aims to optimise renewable energy usage and expedite new connections for net zero goals.	1. NGESO interface platform, to be developed by Frazer-Nash through NIA.
Innovation	SolarPV Nowcasting	1. Develops a deep machine-learning model for probabilistic solar nowcasts using satellite images and weather predictions. 2. Prototype tool displayed in control room, with improved forecast accuracy. 3. Next steps include feedback incorporation and consideration of NGESO utilisation.	1. Improved reliability for weather dependent data.
Innovation	Heatropolis	1. Accelerates decarbonisation of heat networks through data-driven framework. 2. Active demand management and flexible connections using AI simulations and near real-time data exchange.	1. Supports FF's requirement for real-time data exchange. 2. Supports use cases for dynamic decision making and flexibility.

Supporting Initiatives (2)

Category	Initiative	Description	Synergy with Fractal Flow
Innovation	Artificial Intelligence and Machine Learning	1. Demonstrates value of ML for improving network understanding through LV monitoring and fault detection.	1. FF can learn from ML for monitoring and fault detection. 2. FF can further improve network understanding.
NGESO	DAP	1. NGESO Data and Analytics Platform.	1. Broader trend of digitalised systems to support NGESO procedures.
Innovation	Interconnection of WPD and NGC SCADA Systems	1. Establishes a real-time link between NGESO and Western Power Distribution SCADA systems. 2. Objectives include establishing the link, access to data, and security measures against cyber-attacks.	1. Leverage security requirement definition. 2. Learn from real-time link requirements to increase interoperability.
Innovation	Avoiding voltage regulation action conflicts. (In conjunction with LCNF project CLASS)	1. Explores innovative use of dynamic voltage regulation for demand response. 2. Aims to provide better value for money delivery of network services and assesses impact on existing TO assets.	1. FF will support voltage monitoring and conflict management. 2. Data resolution higher than 30 min may be required to provide this functionality.
Innovation	NeRDA: Near Real-time Data Access	1. Makes near real-time data for the Oxfordshire area available to stakeholders. 2. Implements technology solution for near real-time DNO data within the SEPD license area and assesses usability with stakeholder groups.	1. Potential Alpha partners identified. 2. Hosting architecture leverage. 3. Data processing and DNO procedures lessons. 4. API design for near-real time power flow.
Innovation	CIM: Common Information Model	1. Extends data matching process to 33kV, 66kV, and 132kV networks. 2. Tests benefits of CIM format network models in software adoption, data exchange with third parties, and system interfaces.	1. Establish a data format that may provide better interoperability.
Innovation	ABCD: ANM - Balancing Coordination Demonstration	1. Builds on NIA project for coordination between Balancing Services and ANM systems. 2. Upgrades ANM system to enable coordination under various operational scenarios and investigates potential financial impact.	1. FF would provide increased visibility of subnetwork behaviour and capacity, unlocking the innovations associated with ABCD.

Supporting Initiatives (3)

Category	Initiative	Description	Synergy with Fractal Flow
Innovation	Constellation	1. Demonstrates novel approach to protection and control by introducing local intelligence in DNO substations. 2. Aims to improve stability of network operation with adaptive protection systems.	1. Adaptive settings could be used to better optimise DNO power flows. 2. FF would provide a more holistic network view to support such applications.
Innovation	BatSeC	1. Develops new battery model combining data analysis with market understanding in three modules: Markets, Battery, and Dispatch Integration. 2. Provides improved capability for understanding battery storage scenarios.	1. Additional analytics features could be added to FF to support battery location analysis.
Innovation	WARN: Weather Alerts and Risk analysis for Network operators	1. Uses advanced statistical methods to understand weather impacts on network data. 2. Aims to improve monitoring and alerting over short-term, seasonal, and long-term periods.	1. Opportunity to build on approach to gain better predictive capability of power data with weather dependencies.
Innovation	INCENTIVE: Innovative Control and Energy Storage for Ancillary Services in Offshore Wind	1. Addresses stability issues caused by non-synchronous generation. 2. Seeks to maximize efficiency in network upgrades, improve resilience and reliability, and provide a novel approach to infrastructure investment.	1. FF can leverage study to facilitate custom optimisation analytics to support stability.
Innovation	VirtualES: Virtual Energy System	1. Establishes a data sharing infrastructure for interconnected digital twins of the energy landscape. 2. Improves simulation and forecasting abilities to support the vision of operating a zero-carbon electricity system.	1. FF supports the broader theme of network digitalisation.
Innovation	Blueprint	1. Identifies risks and uncertainties for connecting offshore wind farms into constrained areas of the GB network. 2. Aims to devise innovative and collaborative solutions to mitigate risks, including novel connection methodologies.	1. FF's graph network can help determine optimised connection opportunities.
Innovation	Artificial Forecasting	1. Tests machine learning algorithms for load forecasts at transformation points suitable for DSO systems. 2. Develops AI techniques for modelling load connections, integrating demands such as EV charging and local PV.	1. FF can use learnings to develop ML and AI techniques for NGESO and DNO use cases.

