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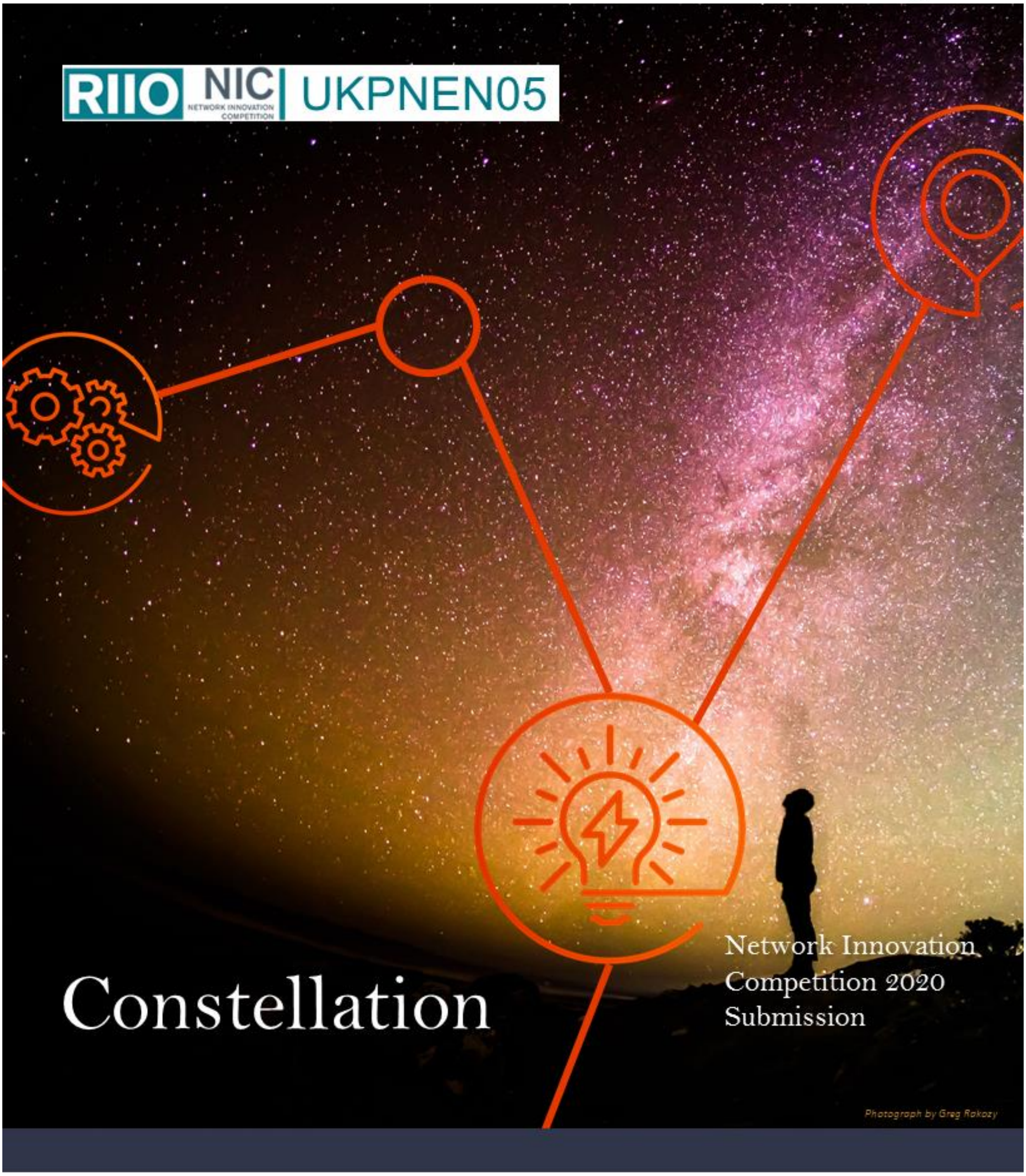

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UK Power Networks
Delivering your electricity

OFG1161

Network Innovation Competition: Full Submission Application (UKPNEN05)

1. Project Summary

1.1 Project Title	Constellation
1.2 Project Explanation	Distributed electricity generation is expected to increase significantly to achieve Net Zero. This will have an impact on the stability of network operation. The Project will demonstrate a novel approach to protection and control by introducing local intelligence in DNO substations. This could save GB electricity customers £132m by 2030.
1.3 Funding Licensee	South Eastern Power Networks Plc
1.4 Project Description	**1.4.1 The problem(s) it is exploring** Along with the significant increase in distributed generation (DG) the Committee on Climate Change recommends DNOs increase the use of smart services (e.g. flexibility) to achieve Net Zero in a "low regrets and low cost"[1] manner. As we increase our reliance on DG and flexibility in the future, we cannot afford to interrupt these services due to communication issues or transient instability events. Furthermore, we are limited in how quickly and to what extent we deploy smart solutions, as they are typically deployed within dedicated relay hardware. **1.4.2 The Method(s) that it will use to solve the Problem(s)** Demonstrate a local intelligence system with software functionality for: Method 1: Local intelligent control / Local ANM: Local network optimisation at the substation level to provide resilience to DER operation against loss of communication with the central ANM system. Method 2: Wide area and adaptive protection: Provide resilience to DG operation against transient instability events triggering the conventional generator protection. Dynamically assessed protection settings and enhanced wide area control to enable more capacity for DER connections. **1.4.3 The Solution(s) it is looking to reach by applying the Method(s)** Constellation is a transformational initiative which will demonstrate novel approaches to network protection and control. It will protect the smart services DNOs will rely on to operate the network, which will both reduce the risk of system wide frequency events and the cost of system balancing. It also supports achieving Net Zero through unlocking network capacity for DER to connect. Finally, the Project provides an environment for quick and scalable deployment of smart network functionality as software. **1.4.4 The Benefit(s) of the Project**

[1] The Committee on Climate Change, Net Zero: Technical Appendix, 2019

	We estimate that by 2030, the Constellation solutions could save customers £132m in cost efficiencies. The project Methods also enable Carbon Savings of 1.9m tCO2. and Capacity Benefits of 1.98GVA by 2030.		
1.5. Funding			
1.5.1. NIC Funding Request (£k)	£14,384.07	1.5.2. Network Licensee Compulsory Contribution (£k)	1,627.32
1.5.3. Network Licensee Extra Contribution (£k)		1.5.4. External Funding – excluding from NICs (£k)	£1,550.70
1.5.5. Total Project Costs (£k)	£17,823.92		
1.6. List of Project Partners, External Funders and Project Supporters (and value of contribution)	Project Partners: ABB (£228k), GE (£344k), University of Strathclyde - PNDC (£175k), Siemens (£658k), Vodafone (£145k) Project Supporters: SSEN, SPEN, Fundamentals		
1.7. Timescale			
1.7.1. Project Start Date	03/05/2021	1.7.2. Project End Date	30/09/2025
1.8. Project Manager Contact Details			
1.8.1. Contact Name and Job Title	Ian Cooper Innovation Lead	1.8.2. Email and Telephone Number	Ian.Cooper@ ukpowernetworks.co.uk +44 (0)1293 657641
1.8.3. Contact Address	UK Power Networks, Newington House, 237 Southwark Bridge Road, London SE1 6NP		
1.9. Cross Sector Projects (only complete this section if your project is a Cross Sector Project, i.e. involves both the Gas and Electricity NICs).			
1.9.1. Funding requested the from the [Gas/Electricity] NIC (£k, please state which other competition)	n/a		
1.9.2. Please confirm whether or not this [Gas/Electricity] NIC Project could proceed in the absence of funding being awarded for the other Project.	n/a		
1.10. Technology Readiness Level (TRL)			
1.10.1. TRL at Project Start Date	5	1.10.2. TRL at Project End Date	8 (Appendix 10.9 Technology Readiness Level (TRL) for key

			Constellation elements for more details)

2. Project Description

The expected uptake of Distributed Energy Resources (DER) to enable Net Zero, will have a significant impact on the electricity distribution network. Constellation will transform our network by demonstrating distributed and digitalised network operation to manage these effects.

2.1. Aims and objectives

Constellation is a transformation project aiming to enable DNOs to revolutionise the existing management and control models of traditional electricity distribution. It will introduce a first of its kind local intelligence and local intelligent operation at the substation level that complements existing functionality, in a sustainably cost-efficient manner for our customers. Constellation will seek to answer three core questions relating to the implementation of local intelligence and distributed network operation.

Table 1 – Key Project questions

1. How do we ensure services to the network (e.g. flexibility) are resilient to loss of communication with central systems?	We will demonstrate the ability to carry out local (substation level) state estimation and generation output forecasting. We will evaluate the distributed control capabilities to prevent unnecessary curtailment of DG.
2. How do we ensure the services we obtain from DER assets are protected from transient instability events?	We will assess the ability to securely transfer low latency communication between sites. We will evaluate the wide area protection capabilities needed to maintain system stability, unlock capacity and prevent unnecessary curtailment of DG.
3. What is a future-proof architecture and virtualisation approach for network control and real-time protection functions?	We will develop and demonstrate the Constellation system architecture which will combine protection, control and data management applications. We will prove the virtualisation approach is suitable for providing the necessary hardware, software and cyber security requirements for both protection and control functions.

Through answering these questions, we can accelerate the transition towards distributed and autonomous network operation. Constellation is about local intelligence: the hardware to enable it, the software to manage it, the rules to govern it and the methodology to deploy it consistently across multiple vendors at lowest cost.

2.1.1 The problem

2.1.1.1 Net Zero and associated challenges

The energy industry sits at the heart of the UK's ambitious 2050 Net Zero target. This means our customers are becoming more aware of their energy usage, adapting their behaviour, generating electricity and exploiting the benefits of low carbon solutions for their needs. These changes have introduced a mix of technical and commercial challenges to electricity distribution. Therefore, as DNOs we need to ensure our networks are ready for the high penetration of Low Carbon Technology solutions required in the Net Zero future. We are keenly aware that we must do this cost effectively to avoid negatively impacting those already in vulnerable or fuel poor circumstances.

The Committee on Climate Change (CCC) recommends that electricity generation produced by low carbon sources quadruple 2019 volumes by 2050[2]. Distribution scale generation and storage can require significant network capacity. As such, it is essential to facilitate sufficient capacity for the quick and economic connection of DER across the entire network. Another aspect in the Net Zero future is that more of our customers may rely on electricity to travel and to keep warm, in addition to keeping the lights on. As such, it is equally important to increase the whole system's resilience, evidenced by the 9 August 2019 transient Low Frequency Demand Disconnection (LFDD) event, when the estimated loss of up to 430MW of DG contributed to the disconnection of 1.1m customers[3]. Ultimately, network operators need to manage greater risk and the increasing complexity of electricity distribution.
To address some of these challenges, our industry has developed sophisticated and powerful central capabilities, such as Advanced Distribution Management Systems (ADMS) and Active Network Management (ANM). These systems deliver significant advantages in terms of the ability to actively control large volumes of demand and generation on the network quickly and at low cost. However, central systems can have limitations in their ability to continue to operate optimally when communication links are unavailable, and to carry out safety critical actions in protection timescales, of under 10 seconds.

2.1.1.2 Reliance on communication to central systems
Our ANM system ensures DER connected to the network can operate safely without breaching network limits by relying on continuous communication with the respective DER sites and the points of constraint on our network. This means that in the situation when communication with either of those two points is unavailable, the capacity released by ANM is lost, DER are curtailed (to a known safe level, typically zero, either immediately or by graceful degradation) and the network loses the services it relies on to operate. Overall curtailment by ANM is low, but at least 15% of occurrences are due to communication issues. Ofgem's decarbonisation plan highlights the importance of utilising DER to support network operation through means such as flexibility and "providing energy services rather than supplying energy"[4]. As we rely on DER to keep our network stable there is a significant future risk: **if high volumes of the ANM managed DER units fail-over simultaneously, this may have severe consequences on the stability of the distribution network and potentially influence grid frequency and transmission network loading.**

2.1.1.3 Protection challenges in a dynamic network
Loss of Mains (LoM) protection, or anti-islanding protection, is set up to disconnect DG when connection to the main grid is lost. As a result, LoM protection is a compromise between the risk of islanding versus the disconnection of a generator unnecessarily. The recent grid code changes to LoM requirements[5] laid the foundation towards eliminating unnecessary disconnection of DER assets, but still errs on the side of disconnect, rather than remain connected. Nevertheless, there is a growing concern over the increased dependence of the electricity system on the availability of the DER. Previously the loss of distribution generation was of little consequence to the network operation. **In the future, the loss of a high proportion of generation at the distribution level will reduce system stability[6] and lead to an increase in disconnection events and potentially blackouts.**

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[2] Committee on Climate Change, Net Zero: The UK`s contribution to stopping global warming, 2019
[3] Ofgem, 9 August 2019 Power Outage Report, 2020
[4] Ofgem, Ofgem decarbonisation programme action plan, 2020
[5] Energy Networks Association, Accelerated Loss of Mains Change Programme, 2017
[6] Satellite communication based loss-of-mains protection, A. Dysko, G.M. Burt, P.J. Moore, I.A. Glover, J.R. McDonald, IET 9th International Conference on Developments in Power System Protection, 2008

By 2050 we expect 2,448MW of DER capacity to be at risk of unnecessary disconnection due to nearby faults triggering DG LoM protection despite no risk of an island. As such we see a need to change the protection approach to one that keeps DG connected if possible, rather than disconnected.

In addition, traditionally protection settings are manually calculated and applied to the electricity network protection relays. By design they are based on all running arrangements and are conservative to ensure that as the network is reconfigured the protection continues to operate reliably. This is generally necessary as 71% of protection uses electromechanical relays with no ability to remotely change settings. Specifically, the directional overcurrent (DOC) protection, designed to protect the network from back-feeding faults, limits the amount of DG that can be connected.

Our traditional solution is load blinding. This allows the protection to use a pre-calculated power factor to differentiate between network faults and generation/load. With a single static setting this has limitations. Specifically, in sites which can be supplied through multiple grid supply points either directly or through loose couples, the changing power flows present particular challenges for this application and need to be managed dynamically. As we look to move to DER's providing voltage control services and utilising CLASS functions, the load blinding solution will face further challenges with fixed settings. As a result, there will be areas on the distribution network, where DOC settings could be the limiting factor to the available capacity rather than the rating of the assets. Because of this, parts of the network have spare capacity which is not utilised to connect more DER to support our transition to Net Zero.

2.1.1.4 Growing need for digitalisation and interoperability in network operation

Our local substations have not evolved at the same pace as our central systems. The Government Smart Systems and Flexibility Plan highlights the importance of interoperability to making energy systems flexible, scalable and secure[7]. Current substation solutions come as dedicated hardware and require lengthy installation, commissioning and maintenance processes. The existing solutions are also hard to integrate and have limited flexibility to adapt their functionality. The Energy Data Taskforce recommend maximising the value of smart digital solutions, rather than solely relying on the mass deployment of equipment[8]. As such, there is a growing need for single hardware containers hosting a number of flexible and easy to implement virtual (software) solutions. Network operators and technology developers need to exploit the new developments in software engineering and real time operation to enable interoperable solutions, which can run as virtualised functionality and improve our digital and cyber security capabilities.

Ultimately, we need to operate a full top-to-bottom smart, scalable, flexible and future proof network to enable Net Zero at the lowest cost to our customers.

2.1.2 The Constellation Methods

In order to overcome the limitations of our existing capabilities and facilitate Net Zero we need to enhance our local substations by making them more intelligent, digital, interoperable and enable secure, scalable communication between them. Constellation achieves this through a scalable, flexible, future proofed system for local intelligence working in partnership with central systems, which in turn, enables two distinct Methods (as shown in Figure 1):

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[7] BEIS, Ofgem, Upgrading our Energy System: Smart Systems and Flexibility Plan, 2017

[8] BEIS, Ofgem, Innovate UK, Energy Data Taskforce Report: A strategy for a modern digitalised energy system, 2019

1) **Local intelligent control / Local ANM -** Local power flow forecasting and state estimation to maintain the optimal DER asset operation during events when the central ANM system is unavailable
2) **Wide area and adaptive protection -** Site-to-site communication via Routable Generic Object-Oriented Substation Event (GOOSE / R-GOOSE) messaging to enable wide area protection and control actions which will keep the DER running through transient instability events occurring elsewhere on the network. Real time collection, calculation and deployment of protection settings for load blinding (in areas where DER provides reactive power services) to release additional network capacity.

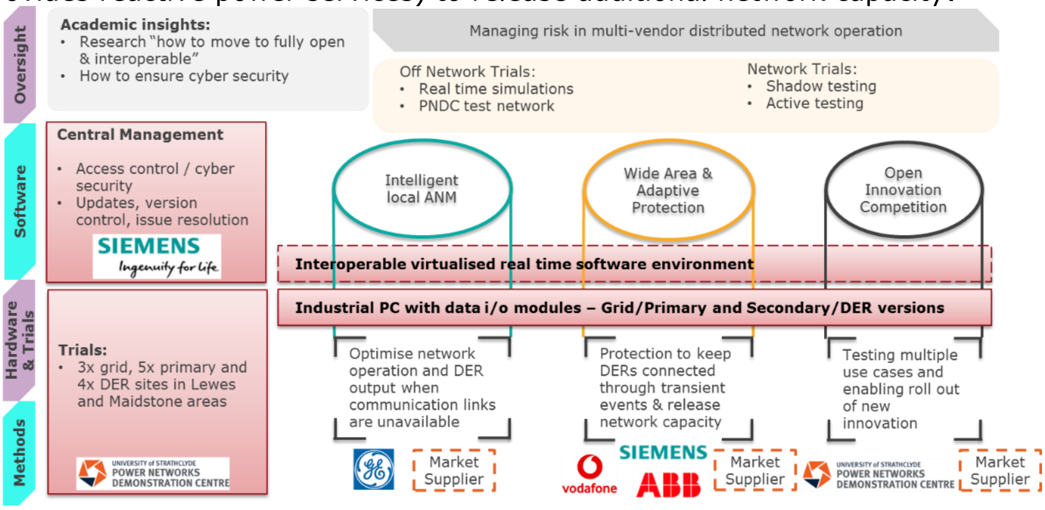

Figure 1 – Constellation summary diagram (with key partners for each Project element)

2.1.2.1 Method 1 – Local intelligent control/Local ANM

The aim for Method 1 is to enable a layered approach to network management. The central ANM system continues to perform the overarching constraint management function and will identify the "global optimum" for network operation. Whenever the central system is unable to communicate with our local network assets and DER sites, the local intelligence will take over optimisation for that specific DER, substation or area. This will enable the network to be operated more optimally, controlling locally within the global optimum, compared to using static set points. In some instances, central ANM will continue to have communication to parts of the area, so the local and the central system will work in tandem to ensure DER output is maximised within the constraints of the network.

For some network control actions, such as voltage and frequency response, the local ANM system is better suited to carry out the actions. If successful, this Method is the first step towards fully distributed and autonomous network control.

2.1.2.2 Method 2 – Wide area and adaptive protection

Wide area protection

Islanding prevention can be achieved through a direct fibre or microwave communication link between the generator and the connection point to the electricity network. This is typically cost prohibitive for the majority of 33kV and 11kV connected generation, which relies on the detection of islanding through monitoring of voltage and frequency[9]. The wide area protection aspect of Method 2 will demonstrate sophisticated protection algorithms (potentially using

[9] Energy Networks Association, Engineering Recommendation G99, Section 10, Issue 1 – Amendment 6, 2020

phasor measurements or R-GOOSE analogues) to identify if the DER should disconnect, if events have caused islanded operation. This will rely on economic, low latency communications via 5G slicing (described in section 2.2.1.3 Secure site-to-site communication). Method 2 will protect the critical services that DER will be providing to our network from unnecessary disconnection and improve resilience of flexibility services.

Adaptive protection
The adaptive protection in Method 2 will develop the ability to provide real time protection settings information from the substation, validate them and modify settings as required in real time. This will allow the load blinding application to adapt to the power flows on the network and correctly discriminate between genuine faults and generation/load.
This solution has the potential to release 823MVA capacity, of the total 1.98GVA capacity benefit, by 2030 for DER to be able to connect to currently constraint areas quickly and efficiently across GB. Section 3.4 Constellation capacity benefits has further detail on the capacity benefits.

2.1.3 Development or Demonstration being undertaken
In addition to Methods 1 and 2, Constellation will deliver key elements to enable distributed network operation, specifically developing:

- **The architecture:** specifying the data flows necessary for real time protection, control and data management actions, which all have specific priority, latency and quality requirements;
- **The virtualisation approach**: creating a platform capable of allocating the shared hardware resources (e.g. memory and processor capacity) across the two Constellation Methods. The development will need to take into account the criticality of the protection and control aspects as well as enable future "applications" to be deployed on this containerisation platform;
- **The testing approach**: creating the automated and remote testing over wide area network (WAN). This will also drive the requirements for better interoperability through standardisation of multi-vendor equipment including tools for testing and commissioning (further details on the testing see Appendix **10.4.9** Testing and commissioning); and
- **The central management of the Constellation system:** creating the ability to remotely manage the local intelligence system and to configure Intelligent Electronic Devices (IEDs) on site via the hardware for local intelligence.

2.1.3.1 Open Innovation Competition (OIC)
Constellation includes an OIC call for third parties to rapidly develop and deploy functionality (in addition to Methods 1 and 2) to address business needs and provide additional value to our customers. This will further de-risk the Constellation approach to local intelligence using an open platform and prove the wide range of applications that could be deployed on it, including innovations from third parties who do not have a foothold in the existing substation automation market. Further details including a list of 16 use-cases are in Appendix 10.4.8 Open Innovation Competition (OIC).
2.1.3.2 Future governance, rules and academic insight
To ensure that Constellation delivers the solution and is suitable for BaU rollout, four research streams have been included the Project. These will critically review key project elements and inform the consortium of partners and the wider industry. Appendix 10.4.7 Academic insights and future governancehas further details.
The research streams are:

- **Communication and data architecture:** an optimised communication architecture, combining wired and wireless components;

- **System reliability and distributed control:** a set of system study results to enhance understanding of the impact of large-scale implementation of the distributed control;
- **Adaptive and LoM Protection**: comparative off-line modelling and testing studies to provide assurance; and
- **Governance**: insights and recommendations for the industry on the commercial and contractual arrangements needed for interoperable solutions for protection and control.

The Project will undertake trials to demonstrate the two Methods and OIC outputs both off- and on-network. Off-network trials will take place at the Power Networks Demonstration Centre (PNDC). Once validated, the Methods will be trialled on a live network in two trial areas. As part of the trials, the hardware for local intelligence and the site-to-site communication via 5G slicing will be demonstrated.

2.1.4 The solution which will be enabled by Constellation

The two Methods are expected to deliver environmental, financial and capacity benefits, as described in Section 3.1 Summary of Constellation benefits. Constellation is expected to repay the Project costs within two years of project completion at the estimated roll out rates. In the Net Zero future, DNOs will rely on services provided by DER assets to operate their networks optimally and reliably. The two Methods will enable a resilient and flexible wide area approach to network protection and control, to enable DER to support the network. Furthermore, we will obtain valuable quantitative evidence to assess how wide area protection and control can improve network stability. Constellation will also save the capacity unlocked by our smart systems from abnormal events and reduce system balancing costs by allowing DER to ride through transient instability events.

2.2. Technical description of Project

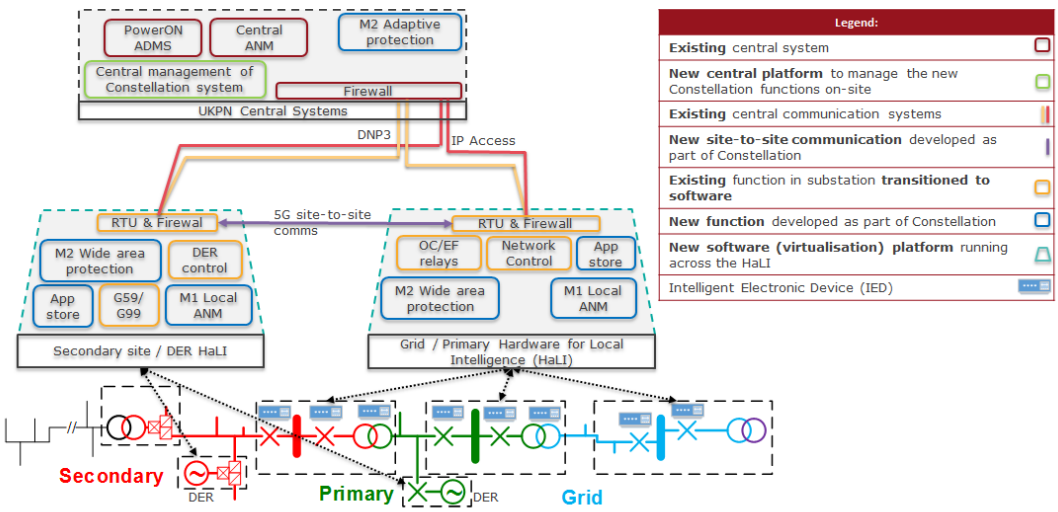

Figure 2 – Conceptual Constellation architecture

The conceptual architecture for Constellation is shown in Figure 2. This will be revisited at the start of the Project and revised in the detailed design phase. We have agreed an internal stage gate (section 6.2 Evidence of the measures in place to minimise the possibility of cost overruns or shortfalls in Direct Benefits) with our partners to revisit their plans and costs once the detailed design is complete. At the same time we will also stimulate the market by procuring a second provider each of local ANM and wide area protection elements. This will verify our pricing and ensure there is a market for these solutions post completion of the project.

2.2.1 Description of the Constellation elements

2.2.1.1 Hardware for Local Intelligence (HaLI) and virtualisation platform

The HaLI will provide the physical resources for the data collection, processing, communication, security and is capable of hosting software applications developed by any vendor. It is based around ruggedised substation PCs from Welotec and communication switches and 5G hardware from Ruggedcom, with IEDs from existing vendors and test equipment (for the duration of the trial) from Omicron. Site design and installation will be by UK Power Networks staff and framework contractors.

The HaLI will be deployed in two forms:

- **Full intelligence** deployed at grid and primary sites: two substation PCs (for resilience) with full processing and memory capabilities, and ability to extend the interface to IEDs based on the site requirements; and
- **Partial intelligence** deployed at DER and secondary sites: single substation PC with lower processing capabilities and limited number of interfaces.

New technology developments in software engineering and real time operation can be deployed to tackle the issues with dedicated hardware solutions. A hybrid containerised approach is proposed and is detailed in Appendices 10.4.4 and 10.4.5.

2.2.1.2 Central management of the Constellation system

This element will enable the management of the Constellation system and will be integrated into UK Power Networks' central control system infrastructure and is provided by Siemens. This element is key to building cyber resilience because it will allow the integration of the Constellation system to UK Power Networks' cyber security facilities. During the trial phase, we will carry out penetration testing on the Constellation system to ensure the security of the full solution meets relevant standards.

In the substations the central management system will act as a "functionality store", will be virtualised, running on the substation PC. This will link (data exchange) the IEDs on site and the central management system. This will enhance the cyber security design by keeping the substation PC as the only point of access between UK Power Networks' central systems and the site IEDs. The central management system will be responsible for software and firmware updates to the Constellation system (including IEDs), as well as version control, issue resolution, settings configuration and remote deployment of the Methods and OIC products onto the substation PC. Appendix 10.4.3 Central management of Constellation system from Siemenshas further details.

2.2.1.3 Secure site-to-site communication

A key element to enable the wide area protection and control functionality in Methods 1 and 2 is the low latency, secure, economic site-to-site communication. Optical fibre or microwave connections between sites are costly or disruptive to build. The recent developments in communication technology, specifically 5G, offer a solution that is economically scalable across the lower voltage levels of electricity distribution. 5G mobile networks introduce a novel architecture that allows the creation of a set of logically independent networks that run on a common physical infrastructure. Each of these networks ("network slices") can logically partition a mobile network, with appropriate isolation, resources, optimised topology and specific configuration.

For Constellation, our partner Vodafone will design a 5G slice to accommodate continuous, fast data traffic over low latency [redacted], high reliability, self-healing, secure communication between sites. We will use R-GOOSE to send messages between sites for the protection and control purposes of Methods 1 and 2. Appendix 10.4.6 Site-to-site communication via 5G slicing from Vodafone has further details.