Supporting Initiatives (4)

Category	Initiative	Description	Synergy with Fractal Flow
Innovation	Optimal Coordination of Active Network Management Schemes and Balancing Services Market	1. Identifies and defines optimal T&D coordinated ANM schemes and evaluates their technical and commercial requirements. 2. Develops test cases to evaluate DER participation in ANM functions and balancing actions. 3. Aims to optimise coordination of ANM schemes with the balancing services market and develop a deployment plan.	1. FF core functionality is designed to unlock the generation potential of distribution level assets by provide increased visibility.
Innovation	Community DSO	1. Explores smart local energy systems as an approach to future energy systems architectures. 2. Aims to understand technical, social, and economic issues, assess viability, and identify implementation barriers.	1. FF can leverage DSO understanding of local energy systems to improve system definition.
Innovation	AI Centre of Excellence	1. Established an AI Centre of Excellence to support AI and ML in delivering innovation projects for net zero targets. 2. Created an AI use case framework and identified 100 AI/ML opportunities.	1. FF supports innovation net zero aims. 2. FF contributes to understanding of AI in this domain and can support the AI Centre of Excellence's objective.
Innovation	Electricity Flexibility and Forecasting System (EFFS)	1. Provides short-term forecasting for DSOs and enables automated constraint analysis. 2. Getting closer to real-time power flow and forecasts improves procurement.	1. FF supports forecasting and constraint analysis. 2. Learnings to support FF real-time data exchange. 3. FF consulting a solutions architect. Discussions with NGESO architect underway.
Innovation	Flexr	1. A data provision and standardisation service for DNOs and their customers. 2. Provides data for flexibility markets and is a central data service for planning, forecasting, operation and energy system data-driven integration.	1. Provides key datasets, DNO data and DER register and smart meter data. 2. Have created a UK Protect cloud-hosted solution for GB network data.
Innovation	Predict4Resilience	1. Prototype the Fault Forecasting Engine: Develop a statistical model using weather forecasts and historical data for predicting faults. 2. Further user engagement: Gather feedback from DNOs and infrastructure operators to ensure commercial viability and maximize uptake. 3. Build Wireframes/Mock-Ups: Create user interface designs to inform the Beta Phase development and incorporate Agile Methodology for fast implementation.	1. Real-time data access: Integrates real-time weather data and historical information to enhance fault prediction accuracy. 2. Power network visibility: Provides insights into the power network's status and potential vulnerabilities, enabling proactive response measures during severe weather events.

Supporting Initiatives (5)

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Category	Initiative	Description	Synergy with Fractal Flow
Innovation	Crowd Flex	1. Decarbonisation will result in greater low carbon technology in homes, reshaping demand and unlocking flexibility. 2. Flexibility cuts bills by shifting demand and supports the power system operation my smoothing the load profile. 3. Uncertainty exists about domestic flexibility's technical availability and effective incentivisation. 4. CrowdFlex Phase 1 quantifies household flexibility, identifies key parameters, and guides market development using Octopus Energy and Ohme's datasets.	1. Network visibility and real-time data access enhance understanding of domestic flexibility potential. 2. Real-time data allows for immediate adjustments to grid conditions. 3. Improved visibility enables more accurate forecasting of demand and supply. 4. Real-time access enhances the effectiveness of incentive mechanisms. 5. Combined, they support more efficient integration of flexible resources into the grid.
Innovation	Digital Spine	1. A digital spine facilitates data exchange of diverse datasets across multiple participants within a single integration.	1. FF can integrate with a digital spine, access the data flows, and undertake graph-based analytics and ML to support network visibility and forecasting.
Innovation	Data Sharing Infrastructure	1. Ofgem has made progress in data best practices and digitalisation but requires a seamless, secure data-sharing infrastructure, interoperable with other sectors. The FSO will need high-quality data for strategic decisions, and Ofgem should establish a task group to develop this infrastructure. This will support various regulatory models and enhance efficiency. A cultural shift towards digitalisation and adaptive regulation is essential. The initial focus should be on using data for network planning and incentive regulation, with the potential benefits of ex post regulation evaluated later.	1. Skill Development: Building expertise in managing real-time data. 2. Vision and Consultation: Setting standards for real-time data sharing. 3. Energy Digitalisation Orchestrator: Coordinating the development of data infrastructure. 4. Interim Task Group: Establishing early frameworks for real-time data sharing. 5. FSO Role: Ensuring continuous improvement of real-time data capabilities. 6. Incentives: Promoting connected digital twins and cross-sector data integration.
ONP	ENA Open Networks Project: Operational Forecasting	1. Reviews ML methods for operational forecasting across DNOs, using weather data, AI/ML models, and historic metering data. 2. Results in a significant improvement in forecasting accuracy, with DNOs benefiting from NGESO sharing data and forecasts.	1. Supports and advises selection of best ML methods for FF use cases. 2. Supports integrating weather data to FF. 3. FF to facilitate NGESO and DNO data sharing. 4. Supports NGESO and DNO forecasting use cases.

Supporting Initiatives (6)

Category	Initiative	Description	Synergy with Fractal Flow
ONP	Operational Data Sharing	1. Technical Working Group under ENA aims to standardise bilateral Tx-Dx data exchange. 2. Aims to ensure consistency in P,Q data exchange across GSPs.	1. Information on the operational capability of ICCP (data link requirements)
RDP	MW Dispatch	1. Provides a route for smaller parties to offer flexibility services to NGESO. 2. Aims to manage transmission network constraints through real-time dispatch of non-BM DER with commercial arrangements. 3. Requires operational visibility and commercial controllability for DER down to 1MW capacity.	1. Lessons learnt from existing procedures, 24hr notice vs hourly visibility.
RDP	GSP Technical Limits	1. Establishes a data-sharing link between NGESO and DNOs to share power flows at the GSP-level in real-time. 2. Aims to reduce connection time for distribution connected assets by relaxing technical constraints on physical assets in exchange for data.	1. Establishes data and constraint requirements at GSP.
RDP	UKPN Long-Term Forecasting Platform (Strategic Forecasting System)	1. Provides medium to long-term forecasting of demand and generation, shared openly with stakeholders.	1. FF facilitates data sharing among stakeholders. 2. FF can take learnings from forecasting medium to long-term.
RDP	TRANSITION	1. Selects and dispatches tool for automatic constraint prediction and economic optimisation for flexibility at scale. 2. System architecture includes automated APIs, forecasting at 11kV, reforecasting within a day, and visualisation for decision making. 3. Vertically integrated digital model of distribution network used to identify constraints and determine flexibility requirements.	1. FF supports power dispatch decisions and optimisation. 2. FF to use learnings: network modelling, API integration, visualisation, software architecture. 3. Demonstrated use of CIM for applying to FF. 4. FF aims to identify constraint and support flexibility. 5. Demonstrated use of tool in a limited area.
Regulation	G99	1. Emphasises data sharing, network visibility, stability, and real-time control for UK regulations. 2. Mandates comprehensive data exchange, robust monitoring, stability enhancement measures, and responsive control mechanisms.	1. FF can gain insight into modern and new generation connections from analysing G99 connection agreements.