2.2.1.4 Method 1 – Local intelligent control/Local ANM

Method 1, provided by our partner GE and purchased from the market, will develop locally processed powerful state estimation, advanced data analytics and local forecasting and deploy it on our network. This will be virtualised to run interoperably on the Constellation platform in coordination with the central ANM system when a connection is available. As shown in Figure 3, in this state the local intelligence will learn what is "normal" and the acceptable operating parameters at different times. It will also learn from remote sites, via the 5G slicing communication, how its output impacts network constraints.

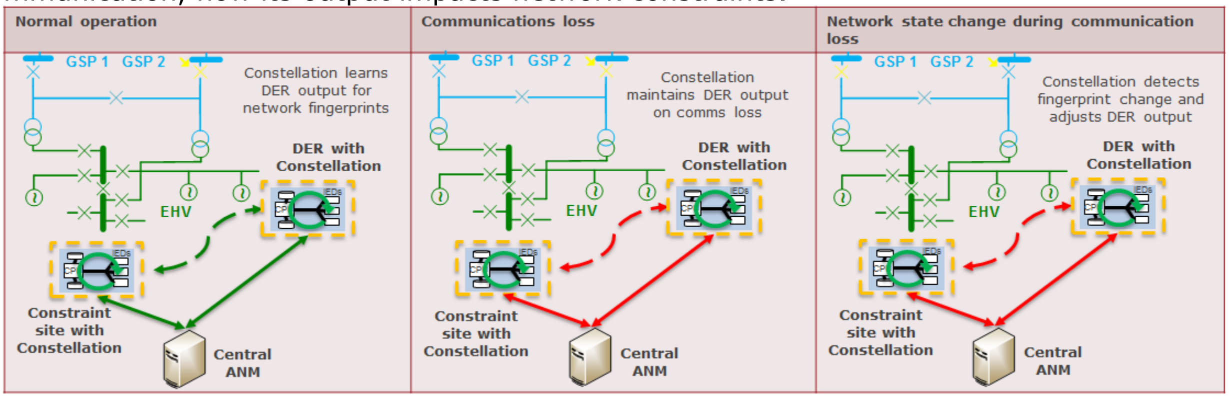

Figure 3 – Local ANM high level operation

Should the connection to the central ANM system be lost, the local intelligence will draw on both local and remote measurements over 5G slicing to provide the maximum safe output. Should all communication be lost then the local intelligence will rely purely on local measurements to safely maximise DER output, as the central ANM would. Should it detect any change in network parameters representing a change in network topology or condition it can respond accordingly, based on what it has learnt. The solution will be designed with a fail-to-safety principle, such that in a rare event of failure of all intelligent functionalities, the solution will apply the most conservative fail-safe action to prevent damage to the network. Further technical details on Method 1, refer to Appendix 10.4.1 Method 1: Local intelligent control / Local ANM.

2.2.1.5 Method 2 – Wide area and adaptive protection

Wide area protection

The wide area protection aspect of Method 2, provided by our partner ABB and purchased from the market, will use local logic, phasor measurements or R-GOOSE analogues to decide whether a DER should disconnect, enabling them to continue to provide critical services to the network. Due to the nature of Loss of mains protection requirements, this will be done quickly (under 500 ms) and reliably via the 5G communications between sites. This functionality will be virtualised and run on the Constellation platform.

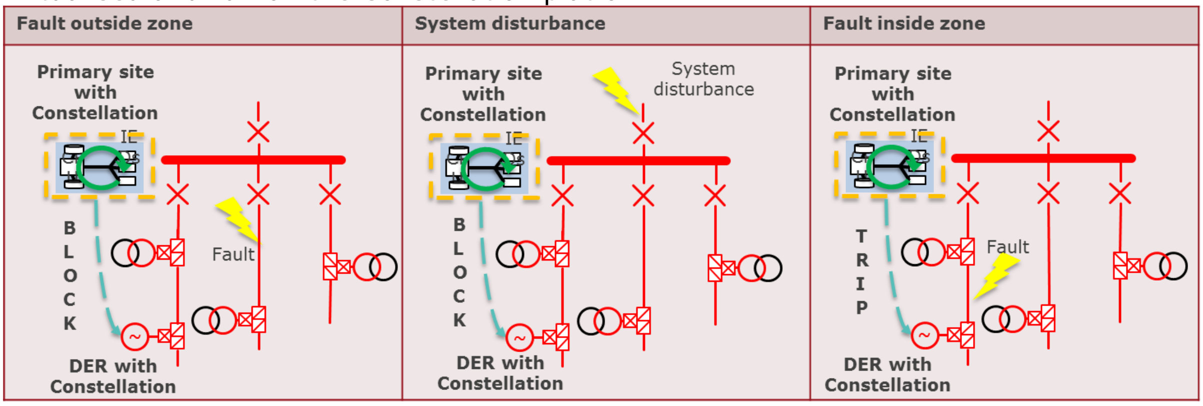

Figure 4 – Wide are protection: high level operation

Figure 44 shows the fundamental operation of wide area protection. The local intelligence is installed at the primary site and the DER site. The primary site has greater visibility of the local area than the DER site. Whenever it detects an instability event outside the feeder connecting the substation and the DER site or a wider system disturbance, the Constellation system will signal the DER to continue to operate uninterrupted. In more complex networks where the DER is not connected via a dedicated circuit, the local intelligence will communicate and cooperate with the other grid and primary substations to ensure wide area stability. This functionality could also include wide area control to leverage the local DER sites to maintain voltage and frequency support (both of which need to be triggered in sub-second timescales). For further technical details refer to Appendix *10.4.2.1* Wide area protection.

Adaptive protection

The adaptive protection aspect of Method 2, provided by our partner Siemens, will employ a balanced approach to dynamically validate and deploy new protection settings. More specifically, this will release capacity through the adaptive load blinding settings. For further technical details refer to Appendix *10.4.2.3* Adaptive protection.

The functionality will be carried out by the local intelligence on-site and the central management system together. As shown in Figure 5, the on-site local intelligence will identify a trigger to pull the protection settings from the IEDs on the local network. These settings will then be sent to a central location for validation and analysis, including protection discrimination upstream and downstream. After the settings have been verified the new ones (or a verification success signal) will be sent back to the local Constellation system, which will configure the settings into the IEDs.

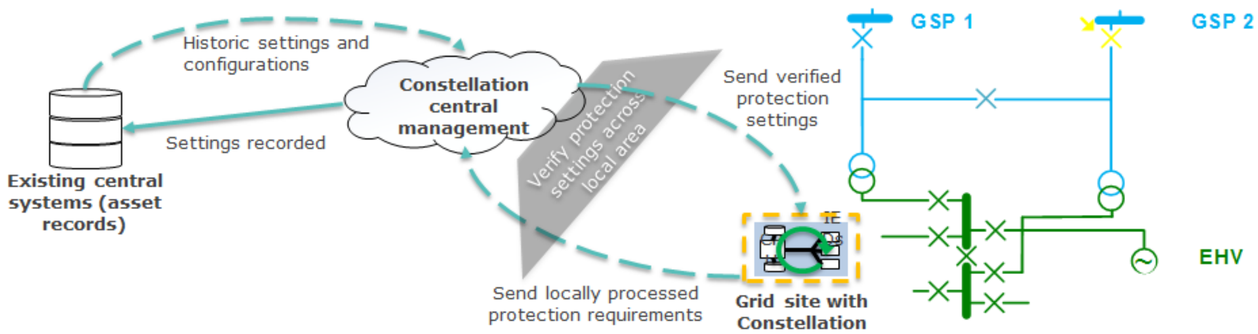

Figure 5 – Summary operation of adaptive protection load blinding settings

2.3. Description of design of trials

2.3.1 Aim of trials

The aim of the Constellation trials is to ensure a sufficient level of de-risking is achieved for the Project Methods by advancing their TRL and successfully demonstrating their operation. The trials will be carried out in a controlled test and demonstration environment implemented in the PNDC and followed by live network trials in selected UK Power Networks sites. In order to ensure the success of the trials, the following specifications are to be produced in advance of trials commencement:

- **PNDC test specification**: this implements a test environment and regime to advance the Constellation Methods to TRL 7;
- **Network trials specification**: detailing the trial networks selection criteria, network configuration and tests to be carried out to achieve TRL 8 of the Constellation Methods; and
- **Data analysis plan**: this defines the data volume, fidelity and means of collection for the data generated during trials as well as the type of analysis required to provide an evidence base of the performance of the constellation Methods necessary to support a BaU transition case.

2.3.2 Trial outputs

The trials will provide the learning and confidence necessary to accelerate the development of the Constellation platform and Methods and increase the success of adoption into BaU. There are four main outputs of the trials:

- Documentation and dissemination of learning and data associated with the Constellation platform to ensure scalability across networks in GB and globally;
- Development of a collaborative environment that focuses end users and multiple suppliers' efforts on producing a 'working' demonstration of Constellation;
- Kick-starting an eco-system for suppliers to innovate in the substation environment by reducing barriers to entry through opening up substation computation platforms; and
- Learnings from the trials will identify the requirements for compliance and certification to ensure an equivalent level of traceability to that of existing protection and control systems.

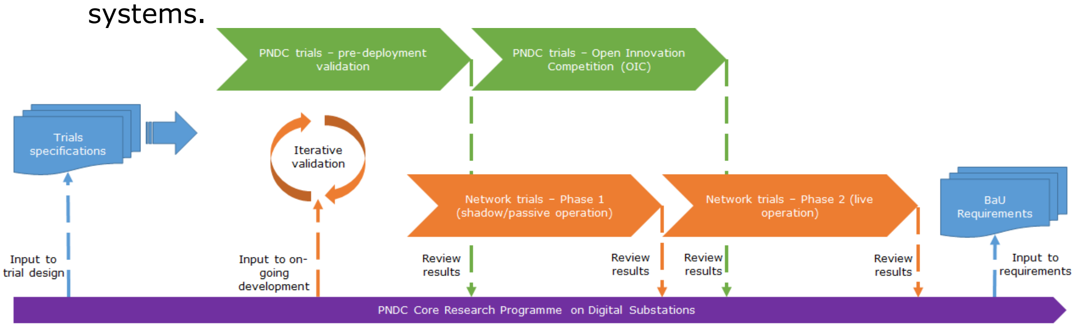

Figure 6 – Constellation trial process

2.3.3 Trial areas

During the bid development we have identified two suitable areas for the demonstration of the two Methods which will be confirmed in the first year of the Project: Maidstone Grid and Lewes Grid. These areas should enable us to demonstrate all aspects of the Constellation Methods and Solutions in stages. Maidstone area is simple for ANM but complex for protection, Lewes is simpler for protection but is complex for ANM with several connected generators. For more details on the proposed sites, refer to Appendix 10.4.10 Trials. The trial areas require three full HaLI, nine partial HaLI units and 138 IEDs. Please note two additional full HaLI and one additional partial HaLI are being purchased for testing and development in UK Power Networks control centre facilities.

2.4. Changes since Initial Screening Process (ISP)

Significant development of the Project concept and technologies has taken place since submission of the ISP. Nevertheless, the Project's intent has not altered. We have refined the Methods and clarified their names within this document.

As a result of a more detailed understanding of the project since ISP and with actual prices from suppliers and project partners, the overall project cost has increased by 23%. The NIC Funding Request has increased by 15%. We have added a second trial area to better prove the Methods in a range of real-world environments, which has increased the equipment and installation costs. Receiving feedback from the FITNESS project team we have increased the testing and system integration scope, increasing the total cost by approx. £1m. The Project cost breakdown is shown in Section 4.2.3 Summary cost tablesand the accompanying Full Submission Spreadsheet. Despite these changes Constellation, if successful, will deliver significant benefits to customers representing great value for money.

Lastly, we have partnered with ABB, GE, Siemens and Vodafone in addition to the PNDC to ensure that across the consortium we have the necessary skills and expertise to successfully deliver Constellation. Appendix 10.10 Changes from Constellation 2019 lists the key changes from the 2019 Constellation proposal.

3. Project business case

By 2030, Constellation will save GB DNOs and electricity customers £132m and release 1.98GVA of capacity through securing flexibility and reduced curtailment. It will enable 7.6 TWh of renewable electricity generation, enough to drive a Tesla to Mars and back 254 times over 1.9 m tCO_2. of carbon savings. The project will break even by 2028.

3.1 Summary of Constellation benefits

In 2019, the UK became the first major economy in the world to pass laws to end its contribution to global warming by 2050. This target will require the UK to bring all greenhouse gas emissions to Net Zero by 2050, compared with the previous target of at least 80% reduction from 1990 levels.

This is the latest national commitment on the journey to decarbonisation. We have a co-ordinated strategy of innovation projects to address the diverse set of challenges to decarbonisation – from Active Response, releasing capacity on the HV and LV network, to Optimise Prime which is focused on assessing the impact of the electrification of commercial fleets. These link together with a common aim of facilitating Net Zero reliably and at the lowest cost to our customers.

The distributed network operation delivered through Constellation, will unlock novel approaches to protection and control. The Project will build on other innovation projects looking at digitalised network operation (such as FITNESS and Open-LV), and those focusing on smart services (such as RaaS and Power Potential). In developing the business case, we have evaluated the impact of loss of flexibility services due to communication issues (Method 1) and due to transient instability (Method 2). As such, Constellation is projected to be deployed only at sites where it will support DER operation and provide customers with best value for money.

There are significant benefits which will accrue to both network customers and DER customers, as the Methods are deployed across UK Power Networks and GB electricity networks. In total the **gross financial benefits are £1,158m across GB by 2050**.

Table 2 – Financial, network capacity and carbon benefits

Network Benefits	**DNO savings in virtualisation of hardware** – Constellation creates interoperable standard hardware, communication and data models across protection and control systems. This enables DNOs to quickly deploy smart functionality in the form of virtualised "apps" at scale. Furthermore, new developments in communication (5G) enable scalable and secure site-to-site communication. As a result, Constellation is more economical for deploying functions than fitting bespoke hardware which carries a high capital cost. The estimated benefits are **£467.6m** (out of the £1,158m total gross benefits) across GB by 2050.
	Financial benefits associated with securing flexibility (smart services) – Constellation secures the capacity required by the network from flexibility service providers at grid and primary substations. This capacity would otherwise require significant network reinforcement or

	increased flexibility service procurement. In addition to flexibility, Methods 1 and 2 will also protect other smart services (such as voltage and frequency support). We note that this will indirectly reduce system balancing costs but have not quantified this. The estimated direct financial benefits are **£468m** (out of the £1,158m total gross benefits) by 2050 across GB.
	Capacity release – Constellation delivers adaptive load blinding settings (adaptive protection) which can release network capacity in the future as DER provide voltage control services (Appendix *10.4.2.3* Adaptive protection). The Project will enable the roll out of load blinding across parts of the network where it is currently not possible. It is estimated this will release **1.4GVA** (out of the 4.3GVA total capacity benefit) across GB by 2050.
DER Benefits	**Avoided DER curtailments –and reduced costs associated with central ANM hardware and conventional site-to-site communication** – Constellation will enhance a network's ability to withstand and reduce the magnitude and/or duration of DER curtailments in system events such as network faults on communication interruptions. This provides more revenue to DER through reduced curtailment. We used the average wholesale electricity price from 2019 for this but believe the recent volatility in the market will increase in the future. The Project will also reduce the need for dedicated communication and control hardware for central ANM in DER sites through the 5G site-to-site communication and the virtualisation of the functionality. The direct financial benefits (out of the £1,158m total gross benefits) **to the DER customers** are estimated to be: • Providing savings through reduced communication and control hardware costs: **£134.8m** across GB by 2050; and • Avoided energy curtailment: **£92.5m** by 2050 across GB.
Carbon benefits	Constellation will release network capacity to connect more renewable generation faster and more cost efficiently than through building additional network capacity. The two Methods will also reduce curtailment of connected generators. In total this is equivalent to **17.8** m tonnes of carbon savings (tCO2).

Additionally, Constellation will deliver further benefits:
Improved network response to low frequency events – Constellation will enhance a network's ability to withstand transient instability occurrences which includes the capability to anticipate, absorb, adapt to, and rapidly recover from such events.
Improved cyber security – Constellation's software-based approach to substation functionality improves cyber security using security-by-design principles and the ability to quickly detect, report on and address threats; this is an important step towards compliance with the European Networks and Information Systems (NIS) directive.
Improved network operation – by ensuring that protection settings are correct for any network arrangements in operation and by having greater directional power flow control we can be sure that the active network of the future will operate safely.
More competitive vendor landscape – Creating an environment for software deployment of functionality reduces the barriers to entry for new players in this market. The OIC kick-starts the development of applications in a cost-effective way while also broadening the vendor landscape through competition.

3.2 Business case methodology

The quantified financial, capacity and carbon benefits included in the figures here and in Appendix 10.1 Benefits Tables – forecast of benefits resulting from the Methods have been calculated using our Constellation business case Cost Benefits Analysis (CBA) model. This is explained in detail in Appendix 10.2 Project Business Case Modelling – description of the methodology used in section 3: Project business case with the assumptions detailed in Appendix 10.3 Detailed Business Case Assumptions – description of assumptions used in section 3: Project business case. The key components of this modelling are described below:

- **Forecast of the types of DER connection:** We have split all DER connections into four groups depending on their connection type: if they are connected through ANM or not and, if they provide flexibility services (or not). The model combines the National Grid Future Energy Scenarios (FES), UK Power Networks' Distribution Future Energy Scenarios (DFES) and our flexibility forecast to identify how much DER capacity is connected for each group (Table 14 in Appendix 10.2.2 Business Case Methodology provides details). Our model also forecasts the volume of substations which will be connected to DER up to 2050.
- **Forecast of the number of deployments for each Method**: There are a set of criteria that need to be met for the installation of the Methods. The selection of the Method will depend on the type of DER connection. This is detailed in Appendix 10.2 Project Business Case Modelling – description of the methodology used in section 3: Project business case. Both of the Methods require the installation of the Constellation platform. Our model makes the necessary assumptions around the deployment criteria for each Method to forecast the numbers of installations up until 2050 over UK Power Networks and GB.
- **Assess the benefits of the roll out of each Method:** The cost, capacity released, and carbon cases for each Method are then assessed over a UK Power Networks and GB-wide roll out. The costs are discounted to 2020 values, using a discount factor of 3.5% up to 2049, and 3% in 2050.

3.3 Constellation financial benefits

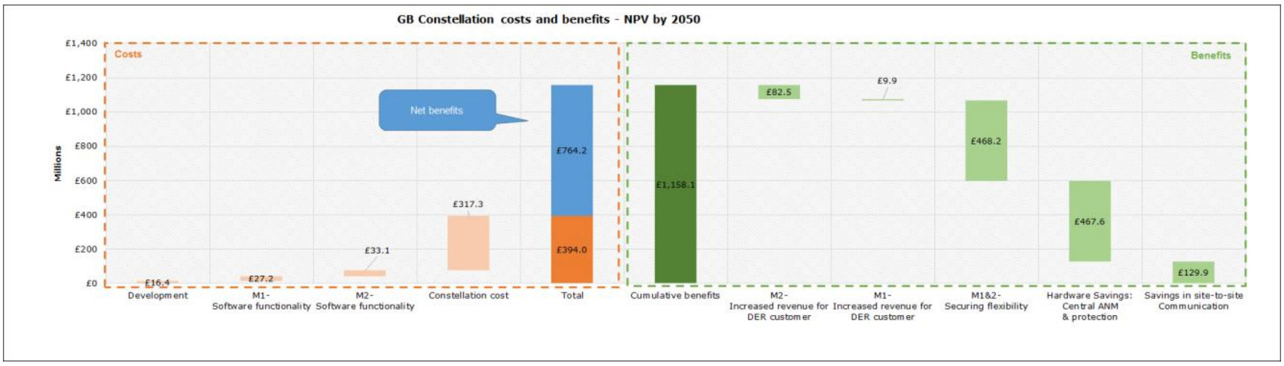

Figure 7 – Forecasted financial benefits to both DNO and DER owners / operators

The graph illustrates that there is a considerable financial benefit of the Constellation Methods up to 2050 for both the network (and its customers) and the DER owners / operators. The main benefits for DER are the revenue from the reduced curtailment (assumed based on 2019 average energy market prices) and savings from reduced communication costs.
The costs have been separated into the deployment of the Constellation platform (consisting of the hardware and IEDs described in Appendix 10.4.4 Hardware for Local Intelligence

(HaLI)); the cost of Method 1 virtualised functionality; and the cost of Method 2 virtualised functionality. Figure 8 shows the cumulative financial benefits up to 2050.

Table 3 shows the gross financial benefits and the cumulative installations for each Method for 2030, 2040 and 2050:

Table 3 – Gross financial benefits and cumulative installations for each method

Licensee scale	2030	2040	2050
Method 1 (£m)	30.6	97.4	126.6
(cumulative installations)	239 DER sites; and 125 primary and grid substations	541 DER sites; and 346 primary and grid substations	607 DER sites; and 347 primary and grid substations
Method 2 (£m)	35.9	103.9	118
(cumulative installations)	255 DER sites; and 134 primary and grid substations	577DER sites; and 370 primary and grid substations	649DER sites; and 371 primary and grid substations
GB scale	**2030**	**2040**	**2050**
Method 1 (£m)	126	458	605
(cumulative installations)	989DER sites; and 584primary and grid substations	2,755 DER sites; and 1,615 primary and grid substations	3,048 DER sites; and 1,620 primary and grid substations
Method 2 (£m)	148	481.5	552.8
(cumulative installations)	1,057 DER sites; and 624 primary and grid substations	2,943 DER sites; and 1,726 primary and grid substations	3,257 DER sites; and 1,731 primary and grid substations

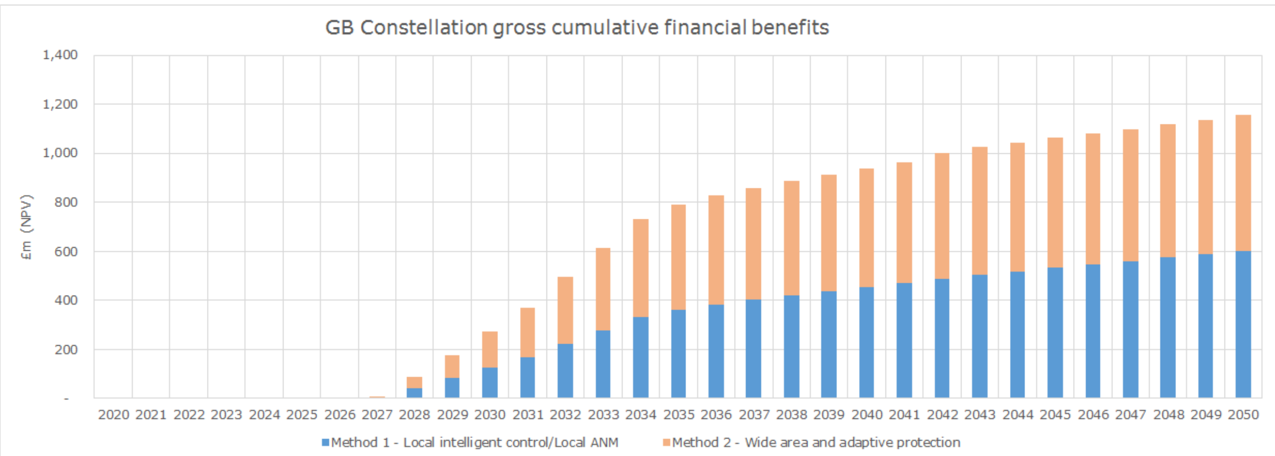

Figure 8 – Forecasted financial benefits to 2050 (GB scale, £m NPV)

Method 1 is deployed across DER sites which are forecasted to be connected through ANM and the substations they are connected to only. Whereas, Method 2 is deployed across all DER sites and the substations they are connected to in order to ensure resilience against transient instability events triggering LoM protection. To avoid double counting the deployment of the Constellation hardware across sites which will be equipped with both Methods, we have separated the costs as described in Appendix 10.3 Detailed Business Case Assumptions – description of assumptions used in section 3: Project business case.

The model only focuses on the part of the smart services impacted by communication issues (Method 1) and wide area instability (Method 2). Therefore, we avoid double counting the full benefit of flexibility services. The other key financial benefits unlocked by the Constellation platform are the virtualisation of functionality that is typically deployed as hardware solutions. The model is conservative as it does not quantify the benefit in standardising engineering design and reduced inspection and maintenance costs of installing software instead of hardware.

3.4 Constellation capacity benefits

The core of Constellation is the two types of capacity benefits: **protected capacity** and **released capacity**. The combined capacity benefit is shown in Figure 9 and Figure 10. **The protected capacity** is as a result of the resilience against the loss of communication to central systems (ANM) and wide area instability events. This capacity will enable DNOs to reduce the volume of flexibility services required or in some instances reduce the need for reinforcement. We estimate that **2.9GVA can be protected** (out of the 4.3GVA total capacity benefit) across GB by 2050.

To assess how much capacity is protected we analysed historic ANM operational data as well as historic faults affecting existing DER.

- Loss of comms: we calculated the annual loss of DER capacity due to communication issues. We only accounted for the energy lost and did not include any flexibility benefits for the capacity unaffected by communication issues;
- Wide area faults: we examined all interruptions to DER operation due to faults and assessed the volume that was "unnecessarily" interrupted. We then applied a coincidence factor to ensure we account for the reduction in flexibility services in the late 2030s, as we have deferred reinforcement as far as possible; and
- Both loss of comms and wide area faults: We applied an alignment factor to account for the duration flexibility services are needed annually and scaled that across to 2050.

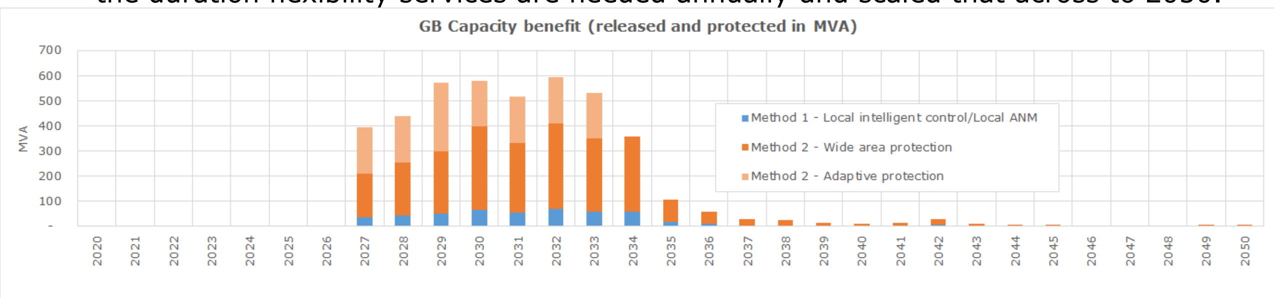

Figure 9 – Forecasted capacity benefit up to 2050 (GB scale, MVA)

The released capacity is as a result of the adaptive protection which allows the deployment of load blinding in areas where DER are providing reactive power as a voltage support service. This will impact the power factor which will result in the load blinder static setting to be no longer accurate. This in turn loses the capacity released by load blinding.

Adaptive (load blinding) protection will release capacity quickly and in areas with high penetration of DER at a lower cost and carbon impact compared to traditional methods. This capacity will enable the connection of more DG quickly and cheaply by mitigating the need for costly reinforcement. We estimate that **1.4GVA can be released** (out of the 4.3GVA total capacity benefit) across GB by 2050. In order to assess the capacity release benefit, we have:

- Forecasted which substations will have DER connected to them providing services to the network based on our smart services forecast and National Grid's FES;
- We have identified which of these sites are connected in a complex network configuration and are supplied through multiple GSPs; and
- We have assumed that this will release an additional 25% of capacity on those sites, which would currently be constrained to 50% of the firm capacity, this is conservative to account for other factors on these sites, typically load blinding can support up to 40% more reverse power capacity (90% firm capacity).