Grid Codes (1)

Category	Initiative	Description	Synergy with Fractal Flow
Grid Code	GC 0139: National Grid ESO Balancing Mechanism Data	1. To increase the scope and detail of planning-data exchange between DNOs and National Grid ESO to help facilitate the transition to a smart, flexible energy system. This modification will enhance and align certain data exchange processes, providing greater granularity of data at a wider range of operating conditions; this will help facilitate improved coordination and more efficient planning of the networks for all parties.	1. Enhanced network visibility during the planning phase allows for more comprehensive monitoring of operating conditions, enabling better coordination and efficiency in network planning, ultimately supporting the transition to a smart, flexible energy system. Fractal Flow could provide useful insight into this area during future phases.
Grid Code	GC 0117: Improving transparency and consistency of access arrangements across GB	1. The current lack of consistency in access arrangements across Great Britain's Grid Code hinders the development of a unified market for power generating module (PGM) technology, resulting in varying requirements for generators based on their location and capacity. These disparities contradict the objectives of the European Network Codes and lead to unintended consequences such as under-sizing generators to meet arbitrary thresholds, reducing efficiency and increasing costs for consumers. To address this, amendments to the Grid Code are proposed to establish a single, harmonized set of requirements for Type C and Type D generators, aligning with EU standards and promoting market integration. Through industry collaboration, this modification aims to streamline access arrangements, ensuring transparency and proportionality in applying new requirements and fostering a more efficient and effective energy system operation.	1. Real-time data access is crucial for monitoring the performance of generators, harmonising the generator categories will improve the data exchange for new generators and give a better understanding of generator performance and system operation. This data will link into Fractal Flow and be an enabler for facilitating informed decision-making and more efficient allocation of resources to meet demand.
Grid Code	GC 0140: Enabling derogation from certain obligations to support small-scale trials of innovative propositions	1. To enable parties to be derogated from specific Grid Code obligations to conduct small-scale, time-limited live trials of innovative technologies, connections, products or services.	1. Real-time data and network visibility are crucial for Fractal Flow, as it provides insights into the performance and effects of the innovative technologies or services being trailed in real-world grid conditions.
Grid Code	GC 0143: Last resort disconnection of Embedded Generation	1. This modification sets out that under emergency conditions and as a last resort the ESO may instruct a DNO to disconnect embedded generators connected to its system.	1. Fractal Flow will help provide real-time data access to give greater visibility of grid conditions beyond a GSP for NG ESO and for DNOs to have improved understanding of the volumes of distributed generation. 2. Improved Network visibility will facilitate accurate decisions on generator disconnection.

Grid Codes (2)

Category	Initiative	Description	Synergy with Fractal Flow
Grid Code	GC 0145: Updating the Grid Code to include the Manually Activated Reserve Initiative (MARI)	1. Article 20 of the European Balancing Guidelines requires TSOs to create a platform for balancing manually activated frequency restoration reserves (mFRR) by July 2022. The Manually Activated Reserve Initiative (MARI) supports this, clarifying Grid Code requirements for participants of the EU Balancing Product.	1. Fractal Flow will help provide real-time data access to enable NG ESO to monitor grid conditions and available manual reserves. 2. By aligning compatibility of the 'data submission and acceptance' to be developed as part of this Grid Code change, fractal flow could help facilitate visibility of the available MARI capacity.
Grid Code	GC 0148: Implementation of EU Emergency and Restoration Code Phase II	1. In December 2019, National Grid ESO submitted final proposals to Ofgem for implementing the European Network Code Electricity Emergency and Restoration Code (NCER). The modification aims to outline work needed in Great Britain for NCER compliance and address related items within the Emergency and Restoration Code framework.	1. Fractal Flow will help provide real-time data access to aid in monitoring grid conditions to ensure compliance with the NCER and promptly address any deviations. 2. Network visibility facilitates tracking progress on NCER implementation tasks and identifying areas needing improvement for better alignment with the Emergency and Restoration Code framework.
Grid Code	GC 0151: Grid Code Compliance with Fault Ride Through Requirements	1. The proposal aims to amend the Grid Code regarding the process for Users, Network Operators, and the ESO during Fault Ride Through occurrences, when a User's site or Network Operator's asset(s) coincidentally trip or de-load.	1. Fractal Flow will help provide real-time data access to enable detection of Fault Ride Through occurrences, allowing for rapid response and mitigation. Note, this will likely require resolution higher than 30 mins. 2. Network visibility ensures clear monitoring of grid conditions during Fault Ride Through events, facilitating coordination between Users, Network Operators, and the ESO for effective resolution.

Wider Project Synergies (1)

Operational Data-Sharing Technical Working Group (ODS TWG):

- The ODS TWG is tasked with harmonising and standardising Transmission-Distribution operations and establishing protocols for data exchange between ESOs and DNOs.
- It operates under the ENA's "Open Network Programme" (ONP), which focuses on Distributed System Operation (DSO) and flexibility markets to streamline customer experiences and simplify network connections, particularly for renewable distributed energy resources.
- The ODS TWG effectively supports real-time operational data sharing among ESOs, DNOs, and other stakeholders. Its responsibilities include:
    - Providing real-time operational data for system and network operators
    - Standardising datasets and processes
    - Involving all DNOs and NGESO in governance
- Our current understanding from this governance is that ICCP is planned to be implemented across all DNOs.
- Tracking and monitoring discissions within the Operational Data-Sharing Technical Working Group will help to guide system and performance definition during the Alpha to help give a clearly defined dataset for use within Fractal Flow.

Wider Project Synergies (2)

- Fractal Flow supports the Energy Digitalisation Taskforce recommendation for developing a 'digital spine' for the energy system [1].
  - A digital spine facilitates data exchange of diverse datasets across multiple participants within a single integration.
  - Australia's Project EDGE trialled a digital spine for 333 days demonstrating how it enables data exchange [2].
  - IEEE 2030.5 is suggested as a standard for TCP/IP data communication for a digital spine [3].
- A digital spine is a potential enabler for FF facilitating data flows between energy system participants.
- FF can integrate with the digital spine, access the data flows, and undertake graph-based analytics and ML to support network visibility and forecasting. Such an approach may form a key enabler for the development and delivery of FF at scale.

[1] Energy Digitalisation Taskforce, 2021, 'Delivering a Digitalised Energy System', https://esc-production-2021.s3.eu-west-2.amazonaws.com/2022/01/ESC-Energy-Digitalisation-Taskforce-Report-2021-web.pdf

[2] AEMO, October 2023, 'Project EDGE Final Report', Version 2, https://aemo.com.au/-/media/files/initiatives/der/2023/project-edge-final-report.pdf?la=en

[3] IEEE, 06/12/2023, 'IEEE 2030.5-2023 IEEE Approved Draft Standard for Smart Energy Profile Application Protocol', https://standards.ieee.org/ieee/2030.5/11216/

Wider Project Synergies (3)

Regen have recently published a paper [1] investigating what it will take to ensure the distribution network is ready for Net Zero. The key conclusions from this report included:

UK Government:

- Upgrade the local grid as a critical infrastructure program to achieve Net Zero by 2050.