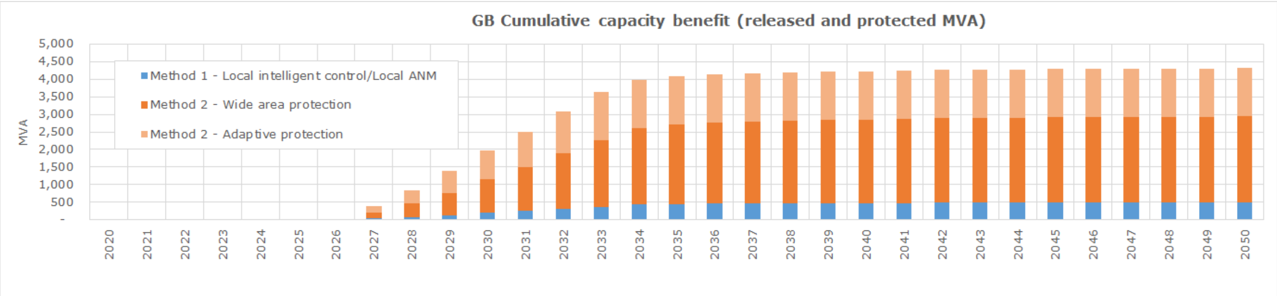

Figure 10 – Forecasted combined cumulative capacity benefit up to 2050 (GB scale, MVA)

3.5 Carbon benefits

Constellation facilitates low carbon electricity generation by reducing curtailment on connected DERs and by releasing network capacity to connect more renewable generation. The carbon benefits, shown in Figure 11, are derived from the difference in carbon intensity between the current generation mix and renewable generation. The diminishing carbon benefits over the years is a result of the overall grid decarbonisation over time. Detailed assumptions are further explained in Appendix 10.2.6 Carbon and capacity.

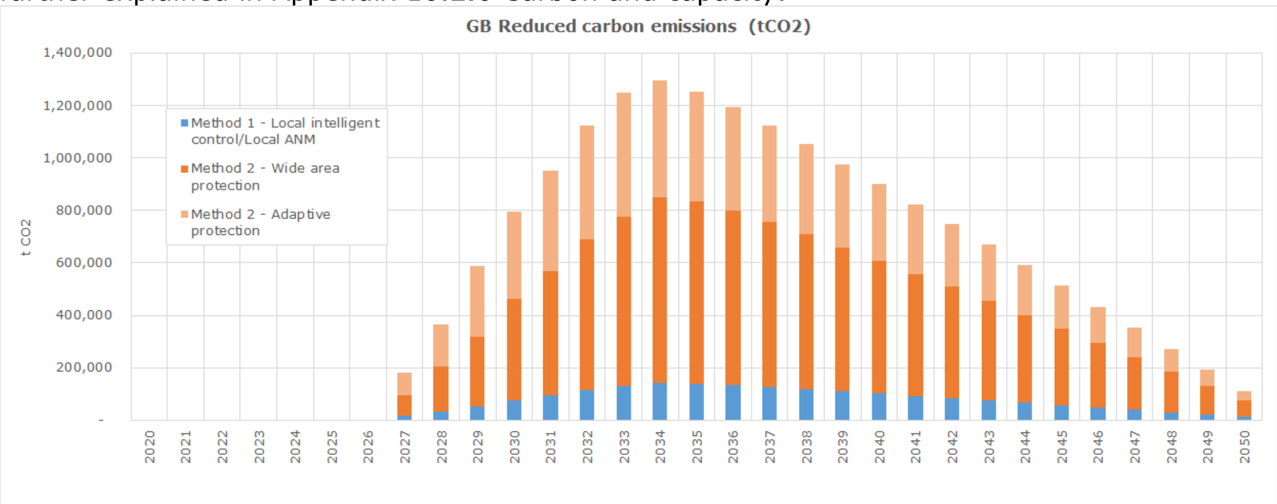

Figure 11 – Forecasted carbon benefits up to 2050 (GB scale, tCO2)

The solutions deployed as part of Constellation, will directly support the Carbon Plan`s aim of reducing emissions from electricity generation by integrating more renewable sources[10]. Furthermore, both Methods will also enable the rapid decarbonisation required in the late 2020s and 2030s by ensuring a reliable, stable and optimised network operation.

[10] BEIS, The Carbon Plan: Delivering our Low Carbon Future, 2011

4. Benefits, timelines, and partners

Constellation's multi-sector collaboration builds novel, cost effective solutions to resolve current and future challenges with the transition to Net Zero.

4.1 (a) Accelerates the development of a low carbon energy sector and/or delivers environmental benefits whilst having the potential to deliver net financial benefits to future and/or existing Customers

To demonstrate the benefits of Constellation we have focussed on three key areas:

1. **Capacity benefits**: 1.98GVA of capacity can be released by 2030 by deploying Constellation across GB.
   - Directly released capacity: a benefit of the adaptive protection (through adaptive load blinding) element of Method 2 is the release of additional network capacity, quickly and at a lower cost and carbon impact than the traditional method. 823MVA of capacity can be directly released by 2030 across GB; and
   - Protected capacity: a benefit of Constellation is to enable the use of DER assets to support the network stability and to prevent unnecessary curtailment. 1.16GVA of capacity can be saved by 2030 across GB.
2. **Financial benefits** of £132m
   - For DNO/connected customers benefit: rolling out Constellation across GB would save customers a total of £111m by 2030 through reducing volume of flexibility services required or deferring network reinforcement and virtualisation of solutions which are traditionally installed as bespoke hardware; and
   - For DER owner/operator benefit: rolling out Constellation across GB could facilitate an additional £21m of revenue due to the reduction in curtailment.
3. **Environmental benefits**: Constellation has the potential to greatly reduce carbon emissions by enabling more low carbon DG to connect, as well as reducing the curtailment of existing DG. Our nation's carbon emissions can be reduced by 1.9m tCO_2 to 2030, when Methods 1 and 2 are deployed across GB.

4.1.1 Supporting Net Zero and the importance of smart energy services

Currently there is 108GW of generation capacity on the system, split as 71% connected to transmission and 29% connected to distribution. In order to achieve Net Zero, the ESO estimates that between 38% and 58% of power generation needs to connect to the distribution network[11] up to 135GW in total, depending on the extent of decentralisation. Furthermore, to enable the transition to Net Zero at the lowest cost to customers, networks need to employ smart energy services such as flexibility. **Therefore, DNOs need to be capable to both facilitate the required capacity to connect DG, and equally, enable opportunities for the provision of smart services to support efficient and low carbon network operation.**

The CCC advises that leveraging the benefits of smart services, can potentially reduce electricity system costs by £3-8 billion annually by 2030[12]. Constellation, through the

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[11] National Grid ESO, Future Energy Scenarios 2019, 2019

[12] The Committee on Climate Change, Net Zero: Technical annex, 2019

distributed and digitalised network operation, can protect the flexibility services as well as quickly and reliably dispatch other services, such as voltage and frequency support, from local DER. Furthermore, the Constellation system will provide the environment for rapid deployment of the smart services such as flexibility, which we will rely on to keep our network optimised and secure.

4.1.2 Impact on resilience

Our distribution forecasts indicate that by 2050 our network would need to facilitate more than two and a half times more generation capacity[13] (based on the medium uptake scenario) than the currently connected 7.9GW. Additionally, we believe that the upcoming changes to the network access and forward-looking charge arrangements from 2023, will contribute to the increase in service provision to our network by connected DER. This means that in the future, we need to protect the services we rely on to operate our network. It is especially important for the industry to use the lessons learned and take steps to reduce the knock-on effect of wide area instability to cause a collapse in generation across the distribution network.

Constellation provides a step change improvement in providing greater resilience on the network and will enable DER to remain connected and support system stability during low frequency events. Methods 1 and 2 can protect 2.9GVA of capacity from curtailment due to communication loss and wide area faults when rolled out across GB by 2050. Further detail in Appendix 10.2.2 Business Case Methodology.

4.2 (b) Provides value for money to electricity distribution Customers

Constellation will enable distributed and optimised network operation through Methods 1 and 2 and could deliver £22.2m in net financial benefits rolled out across UK Power Networks' licence areas by 2030; £132m rolled out across GB. A GB-wide rollout would provide 9 times the return on the £14.4m NIC funding requested in benefits to customers by 2030.

4.2.1 Potential direct impact on the network

The Project will transform the traditional philosophy for protection and control as well as the shift away from bespoke hardware solutions to software functionality. This will unlock more optimised operations and more efficient and automated engineering design processes, which are less prone to error. Additionally, both Methods can be deployed rapidly and at scale across the distribution network due to the virtualisation of protection and control functionality. Furthermore, while the trial site selection will be finalised during the Project, we have selected two demonstration areas which will enable us to release capacity in parts of the network currently saturated with generation.

Overall, Constellation will enhance our existing capabilities and develop new ones required to ensure our network is resilient and ready for the Net Zero future:

- Method 1 will demonstrate distributed network control and complement existing central systems to maintain optimal network operation. The aim is to reliably carry out optimisation based on local observability and powerful on-site state estimation analysis; and
- Method 2 will demonstrate wide area protection to ensure DER assets are not interrupted due to transient instability events. As a result, the overall resilience will improve by allowing local flexibility resources to continue to provide support to the

[13] UK Power Networks, Distribution Future Energy Scenarios, 2020

network. Method 2 will also test dynamically verifying, calculating and configuring protection settings. This will offer a solution for issues with DER providing voltage support services (reactive power) and the load blinding protection settings (Appendix *10.4.2.3* Adaptive protection).

As such, both Methods will have a direct impact on distribution networks, increasing the available capacity for new connections and maximising the utilisation of existing network assets through reduced curtailment of DER.

4.2.2 Project costs
To ensure the Project is delivered at a competitive cost, figures have been calculated with a bottom-up approach. This is based on the Project plan, across each of the Project Deliverables and workstreams with inputs from UK Power Networks' senior management, and the partners. The costs have been reviewed by multiple levels of relevant internal stakeholders, including fellow innovation project managers, up through key directors as part of our innovation funding governance process. Our cost estimates are based on:

- Inputs from UK Power Networks' experts for labour requirements, including during procurement, legal and dissemination activities;
- Inputs from UK Power Networks' technical specialists for labour, documentation and equipment installation activities;
- Quotations received from partners and suppliers; and
- Project management costs from previous experience in delivering similar NIC projects.

Two of the specialist suppliers we have identified and engaged are Omicron electronics GmbH (OMICRON) for offsite, laboratory testing and vendor-independent factory acceptance testing (FAT) and site acceptance testing (SAT) support, and RuggedCom for secure communications equipment and 5G testing support. More detail on testing is available in Appendix 10.4.9 Testing and commissioning. Additionally, a competitive procurement process will be used (or will have been used where suppliers are already on our framework) to select suitable suppliers for other elements of the Project where several potential suppliers are available. This includes the site preparation and installation works, the second providers of Methods 1 and 2, as well as the Open Innovation Competition and the Academic Insights research (sections 2.1.3.1 Open Innovation Competition (OIC)and 2.1.3.2 Future governance, rules and academic insight). Where possible we will award this work in stages of fixed price and scope. This will allow us to manage any scope creep and avoid unexpected cost overruns.

Costs will be minimised as far as possible by using existing platforms and interfaces (or those already under development). This includes UK Power Networks' corporate cyber security network and licenses. Additionally, to ensure scalability and consistency across the developed functionality for Methods 1 and 2, UK Power Networks will procure the HaLI (Constellation system hardware platform). Lastly, Methods 1 and 2 will require integration to the ADMS, ANM and asset registry systems and we have allocated £1.75m based on quotes from the respective subcontracted parties and estimates from similar work.

We believe that trialling multiple Methods for solving network limitations represents good value for money to customers, providing efficiency benefits in innovation overheads and creating solutions that work for a range of different network configurations. There are a number of elements (the central management, virtualisation platform and the site-to-site communication) that enable the Methods which, to deliver as separate projects, would significantly increase the total cost.

Furthermore, we believe demonstrating each Method with one technology development partner as well as one procured supplier will ensure the Constellation system is flexible and interoperable and that the solutions could be procured from the market in future. This will also ensure we have the "right" experience and expertise on the project, while achieving interoperability cost efficiently.

4.2.3 Summary cost tables

Table 4 – Project costs by workstream

Workstream	Name	Percentage (%)
WS1	Software & Cyber Security Requirements, Design and Development	8.0%
WS2	Functional Requirements, Design, Development and Hardware Specification	30.4%
WS3	Trials & Analysis	38.3%
WS4	Open Innovation Competition (OIC)	5.4%
WS5	Academic Insight & Future Governance	3.4%
WS6	Learnings & Dissemination	1.2%
PM & Contingency		13.2%
Total		100%

Table 5 – Project cost by category (Other consists of materials and preparation for learning dissemination events)

Cost Category	Cost (£k)	Percentage (%)
Labour	£2,114	12%
Equipment	£2,216	12%
Contractor	£4,802	27%
IT/Communications	£6,965	39%
IPR Costs	£-	0%
Travel & Expenses	£147	1%
Payments to users	£-	0%
Contingency	£1,500	8%
Decommissioning	£-	0%
Other	£80	0%
Total	£17,824	100%

The IT/Communications costs include the development of Methods 1 and 2, as well as the 5G communication. The Contractor costs include the testing and commissioning, the site work and the allocated budget for subcontracting the local ANM and wide area protection elements and the PNDC cost.

Table 6 – Project staffing costs (it should be noted that ABB, GE, Vodafone and Siemens will be paid as IT service / development costs, PNDC as Contractor costs)

Project Participant	Workstream	Total (£k)	FTEs	Person days	Cost (£) / Person Day
UK Power Networks	1	[redacted]	[redacted]	[redacted]	[redacted]
	2	[redacted]	[redacted]	[redacted]	[redacted]
	3	[redacted]	[redacted]	[redacted]	[redacted]
	4	[redacted]	[redacted]	[redacted]	[redacted]
	5	[redacted]	[redacted]	[redacted]	[redacted]
	6	[redacted]	[redacted]	[redacted]	[redacted]
	PM	[redacted]	[redacted]	[redacted]	[redacted]
PNDC	1	[redacted]	[redacted]	[redacted]	[redacted]
	2	[redacted]	[redacted]	[redacted]	[redacted]
	3	[redacted]	[redacted]	[redacted]	[redacted]
	4	[redacted]	[redacted]	[redacted]	[redacted]
	5	[redacted]	[redacted]	[redacted]	[redacted]
	6	[redacted]	[redacted]	[redacted]	[redacted]
	PM	[redacted]	[redacted]	[redacted]	[redacted]
Total		£3,161[14]		5,393	

4.3 (d) Is innovative (i.e. not business as usual) and has an unproven business case where the innovation risk warrants a limited Development or Demonstration Project to demonstrate its effectiveness

Constellation is aligned with UK Power Networks' Innovation and Future Smart strategies in digital substation architecture and smart network operation and enables our published vision to transition to a DSO. The innovativeness of Constellation is discussed in this section.

4.3.1 Digitalised distribution system operation

Substations fulfil an increasingly critical role in resolving the challenges of maintaining resilient protection and control functions. This is because the increase of DG and more dynamic network operating conditions necessitate adopting a more flexible means of introducing novel and validated control and protection functionality. Constellation pulls together the breadth and depth of experience of the Project Partners to create a common platform. It enables flexible and rapid deployment of new substation functions that utilise a substation's potential as a data rich environment.

[14] Please note that in all other tables the Labour cost refers to UK Power Networks Labour only. All other Partner Labour costs are split between Contractor (PNDC) and IT (ABB, GE, Siemens, Vodafone).

This collaboration initiative deploys novel approaches for network operation. More specifically, the containerisation technology to deploy required safety-critical, time-critical control (Method 1) and protection (Method 2) functionality is first in GB distribution substations. This holds significant technical and commercial challenges.

Technically understanding the performance of each component (software and hardware) is critical to ensure the safe operation of the network. The protection functions must be re-created to operate in a different environment. The environment must ensure that each function operates 100% reliably within the required timescales, despite any other function operating or possible cyber-attack. Between sites new technology must be developed to exploit to potential opportunity that 5G provides, despite this being as yet unproven. These developments represent a technical risk to the Project and justify the use of NIC funding to trial.

Commercially where we rely on multi-vendor products to protect and control our network we need to have a clear understanding of risk, and how that is treated within contracts. The safety, financial and reputational risks are significant if these do not operate correctly. Where a single vendor provides a protection device there is clear responsibility if the device does not operate correctly. Where distinct vendors provide hardware and software and a function does not operate in time who takes responsibility to identify the root cause and potential liability for any damage? These are questions Constellation intends to address.

Ensuring interoperability between the various elements of the platform is inherent to the platform architecture and is built-in to the multi-vendor collaboration in the Project. This approach opens up the substation environment to third party innovators to address emerging operational challenges, but is testing functionality that is potentially un-proven and would not be possible to procure using a typical Utilities Procurement Regulations compliant method. This is managed and demonstrated through the Project's OIC (Appendix 10.4.8 Open Innovation Competition (OIC)). Furthermore, Constellation's virtualisation approach considers cost of the platform and the functionality it provides over its entire life cycle. As such, long term operational savings can be achieved contrary to a hardware-based approach.

4.3.2 Distributed network operation

The grid modernisation research by the US Department of Energy[15], evidences the need for local intelligence to be deployed to complement the localised production and storage of energy. Furthermore, the future power system architecture (FPSA) project[16], ran by the Institute of Engineering and Technology and the Energy Systems Catapult, has defined a need for new real-time balancing functionality. The two Methods developed through Constellation will demonstrate a novel approach to network operation, which carries significant innovation risk that needs to be tried and tested before roll-out.

The implementation of the Constellation Methods paves the way to demonstrating a robust distributed control architecture that combines the benefits of centralised situational awareness and network state verification with local fast-acting control and protection. This takes forward

[15] US Department of Energy, "Modern Distribution Grid, Volume I: Customer and State Policy Driven Functionality", 2017
[16] The IET & Energy Systems Catapult, "Future Power System Architecture, Project 2, Work Package 2 Final Report – Functional Analysis", 2017

the innovations and learning from previous and live projects (e.g. FITNESS, OpenLV, Unified Protection, EFCC, VSATT, Power Potential, SIARA) as well as commercial state of the art solutions and integrates new functionality in the substation environment.

Method 1 is the first live demonstration of its kind of active network management that is resilient against communication failures, while Method 2 is the first demonstration of wide area-based protection applied in a distribution network setting. Both of which emphasise the importance of providing the control and protection performance required to secure supplies and maximise the contribution of DERs, where otherwise they would be curtailed. Consequently, these Methods enable the increasingly important role of distribution networks in ensuring overall grid stability and resilience. Nevertheless, there are challenges in carrying out sophisticated state estimation, contingency analysis and power flow assessments for wide area protection and control. There is risk that the HaLI (section 2.2.1.1 Hardware for Local Intelligence (HaLI) and virtualisation platform) is not capable of the real-time processing requirements needed. Therefore, the Constellation platform is innovative as it represents a technical and operational risk, which therefore justifies the use of NIC funding to test its implementation.

Furthermore, Constellation recognises the important role of peer-to-peer communications in achieving resilient and secure network operation and is thus trialling 5G network slicing technology that builds on promising early performance results by the cellular technology vendors. 5G slicing is unproven outside of lab testing in GB and poses an implementation risk which justifies the use of NIC investment.

Finally, Constellation is well positioned to build on previous research and demonstration achievements in the digital substation domain and to deliver outcomes and learning that can be readily adopted by the wider industry. The future governance processes (further detail in Appendix 10.4.7 Academic insights and future governance) developed in the Project ensure alignment with business requirements and that mitigating measures are in place to address risks of technology adoption. Moreover, validation and trials constitute a major part of the Project where the technology is not only validated as part of a rigorous testing regime, but also considers the future requirements for technical compliance and certification with a view to rapidly deploy validated functionality. This ensures the timely adoption of technologies and future-proofs the substation environment to meet evolving and dynamic network operational requirements.

4.4 (e) Involvement of other partners and external funding

Constellation will rely on a collaborative approach amongst a carefully selected project team to deliver the Project successfully. Details of the Project Partners, their role within the Project and why they have been selected are contained in Appendix 10.8 Organogram & Partners. Through their membership of the PNDC digital substation working group we have the support and involvement of both SP Energy Networks and Scottish & Southern Energy Networks. They have committed to support as part of the technical design authority on the project and provide funding to aligned research through PNDC. This is described in more detail in Section 5.1. Learning generated.

Table 7 – Project partner costs and contributions

Project Partner	Total Costs (£k)	Contribution (£k)	Contribution (%)	Outstanding Funding Required (£k)
UK Power Networks	[redacted]	£1,627	[redacted]	[redacted]
ABB Ltd	[redacted]	£228	[redacted]	[redacted]
Siemens	[redacted]	£658	[redacted]	[redacted]
GE	[redacted]	£344	[redacted]	[redacted]
Vodafone	[redacted]	£145	[redacted]	[redacted]
PNDC	[redacted]	£175	[redacted]	[redacted]
Total	£17,824	£3,178	18%	£14,646

In

Table 7 our technology partners, ABB, GE, Siemens and Vodafone, are contributing above the minimum required to demonstrate their commitment to the project and its outputs.

4.5 (f) Relevance and timing

4.5.1 The need for smart services to support network operation in Net Zero world
GB is expected to continue to experience unprecedented growth in connections at the distribution level in the coming decades. Our DFES forecast informs us of the rapid increase in the amount of distribution connected generation capacity in the mid-2020s. We have considered all DFES scenarios to ensure Constellation provides good value for money to customers in all uptake scenarios of DER (Appendix 10.2.7 Sensitivity analysis has further detail on sensitivity analysis).
Research by EnergyREV evidences the need for flexible resources as "smart local energy systems lead to cost savings"[17]. Furthermore, since 2018 UK Power Networks has committed to a "flexibility first" approach[18]. This means we are now seeking to procure flexible energy

[17] EnergyREV, Early insights into system impacts of Smart Local Energy Systems, 2020
[18] UK Power Networks, Flexibility Roadmap, 2018

services as the default option in preference to reinforcing or upgrading our assets. We will employ this approach whenever it is the most cost-effective option for our customers. Our forecasts for flexibility services show the rapid increase after 2023 (see Figure 12), which we expect is as a result to the upcoming changes to the network access and forward-looking charge arrangements.

Furthermore, the rapid decarbonisation of the nation towards the Net Zero commitment will enable a market for additional distribution services beyond flexibility, such as voltage and frequency support. At present Power Potential, a NIC project set to conclude in 2021, is an initiative demonstrating the value of utilising distribution connected resources to support the network. Should this Project roll out quickly at scale, the significant change in reactive power output from DER will likely cause problems for some of our network projection such as load blinding.

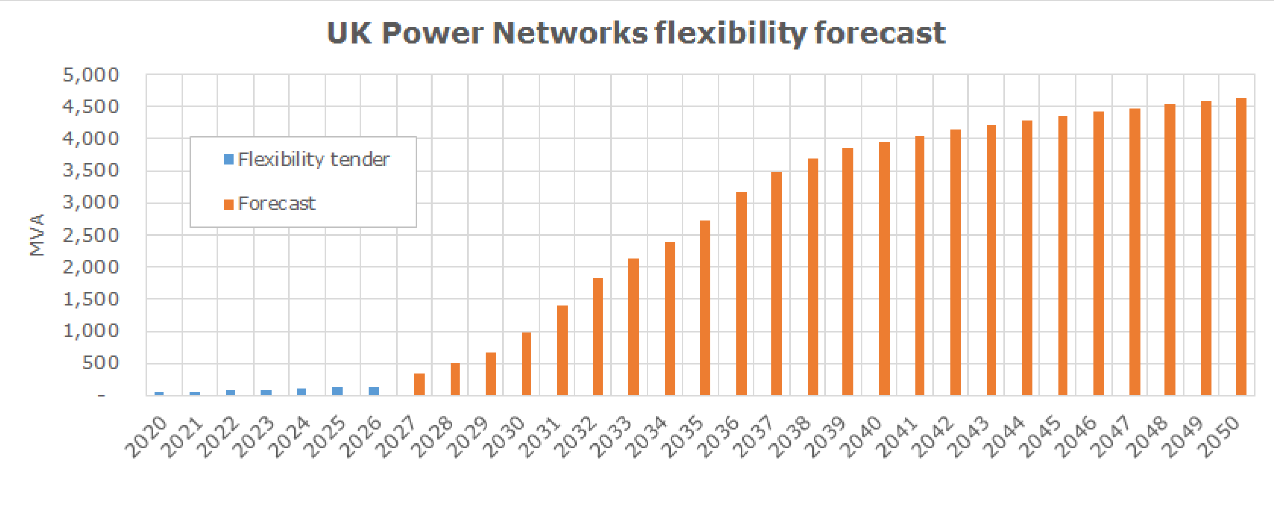

Figure 12 - UK Power Networks Flexibility forecast

Constellation will be on the live network in its trial phase in 2023 and will conclude in 2025 and be ready for GB deployment from 2027. This accounts for both the time to adopt the solution and for 5G to be rolled out nationally. As such, it is set up for deployment at the right time to support the rapid connection of DER and need for smart services to the distribution network.
UK Power Networks will include provision in its RIIO-ED2 business plan submission to roll out Constellation from 2027, after the completion of the project, as we are advised 5G should be largely available across our licence areas by that time. Our business case here includes deploying Constellation to all grid and primary substations with DER by 2033 with achievable roll-out volumes.

4.5.2 Links to industry strategic focus
The development aims of Constellation align well with the goals of other industry projects related to distributed network operation. As shown in Figure 13 Constellation is aligned with previous and on-going initiatives, such as OpenLV, FITNESS, SIARA and Unified Protection. Additionally, Constellation has synergies with on-going initiatives like RAAS, Open DSP and Holistic Intelligent Control System for flexible technologies. Constellation will be set to share the architecture and overarching system design in 2021, in time to support those initiatives and validate their results. We see it as a foundational project to supporting future research

and development into autonomous networks and the future of network control. Discussions are already underway on some of these topics with other GB DNOs.

UK Research and Innovation (UKRI) is investing in a new "Prospering from the Energy Revolution" Industrial Strategy Challenge Fund (ISCF) programme. By 2022, the ISCF initiative is set to deliver replicable, scalable, and large-scale energy system demonstrators that will include new business models that intelligently link supply, storage and demand patterns across power, heat and transport. It therefore follows that, by 2022, it would be highly desirable that network operators throughout GB ensure that they are taking a co-ordinated, integrated approach to maintain control and safe operation of the network at the distribution level. This will be impossible to do if we remain with over two thirds of main protection based on electromechanical relays.

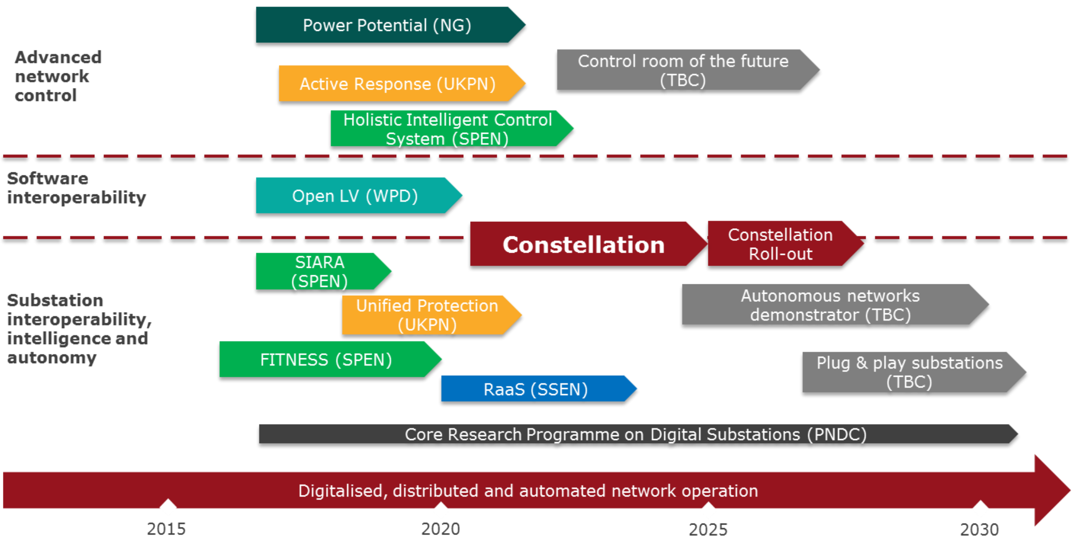

Figure 13 – Constellation fit within wider industry work on digitalised system operation

Furthermore, Constellation will overcome key barriers surrounding the digitalisation of the energy sector. This will feed into the Modernising Energy Data access work supported by BEIS, Ofgem and Innovate UK in addition to providing insight for the Energy Data Taskforce. Constellation will act as an exemplar of how digitalised network operation can improve data quality and operational resilience. The OIC will enable access to rich network data to third parties capable of developing functionality to address business needs.

4.5.3 Timeliness of technology

In order to achieve the necessary optimised network operation needed for a cost-efficient transition to Net Zero it is essential that our local substation layer is enhanced. Projects such as SIARA, FITNESS and Unified Protection have proven some of the initial concepts and hardware. Constellation is starting at the right time, as it can keep the industry momentum going and continue the development of distributed and autonomous network operation. We have engaged with the Project teams for those projects and have identified significant learning about the criticality of testing in multi-vendor initiatives.
The Project is also timely because of the recent technology and commercial developments in 5G communication. 5G slicing is a new concept in cellular service provision and this Project is helping to inform the service development. The trials of Constellation on the live network begin in 2023 which aligns with the deployment of 5G across the trial area.