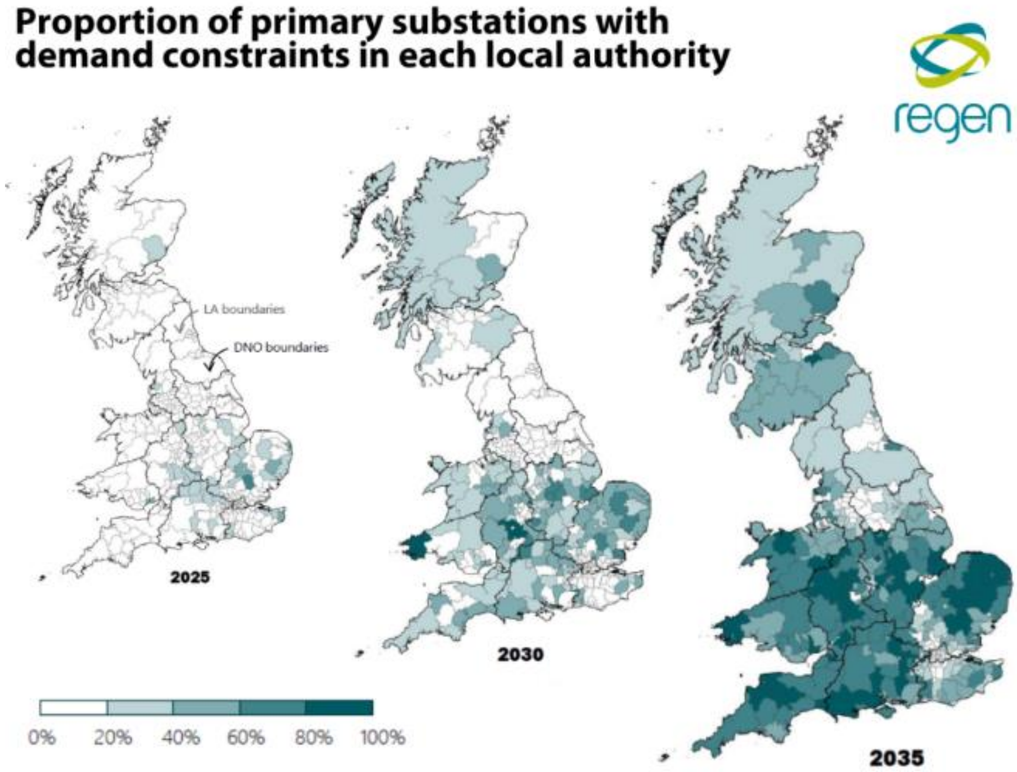
UK Government and Ofgem:

- Coordinate local and national flexibility arrangements to optimise the entire system.

Distribution Network Operators:

- Prioritise publishing data on capacity and constraints of secondary networks.
- Accelerate the development and rollout of local flexibility markets.
- Prepare local network planning for reduced demand diversity due to stronger pricing signals and electrification.
- Deliver a streamlined, digitalised connections process.

The topics highlighted within the ENA are well aligned with the objectives of Fractal Flow such as utilising capacity within the distribution network and assisting in a streamlined connection process.



[1] Regen, 2024, ‘Electrification: The local grid challenge’, https://www.regen.co.uk/wp-content/uploads/Electrification-The-local-grid-challenge-Regen.pdf

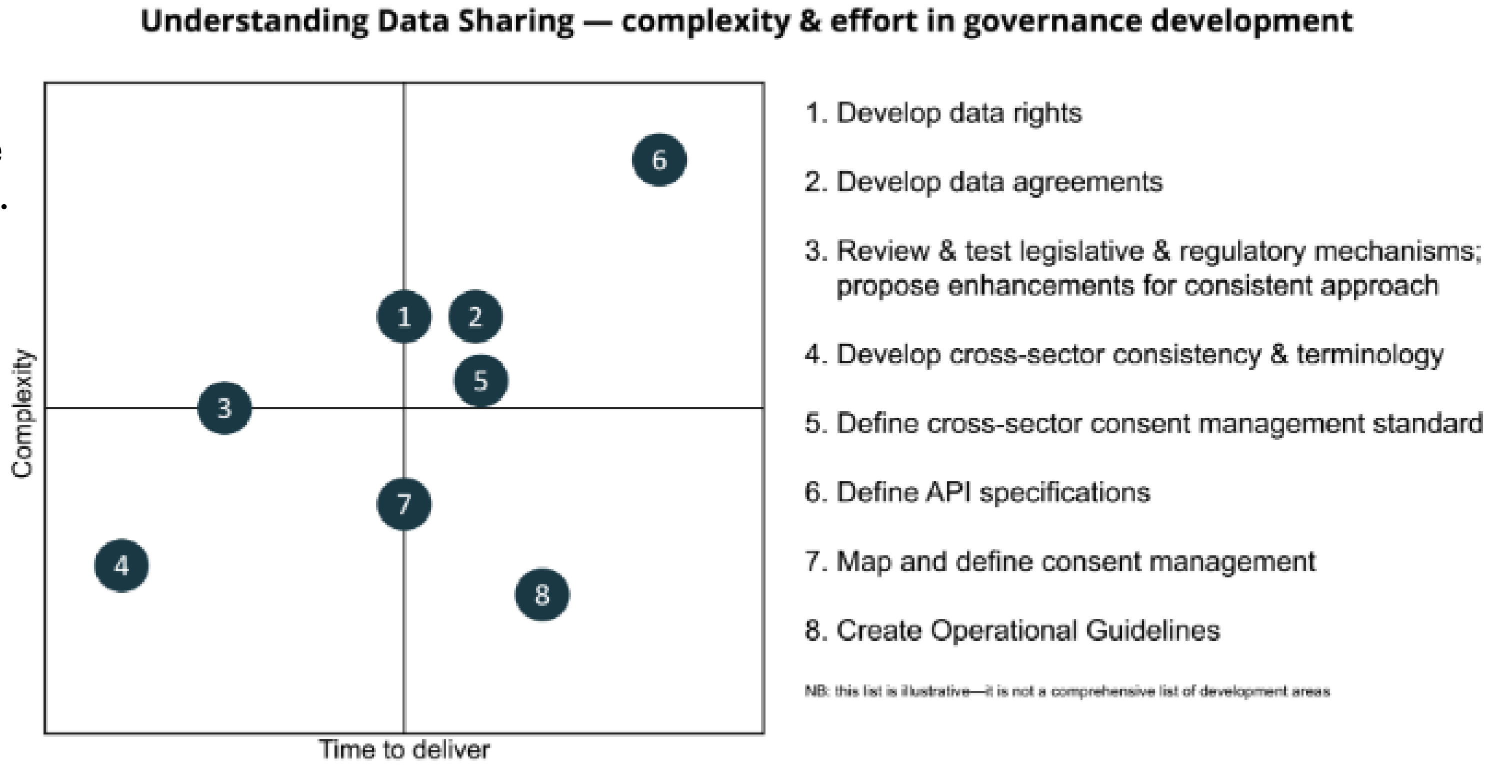
Wider Project Synergies (4)