If proven to be successful, the platform Constellation develops (sections 2.2.1.1 Hardware for Local Intelligence (HaLI) and virtualisation platformand 2.2.1.2 Central management of the Constellation system) will be taken forward as a standard engineering design solution for protection and control in substations. This cost efficiency of moving away from dedicated hardware solutions will be reflected in the business plan submission as well as future price controls. Furthermore, both Methods will be deployed across areas on the network which rely on services DER provide at first. After that, we will gradually roll-out the two Methods as the increase in smart services to the network increase.

5. Knowledge dissemination

UK Power Networks and all Project partners will conform to the default IPR arrangements and share learning at key stages of the Project. We will share these together with the trial outcomes.

The Constellation partnership and procurement approach has been carefully selected to ensure that we have the necessary skills and expertise are available to demonstrate the novel aspects of the Project and can demonstrate enduring value for money. Our partners have all proven their capability through working with us through PNDC or our Unified Protection project and demonstrated they are at the cutting edge of development in their fields. To verify that we are providing value for money and stimulate the market for rolling out the Constellation Methods we will procure additional suppliers to demonstrate the Local ANM and wide area protection elements

In order to ensure scalability of the results, lessons learned and system designs across the other distribution networks in GB, we will align Constellation with PNDC's innovation programme on digital substations. The programme is funded by PNDC members, including Scottish Power Energy Networks and Scottish and Southern Electricity Networks, who own and operate two distribution licence areas each. This alignment has been approved by the PNDC technical board and support from the members is appended in Appendix 10.11 Letters of Support – letters from project supporters. The working group will assume two roles for the Constellation project:

- Input and opportunity to steer and take part in the OIC; and
- Design authority to represent the other DNOs and wider industry and ensure Constellation's results are scalable.

As a result, this provides necessary confidence to the wider DNO community in our solution, fast-tracking BaU deployment in at least seven of the 14 GB distribution licence areas and validating the benefits for GB-wide scalability and applicability.

5.1. Learning generated

At UK Power Networks we deliver innovation projects by using a 'learning by doing' approach. We believe that network demonstration of novel solutions generate invaluable knowledge and learnings, which provides the required confidence for the industry to adopt the technology into BaU. In this way, through the network trials and regular knowledge sharing events, Constellation will enable the adoption of distributed intelligence and autonomy to a BaU deployment readiness level.

The primary aim of Constellation is to demonstrate and understand the benefits of local intelligence and distributed network operation in response to the upcoming challenges with Net Zero. The benefits are relevant and scalable across the entire GB DNO community as we continue to optimise our networks to enable a low carbon future.

The two Methods of Constellation will demonstrate significant new learning over and above what has been currently achieved by the industry:

- Method 1 – Local intelligent control/Local ANM: provides network control, and optimisation as a balance between local and central operation. This is an entirely novel approach, as traditionally ANM have been delivered by a dedicated point-to-point link

or managed centrally. We expect this Method to deliver entirely new learning using a novel architecture unproven elsewhere;
- Method 2 – Wide area and adaptive protection:
  - The wide area element of this Method provides protection capability across wider local areas through secure and scalable site-to-site communication. This represents a change in approach to generator protection, where the focus is to keep the generation connected if at all possible, as opposed to disconnect it if there is any risk.
  - Virtualising protection has some overlap in the learning generated by NIA project Unified Protection. However, Constellation goes beyond the hardware and tools used in Unified Protection and will implement more protection functionality within Method 2 on a substation PC provided by a different vendor as described in section 2.2.1.1 Hardware for Local Intelligence (HaLI) and virtualisation platform, rather than a machine from the same vendor as the protection, which was not considered in Unified Protection;
  - The adaptive protection element of this Method provides dynamically verified and configured protection settings. This is a different approach to the traditional statically designed and rarely changed settings or to the approach of a small number of settings "groups" for a site; and
- Constellation platform: provides the environment and physical resources needed for Methods 1 and 2 to function as virtualised software. This is a novel approach to substation functionality design and implementation. While this aspect will build on learnings on interoperability and multi-vendor interactions from FITNESS and OpenLV, it will deliver significant new learning using a novel architecture, which is unproven.

Error! Reference source not found. demonstrates what learning will be generated through each of the workstreams.

The quality of the learning is ensured through a combination of our experienced staff, our knowledgeable and respected project partners and our expert advisers and reviewers. The learning products of the Project are directly applicable to other DNOs in GB, evidence by the unanimous approval of aligning Constellation with PNDC's core research programme on digital substations (evidenced in Appendix Appendix 10.11 Letters of Support – letters from project supporters).

Furthermore, apart from DNOs, we are confident Constellation will deliver learning that is valuable for the wider industry:
- **Policy, regulators and associated bodies:** the trials will enable Ofgem to gain valuable insight about potential opportunities to increase the system resilience. Additionally, the demonstration results will enable the CCC to recommend appropriate carbon budgets having a better understanding of the value and risk with flexible service provision;
- **Industry groups, associations and professional bodies:** these stakeholders will benefit from the improved understanding on technical details of the enabling elements of Constellation (the hardware, virtualisation environment and testing requirements);
- **Academic institutions:** Constellation will accelerate the shift towards distributed intelligence and local optimisation. Academic and research and development institutions will benefit from access to high quality data from our trials;
- **Customers:** understand the solutions and technology used in the Project;
- **DER owners/operators:** these stakeholders will benefit from gaining access knowledge of how their assets impact the network during instability events; and

- **Technology suppliers/vendors:** these stakeholders will benefit from unlocking the wider market for development of software for substation automation.

Table 8 – Learning generated summary

Workstream	Learning Generated
1. Software & Cyber Security Requirements, Design and Development	The architecture requirements for distributed & autonomous protection and control of the distribution network
	Global industry review of grid edge intelligence to ensure a future proof design is taken forward
	Identification of the necessary tools and models to maintain secure communication between sites with local intelligence
2. Functional Requirements, Design, Development and Hardware Specification	Details of the functional requirements for the reliable operation of Methods 1 & 2
	Review of hardware parameters and designs so that the most suitable infrastructure is in place to facilitate the local intelligence
	Development of wide area protection algorithms and network constraint management functionality
3. Trials & Analysis	Review of the Constellation business case in preparation for optimal BaU roll-out
	Empirical understanding of the performance of the local intelligence system and its components
4. Open Innovation Competition	Practical evaluation of the overall "openness" of the Constellation local intelligence system
	Identification commercial opportunities in substation solution functionality development
5. Academic Insight & Future Governance	Research into the evolution of distributed and localised control after Constellation, assessing both benefits and challenges
	Assessment of the mitigation for the risks with ownership and operation of multivendor interoperable systems
6. Learnings & Dissemination	Effective dissemination of the learning derived over the course of the Project

5.2. Learning dissemination

Constellation will strive to share knowledge through the Project to ensure our customers maximise on the investment in the Project. The Constellation dissemination roadmap is developed based on our previous experience of running successful large-scale innovation projects (Appendix 10.7 Knowledge Dissemination Roadmap). We aim to use this as a live document and update it as we progress with the Project Deliverables. The purpose of the roadmap is to inform all stakeholders of what knowledge will be produced, how it will be shared and at what stages of the Project. We will strategically aim to present Constellation at events as one of UK Power Networks' flagship projects aimed at transforming the existing network management approach.

In order to ensure knowledge transfer with all key stakeholders we will:

- Leverage the experience we have over the last decade of running high profile innovation initiatives: we have gathered an extensive contact list of stakeholders, which we will use as an initial list;
- We will seek input from other DNOs who have run or are still running digitalisation projects;
- We will leverage the experience and connections of our consortium of partners to include all relevant stakeholders; and
- We will conduct market research to identify stakeholders who would be interested and how they could benefit from this Project.

5.2.1 Learning dissemination approach

We aim to raise awareness and understanding of the new opportunities unlocked through our innovation in distributed network operation. We will make our progress and findings transparent and easily accessible through a variety of dissemination channels which will give stakeholders the discretion to choose how they would like to be informed, described in Table 9.

Table 9 – Dissemination approaches

Channel	Description	Outputs
Websites	Our innovation website which features details on all previous and on-going innovation funded project. (https://innovation.ukpowernetworks.co.uk/) Users will have access to documents, videos, datasets and online learning events. Similar information will also be made available via the ENA Smarter Networks Portal.	Articles, data, video materials, training materials, news
Press & Social Media	Publications in industry news providers, magazines, blogs, LinkedIn updates and Twitter.	Notifications, updates, news and announcements
Stakeholder forums & workshops	Direct and timely learning dissemination to allow active engagement and sufficient opportunity for questions.	Face to face meetings, workshops, video conferences, posters and other printed materials
Industry conferences & events	Constellation will be presented alongside other flagship UK Power Networks projects annually at the LCNI conference. This will enable the wide audience to interact with the Project and learn from the lessons gained.	Knowledge exchange and collaboration opportunities
PNDC innovation programme on digital substations	The PNDC digital substation working group will hold the design authority role for Constellation. We intend to collectively raise awareness to the research into digital substations through joint dissemination events with the board members.	The opportunity to explore how UK industry can support DNOs to upskill their staff in distributed network operation
Joint white papers &	The Project partners have expressed interest to publish technical research papers on the	Technical reports and R&D papers

research publications with the Project partners	findings of the various project elements. UK Power Networks intends to freely share our approach to distributed network operation in order to accelerate the uptake into BaU.	

5.2.2 Availability of trial data
All of the Project trial result data will be stored within the Project consortium shared working space and will be made available to interested parties and on our Open Data page at the end of the Project as specified in version 3 of the NIC Governance Document.

5.3. IPR

The delivery of this Project by the consortium of Project Partners, and any products that are developed, will adhere to the default IPR arrangements set out within the NIC governance. Project contractors, consultants and suppliers will be required to comply with the default IPR arrangements as part of the selection criteria of the competitive tendering.

All project partners will agree on a joint collaboration agreement, setting out the NIC requirements for collaborative development and demonstration. After that, UK Power Networks will enter into individual contracts with each project partner. The individual contracts will align to the overarching collaboration agreement and will set out the deliverables, payment milestones and acceptance criteria.

It should be noted that the third parties who enter the OIC will need to agree and comply with the NIC Governance IP requirements in order to participate. Once a participant has been selected to develop an app, contracts reflecting the NIC Governance requirements will be signed. Any existing source code and architecture will be treated as Background IP that remains that remains the property of the participant. Any Foreground IPR developed solely by the participant, such as any further software development, will remain theirs. Relevant Foreground IPR developed jointly, such as learning related to deploying their software on the Constellation platform and using it on the network will be jointly owned and will be shared with all network licensees.

6. Project readiness

UK Power Networks has undertaken significant preparatory work, including the creation of a robust plan to ensure the Project can begin and deliver the Project successfully.

The Project was developed and will be managed in accordance with UK Power Networks' Innovation procedure, SR 07 005i. This procedure has been developed so that all of our innovation ideas are subject to the appropriate level of review and governance via a stage gate review process, in accordance with Project Management best practice as summarised in Figure 14.

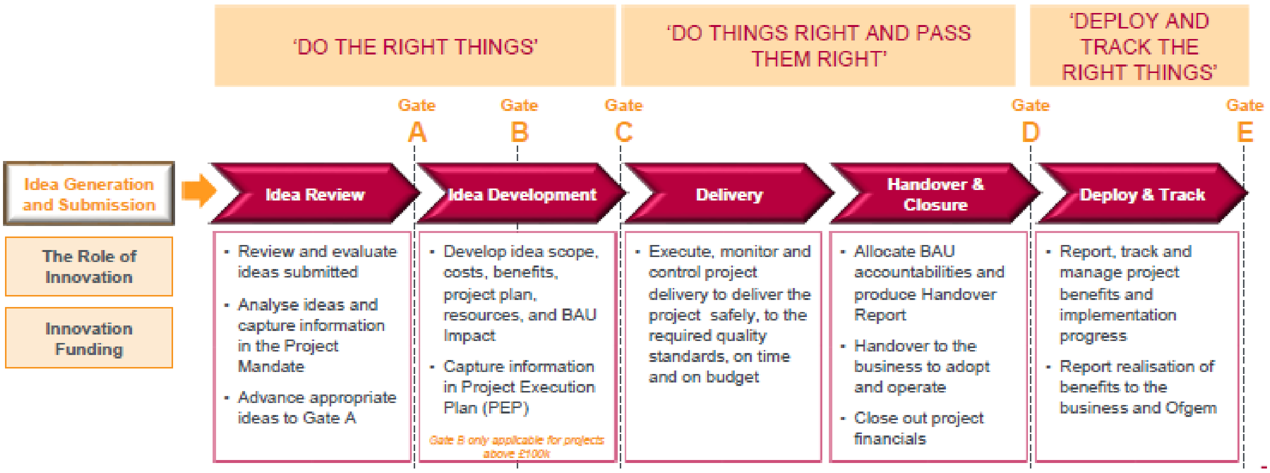

Figure 14 – UK Power Networks governance system for Innovation projects

Constellation is a transformation project with highly innovative elements and, as such, will have a higher risk profile than more traditional projects, where the requirements and outcomes can be precisely defined during the development. However, the NIC is funded through GB's customers and there must be certainty that the money is well spent from the outset. This section is dedicated to providing confidence that we, across the partner consortium, have carried out the necessary planning to assure Ofgem and all the parties involved that the Project will be delivered successfully on time and on budget.

6.1 Evidence that the Project can start in a timely manner

As part of the bid development for Constellation, we have invested significant amount of time and preparatory work to ensure the Project can begin promptly after funding has been awarded. We have developed the initial Constellation system design (described in section 2.2. Technical description of Project) based on engineering studies and desktop analysis. We have also provisionally selected 12 sites for the network trials based in the Maidstone and Lewes areas in our South Eastern network license area, with other possible trial sites identified. Furthermore, our partners have carried out initial studies to inform the Method impact for the business case. The outcomes of this preparation are:

- Strong support from UK Power Networks, including senior management;
- Highly engaged, committed and qualified consortium of partners, including project team members;
- A clearly defined project management and governance structure;

- A robust and detailed Project plan (Figure 16 and Appendix Appendix 10.5 Project plan – detailed project plan) which enables the Project to commence as planned; and
- Identification of key project risks and mitigating actions.

6.1.1 Strong support from UK Power Networks

The Constellation project was developed with the support from our internal business to ensure we have captured expert input and gained commitment for delivery. This includes support from:

- Key members of the Executive Management team, who committed management time and ensured the availability of input and support from in-house specialists.
- Business experts and specialists who provided input and committed to continued support during the Project delivery. They are engaged through regular meetings in the development of the Project plan with internal senior managers and other senior discipline leaders with expertise in network protection, control and cyber security.

The Project has progressed through UK Power Networks' internal Innovation and Project Governance and Control Governance processes (SR 07 005i). This ensures that all the relevant internal stakeholders are fully engaged and formally committed to the Project.

6.1.2 Highly engaged, committed and qualified team members

We are confident that the consortium of partners for Constellation is experienced and capable to successfully deliver large, complex, technical projects on time, budget and with quality Deliverables.

Constellation is a multi-disciplinary initiative spanning the IT, energy and engineering sectors. To successfully advance the enabling technology for the two Methods and the Constellation system, we have commitment from global technology developers (ABB, GE, Siemens), communication systems experts (Vodafone) and independent testing experts and academia (PNDC). They are all supportive to bring commercially viable products to benefit network operators in GB and their customers. We have kept continuous engagement with these partners throughout the bid development to ensure we are all ready for a timely project start. The Project team and their roles are detailed in Appendix Appendix 10.8 Organogram & Partners.

6.1.3 Clear and well-defined project delivery and governance structure

We have created a Project Execution Plan (PEP), based on project management best practice and learning gained from the experience we have running award winning and exceptional large innovation projects for nine years such as Flexible Plug and Play (FPP), Active Response and Optimise Prime. All our relevant projects have received Successful Delivery Reward recognition as being well run projects.

Table 10 – Constellation workstreams

Workstream	Name
WS1	Software & Cyber Security Requirements, Design and Development
WS2	Functional Requirements, Design, Development and Hardware Specification
WS3	Trials & Analysis
WS4	Open Innovation Competition (OIC)
WS5	Academic Insight & Future Governance
WS6	Learnings & Dissemination

The PEP will guide the Project progress as it transitions from NIC bid into innovation project delivery. It specifies the overall aims of the Project as well as the success criteria for the Deliverables. It includes the organisational structure, stakeholder engagement plan and the governance structure to enable clear decision making. It also specifies the key reporting and control processes that support the delivery governance structure. The PEP is used as a "living document" and is updated as the Project progresses. This approach will provide transparency, facilitate cohesion and collaboration amongst the stakeholders to avoid duplication of work.

We have defined the Project management and governance structure to enable the Project to commence in a timely manner. The Project will be delivered via six workstreams as shown in Table 10. The first three workstreams represent the core of the Project; they will provide learning and data which informs other DNOs on the BaU scalability of the Project to deliver the benefits.

The third workstream will be led by PNDC and will be focused on delivering the trial specified in section 2.3. Description of design of trials. This workstream will allow the Project team to gather data and real-world insights for the two Methods. We have assumed that the PNDC trial will run for up to six months and that both phases of the network trial will run for 12 months each.

The data and learnings from Workstreams 1, 2 and 3 will be used in Workstream 4 to ensure the OIC is successful and delivers business value. This workstream is also lead by PNDC and they will be responsible for the incubation of the successful participants.

Workstream 5 is fundamental in ensuring that Constellation delivers a future-proofed system capable of increasing the electricity system resilience. It is aimed at answering the complex technical, commercial and contractual challenges (Appendix 10.4.7 Academic insights and future governance) of distributed network operation. It will be carried out through four investigation packages delivered by academic researchers and validated across the Partner consortium and the PNDC core research programme working group. Workstream 6 is a supporting function which has a vital role. It will design and deliver the learning dissemination activities set out in Section 5: Knowledge dissemination.

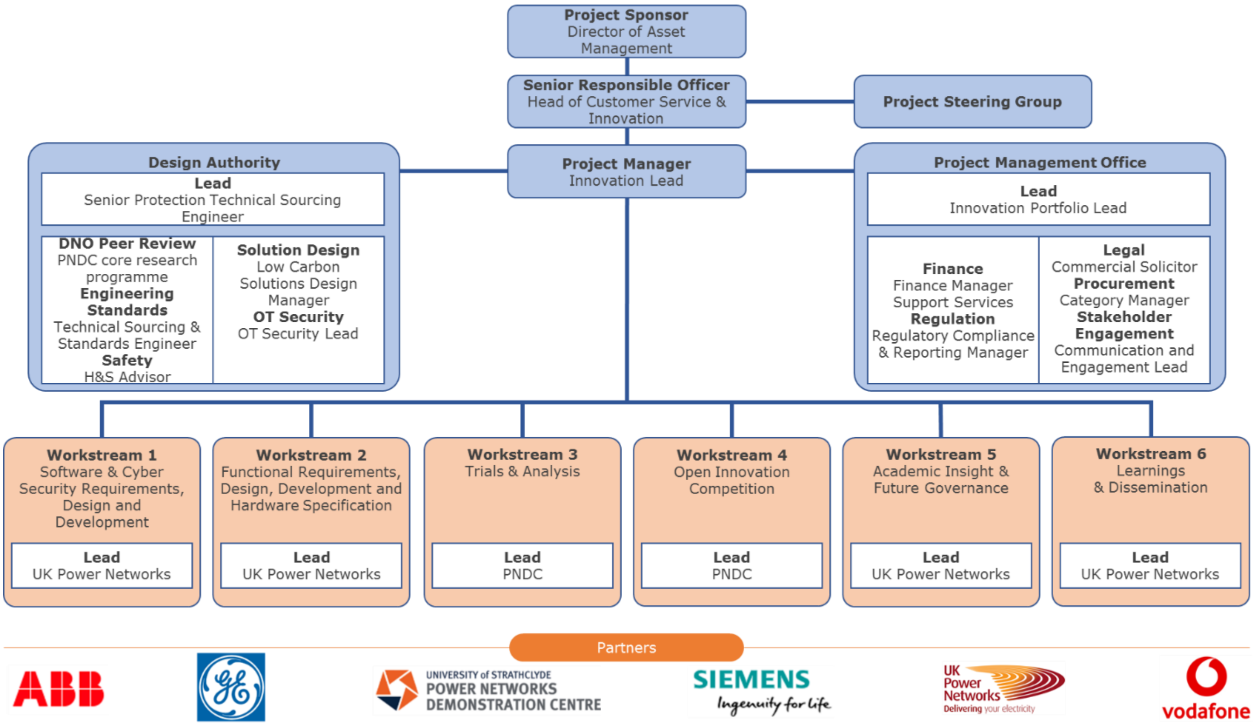

Figure 15 – Constellation organogram

The key project roles and responsibilities shown on the organogram in Figure 15 are:

- **The Project Steering Group**: comprises key stakeholders and decision makers within UK Power Networks, including the Project Sponsor Barry Hatton (Director of Asset Management) and chaired by Senior Responsible Owner Ian Cameron (Head of Customer Service & Innovation). This group is ultimately responsible for the Project and will make decisions that have an overall impact on the benefits and outputs that the Project will deliver;
- **The Project Manager:** will be responsible for the day-to-day management of the Project. This includes but is not limited to reviewing the Project progress against plan, presenting the Project progress report to the Project Steering Group, updating the Project plan, monitoring project risks and project budget;
- **The Design Authority:** reviews and approves all key project deliverables. However, ultimate responsibility for the delivery of the solutions rests with the Project delivery team. For Constellation, this role will include the PNDC digital substation WG. This includes key experts from UK Power Networks, SPEN, SSEN and representatives of the wider industry. This will ensure Constellation delivers scalable learning all can benefit from with scope to deploy across half of GB;
- **The Project Management Office**: provides support to the Project Manager as required; and
- **Project Support and Workstream Leads**: across all project partners, assist the Project Manager to discharge their duties, particularly those associated with the delivery of key project deliverables.

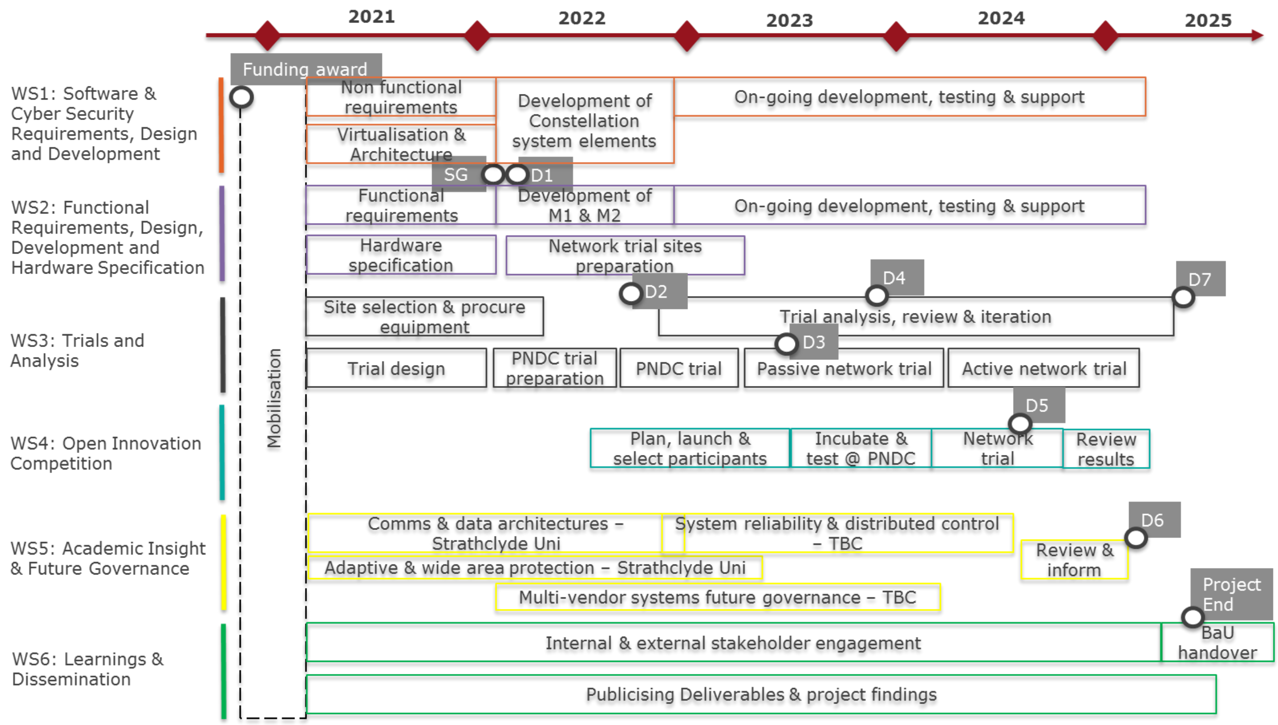

Figure 16 – Constellation high level timeline (with Maidstone & Lewes trial areas)

6.1.4 Robust project plan

The project plan has been drawn up using the experience from our innovation team managers and lessons learned from earlier large innovation projects such as FUN-LV, Smarter Network Storage, and Active Response to develop the Project plan. The plan has been validated by our senior management team and our project partners' management for their inputs on the Project scope and delivery phases. This combined input, feedback and guidance ensures that the resulting project plan is robust. A high-level timeline is in Figure 16 and the detailed project plan can be seen in Appendix 10.5 Project plan – detailed project plan. This robust project plan will enable the Project to commence in May 2021, after the initial mobilisation has completed.

6.1.5 Identification of key project risks and mitigation planning

In order to identify project risks and adequate mitigations, we used our own internal project learning reviews and relevant close-down reports from previous LCNF Tier 2 and NIA/NIC projects. We also reviewed innovation projects from other DNOs to ensure we capture the full spectrum of risks. We have maintained our learning approach from our most recent project experience and have adapted procurement and contracting to occur earlier in the delivery of the Project. This is to ensure we have all project partners and suppliers fully signed-on and committed to the Project on terms acceptable to all project parties.

With this in mind, we have a high level of confidence that no insurmountable problems will be encountered, see
Appendix 10.6 Risk Register & Contingency plan – tables of risk and mitigationsfor the full risk register and contingency plan. Lastly, the trials have been designed to build upon one another in a logical manner and allow risks between the individual project elements to be decoupled.

6.2 Evidence of the measures in place to minimise the possibility of cost overruns or shortfalls in Direct Benefits

The Project consortium members have a strong track record for minimising project overruns and delivering projects within budget. We will ensure successful project delivery through best practice project management approach, which defines project control processes in detail and provides effective mechanisms to manage and control the Project scope, cost and schedule.

In Constellation we have identified a key risk around the development costs for project partners. To mitigate this risk and to proactively manage project cost we have included an internal stage gate at the completion of the detailed design phase. At this point we will request revised prices from our partners and review the expected cost for the remainder of the project. Our partners have held a portion of risk cost within their pricing, so we expect the overall project cost to reduce at this point rather than increase.

We will implement the same five key control measures as used in previous projects. These defined processes and document controls will help the Project board and steering committee to initially agree to the workstream initiation documents, plans and designs and then maintain control of the Project to ensure the Project delivers to its overall aims, as defined in the Project proposal.

A summary of these processes is provided below:

- **Risk and Issue Management**: this process ensures the capture, communication and escalation of key risks and issues within the Project and defines where decisions will be made and how these will be communicated back to the workstream where the risk or issue has arisen. The initial Risk Register is included in
- Appendix 10.6 Risk Register & Contingency plan – tables of risk and mitigations;
- **Change Management**: the purpose of this process is to control and agree any changes to the agreed baseline of the Project, whether the change relates to time, cost or quality. A key interaction in this process is between the design authority board and the Project board to check and approve proposed quality changes. Approvals for changes will have to be within the board's delegated authority; otherwise the change will need to be escalated further up the governance structure;
- **Review Process**: all formal outputs from the Project will go through a formal review process. An output will not be deemed complete until it has passed this review process. It is the responsibility of the workstream leads and project manager to ensure all outputs are placed under review;
- **Approval Process**: this will be implemented to ensure all deliverables are adequately approved before they are agreed as complete and released. The governance board will ensure each deliverable is completed to the quality, cost and timescales as agreed in the initiation documents and detailed plans and designs for each workstream; and
- **Sign-off Process**: the process of internal review and modification used to sign off all formal documents, ensuring accuracy and quality.

We will adopt project monitoring and reporting procedures as follows:

- Quarterly reporting to the Steering Group and to the UK Power Networks' Executive Management Team by the Project Sponsor to provide regular review points and allow full financial and project control;
- The project management team comprising the Project Manager, Workstream leads and Programme Management Officer, will meet fortnightly to monitor the Project progress against its plans, project risks and project issues; and
- Workstreams will be managed in accordance with milestone plans supported by

detailed project plans and a clearly defined list of deliverables for each workstream. These will be produced in consultation with our project partners to ensure a strong foundation for clarity of scope, objectives, approach, and deliverables.

In addition to the Project monitoring and reporting procedures, we will embed risk management within project roles and responsibilities by:

- The Project Steering Group will assess change requests, review the impact on the Project business case, and identify and review risks and issues associated with major change requests;
- The Project Board is responsible for the operational management of the Project, focused on reviewing progress against plan, and resolving risks and issues. They will also approve change requests within a defined tolerance and prepare change requests for submission to the Steering Group for changes;
- Regular risk reviews undertaken by the Project Manager with results reported to the Project Sponsor and Project Steering Group;
- A Design Authority (a role undertaken on this Project by the technical board of the core research group on digital substations) who will review and approve all key project deliverables to ensure they are fit for purpose. Change requests may be initiated by the Design Authority directly or by the Workstreams. Change requests initiated by the Workstreams will be reviewed by the Design Authority prior to submission; and
- Quarterly project partner/supplier reviews will track and discuss progress and risks to project delivery.

We have produced a risk register which details the identified risks and mitigation strategies in Appendix 10.6 Risk Register & Contingency plan – tables of risk and mitigations.

6.3 Accuracy of information

UK Power Networks has endeavoured to ensure all of the information included within this full submission is accurate. Information included within the proposal has been gathered from within UK Power Networks, the Project partners, suppliers and other subject matter experts. All of this information has been reviewed to confirm and refine understanding, whilst evaluating the validity and integrity of the information. Where assumptions are used to develop numbers particularly in the project business case these are recorded in the appropriate sections.

6.4 Managing change and contingency

Through our strong track-record of delivering successful innovation projects, it is clear that the nature of innovation projects inherently includes the unexpected. It is essential, therefore, that there are effective mechanisms to manage change. The process used is one of the five project control processes described earlier in this section, and is illustrated in Figure 17 via an extract from our "Interactive Innovation Procedure (SR 07 005i)".

The first stage of Constellation, the detail design, is critical for managing the contingency in the Project. Changes to the proposed architecture, virtualisation approach and hardware will have a substantial impact on the development costs, and there is risk that new hardware may be needed. We have carried out significant work during the bid development to minimise this risk, but have still included a stage gate at the end of the detailed design that will provide a clear decision point on what portion of the contingency budget will be needed, or whether partner costs reduce. This decision will made by the Project steering group.

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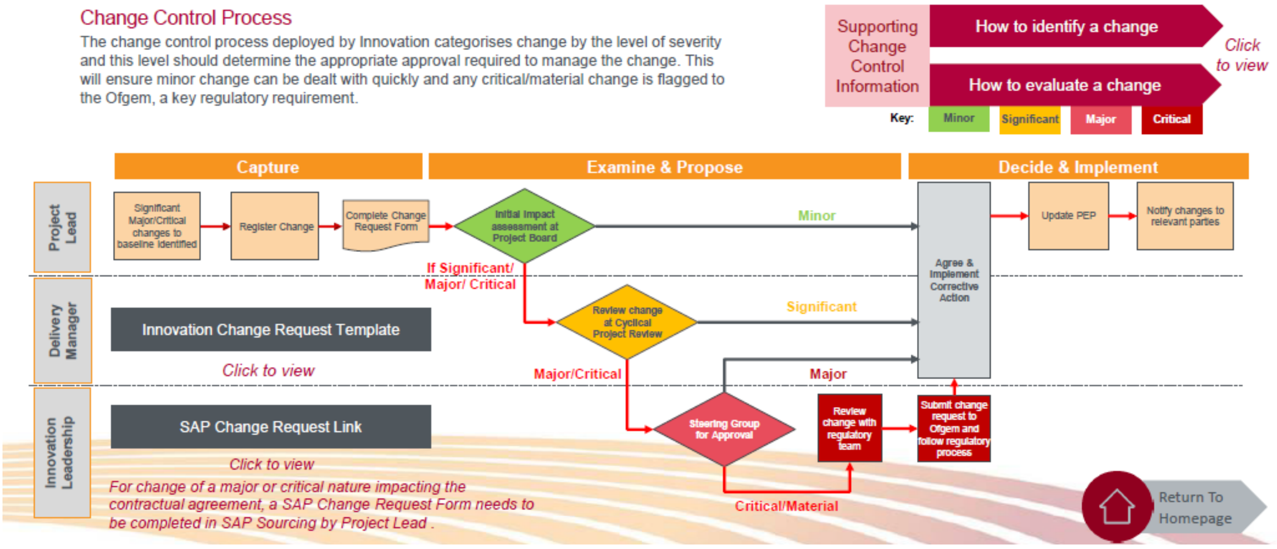

Figure 17 – Change control process

6.5 How learning would still be gained in the event that the take up of low carbon technologies slows down

Constellation has been developed to enable DNOs to optimise the use of their existing assets and enable GBs transition to a Net Zero future. All scenarios from the FES[19] and our DFES[20] show a significant increase in DER if GB is to meet its legally binding 2050 Net Zero target. In all cases Constellation represents good value for money for customers.

The trial sites we have provisionally selected (details in Appendix 10.4.10 Trials) will not be impacted by a low uptake of LCT, as they already have sufficient DER connected for us to demonstrate both Methods.

Whilst substantial learning can be gained from the ability to connect additional DG, this is by no means the only area of learning arising from Constellation. The Project will enable significant learning on the operation of interoperable software functionality for protection and control. Constellation will also provide learning for DNOs on the benefits of distributed network operation to optimise performance and ensure system reliability.

Furthermore, the shift from hardware-based systems to software has been evidenced in other industries, and whilst offering great benefits in terms of deployment speed and flexibility, it also carries risk (particularly in cyber security) which will be assessed and understood throughout this Project.

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[19] NG ESO, Future Energy Scenarios, 2019
[20] UK Power Networks, Distribution Future Energy Scenarios, 2020

6.6 The processes in place to identify circumstances where the most appropriate course of action will be to suspend the Project, pending permission from Ofgem that it can be halted

As part of the UK Power Networks' internal governance, there are number of processes in place to identify, assess and manage any issues that may affect the Project. These processes help to maintain the smooth running of the Project, whilst also aiding identification of the most appropriate course of action at any point.

The internal UK Power Networks' Project Governance and Control process, based upon the PRINCE2/APM methodology, has a gate approval process which reviews the Project at critical stages throughout its life cycle. The Project must meet the mandatory entry/exit criteria for any particular gate (which takes into account business case, risks, issues, benefits realisation and financial position), which the Project Manager will need to provide evidence. If the Project does not meet the mandatory entry/exit criteria, the Project Steering Group has the authority to suspend the Project where it is the most appropriate course of action, pending permission from Ofgem that the Project can be halted.

Project progress is reviewed monthly including progress, cost spent and forecast to completion. If a deviation is identified that takes the project outside the allowed tolerance it will be escalated immediately, investigated and a recovery plan put in place.

The Project Steering Group is also able to suspend the Project outside the gate approval process if it is the most appropriate course of action. This could be triggered by an escalation from the Project Manager for a risk or issue that has exceeded the agreed tolerance.

7. Regulatory issues

It is not expected that Constellation will require a derogation, licence change, licence exemption or a change to the current regulatory arrangements in order to implement the Project.

It should be noted that during the network demonstration, UK Power Networks and the DER connected to the trial network may agree to a deviation from the standard G99 (or G59 for older generators) protection setting requirements. This will be under our "DNO discretion" as specified in the requirements section of G99[21].

8. Customer impact

Constellation will be delivered with minimal impact on customers.

Constellation will be deployed at grid, primary and DER sites on the 132kV, 33kV and 11kV networks. We anticipate no impact on domestic customers.

We will interact with the DER sites connected to the trial areas. While the site selection will be finalised during the Project, we have identified two suitable areas (Maidstone and Lewes) with four 33kV connected DER:

- [redacted];
- [redacted] PV;
- [redacted] PV; and
- [redacted] PV.

In preparation of this bid we have engaged with the sites above and informed them of the project proposal. We are likely to need some limited site access and there is a potential for the need for short outages to install equipment at their point of connection.

It will be arranged in accordance with our normal operational procedure for those locations, taking care to minimise disruption/impact to the customers.

Overall, the Constellation solution should reduce disruption and impact to customers in the trial areas by keeping generation connected and operating when it might otherwise have to disconnect, should the situations arise. All outages will be recorded in our Interruptions Incentive Scheme (IIS) returns in accordance with requirements.

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[21] Energy Networks Association, Engineering Recommendation G99, Issue 1 Amendment 6, 2020

9. Project deliverables

The Project's deliverables have been designed to demonstrate clear progress towards the Project objectives and disseminate data, practical methods, tools and valuable learning. Based on this approach, we propose the following deliverables and related evidence. All reports, once issued to Ofgem, will be published on the UK Power Networks' Innovation website, the Smarter Networks portal, and will also be sent directly to key stakeholders.

Prior to the issue of each deliverable, the Project Team will conduct a detailed review. In addition, prior to the close of the Project and in accordance with the Network Innovation Competition Governance Documents, we will obtain "Independent Verification" that the Project deliverables have been achieved.

Table 11 – Constellation Deliverables

Ref	Project Deliverable	Deadline	Evidence	NIC funding request* (%)
1	Details of the system design and architecture for protection and control on a substation with local intelligence	28/02/22	(WS1 and WS2) Report on the system design of Constellation and the associated architecture for communication, protection and control across Methods 1 and 2	16%
2	Description of the trial design and site selection criteria process for Methods 1 and 2	31/08/22	(WS1 and WS2) Report containing: • A description of the trial site selection criteria process for each phase of the network trials; and • Details of the trial requirements for the demonstration of each element of Constellation	14%
3	Initial learning from off-network PNDC trial, and learning from development and virtualisation of Methods 1 and 2	30/06/23	(WS1, WS2 and WS3) Report containing: • Details of the key learning from the design and development of Methods 1 and 2; • Details of learnings from design of 5G slicing; and • Testing preparation and early lessons from the off-network testing	33%
4	Review and insights following site installation and learning from mid trial passive network demonstration	30/11/23	(WS2 and WS3) Report containing: • Key lessons from site installation process at DER sites and primary/grid substations; and • Early learning from the passive network demonstration	17%
5	Learning from the Open Innovation Competition (OIC)	31/07/24	(WS3) Report containing key learning on the OIC use case prioritisation, participant selection and incubation process	4%

Ref	Project Deliverable	Deadline	Evidence	NIC funding request* (%)
6	Learning from academic insights and the governance required to prepare for the future world of distributed network operation	28/02/25	(WS7) Report containing analysis by the academic partner on the opportunities, risks and barriers to full distributed and interoperable future network operation	6%
7	Analysis and presentation of findings from the trials and plan for BaU deployment	30/09/25	(WS3) Report containing findings from the trials and appraisal of the business case including key learning and plan for BaU deployment	10%
[Note this is a common Project Deliverable to be included by all Network Licensees as drafted below]				
N/A	Comply with knowledge transfer requirements of the Governance Document.	End of Project	1. Annual Project Progress Reports which comply with the requirements of the Governance Document. 2. Completed Close Down Report which complies with the requirements of the Governance Document. 3. Evidence of attendance and participation in the Annual Conference as described in the Governance Document.	N/A

*** must add to 100%**

10. Appendix

The Appendix consists of the following sections:

- Appendix 10.1 – Benefit Tables – forecast of benefits resulting from the Methods
- Appendix 10.2 – Project Business Case Modelling – description of the methodology used in section 3: Project business case
- Appendix 10.3 – Detailed Business Case Assumptions – description of assumptions used in section 3: Project business case
- Appendix 10.4 – Technical Description of the Project – further details of the solutions described in section 2: Project description
- Appendix 10.5 - Project plan – detailed project plan
- Appendix 10.6 - Risk Register & Contingency plan – tables of risk and mitigations
- Appendix 10.7 - Appendix 10.7 Knowledge Dissemination Roadmap
- Appendix 10.8 - Organogram & Partners
- Appendix 10.9 - Technology Readiness Level (TRL) for key Constellation elements
- Appendix 10.10 – Changes since Constellation 2019
- Appendix 10.11 – Letters of Support

Appendix 10.1 Benefits Tables – forecast of benefits resulting from the Methods

Scale	Method	Base Case Cost	Method Case Cost	Forecasted Benefit			Notes
				2030	2040	2050	
Post-trial solution *(individual deployment) (£m)*	Method 1	0.57	0.43	0.14	0.36	0.51	The business case is built at the licensee scale and the benefits are per primary and grid substation (s/s) and calculated on using the number of DER connection types (Appendix 10.2 Project Business Case Modelling – description of the methodology used in section 3: Project business case, Table 14). The individual deployment is a Constellation solution at a primary or grid s/s and at least one DER site. We have used the costs to install at grid sites to give a conservative estimate of an individual deployment. As a result, the individual deployment is not representative as costs and benefits are sensitive to the type of s/s. We have used a detailed breakdown of DERs and s/s types for the deployment costs and benefits in the CBA model at UK Power Networks level and GB scale.
	Method 2	0.54	0.41	0.13	0.27	0.31	
Licensee scale *(£m)*	Method 1	22.2	13.3	8.9	54.7	80.3	The benefits at UKPN scale are calculated using the DFES DG forecasts and assumptions described in Appendix 10.3 Detailed Business Case Assumptions – description of assumptions used in section 3: Project business case . The Constellation platform (hardware and associated IEDs) is expected to be rolled out across 718 s/s in UK Power Networks by 2050. Method 1 (virtualised) will be rolled out across 347 s/s and Method 2 (virtualised) across 371 s/s. The UK Power Networks forecasts include assumptions of the anticipated percentage of ANM connections and the percentage of flexibility service providers. The numbers in this table reflect our Central Case, which has moderate assumptions. We performed a sensitivity analysis on the benefits model, and even in the extremely low case, the benefits of the Methods combined came to £11.7m by 2030 over UK Power Networks, and in the extreme high case, the benefits came to £52.9m.
	Method 2	44.9	31.6	13.3	58.2	68.1	
	Total benefit from both Methods			22.2	113	148	
	Method 1	108	51.3	57	287	416	

GB rollout scale /(£m)	Method 2	199	125	74.8	296	348	The benefits at GB scale are calculated using the FES DG forecasts and assumptions described in Appendix 10.3 Detailed Business Case Assumptions – description of assumptions used in section 3: Project business case.
	Total benefit from both Methods			132	583	764	

Scale	Method	Forecasted Benefit (MVA)			Notes
		2030	2040	2050	
Post-trial solution *(individual deployment) (MVA)*	Method 1	0.44	0.44	0.44	The business case is built at the licensee scale and the benefits are per primary and grid s/s and calculated on using the number of DER connection types (Appendix 10.2 Project Business Case Modelling – description of the methodology used in section 3: Project business case, Table 14). The values in this table are influenced by the assumptions described in Appendix 10.3 Detailed Business Case Assumptions – description of assumptions used in section 3: Project business case. We have used the costs to install at grid sites to give a conservative estimate of an individual deployment. As a result, the individual deployment is not representative as costs and benefits are sensitive to the type of s/s. We have used a detailed breakdown of DER and substation types for the deployment costs and benefits in the CBA model at UK Power Networks level and GB scale.
	Method 2	1.06	1.06	1.06	
Licensee scale *(MVA)*	Method 1	46	97	101	The benefits at UK Power Networks scale are calculated using the DFES DER forecast and assumptions described in Appendix 10.3 Detailed Business Case Assumptions – description of assumptions used in section 3: Project business case. The Constellation platform (hardware and associated IEDs) is expected to be rolled out across 718 substations in UK Power Networks by 2050. Method 1 (virtualised) will be rolled out across 347 substations and Method 2 (virtualised) across 371 substations. The numbers in this table reflect our Central Case, which has moderate assumptions. We performed a sensitivity analysis on the benefits model, and even in the extreme low case, the benefits of the Methods combined came to 398MVA by 2050 over UK Power Networks, and in the extreme high case, the benefits came to 1,439 MVA.
	Method 2	407	777	795	
	Total benefit from both Methods	453	874	896	
GB rollout scale (MVA)	Method 1	194	477	492	The benefits at GB scale are calculated using the FES DER forecast and assumptions described in 10.3. The Constellation platform (hardware and associated IEDs) is expected to be rolled out across 3,351 substations in GB
	Method 2	1,789	3,744	3,820	

	Total benefit	1,983	4,221	4,312	by 2050. Method 1 will be rolled out across 1,620 substations and Method 2 across 1,731 substations.

Scale	Method	Forecasted Benefit (Carbon)			Notes
		2030	2040	2050	
Post-trial solution *(individual deployment)* ***(**k tCO_2**)***	Method 1	1.0	2.3	2.8	The values in this table are influenced by the assumptions described in Appendix 10.3 Detailed Business Case Assumptions – description of assumptions used in section 3: Project business case. Our assumptions of the carbon benefits are conservative because we have accounted for a decreasing carbon intensity in the overall electricity generation mix from now until 2050. Based on Ofgem's CBA template (Template CBA RIIO ED1), we apply a straight line decrease down to 10g CO2 per kWh by 2050.
	Method 2	2.3	5.5	6.6	
Licensee scale ***(**m tCO_2**)***	Method 1	0.04	0.3	0.4	The benefits at UK Power Networks scale are calculated as described above. The UK Power Networks forecasts include assumptions of the anticipated percentage of ANM connections and the percentage of flexibility service providers. The numbers in this table reflect our Central Case, which has moderate assumptions. We performed a sensitivity analysis on the benefits model, and even in the extreme low case, the benefits of the methods combined came to 1.68 million t CO2 by 2050 over UK Power Networks, and in the extreme high case, the benefits came to 6.9 million t CO2. Note that Method 2 – wide area protection is assumed to enable more capacity for DG connections, and so the carbon of the reinforcement will be felt eventually. Method 1 – Local ANM and Method 2 – wide area protection carbon savings are immediate as they are reducing the curtailments associated with the Fault or Comms.
	Method 2	0.4	2.5	3.4	
	Total benefit from both Methods	0.5	2.8	3.8	
GB rollout scale **(**m tCO_2**)**	Method 1	0.2	1.4	1.9	The benefits at GB scale are calculated using the FES 2019 forecasts and assumptions described in Appendix 10.3 Detailed Business Case Assumptions – description of assumptions used in section 3: Project business case. The Constellation platform (hardware and associated IEDs) is expected to be rolled out across 3,351 s/s in GB by 2050. Method 1 (virtualised) will be rolled out across 1,620 s/s and Method 2 (virtualised) across 1,731 s/s.
	Method 2	1.7	11.6	15.9	
	Total benefit from both Methods	1.9	13	17.8	

Appendix 10.2 Project Business Case Modelling – description of the methodology used in section 3: Project business case

10.2.1 Summary of Constellation benefits

The Project will demonstrate distributed network operation by deploying the Constellation platform (hardware, central management, 5G site-to-site comms) and the two Methods across the network. This will enable the following benefits to the network, the DER operators and the environment:

- **Financial**, through reduced curtailment of DER operation due to central system communication failure and wide area instability events. This will be referred to as increased revenue for DER customers;
- **Financial**, through reduced need for hardware associated with traditional central ANM. This will be referred to as providing savings through reduced hardware requirements for central ANM;
- **Financial**, through the reduced capital investment in traditional site-to-site communication compared to 5G slicing. This will be referred to as providing savings through more economic site-to-site communication;
- **Financial**, through more cost-efficient deployment of protection functionality as software rather than dedicated hardware. This will be referred to as providing savings through deployment of software based protection;
- **Financial**, through reducing the volume of flexibility services required or in some cases reinforcement. This will be referred to as protecting flexibility services from communication loss or from faults;
- **Protected capacity**, through keeping DER services intact through comms failure and wide area instability events. This will be referred to as protecting the capacity released through flexibility services;
- **Released capacity**, through enabling load blinding in areas supplied through multiple GSPs and connected to DER providing voltage control services. This will be referred to as released capacity through adaptive load blinding settings; and
- **Carbon** benefits, through the protected operation of low carbon generation and the capacity to connect more.

In order to build up Constellation Business Case, the benefits of each of each Method needs to be understood in detail. It is also necessary to forecast the need for these solutions into the future, up to 2050. The approach and assumptions for these aspects are described in the sections below. Both of the Methods being trialled bring a set of financial, capacity, and carbon benefits. Sections 3.1 Summary of Constellation benefitsand 4.1 (a) Accelerates the development of a low carbon energy sector and/or delivers environmental benefits whilst having the potential to deliver net financial benefits to future and/or existing Customerssummarise the Constellation Methods and the resulting benefits.

Table 12 – Constellation Methods

Method	
Method 1	Local power flow forecasting and state estimation to maintain the optimal DER asset operation during events when the central ANM system is unavailable.
Method 2	Site-to-site communication via R-GOOSE messaging to enable wide area protection and control actions which will keep the DER running through transient instability events occurring elsewhere on the network. Real time collection, calculation and deployment of protection settings to release additional network capacity.

10.2.2 Business Case Methodology

The quantified financial, capacity and carbon benefits included above, in the benefits tables and figures have been calculated using our Constellation business case Cost Benefits Analysis (CBA) model. Figure 18 shows the overall structure of the model.

DER Capacity forecasts from FES and DFES together with fault data from PowerOn fusion and the LTDS are used to calculate the indicative capacities and volumes of DERs expected till 2050. Considering a roll-out strategy we worked out the number of sites eligible and calculated the DER capacity at risk of curtailment, and volumes of DERs and sites per year. We used assumptions in category inputs to calculate the costs and benefits of each Method which in turn we converted to a discounted cash flow and used for the NPV calculation. Also, we used "capacity released" to calculate the carbon savings associated with Constellation.

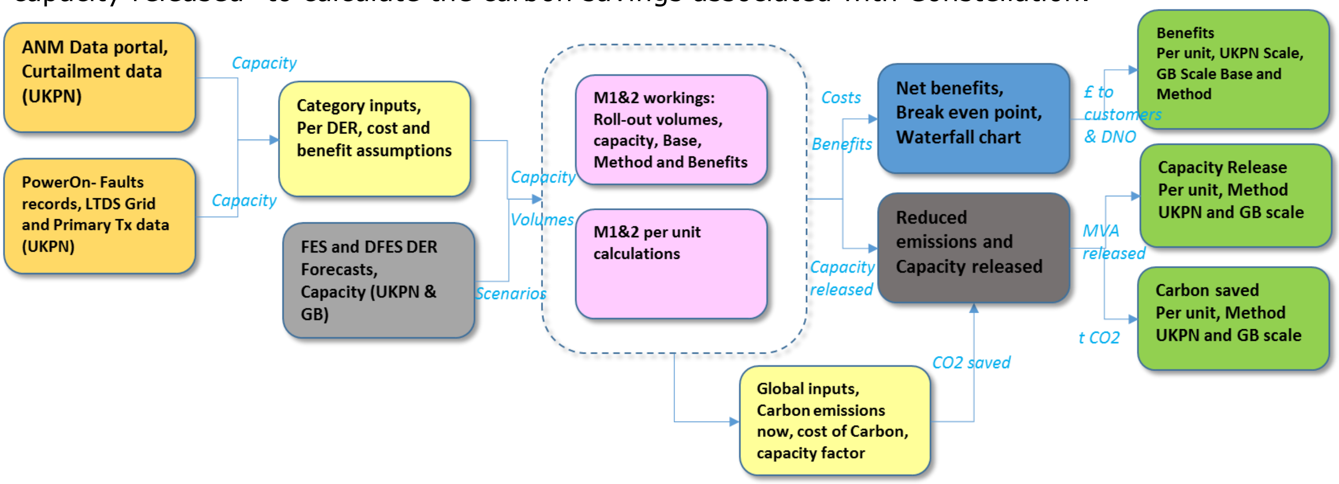


Figure 18 – CBA structure to calculate financial, capacity and carbon benefits of Constellation

10.2.2.1 Modelling generation forecasts to 2050

Our model forecasts volume and capacity of DERs connected to primary and grid substation in UK Power Networks' licence areas, based on our DFES up to 2050. There is an uncertainty about the future volume, capacity and type of DER connections (firm or ANM connected) which has an impact on the costs and benefits of Constellation's Methods. In order to minimise this impact, different scenarios are investigated in the sensitivity analysis detailed in Appendix 10.3 Detailed Business Case Assumptions – description of assumptions used in section 3: Project business case.

Figure 19 and Figure 20 show both FES and DFES forecasts at UK Power Networks and GB level. As it can be seen, there are two distinct uptake curves to 2050. As a conservative estimate we have taken the low scenarios (Steady progression from DFES and Two Degrees from FES) for our analysis but have also run the sensitivity analysis with the high scenarios.

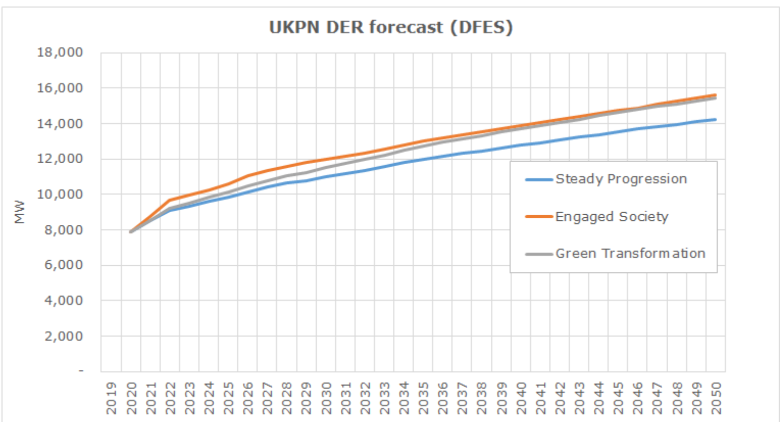


Figure 19 – Forecast DER growth from UK Power Networks DFES

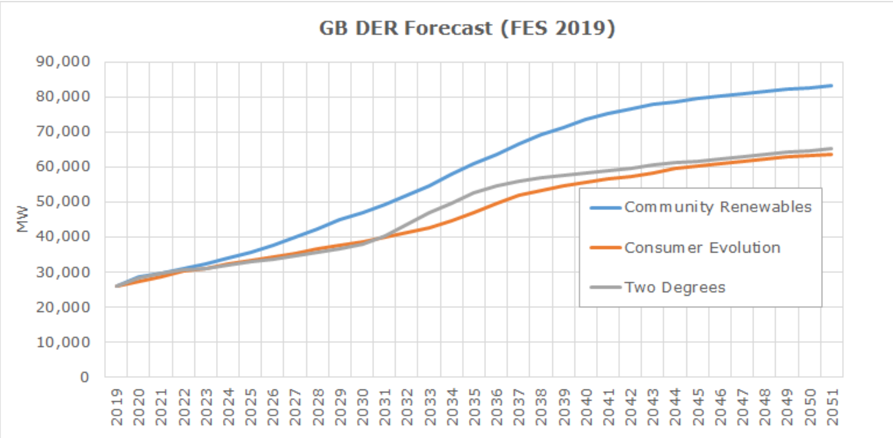


Figure 20 – Forecast DER growth from National Grid FES

10.2.2.2 Modelling Constellation deployment
There are a set of criteria that need to be met for the installation of the Methods. The selection of the Method will depend on the trigger points described in Table 13.