Icebreaker (IB1) is an initiative via the Energy System Catapult supported by Ovo Energy, to investigate industry-wide data sharing mechanisms.

Real-Time Data Access: Open Energy's secure APIs (FAPI and OAPI) intend to enable immediate and controlled access to up-to-date energy data.

Network Visibility: The platform's metadata standards and search functions enhance visibility across various datasets and providers, improving the understanding and monitoring of energy networks.

The report identifies APIs as complex and time consuming to develop. Fractal Flow will address these issues during the Alpha and Beta phases.



This initiative does not address the supporting analytics that will improve the usability of such datasets, which is a topic that Fractal Flow will resolve within the context of network operators.

[1] Icebreaker One, https://icebreakerone.org/open-energy-uk/#:~:text=Icebreaker%20One%20is%20a%20non,Shared%20Data%20or%20Open%20Data).

Fractal Flow – WP 3 – Conclusions

FRAZER-NASH CONSULTANCY
A KBR COMPANY

- The Discovery Phase has highlighted a range of complementary initiatives that support Fractal Flow's requirements for data infrastructure and data sharing.
    - The initiatives include both technical solutions (e.g., ICCP, CIM, Digital Spine) as well as regulatory and governance initiatives (e.g., GC 0139, Data Sharing Infrastructure, Open Network Panel).
- Fractal Flow will utilise these initiatives to avoid duplication of effort. The Alpha Phase will not develop new data link technology nor innovate new data standards but will be designed to accommodate the most appropriate and optimal of these existing initiatives.
- The core innovation of Fractal Flow at Alpha is to:
    - Develop the analytics and machine learning capabilities required to demonstrate the primary use cases around 'real-time' control of DERs.
    - Produce a data visualisation that provide the insights required by DNO/NGESO control rooms.
    - Design a solution architecture that leverages other innovations around data sharing and is interoperable with NGESO and DNOs networks and IT infrastructure.