Table 13 – Trigger points

	BAU trigger points	Constellation Business Case model trigger points.
Method 1	During events when the links between the central ANM system and either the constraint substation or any DER is broken, ANM curtails the DERs. If the fault is related to the DER, ANM system disconnects the DER in question. If the fault is related to the substation, ANM curtails all the DERs under that constraint zone.	The historical curtailment data is available from ANM portal, we have identified the number, type and duration of each curtailment event. Two trigger points were used for this Method: A) DER has a flexible connection which means it is managed by the ANM system. B) DER is providing flexibility to the network. If both are met, we anticipate that Method 1 could save 15% of all ANM curtailment events. This is an average assumption based on three years historical data.
Method 2	When DER are providing voltage control services in areas supplied through multiple GSPs, it causes issues for load blinding. The static power factor setting will lose the ability to differentiate between genuine faults and reverse power flow. As a result, the area will have a capacity restriction due to the DOC protection. In the event of a fault or another network instability event the DER can be unnecessarily curtailed.	Using LTDS data, we have identified the sites that are eligible for adaptive protection. It is estimated that 294 MVA export capacity could be released for across 15 sites over UK Power Networks and 1.4GVA to 2050 across 70 sites in GB as a conservative estimate. This is an average assumption based on LTDS data. Fault events from our ADMS were analysed to identify the number of events and duration of DER interruption. Average number and duration of event were selected for the Central Case. The technical potential assumption used for this calculation is given in Appendix 10.3 Detailed Business Case Assumptions – description of

	assumptions used in section 3: Project business case.

As both Methods are based on the same hardware platform, our model makes the necessary assumptions around the deployment criteria for each Method to forecast the numbers of installations up until 2050 over UK Power Networks and GB.

A key driver behind the number of installations is the number and type of DER sites. We categorised the sites into four groups and their associated Methods in Table 14.

Table 14 – Truth table of DER connections

DER Category	DER type	Method application
1	ANM connected: No Flexibility provider: No	Method 2 (Fault curtailments)
2	ANM connected: No Flexibility provider: Yes	Method 2 (Fault curtailments)
3	ANM connected: Yes Flexibility provider: No	Method 1 and 2 (Comms and fault related curtailments)
4	ANM connected: Yes Flexibility provider: Yes	Method 1 and 2 (Comms and fault related curtailments)

Method 1 is only applicable to groups 3 and 4, while Method 2 applies to all the categories. It should be noted that the flexibility benefit is only quantified for groups 2 and 4, as those are the only two that provide flexibility services. Groups 1 and 3 provide DER customer benefit only. Figure 21 shows the splits between the categories based on the current and forecast levels of ANM connection and percentage of expected Flexibility providers. Using the data taken from our ANM system and Flexibility Tender documents we have made the following assumptions:

- Based on the number of ANM connections we receive every year we have assumed that they increase gradually from 25% in 2021 to 48% in 2025 and remain constant afterwards.
- We assumed that percentage of flexibility providers reaches to 25% by 2024 due to the access and charging reforms and as a result of our "flexibility first" approach. We have conservatively assumed no change after that although expect it to increase.

To assess the impact, we performed a sensitivity analysis on the flexibility and Flex provision with the assumptions detailed in Appendix 10.3 Detailed Business Case Assumptions – description of assumptions used in section 3: Project business case.

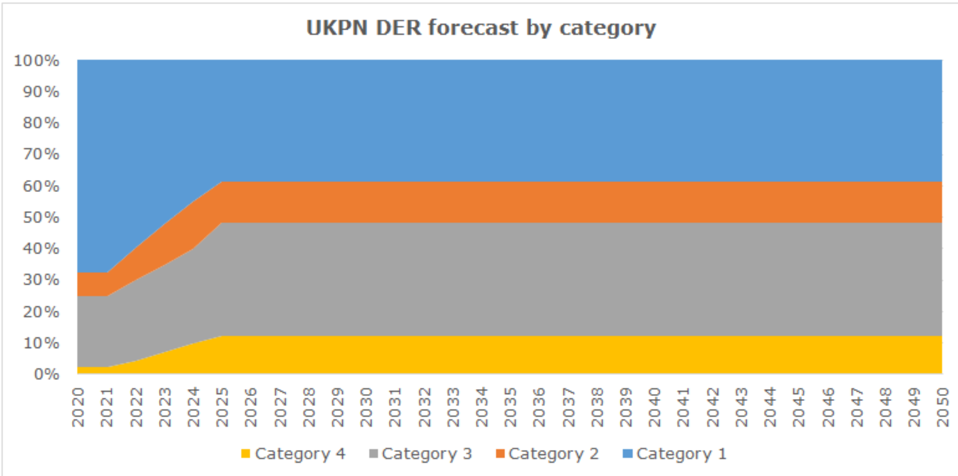


Figure 21 – Splits between DER categories over time

Based on the average capacity assumptions given in Appendix 10.3 we have calculated the volume and capacity of existing connected DERs to UK Power Networks' network. We then identified the number of sites with connected DERs over time using DFES forecasts.

Knowing DER volumes, capacities, and the number of eligible sites, we then calculated a backlog of DERs by 2027 when the roll-out is expected. Clearing the backlog is based on the assumptions described in Appendix 10.3. Figure 22 shows the deployment volume including backlog and new DERs.

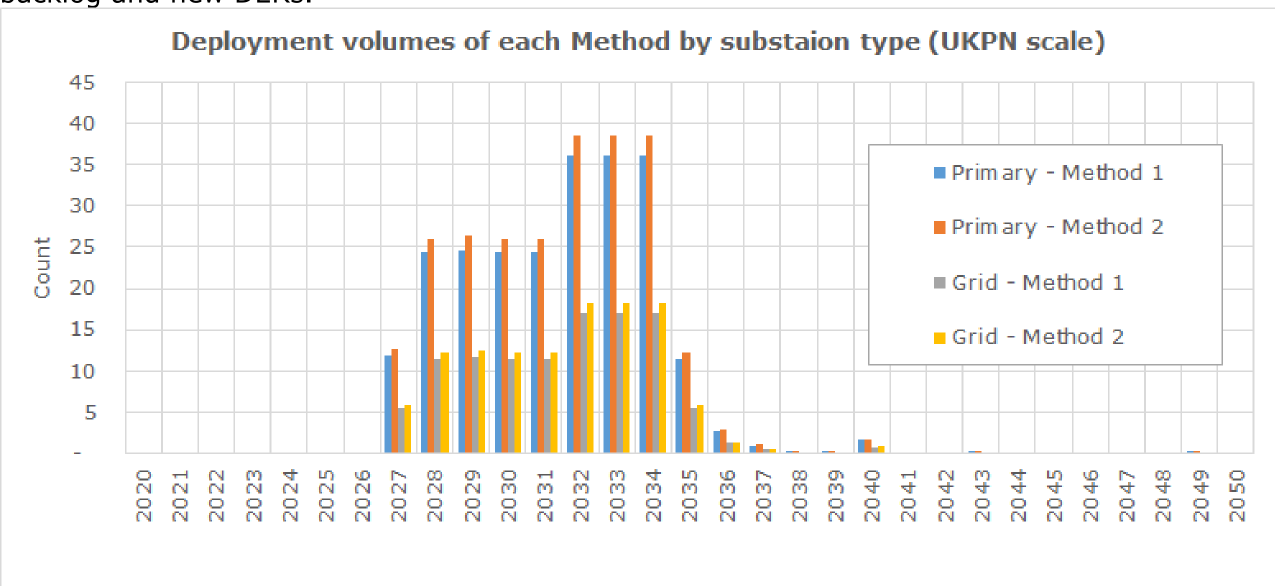


Figure 22 – Deployment volumes of each Method by substation type (UK Power Networks scale)

The output of this process is used to determine the costs and benefits of Constellation which are described below.

10.2.2.3 Modelling Constellation costs

Constellation creates interoperable standard hardware, communication and data. We used a technology reduction curve cost reduction estimate for electronic/electrical industries to account for cost reduction with time and volume but introduced this as a step-change reduction of 15% after significant deployment beyond 2036.

There is significant uncertainty around the cost of software licencing for each Method. This is also the case for 5G communication. As such the 5G costs are estimated as a continuous license cost. These assumptions are in Appendix 10.3 and the overall cumulative cost of Constellation is shown in Figure 23.

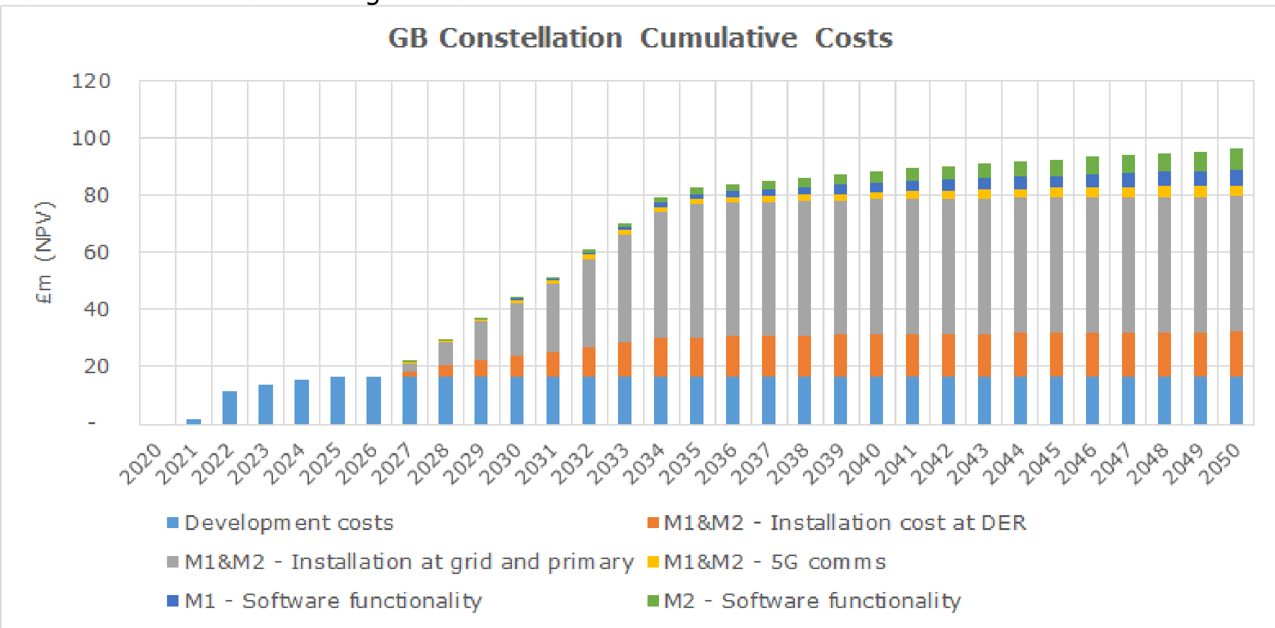


Figure 23 – Constellation cumulative costs (GB scale, £m NPV)

10.2.2.4 Modelling Constellation benefits

Constellation offers significant direct financial benefits to the customers and DNOs. Detailed assumptions on calculating the financial benefits are given in Appendix 10.3. The overall cumulative benefits of Constellation are shown in Figure 24.

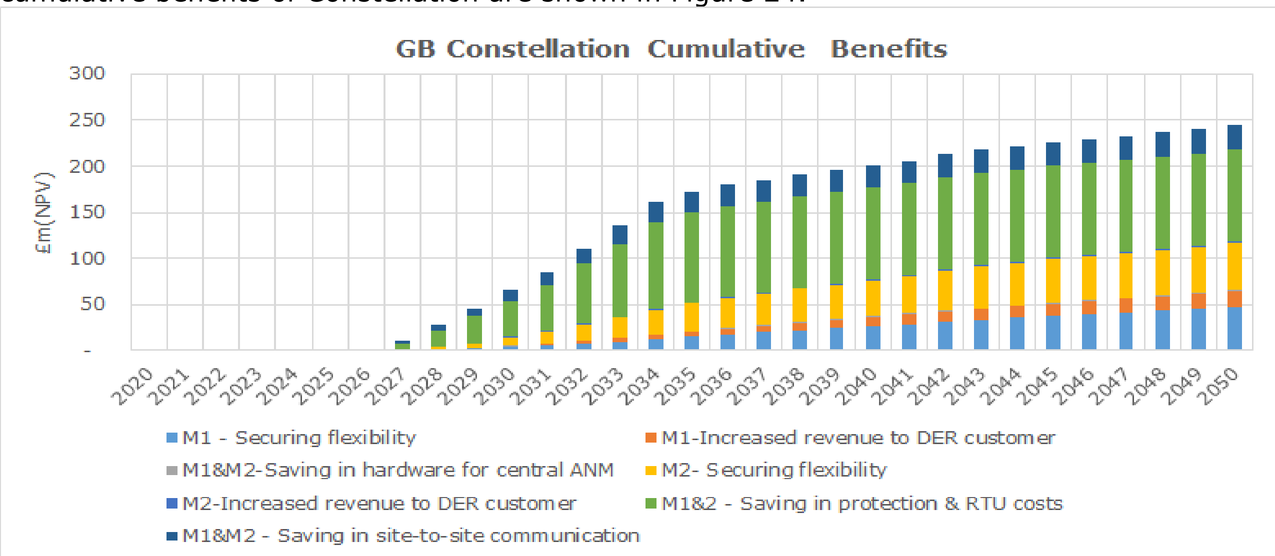


Figure 24 – Constellation cumulative benefits (GB scale, £m – NPV)

10.2.3 Constructing the business case

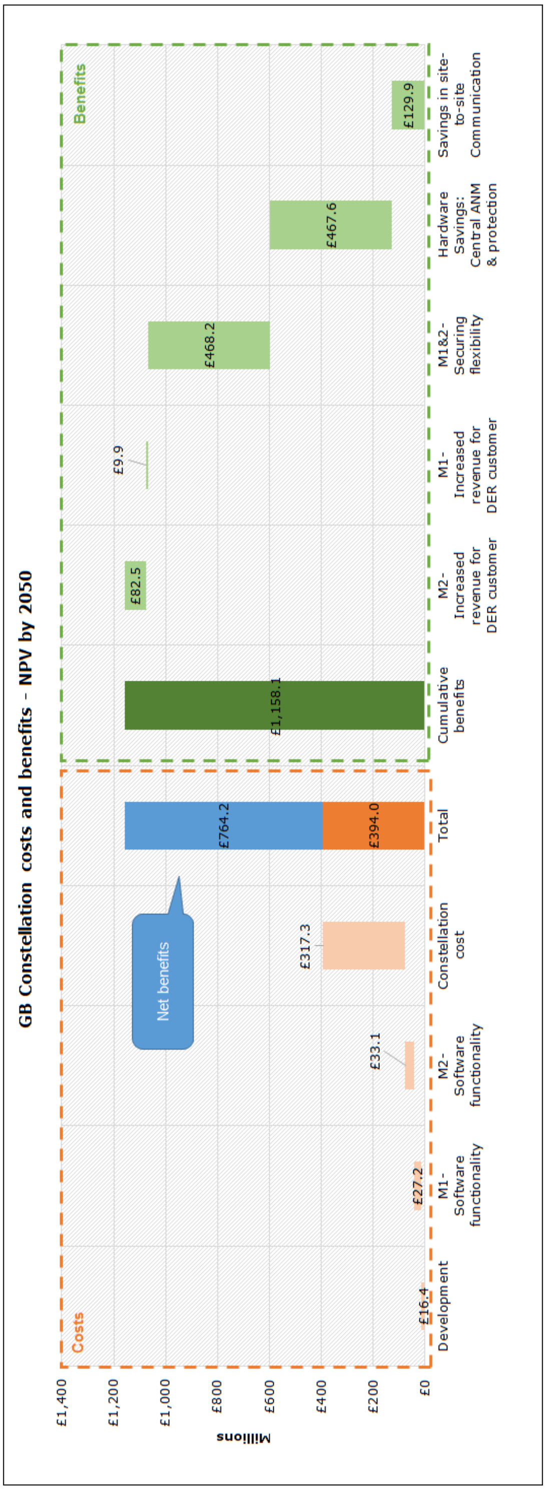
As indicated in Figure 24 and Figure 25 some of the costs and benefits are shared between Method 1 and Method 2. In order to separate the cost and benefit of each Method, we used the DER connection categories as described in detail in Appendix 10.3 Detailed Business Case Assumptions – description of assumptions used in section 3: Project business case. This enables us to evaluate the costs and benefits of each Method separately without double counting the Constellation platform costs, which are common across both Methods. In setting up the Business Case we have used a Base case and Method case for each solution and worked out the net benefits, capacity and carbon benefits for each Method.

Method 1 Local intelligent control/local ANM:
Base Case:

- Cost of hardware required for the central ANM;
- Cost of over-procuring flexibility or reinforcement; and
- DER income loss due to comms related curtailments.

Method Case:
Increasing revenue for DER customer by reducing comms related curtailments

- Protecting flexibility services from communication issues with central systems;



- Protecting capacity released through flexibility services;
- Providing savings through deployment of software based protection;
- Providing savings through reduced hardware requirements for central ANM;
- Providing savings through more economic site-to-site communication;
- Cost of the Constellation platform including hardware, central management, installation and 5G site-to-site comms; and
- Cost of Method 1 as software functionality.

Method 2 – Wide area and adaptive protection:
Base Case:
- Cost of hardware required for protection and conventional site-to-site communication;
- Cost of higher flexibility requirement; and
- DER income loss due to fault related curtailments.

Method Case:
- Increasing revenue for DER customer by reducing fault related curtailments.
- Protecting flexibility services from faults;
- Protecting capacity released through flexibility services due to faults;
- Providing savings through deployment of software based protection;
- Providing savings through more economic site-to-site communication;
- Adaptive protection only: capacity release in areas supplied through multiple GSPs; where DER provide voltage control services;
- Cost of the Constellation platform including hardware, central management, installation and 5G site-to-site comms; and
- Cost of Method 2 as software functionality.

Figure 26 shows the results of the cost and benefit analysis. There is great benefit in doing the project. The net benefit by 2050 is £764m more than double the amount of cost investment of £394m to deploy the solution across GB.

A breakeven assessment, shown in Figure 26, was carried out based on the cash flow analysis of the project and ongoing benefits. This is based on the Central Case, and the roll out over GB. The project breaks even in 2028 and starts to bring net benefits to customers' initial investment in 2027. The cash breakeven analysis has a particularly fast breakeven as this includes the cash flow benefits of reduced costs through deployment of software-based protection and protecting flexibility services.

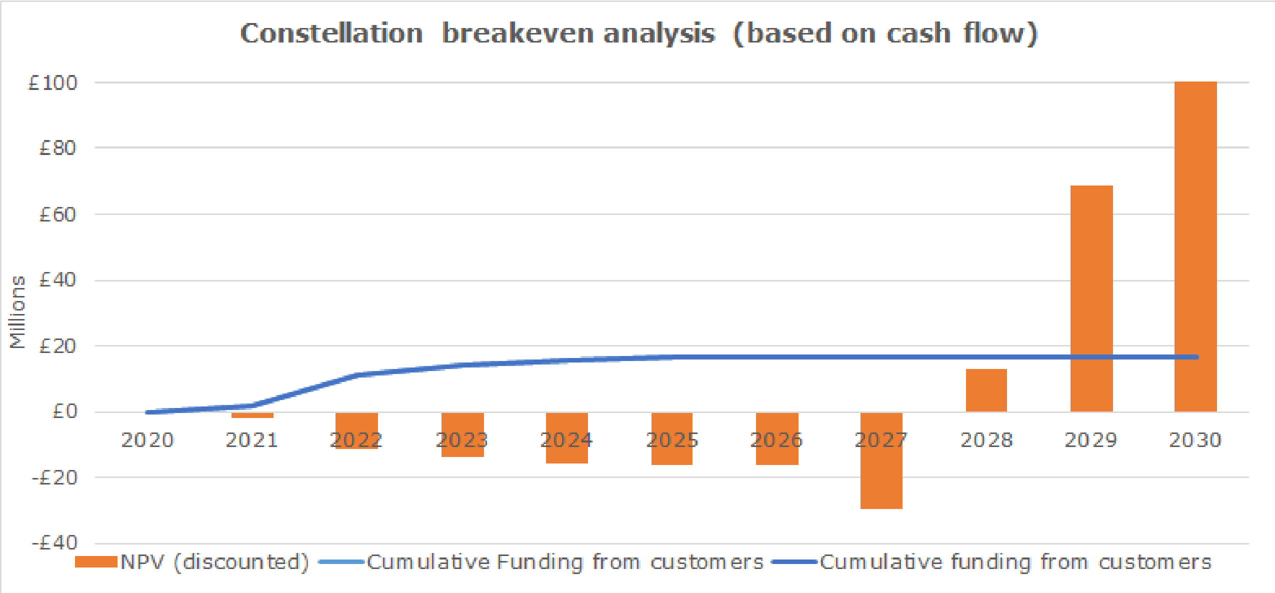


Figure 26 – Breakeven analysis

10.2.4 Taking the customer's view

We wanted to ensure that Constellation would develop solutions that are not only beneficial to GB customers via the DNO but also to the DER customer. It will greatly reduce the capital costs of conventional installation of site-to-site communication. It will also reduce the impact of system events such as network faults or central systems communication loss on the services provided by DERs. Figure 27 shows the direct financial benefits to the DER customers estimated to be:

A) Savings through hardware costs associated with central ANM and conventional site-to-site communication: £130m gross financial benefit across GB by 2050

B) Avoided DER curtailment: £92.5m gross financial benefit across GB by 2050.

The net benefit across GB is estimated at £149m by 2050. Furthermore, this will increase the customer satisfaction as it reduces the number of interruptions for the DERs.

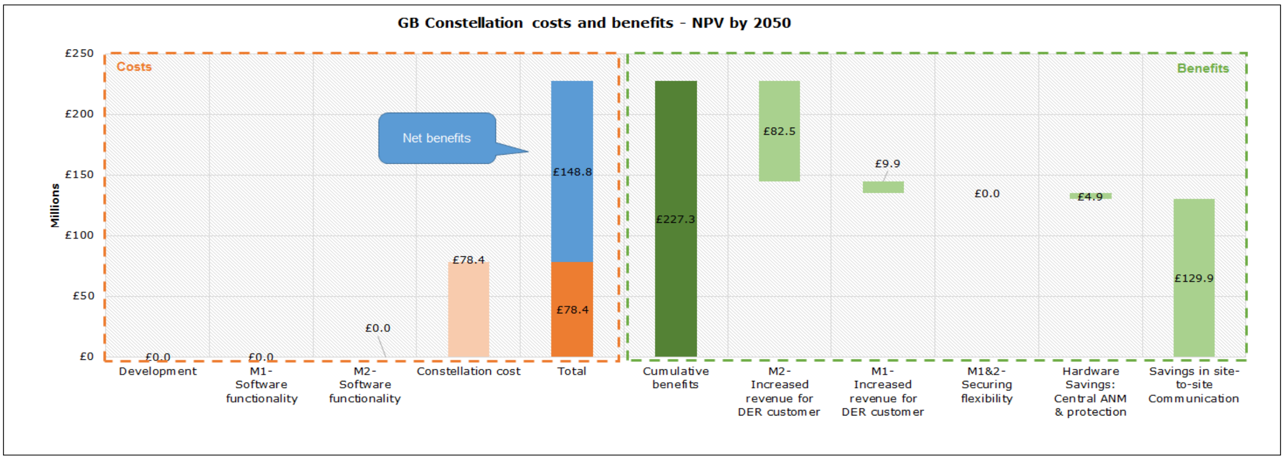


Figure 27 – DER customer view of costs and benefits to 2050 (GB scale, £m NPV)

10.2.5 Taking the DNO's view

As it can be seen in Figure 28, Constellation offers excellent value by reducing the cost associated with protection hardware replacement, as well as securing flexibility services offered by DERs. The net benefits for GB customers via the DNO are £615m to 2050 across GB. The other key benefit is protecting the flexibility services which are essential for the future network operation and without them the network would need to be upgraded.

A) Providing savings through deployment of software-based protection: £467.6m gross financial benefit across GB by 2050
B) Protecting flexibility services through Method 1 and 2: £468m gross financial benefit across GB by 2050

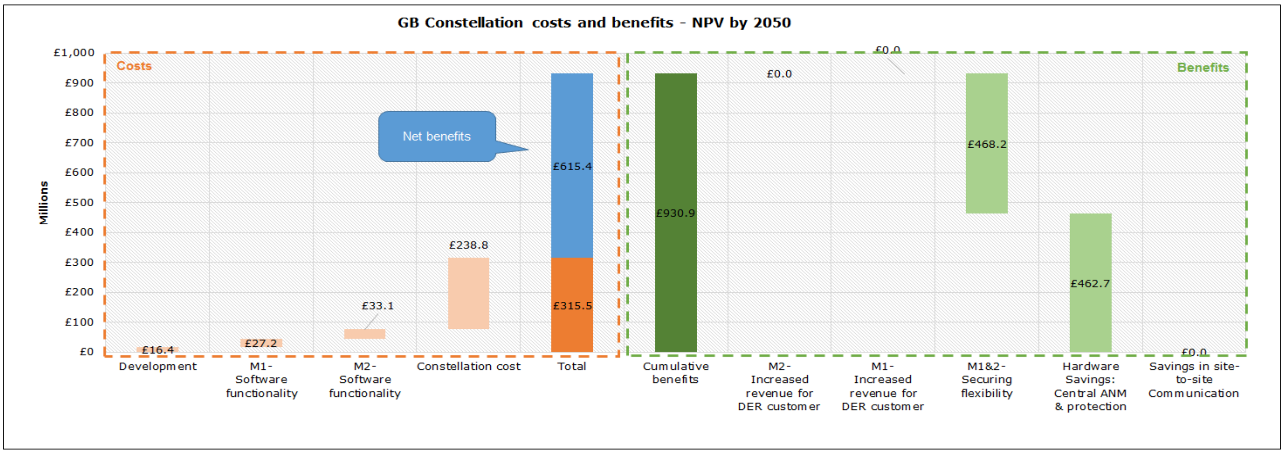


Figure 28 – DNO view of costs and benefits to 2050 (GB scale, £m NPV)

10.2.6 Carbon and capacity

The network capacity benefit is in two forms (a) protecting the capacity created by flexibility services, and (b) releasing capacity in areas where DER are providing voltage control services. Overall, this will enable the connection of DG to the network more quickly and cost-efficiently by deferring or mitigating the need for costly reinforcement without negatively impacting its robustness.

The capacity benefit is dependent on the number of installations of each Method and is therefore driven by the capacity related benefits explained in the benefits section 3. Project business case. Figure 29 shows the capacity-released at across GB. It should be noted that capacity protected by Method 1 and the wide area protection element of Method 2 is related to DER sites providing flexibility. Whereas for the adaptive protection element of Method 2, capacity is released in parts of the network which is connected to multiple GSPs and has DER providing reactive power services. The total Capacity benefit is approximately **4.3 GVA across GB by 2050.**

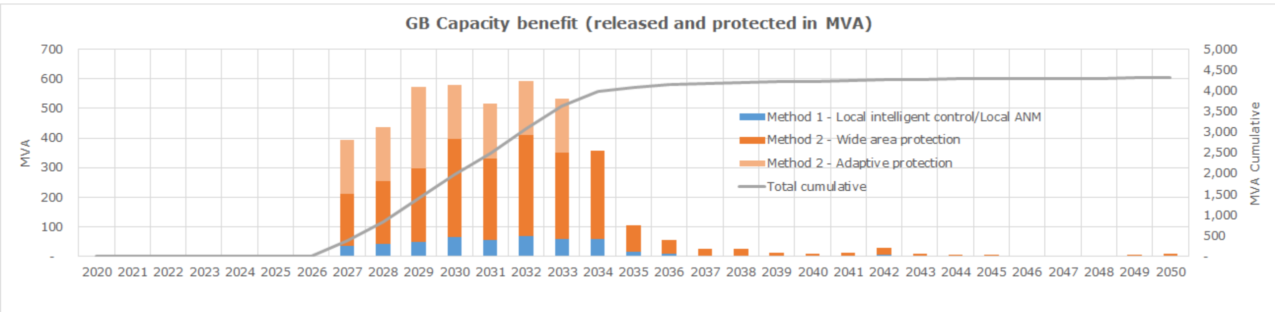


Figure 29 – Capacity benefit (released and protected) from Constellation (GB scale, MVA)

The direct carbon benefits of Constellation, shown in Figure 30 – Carbon benefits from Constellation (GB scale, tCO2), are driven by the creation of capacity for generation with a lower carbon impact than the existing carbon intensity of electricity generation. The assumptions made within the carbon savings model, including the carbon cost of each Method and its associated base case are described in Appendix 10.3 Detailed Business Case Assumptions – description of assumptions used in section 3: Project business case. The carbon benefit for adaptive protection grows over time with the release of more capacity at grid or primary sites, providing significant carbon benefit over time.

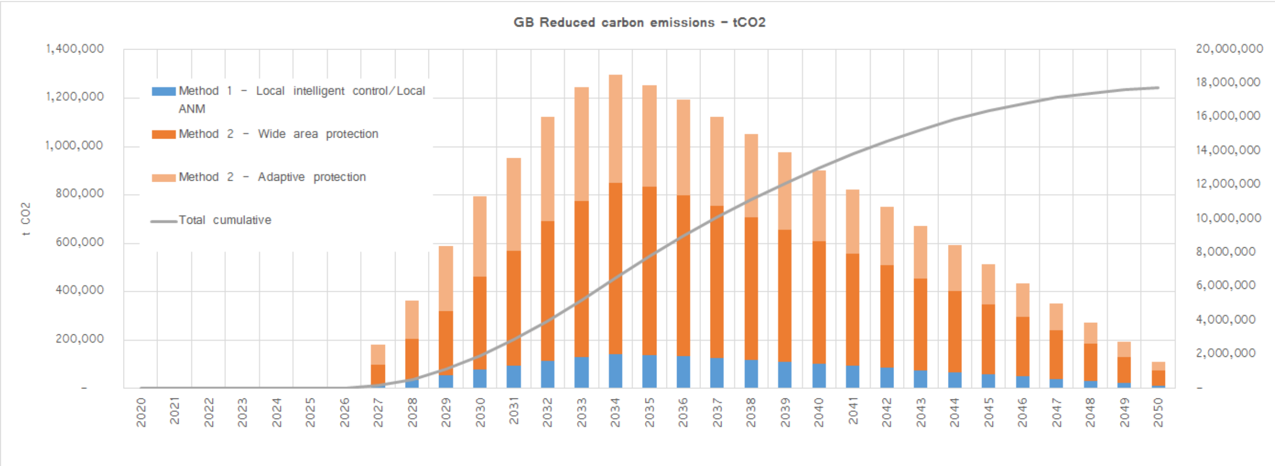


Figure 30 – Carbon benefits from Constellation (GB scale, tCO2)

10.2.7 Sensitivity analysis

The most extreme scenarios analysed as part of this sensitivity analysis were the extremely high case (the most ambitious DER uptake forecast, high number of fault and comms curtailment events, connection of large DER), and the extreme low case (the least ambitious DER uptake forecast, low number of faults and comms curtailments and connection of small DER). The impact of these assumptions on the Constellation business case (both Methods combined) is shown in Figure 31.

The impact of these assumptions on the results of the business case is understandably significant. However, even in the most pessimistic case, the project benefits are approximately £331.6m, justifying the customer funding and producing additional benefit. In the highest benefit case, the project has the potential to deliver more than £1.3bn of benefits across GB by 2050.

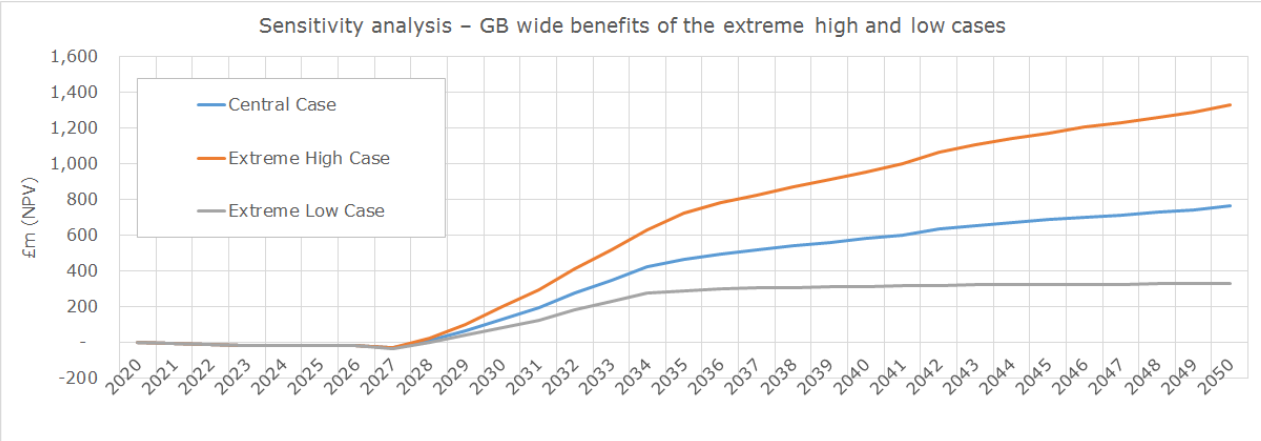


Figure 31 – Sensitivity analysis of Constellation benefits (GB scale, £m NPV)

Appendix 10.3 Detailed Business Case Assumptions – description of assumptions used in section 3: Project business case

This section contains three lists detailing all the assumptions used in the development of the Constellation business case, and the impact each has should the assumption not prove true. The first list covers the assumptions that underpin the whole business case. The second list is for assumptions for Method 1, the third for Method 2.

10.3.1 Detailed business case assumptions for Constellation:

1. **Discount factor 3.5% for 30 years and 3% thereafter:** The costs are then discounted back to 2020 prices. The discount factor is 3.5% for 30 years and 3% for 2050. The modelling ends in 2050. For NPV at UK Power Networks scale, we have included the development costs and assumed NPV value at the project year. For the GB roll-out, we assumed no development costs.
2. **DER Scenarios:** At UK Power Networks scale we used Steady Progression, at GB scale we used Two Degrees. The overall net benefit of the project depends on the forecasted DER capacity. We have also run sensitivity analysis with high uptake including Engaged Society and community renewable at UK Power Networks and GB scales which increased the benefits by 86%.
3. **Percentage of DER which are connected through ANM: up to 48%:** Based on the number of ANM connections requests UK Power Networks receives every year (48% are ANM connections) we have assumed that percentage of ANM connections increase gradually from 25% (expected ANM connections in 2021) to 48% in 2025, and remain constant afterwards.
4. **DER which provide flexibility**: Up to 25% - we have assumed that the percentage of flexibility service providers reaches 25% by 2024 when access charge reform will be rolled-out. To reduce the impact, we performed a sensitivity analysis on the percentages of ANM connections and flexibility service provides detailed in Appendix 10.2 Project Business Case Modelling – description of the methodology used in section 3: Project business case. Flexible range:36-48%, flexibility sensitivity: 20-28%.
5. **DER average capacity: 12.18 MVA:** The average capacity of a typical DER is 12.18 MW which is based on the volume and capacity of existing DERs on our network. We assumed the relative spread of DERs across the network remained consistent. These assumptions will change the volume of DER and has a direct impact on cost and benefits. Overall NPV of the project expected to be not impacted. As more benefits are expected from the larger DERs, we carried out a sensitivity on DER capacity range: 5MVA-15MVA.
6. **Load Factor for Carbon Calculations:** A load factor of 30% adopted based on Power Potential FSP. This is used to calculate the energy associated with the capacity release for both Methods[22]. Sensitivity range: Low: 28.4%, High: 33.9%
7. **Current and future carbon intensity of electricity generation:** Based on the factors provided by BEIS and DEFRA[23] The current carbon intensity of the network is considered to be 233 kg CO2 per MWh, consistent with Ofgem's CBA template, we assumed that by 2050 it will drop to 10 kg CO2 per MWh. This impacts the carbon emission saved due to Method 1 and 2.

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[22]https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/736148/DUKES_2018.pdf

[23] https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2020

8. **Value of protecting flexibility services: [redacted]/ MVA:** These are indicative values based on UK Power Networks' Flexibility tender documents. They have a direct impact on the Base and Method case for both Method 1 and 2. It should be noted that this is a conservative value and is much lower than the value of reinforcement or grid services such as FFR which could be 10 times higher[24].
9. **Cost of wholesale energy: £33.59 per MWh:** We have used the average wholesale energy cost from 2019[25]. We assumed this value remains the same over time. This has a direct impact on curtailment-related benefits. Given that the Flexibility events normally occur at peak time, this seems to be a conservative assumption.
10. **Unity Power Factor for capacity calculations:** We have used power factor of one in the CBA model. The impact on capacity calculations is expected to be minimal.
11. **Energy required to drive a Tesla to Mars: 99.6GWh** – The average tested miles per kWh rate for a tesla in 2020 is 2.58[26]. The next Mars close approach, on 6 Oct 2020, is 38.6 million miles[27]. With 7.6TWh saved a Tesla could drive approx. 19.6 billion miles, enough for 508 single trips to Mars or 254 return journeys. Please note this does not account for energy required to escape from a planetary gravity field or keep the car occupants warm along the way.
12. **Hardware, installations and commissioning costs:** The costs are calculated based on average hardware costs for labour and material. As technology improves, we have assumed up to 15% reduction in Hardware costs after 2036. The installation and commissioning costs are based on our experience with the Unified Protection (NIA project) deployment on our network.
    a. Hardware cost: (i) Grid site installation with 12 circuit breakers £[redacted] per site; (ii) Primary site installation with 20 circuit breakers £[redacted] per site; (iii) DER site £[redacted] per site; and
    b. Installation and commissioning costs £[redacted]k per substation and £[redacted]k per DER site
13. **Method 1 and 2 - Savings in Grid and Primary protection equipment -** Number of Grid and Primary substations multiplied by the avoided cost of protection relays.
    a. Hardware required for conventional (central) ANM: £[redacted]k per site;
    b. Protection relay replacement saving per primary site: £[redacted]k
    c. Protection relay replacement saving per grid site: £[redacted]k

Above costs have a direct impact on benefits for Method 1 and 2 based on the cost savings of deploying software functionality and the known costs of the traditional hardware alternatives.

14. **Method 1 and 2 - Savings in conventional site-to-site communication costs-** Based on an assessment of the cost to install conventional site-to-site communication and the expected deployment cost of 5G slicing: £[redacted] saving per site. It should be noted that due to the service novelty this cost will verified as part of the Project. The approximate proportion of DER sites which require conventional fibre optic is 13%, based on a conservative assessment of our existing communication upgrade work.
15. **Methods 1 and 2 separation (**Table 15**):**

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[24] https://smartgrid.ukpowernetworks.co.uk/flexibility-hub/
[25] https://www.epexspot.com
[26] https://www.whatcar.com/news/what-car-real-range-which-electric-car-can-go-farthest-in-the-real-world/n18162
[27] https://mars.nasa.gov/all-about-mars/night-sky/close-approach/

Table 15 – Methods 1 and 2 separation methodology

Method	Name	Separation methodology
M1	Constellation platform cost (hardware & 5G)	Apportioned by Category 3 and 4 DERs
M1	Method 1 installation cost	Apportioned to all Category 3 and 4 DERs
M2	Constellation platform cost (hardware & 5G)	Apportioned by Category 1 and 2 DERs
M2	Method 2 installation cost	Apportioned to all Category 1, 2, 3 and 4 DERs
M1	Savings associated with deployment of hardware for ANM	Apportioned by Category 3 and 4 DERs
M1	Securing flexibility services	Apportioned to all Category 3 and 4 DERs
M1	DER energy export curtailment (due to comms issues)	Apportioned to all Category 3 and 4 DERs
M2	Savings associated with deployment of hardware for protection and conventional site-to-site communication	Apportioned by Category 1, 2, 3 and 4 DERs
M2	Securing flexibility services	Apportioned by Category 1, 2, 3 and 4 DERs
M2	DER energy export curtailment (due to faults)	Apportioned to all Category 1, 2, 3 and 4 DERs

10.3.2 Detailed business case assumptions for Method 1:

1. **Percentage of communication loss related curtailment: 15%:** This is the current percentage of all curtailment through ANM. It based on three years of historical data on the performance of the central ANM system. It is assumed that the likelihood of comms issues remain constant over time. This is used to calculate DER and DNO benefits related to comms related curtailments. We have identified that Constellation is a more effective / lower risk option than simply duplicating the existing communications systems. Sensitivity Range: Low: 10%, High: 20%
2. **Savings through Providing savings through reduced hardware requirements for central ANM: £[redacted] per DER site:** This is the value that could be saved by installing Constellation on DER sites which are managed through ANM.
3. **Method 1 - Software:** Number of category 3 and 4 multiplied the cost of Method 2 software per year (assumed £[redacted] per year).
4. **Method 1 – Securing flexibility:** Category 4 DER connections cumulative capacity used and apportioned based on historic comms curtailment and value of flexibility (Base case £[redacted] per MVA, Method case £[redacted] per MVA).
5. **Method 1 – Increased revenue for DER customer:** Category 4 and 5 DER connections cumulative capacity multiplied by average energy lost due to comms related curtailment times the whole sale price of electricity.
6. **Method 1 – Saving ANM hardware deployment cost -** The number of DERs in Categories 3 and 4 multiplied by unit cost of ANM associated hardware in DER sites

10.3.3 Detailed business case assumptions for Method 2:

1. **Estimated average number of fault related curtailment of DER operation: 423 faults per year:** Based on the historical data, we have calculated an average and to reduce the impact, we also run a sensitivity based on the following range: 257-588.
2. **Assessed the coincidence factor to account for the actual need for flexibility from now until 2050**: This is because at some point, we cannot defer the

reinforcement further with flexibility services. The higher the coincidence factor the more flexibility needed. The peak of coincidence factor occurs around 2030 at 60% with a second peak at 2042 at 35%, as shown in Figure 32Figure 32. The need for flexibility increases as we get closer to the time of reinforcement. As a result, the number and duration of flexibility required to increase over time and declines after the reinforcement. To take account for this effect, and based on a network assessment, we have calculated a factor based on UK Power Networks the number of reinforcements expected at the Primary level. This impacts the Flex capacity benefits.

3. **Method 2 - Adaptive protection MVA released:** 19.6 MVA of export capacity per site, 1.4GVA across GB.
4. **Number of eligible sites:** 15 in the UK, and 72 over GB. We expect those substations will have DER connected to them which provide voltage control services.
5. **Percentage of faults eligible for Method 2 - AP: technical potential: 35.38%:** This is estimated percentage of faults occur outside of DER feeder zone and cause DER to trip. Constellation could prevent nuisance tripping of the DERs using wide area protection. Sensitivity range: Low: 10%, High: 35.38%.
6. **Method 2 - Securing flexibility:** DERs in Categories 2 and 4 cumulative capacity used and apportioned based on the number of events caused by unnecessary LoM operation and a coincidence factor described in this Section. This was then multiplied by the value of flexibility.
7. **Method 2 - Increased revenue for DER customer**: Applied to all DERs categories cumulative capacities. Apportioned by the estimated number of events caused by unnecessary LoM operation and the coincidence factor multiplied by the whole sale price of electricity.

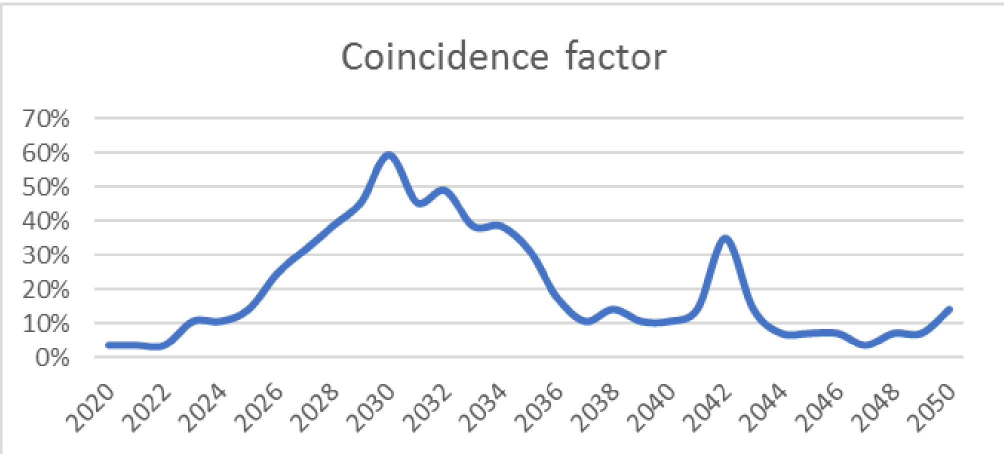


Figure 32 – Coincidence factor to account for the actual need for flexibility through to 2050

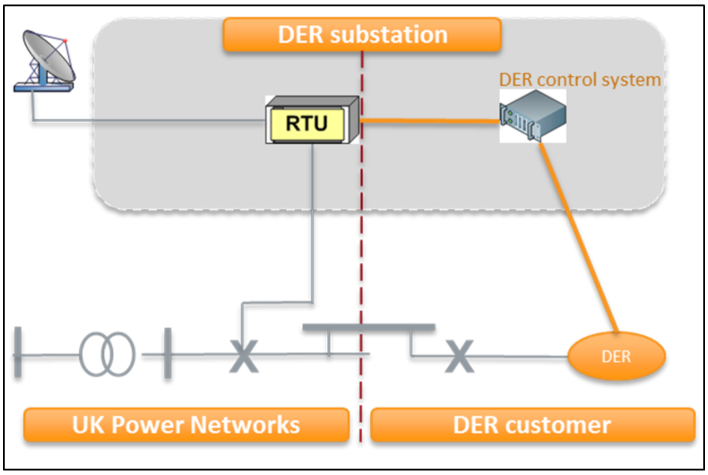
Appendix 10.4 Technical Description of the Project – further details of the solutions described in section 2: Project description

This appendix provides further detail to that in section2.2. Technical description of Project, detailing the problems that will be addressed by Constellation and the technical solutions that will be designed, implemented and trialled as part of the project.

10.4.1 Method 1: Local intelligent control / Local ANM

10.4.1.1 Central ANM solution

This is a UK Power Networks managed server-based platform located at the UK Power Networks control centre. It is responsible for taking real time actions for control of DG, load assets capable of Demand Side Response (DSR) or storage.



ANM is currently used to optimise our network operation. At present, this central system carries out constraint management of our network dynamically. In the future, it will facilitate services to our network (such as flexibility) both technically and commercially. The ANM system carries out sophisticated forecasting, state estimation, contingency and power flow calculations to identify constraints and sends maximum power output set points to connected DER.

Figure 33 – Flexible Connection substation diagram

The central ANM system requires continuous monitoring of both DER and the network constraints as well as the responsiveness of the DER. However, whenever the central system loses connection with both or either of those, the network can no longer be managed reliably through ANM. To manage that risk, we have currently developed functionality in the form of simple logic, which will gracefully turn down generation to a known safe threshold (typically zero).

10.4.1.2 Method 1 – Phasor-based Control & Distributed ANM by GE

Synchrophasor measurements are a valuable resource for controlling and managing transmission and distribution networks. The core measurement technology measures accurately timestamped voltage and current waveforms and converts the waveforms into phasors and frequency. It is possible to incorporate GOOSE or R-GOOSE with phasor measurements for locations where PMUs are not available or economic.

As part of Method 1 (Figure 34), a phasor-based control and distributed ANM will be developed to run in the virtual environment on the Constellation HaLI . Method 1 will be delivered in a way that allows future exploration into many more potential applications. The Distributed ANM will retain as much of the DER operation as possible in events when central ANM cannot reliably optimise the network:

- Local PMU measurements and a small number of measurements from key network locations covering key constraint boundaries; and

- Local PMU measurements only, guided by learned characteristics of the network in normal and stressed conditions that are known at the point of connection of the controlled unit.

Distributed ANM does not rely on a communications path to the central location. In the instance where the distributed ANM scheme has observability of the local area through a primary (33kV to 11kV) or a grid (132kV to 33kV) substation, it applies the control intelligence at the substation, or sufficiently close that loss of communication is not a significant risk. There will be some external measurements from key nodes in the network and remote control of the Local (Distributed) ANM controlled DER sites.

However, if there is a total loss of communications to the managed units, then locally based control will take over and enable the unit to continue running with minimal constraint. This is achieved through a machine learning process during periods when measurements are available, leading to a prediction of the acceptable output using only local measurements and other locally known variables.

Aside from the ANM benefits, PMU-based measurements can enable other network services, such as frequency and voltage support. It can also support microgrid control for managing separation, island running and resynchronisation. The "DER Site investigated" in Figure 35 refers to a point of DER connection which has Constellation Method 1 deployed and using Machine Learning to optimise the local network. Specifically for the Constellation trial, that refers to a DER site where this Method will be trialed.

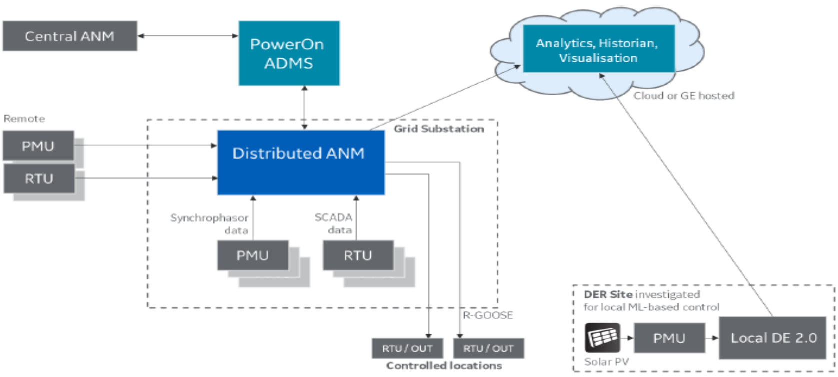


Figure 34 – Distributed ANM from GE

Learned Network Limit (Local ANM)
During normal operation while communications are available, characteristics of network behaviour can be learnt over time. The system behaves differently in conditions when the network is healthy, and when it is experiencing a disturbance, and when there are different loading levels of demand and generation. There are recognisable signs in steady-state and dynamic behaviour that can be learnt from times when communication is available and then used when communication is not available.

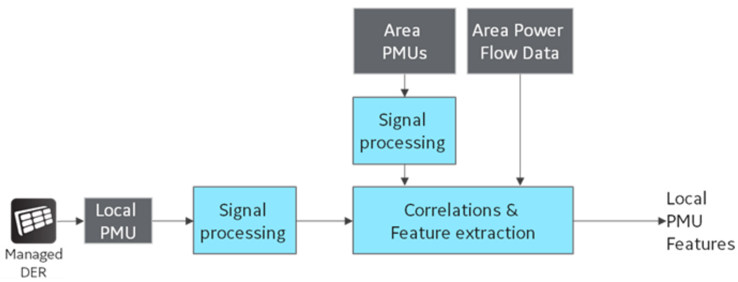


Figure 35 – Processing local and wide area data to extract features which can be observed

The Learned Network Limit (Local ANM) method uses machine learning to provide continuity for the ANM through an extended loss of communication. The PMU data is analysed primarily to relate features that can be determined at the local point of connection of managed DERs and relate to the loading and state of constraints. Essentially, the learning process is intended to select whether the DER can run with little or no constraint, or whether the network is in a condition where the DER cannot be accommodated and must failover to a known safe state or switch off.

The analysis will apply to all available PMU measurements and also use some other SCADA and time-related variables. Although all available PMU measurements are used, it should be noted that the actual learned control will be applied using visibility of only that one location. The first stage is to extract key features from local PMU information at the managed DER site that can be related to external behaviour in the network, as illustrated in .

The second stage involves building a machine learning model that relates observations at the managed DER site with a measure of the headroom in the constraint, as illustrated in Figure 36. The headroom measure is typically the difference between the measured flow in the limiting line or corridor and the value of the constraint. It may also be useful to identify conditions in which Central ANM actively constrains the managed DER and treats this as zero headroom.

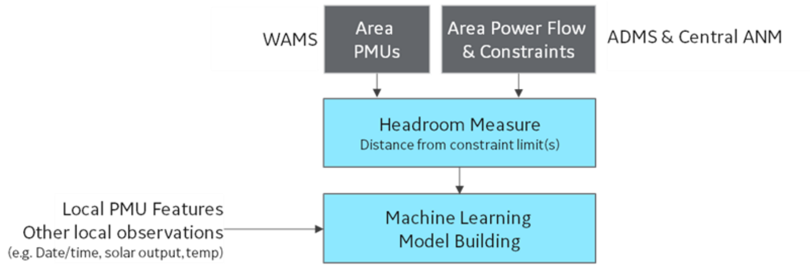


Figure 36 – Machine learning model building

The third stage is to use the machine learning model for continuous estimation of the headroom measure at the local site, using only local data without a need for communication to remote systems. The local process is illustrated in Figure 37. The machine learning model is used to estimate the headroom, which will determine from local measurements whether the external system is at risk of violating constraints. Depending on the headroom measure, the local managed DER can be operated without constraint, or being constrained to the level it was at the time of disconnection, or whether it must be limited to the known failsafe output which may require disconnection. If there is an indication of a nearby fault that is likely to affect the capability of the network, this would require a conservative constraint and potentially failsafe operation. By contrast, a loss in the wider transmission system would not merit a change in the operating condition locally.

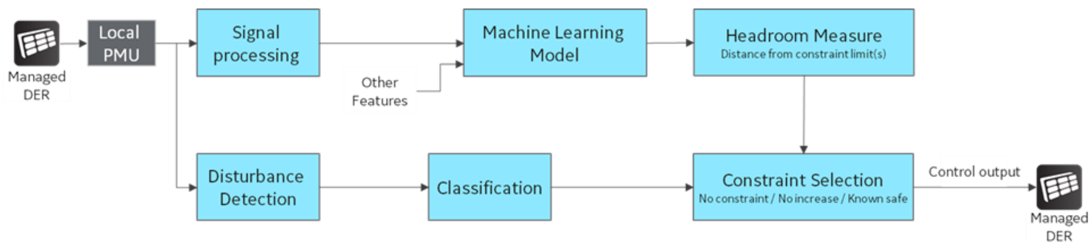


Figure 37 – Local control using machine learning (ML) model for deriving a local constraint

Direct Distributed ANM
Direct distributed ANM addresses the situation where **site-to-site communication is available**, but **communication between managed DERs and the Central ANM system may not be available**. It applies a deterministic ANM approach using data that is available at the substation hub and assumes that control signals can be communicated. This application of ANM will run continuously but will only apply results when the Central ANM is not available. It

will calculate curtailment values based on direct measurements of the constraint variables, or use values of the constraint variables derived deterministically from available measurements. However, it will not actively apply constraints unless one of the following conditions occur:

- There is a loss of connection between Central ANM and the controlled location(s);
- There is an observed violation that has not been addressed by central ANM; or
- Operator selection of Distributed ANM in place of Central ANM.

It is possible for multiple constraints to be managed by Distributed ANM, and a generator may impact more than one constraint. A function in Distributed ANM will receive the curtailment and commands from all constraints and distribute aggregated commands to the units. The Constellation system will send to the controlled units the maximum curtailment or trip command from any of the managed constraints.

If the constraints are directly observed, then the Direct mode is no more conservative than the Central ANM. However, if there are limiting values that are approximated rather than directly measured, the uncertainty in the measurements leads to more conservative operation, but much less restrictive than the fixed "known safe mode".

10.4.2 Method 2: Wide area and Adaptive Protection

10.4.2.1 Wide area protection

The main function of the LoM protection is to disconnect the generator when connection to the main grid is lost. This is to ensure a network island is not created, network parameters remain within statutory limits and safety incidents are isolated correctly. A DER disconnected through LoM experiences a temporary loss of revenue. However, this can be considered relatively insignificant in comparison to the risk of potential damages resulting from the prolonged unintended islanded operation.

As the DG penetration is forecasted to growing at a rapid pace between 2020 and 2050, the LoM detection enters a new level of importance. Previously the loss of DG was of no consequence to the operation of the distribution system, it is now obvious that the instantaneous loss of a high proportion of generation at the distribution level will weaken overall system stability or lead to local blackouts[28].

10.4.2.2 - Wide area protection via 5G slicing by ABB

The proposed approach focuses on communicating between remote nodes on the network and using a virtualised protection relay for wide area monitoring, control and protection applications. ABB REF615[29] relay already possesses most of the required capabilities. Usually communication-based protection and control schemes are built with wired communication technologies, which are uneconomic for scaling across the network. Tests using 4G networks have shown them to be not suitable, but early tests on 5G have shown promise[30]. This approach will utilise the 5G slicing to enable the low latency, high reliability site-to-site communication needed for protection.

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[28] A. Dyśko, G.M. Burt, P.J. Moore, I.A. Glover, J.R. McDonald, Satellite Communication Based LoM Protection, 2008

[29] https://search.abb.com/library/Download.aspx?DocumentID=DistGen2018&LanguageCode=en&DocumentPartId=&Action=Launch

[30] https://www.cired-repository.org/bitstream/handle/20.500.12455/816/CIRED%202019%20-%20341.pdf?sequence=1&isAllowed=y

The wide area protection will implement IEC61850 routable goose (R-GOOSE) technology. Messaging between sites will transfer inter-trip and blocking signals to ensure DER operation is not interrupted during transient instability events. ABB have already developed advanced algorithms[31] and logic for islanding detection[32], many of which are already available in relays on the market such as REF615 and can be virtualised. The exact logic to deploy in Constellation will be developed through discussion with UK Power Networks. The content of R-GOOSE values could in future be mapped to application logic for control functions to enable deployment of support services from DER (e.g. reactive power injection). This enables the building of wide area protection logic along with local virtualized protection within the Constellation environment, as shown in Figure 38.