Fractal Flow – SIF Development Phases

Discovery Phase

Feasibility and Roadmap

- Feasibility assessment of Fractal Flow
- Identification of enablers and barriers
- Roadmap

Alpha Phase

Prototype Development

- Prototype data platform (cloud infrastructure, data links, data formats)
- Data analyses methodology development for real-time control on synthetic data
- Data visualisation development

Beta Phase

Minimum Viable Product

- Scalable data platform
- Live on-ramping of minimum required data
- Integration of data analyses methods with live data
- UI/UX development

Stakeholder Engagement for Alpha

- Through the work conducted during Discovery, ElectraLink have been identified as a potential partner for Alpha.
    - ElectraLink has a strong competency in hosting infrastructure and data management.
    - The have also previously worked with DNOs in this capacity.
    - Frazer-Nash have met with ElectraLink to discuss Fractal Flow.
    - Frazer-Nash and ElectraLink are current developing a commercial and technical arrangement for Alpha.

- Frazer-Nash have also discussed Fractal Flow with IOTICS who are a data broker.
    - IOTICS may provide benefit for broader integration of data sources and management of data access.
    - However, they are not expected to formally engage in Alpha.
- Frazer-Nash have also contacted a 3rd party renewable asset owner and operator to discuss their existing data infrastructure and real-time data access capabilities at equipment and company level, which has informed FF's TRL justifications.
- Frazer-Nash have also met with a network architect at NGESO to support the development of the project. This insight has been captured and will be leveraged to maximise the value of Alpha.
- GridOS was discussed with NGESO network and solutions architects as a potential option for deployment which will be explored more during Alpha.
- Engagement with potential renewable energy partners is on-going as part of development of the alpha application.

Fractal Flow Alpha Development Activities

Following the research undertaken during Discovery, the focus areas of Alpha development have been identified as:

1. Design Fractal Flow's data visualisations with input from the project partners.
2. Explore data links to evaluate performance and requirements for current initiatives, emphasising scalability and interoperability.
3. Develop data analytics as a core feature of the Alpha proof-of-concept.
4. Develop cloud infrastructure with specialist partners to demonstrate the value of Fractal Flow.
5. Create a graph database for efficient data querying and analytics.
6. Progress ontology development.

Wider DNO Engagement and Feedback

All DNOs have been notified about Fractal Flow and were provided with:

Why are you receiving this email?

Your work as a Distribution Network Operator (DNO) is vital in helping the GB power industry transition to net zero, and we are keenly aware of the ongoing constraints within the network. This drive to net zero means more utilisation of Distributed Energy Resources (DERs) which presents new challenges for DNOs and the grid in general.

Optimal real-time control of DERs will require visibility of power flow across the network, both horizontally, at a transmission level, and vertically, at a distribution level. From an NGESO perspective, they will require resolution at the GSP-level of demand and service availability as it evolves in real-time, with an analytics engine that can forecast this information into the future, so they can reliably instruct services in a timely manner given dynamic changes to the grid. To achieve this will require collaboration and data sharing with the DNOs.

Why Fractal Flow? – A SIF Discovery Project

This is where Fractal Flow comes in. Fractal Flow is a SIF Discovery Project recently approved by Ofgem* formed from a collaboration between Northern Powergrid, NGESO, and Fraser-Nash Consultancy.

Fractal Flow seeks to provide a solution to these challenges by developing a vendor-agnostic solution that enables visibility of power flow below the GSP-level by embedding asset and power flow information graphically. This graphical representation enables powerful analytical capabilities, leveraging graph theory and the physical relationships between assets to better identify patterns of how to best utilise assets, as well as simplifying the forecasting problem. We believe this technology will provide yourselves and NGESO with the information and insights you all need to confidently and reliable instruct services in real-time.

What stage are we at?

At SIF Discovery Project stage we are currently defining requirements and a roadmap for Fractal Flow with a focus on providing network power flow visibility below the GSP-level and the analytics required for real-time control of DERs.

How you can be involved

We would really appreciate it if you could consider being involved in the following ways:

1. **Engagement in the Discovery Phase.** We'd like to send you the requirements, feasibility assessment and roadmap as we develop them in this project and get your feedback and comments, identifying how this tool algins with your existing roadmaps.
2. **Involvement in the Alpha Phase.** We'd like to explore the possibility of you being involved in the Alpha Phase of this project. Your participation would allow you to steer the technology and ensure a wider range of DNO input is obtained.

A Follow-up meeting was held with ENWL who have agreed to review FF Discovery and consider engagement in Alpha due to their existing company level NMS / ANM System.

Thank you

Contact:

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