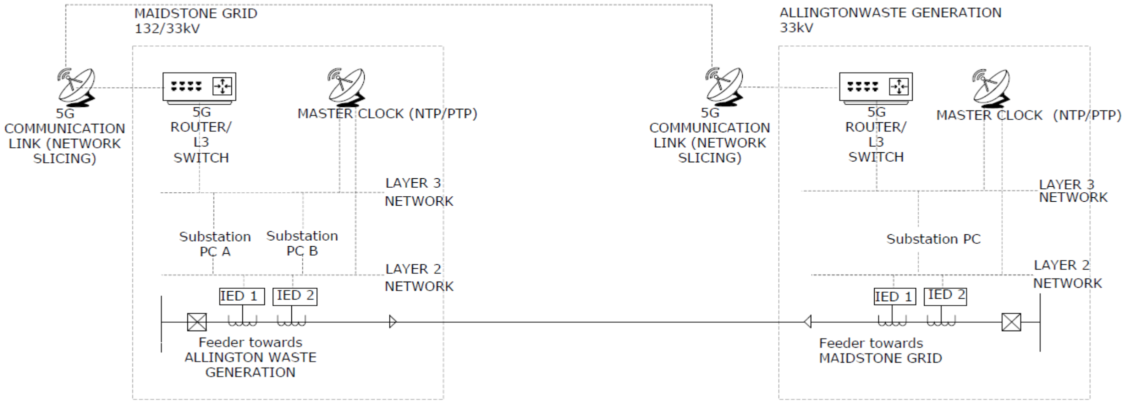

Figure 38 – Example of wide area protection in Maidstone

In addition to the logical functions, the delivered application also contains multiple functions focusing on DER interaction and management, facilitating advanced wide area protection and control applications when R-GOOSE is available. Specific examples are presented below:

- Frequency protection: provides basic over frequency, underfrequency and frequency rate-of-change protection, as well as allowing the use of a combined criteria to achieve more sophisticated protection schemes;
- Directional reactive power undervoltage protection: used at the grid connection point of DG to prevent voltage collapse of the grid due to network faults; and
- Low voltage ride-through protection: allows network operators to define their own Low-Voltage Ride-Through (LVRT) curve for generators, as required for the dynamically changing local network.

10.4.2.3 Adaptive protection

Our current solution to directional overcurrent (DOC) limiting the amount of DG that can be connected in certain parts of our network is through the use of Load Blinding Relays. They are one of the smart solutions introduced to address the challenges associated with reverse power

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31 https://search.abb.com/library/Download.aspx?DocumentID=CIRED2015_0480&LanguageCode=en&DocumentPartId=&Action=Launch

32 https://search.abb.com/library/Download.aspx?DocumentID=24_DPSP_2016&LanguageCode=en&DocumentPartId=&Action=Launch

flows from DG into higher voltage networks. UK Power Networks first trialled them in the Flexible Plug and Play project between 2012 and 2015. These are being rolled out as BaU, and using our learning are now used as a BaU solution at Western Power Distribution and UK Power Networks.

This form of protection assumes a certain phase angle difference between voltage and current (power factor) of "normal" reverse power flow. In contrast, genuine fault power flow typically has a poor power factor, quite distinct from that of load. Therefore, if the load power factor is static and known a "blinding" window can be set which allows higher reverse power flow (as shown in Figure 39). A fault with a power factor that is not "masked" by the load blinding will operate the network.

Should the site be fed from multiple GSPs at different times, or have through power flow due to a "lose couple" (where two sites are connected together via a lower network voltage to reduce circulating currents) the range in normal power factors can make it difficult to set a clear distinction between normal and fault conditions. This results in either a nuisance trip (if the window is too narrow) or a failure to operate (if it is too wide). This is made worse as DER operate with a wider power factor, as it can interfere with voltage management at a site leading to tap stagger and high circulating current which would trip the DOC protection.

In Constellation we will trial the automatic change in protection settings range to enable higher reverse power flow at a site where we cannot apply load blinding at present. This will enable higher utilisation of the thermal capacity of the network and more low carbon generation to connect to the network. While not quantified in the business case, this will become much more widespread as generation provides reactive power services and voltage support, or as CLASS (Customer Load Active System Services) becomes more widely deployed. In both cases the wider range of normal power factors are likely to prevent load blinding deployment. Having had early engagement with Fundamentals we anticipate at least one proposal for voltage management to be presented in the Open Innovation Competition to address any associated issues.

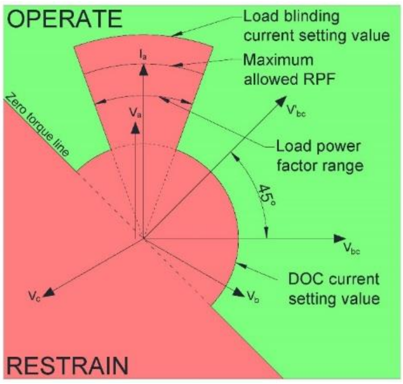


Figure 39 – Vector diagram for the response of a DOC relay with load blinding functionality

10.4.2.4 Adaptive protection: Adaptive Protection System from Siemens
This concept consists of the following:

- Local gateway to read actual protection settings from the protection devices in the field through IEC 61850;
- Protection Data Management System (as part of the OT Asset Management System) to store all settings centrally; settings collected by the local gateway are updated (import of a file exported by the local gateway); settings from relays that do not support settings reading through IEC 61850 can either be entered manually or by import of the respective relay configuration files (functionality available for the most common relay configuration tools); and
- Protection Engineering and Simulation System to simulate protection behaviour in the system and calculate improved (adapted) protection settings that are then brought to the field devices in the reverse order (first updated in the Protection Data Management System as the new reference settings, then brought down to the gateway, then set in

the relays through IEC 61850); a continuously up-to-date CIM-based network model is required for the Protection Engineering and Simulation System that can be loaded from UK Power Networks' ADMS.

10.4.3 Central management of Constellation system from Siemens

It is envisaged to implement a central system to manage the assets (both hardware and software) that are to be implemented as part of Constellation. Increasing the population of software assets in this space increases the need for careful management to ensure correct versions are operated at different sites to ensure continued safe operation.

A suitable central, vendor-agnostic OT Asset Management System for Secondary Equipment exists, to enable the storing and management of firmware versions, serial numbers, installed protocols, installed modules, protection settings of all secondary (protection & control) assets in substations. In addition, the OT Asset Management System will enable the transfer of files (configuration files, commissioning reports, firmware binaries, as additional attributes to these assets) between the substation (via component D, On-Site Device Functionality Store) and subsequently stored within the central platform. It would require some adaption and interfacing to meet the constellation requirements but has already been proven as a platform.

This central system also serves as Protection Data Management System (needed for **Method 2: Adaptive Protection**), and the interface to the "On-site device functionality store" enables online reading of the data. Files (configuration files, firmware binaries, etc.) can be transferred bidirectionally between the central system and this local gateway and are then available locally for deployment with the respective engineering tools (a remote connection to the substation PC can be enabled). Decisions are based on a holistic picture; therefore ingestion of data will be from a mix of the substation equipment gateway as well as Network Model Management System.

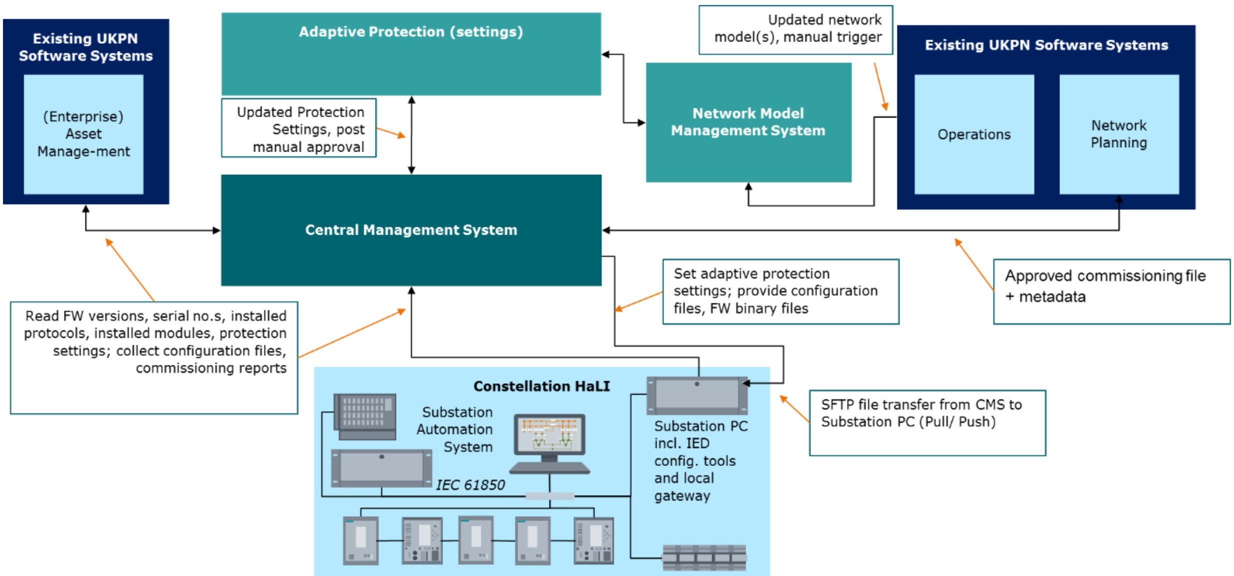


Figure 40 – Central management system high level architecture (adaptive protection element shown for completeness)

A local gateway is installed as a virtualised application in each substation, able to read automatically and cyclically actual firmware versions, serial numbers, installed protocols, installed modules and protection settings online for all devices providing this information in standard protocols (IEC 61850, SNMP (Simple Network Management Protocol)). This information can then be provided to the central OT Asset Management System by file exchange for an automatic update of the date stored there. This gateway shall also allow to set new protection settings to protection devices supporting this functionality through IEC 61850.

10.4.4 Hardware for Local Intelligence (HaLI)

The HaLI is the physical point for the Constellation systems which provides the resources (memory, processing, interfaces) that the virtualised Methods 1 and 2 need. The configuration listed here are for the Constellation project with extensive additional test equipment that would not be required for a BAU roll out.

- Primary and Grid sites are envisioned to have **full intelligence** installed on site: this consists of dual redundancy and expandable interface ports depending on the site requirements; and
- Secondary and DER sites are envisioned to have **partial intelligence** installed on site: this consists of no redundancy and limited interface ports.

The equipment included in the local intelligence builds on the lessons from Unified Protection and from FITNESS and consists of:

- **Substation PC** – Welotec Rugged Substation Automation PC (RSAPC): Server grade performance, reliability and security for the harshest operating environments and meet the stringent certification requirements for substation automation;
- Phasor Measurement Units – capable of capturing samples from a waveform in quick succession and reconstructing the phasor quantity, made up of an angle measurement and a magnitude measurement;
- **Substation simulator Omicron RBX**
    - StationScout is the testing solution that visualises the status of the entire site, detects problems and makes it possible to trace signals. IEC 61850 and its complexity stays in the background; and
    - StationGuard creates a system model of the automation system and then compares every single network packet with this live communications system model. StationGuard provides a combination of attack detection and functional monitoring of the substation also known as "Functional Security Monitoring";
- **RelaySimTest CMC 356** – All CMC test sets do support the subscription and simulation of classical GOOSE via mapping data attributes to logical binary inputs/outputs within the test software. Additionally, CMC test sets supports the simulation of up to four sampled values streams;
- **DANEO 400** – DANEO 400 is a multi-meter for digital substations. It visualises details of IEC 61850 GOOSE (not yet for R-GOOSE, but will be developed before the Constellation trials), Sampled Values, and PTP communication and offers live observation of signals for engineers with oscilloscope, phasor diagram, harmonics spectrum, binary tracks, etc;
- **RuggedCom Layer 2 and 3 managed switches –** powerful high-port density switches and routers with ten Gigabit uplinks. Ideal for high port density applications in the electric power. Can support up to four line modules and includes FortiNet firewalls;
- **OMTC-100 GPS clock and Meinberg M1000 (NTP & PTP server) –** These devices provide a solution to time and frequency synchronise intelligent electronic devices.

10.4.5 Virtualisation platform/environment

The virtualisation platform will provide the environment for software implementation of the functionality for Methods 1 and 2. In Unified Protection, we successfully containarised traditional feeder protection on vendor specific hardware (e.g. ABB relay functions containerised on ABB IEDs). In Constellation we will make a significant change by virtualising our Partners` protection and control functionality interoperably on the third party hardware (described in 10.4.4). In order to deploy Constellation in DER sites, which are space constrained, the RTU will be containerised and run on the substation PC. The proposed approach, validated during the initial stages of the Project, is a hybrid environment which allows functionality to run as a virtual machine (suitable for critical, real-time applications such as protection), or as containers running on an operating system such as Linux.

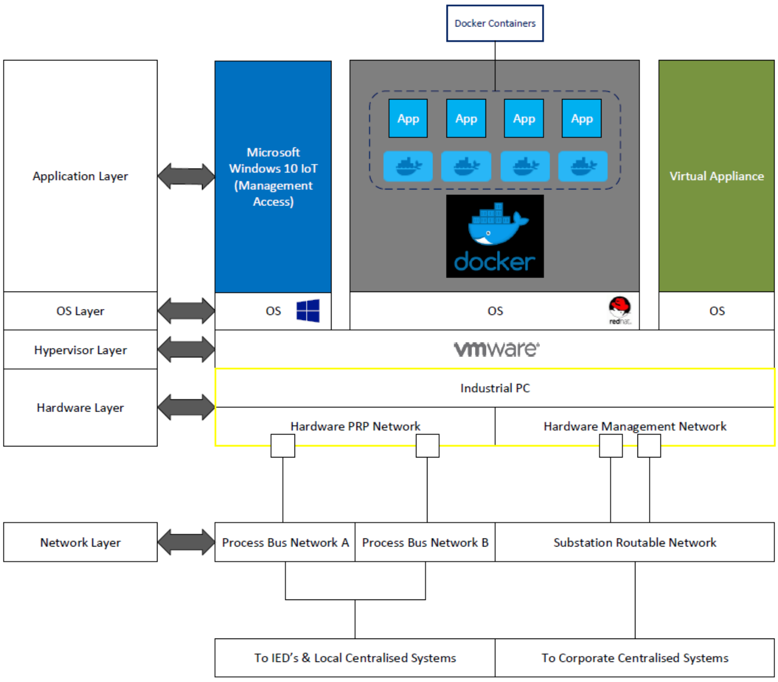


Figure 41 – Hybrid virtualisation environment enabling virtual machines and apps

A container is an isolated, lightweight silo for running an application on the host operating system. Containers build on top of the host operating system's kernel (which can be thought of as the buried plumbing of the operating system) and contain only apps and some lightweight operating system APIs and services that run in user mode. In contrast to containers, VMs run a complete operating system–including its own kernel[33].

Table 16 – Capabilities of Containers and Virtual Machines[22]

Item	Virtual Machine	Container
Isolation	Provides complete isolation from the host operating system and other VMs. This is useful when a strong security boundary is critical, such as hosting apps from competing companies on the same server or cluster.	Typically provides lightweight isolation from the host and other containers, but does not provide as strong a security boundary as a VM.
Operating system	Runs a complete operating system including the kernel, thus	Runs the user mode portion of an operating system and can be tailored to contain just the needed

[33] Microsoft, Containers vs virtual machines, 2019

	requiring more system resources (CPU, memory, and storage).	services for your app, using fewer system resources.
Fault tolerance	VMs can fail over to another server in a cluster, with the VM's operating system restarting on the new server.	If a cluster node fails, any containers running on it are rapidly recreated by the orchestrator on another cluster node.

We envision the protection aspects of Constellation to run as VMs due to their real time requirements. Aspects of Method 1 and the OIC apps will be containerised for ease of configuration and deployment, however this will be reviewed during the project design phase.

10.4.6 Site-to-site communication via 5G slicing from Vodafone

10.4.6.1 Definition

5G mobile networks will provide even more speed and higher quality than their predecessors. They operate on a novel architecture which allows the creation of a set of logically independent networks that run on a common physical infrastructure. Each of these logically independent networks (network slices) can be designed to fulfil specific business needs, making 5G a truly smart network.

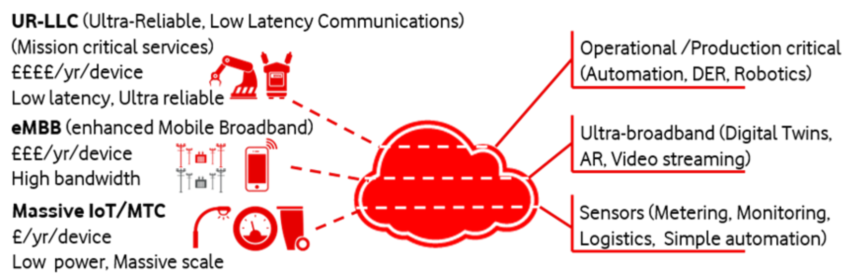


Figure 42 – 5G slicing environments

[redacted] An operator can configure and manage the mobile network to support various types of service classes enabled by 5G, for example eMBB (enhanced Mobile Broadband) and UR-LLC (Ultra-Reliable and Low Latency Communications), depending on the different customers' needs.

10.4.6.2 Operation

Network slicing is about transforming a cellular mobile network from a single network to a network where logical partitions are created, with appropriate network isolation, resources, optimised topology and specific configuration to serve various service requirements. From a mobile network operator's point of view, a network slice is an independent end-to-end logical network that runs on a shared physical infrastructure, capable of providing a negotiated service quality. The technology enabling network slicing is transparent to business customers. A network slice could span across multiple parts of the network (e.g. terminal, access network, core network and transport network) and could also be deployed across multiple operators. A network slice comprises dedicated and/or shared resources slices.

10.4.6.3 5G service in trial locations

[redacted]

[redacted]

[redacted]

10.4.6.4 [redacted] method

A typical approach to communications service testing is progressive phases involving more components until the entire "system" is included. Given the intent of the project and particular the objective for Methods 1 and 2 it would make sense to consider the 5G element as a discrete component and then to expand this through on-site networking infrastructure. Vodafone will collaborate with UK Power Networks on the most appropriate methods and tools to perform the required performance tests, particularly absolute latency, and differential delay if required, as round-trip type methods will not provide a suitable level of accuracy. There will also be a requirement to understand the contribution/impact that the RuggedCom routers will have on the services. It will be necessary to evaluate how they map QoS parameters from the 5G environment and preserve the service performance levels.

The following values will be tested against the success criteria for the defined service types and under variable conditions as outlined in the scope:

- **Latency** – absolute (end-to-end) between IED interfaces and differential if possible
  - Differential latency control is not covered in the 5G architecture technical specification, so the impact of slicing and enhanced QoS controls is at present unknown.
- **Packet loss** – against QoS targets.
- **Availability** – general availability of the links/services, which includes the air interface between the cellular base stations and 5G devices in the test locations.
- **Packet/Payload size** – impact on performance, linked to default maximum data burst volumes.
- **Security impact** – performance impact of security measures.

10.4.7 Academic insights and future governance

To ensure that Constellation delivers effective solutions suitable that are future proof and consider the full spectrum of the state-of-the-art, four research streams have been included in the Project. These will critically review key project elements, enabling optimal development of solutions. While the exact content and scope of each research stream will be finalised during the Project, a summary of the proposed scope is presented below:

10.4.7.1 Communication and data architecture
Theme Focus: This research stream will investigate communication and data architecture designs and will the detail design stage. This work will investigate data requirements, possible communication architectures and efficient networking strategies, in particular, the optimal mix between different communication solutions including wireless links with novel management structures such as network slicing. Furthermore, to manage the impact of the Huawei 5G ban we will investigate alternative communication mediums suitable for the low latency, high reliability site-to-site communication The work will also consider the configuration of different virtualised environments and their management.

10.4.7.2 System Reliability & Distributed Control
Theme Focus: This research stream will study how distributed and localised control can evolve after Constellation, looking at the range of functionalities that will benefit of a more distributed control architecture and assessing both benefits and challenges. This research will, in particular, explore how the new requirements of future energy scenarios with more DG, more prosumers, and new energy market models, and review the suitability of distributed control versus centralised control. Additionally, the theme will investigate the system reliability of the proposed solutions. This research stream will investigate the hardware, software and communication elements of the developed solution to assess the overall system reliability. This research stream will also investigate bandwidth and resilience requirements for both control and configuration, latency and failover situations, and cyber security management and zones of trust. In addition to realising the local intelligent dispatching of DERs' power outputs, it would also be valuable to investigate the feasibility and the benefits distributed control mechanism can enable novel functionalities to enhance the system operability, e.g. enabling frequency response (including emulated inertial response) from DERs.

10.4.7.3 Adaptive and LoM Protection
Theme Focus: This research stream will conduct a systematic evaluation of the performance, potential risks and potential mitigation solutions associated with the adoption of the adaptive and LoM protection methods implemented on the Constellation platform. The scope will cover the analysis and studies that are not possible (or difficult to achieve) in laboratory testing or field trials due to cost and infrastructure limitations. The studies will include examination of the feasibility of prerequisites for enabling such protection solutions; benchmark modelling of the distribution network and the adaptive/LoM protection solutions; assessment of performance under a wide range of events and future energy scenarios; comparative studies with existing solutions; and statistical analysis to quantify dependability, security and reliability. The outcome of this research will provide guidance on configuration, settings and protection policy development. The simulation studies will also inform the specification of requirements for scalability and interoperability.

10.4.7.4 Future Governance in a Net Zero world with distributed electricity system operation
Theme Focus: This stream will consider the complexities that will challenge the current practices and policies of a multivendor system which is increasingly dependent on AI, machine learning. This stream will research, quantify and qualify the commercial and contractual challenges with interoperable multi-vendor solutions carrying out critical network functionality. It will then analyse existing solutions from other industries and propose suitable solutions for the consortium of partners to consider for BaU roll-out. Governance challenges areas to be investigated include:

- How to test and divide ownership of risk in multivendor interoperable solutions;
- Barriers and opportunities in the journey to "full" interoperability in system operation;
- Evolution of network services and their interaction with existing markets; and
- Identification & mitigation of risks in distributed network operation.

10.4.7.5 Academic engagement during the Project
Academic engagement during the project lifecycle will occur through two platforms: engagement through existing consortium innovation partners (PNDC as part of the wider University of Strathclyde) and through a competitive procurement process which will involve several other academic organisations and insights.

Both the communication and data architecture and protection themes (1 and 3) are planned to be delivered during WS1 – an early and critical stage in defining project requirements. To utilise the existing consortium's extensive strengths within these areas, and intimate knowledge of project aims & objectives, both the communication and data architecture and protection themes will be undertaken by the PNDC/University of Strathclyde. The Distributed Control & Reliability and governance themes (2 and 4) will then be tendered by UK Power Networks via a competitive procurement process within the project.

10.4.8 Open Innovation Competition (OIC)
As part of Constellation, we will be running an open Innovation Competition and demonstrating added value from the Constellation platform to various network use cases. At present, we have over 16 different applications (see

Table 18 below) which can provide a benefit in specific areas:

- Inspection & monitoring;
- Cyber security;
- Network reliability; and
- Asset health.

The OIC will act, first, as a kick-starter for an ecosystem where users, developers and incumbent suppliers of substation control and protection technology work in a collaborative environment to meet the business needs, and secondly to generate learning that the aforementioned stakeholders can utilise to refine their development, testing and adoption processes. The OIC will be managed by workstream 3 and its different stages and associated activities are summarised in Table 17.

Table 17 – Stage of the Open Innovation Competition

Stage	Activities
Organisation of the OIC	• Set up of steering and selection panel from project partners and external stakeholders • Drafting of contractual terms and setup of procurement • Definition of selection criteria including maturity of proposal, alignment with project objectives and level or risk and mitigating measures to ensure progress through network trials • Prioritising the uses cases to ensure they fulfil a business need • Produce call for proposals
OIC call for developers	• Publish call for developers including high-level technical requirements using approved channels (e.g. UK Power Networks' open data platform, EIC, the PNDC core research programme, partners' R&D channels) • Manage enquiries from prospective developers

Shortlisting and selection of developers	• Panel to align proposals with preferred list of method and shortlist based on selection criteria and procurement rules • Interview shortlisted developers and announce selection of developers for proceeding to the next stage
Legal	• Contracts signed
Development and incubation period	• Development of methods in accordance with technical requirements • Regular updates and engagement with project partners • Selected developers to incubate developed methods using the PNDC test platform
Off-network trials at the PNDC	• Incubated methods are tested at the PNDC in preparation for the network trials
Network trials	• Tested methods are deployed in the network trial site. Trial sites selected for deployment will depend on the site operational requirements and developed methods
Dissemination	• Constellation project partners will publicise this opportunity in stakeholder forums including LCNI • After the conclusion of the PNDC testing, the developed methods will be showcased as part of an industry engagement workshop hosted at the PNDC

At the conclusion of the OIC, the following learnings and outcomes will have been achieved:

- Process for defining technical requirements for deployment of third-party methods on an open platform owned and operated by the DNO;
- Kick-starting of an eco-system for developing methods and further enhancing the utilisation of the Constellation open platform;
- Qualification of the technical and operational risks and mitigating measures for third-party developers delivering a solution in a substation environment. This is the next step from third party access afforded by cloud-based solutions already deployed in some DNO substations; and
- Refinement of testing and validation processes for third-party developed methods, which feeds into certification and procedures for adoption in to BaU.

Summary of the use cases which have been provisionally identified for the OIC are in Table 18.

Table 18 – Provisional use-cases for development and demonstration through the OIC

Problem / use case	Method	Benefit
IC1 – Transformer I&M As we are reliant on smart solutions to defer reinforcement, the aging asset base is becoming increasingly utilised – specifically transformers	Real time data from scalable sensors processed by Local Intelligence provides detailed insights. Assessing oil quality, loading, temperature, acoustic and electrical signatures can indicate transformer and tap changer health	Extend transformer life and reduce network risk in before need for asset replacement
IC2: Stuck CBs Through their infrequent operation, circuit breakers can become slow or stuck. This can lead to upstream protection to operate and disconnect entire sites	Real time data from scalable sensors processed by Local Intelligence can provide low cost retrofit busbar protection and specific insights. Local Intelligence can process the performance of breakers every time they are operated and proactively diagnose issues	Reliable network operation facilitated through improved protection and scalable and data driven asset management
IC3: Fault location As more DG goes on the distribution network impedance-based fault location becomes less accurate	Use a high sample rate data recorder at a primary / grid substation to carry out Travelling Wave fault location for all feeders	Faster & more accurate fault location, improving reliability and reducing fault costs
IC4: Future protection As fault currents reduce and become more variable simple overcurrent and earth fault detection will become insufficient to effectively detect network issues	Using a high sample rate data recorder to carry out waveform based local protection algorithms to detect low fault current faults and intermittent issues. Proactive action can be taken to carry out repairs before a feeder trip would traditionally occur	Reliable network operation resilient to transient issues and capable of supporting a high penetration of DG. Reduced outage time / equipment stress due to fault current exposure
IC5: High fault level Where DG connect the fault level on the network surrounding the connection becomes high or variable. This often needs the generator to disconnect in abnormal running arrangements	Using adaptive protection, the Constellation platform can support reactive and pro-active reconfiguration of the network to keep DG on normal and abnormal running arrangements ensuring network limits are not breached even when comms to the central system fail	This will allow more generation to connect at lower cost, and enable existing generation to continue to operate in a wider range of network running arrangements than previously possible

Problem / use case	Method	Benefit
IC6 – Voltage Control Integrated voltage control Network voltages exceed allowed tolerances due to increase in generation and demand. This can cause generation to curtail and lights to flicker	Use wide area measurements and DER reactive power control to reduce the voltage transients on the network. Integration with secondary on load tap changers is possible when they become common place.	This allows a wider range of load / generation without having to reinforce the network to cater for the voltage drop / rise. It can also reduce generation curtailed due to high volts at the end of feeders.
IC7 – Timing Due to the increasing volume and reliance on data there is a need for synchronisation to make clear decisions. This is expensive or reliant on GPS, which is susceptible to cyber-attack	Transmit and timing data either using the site-to-site R-Goose signalling or use a wide area time signal via an FM radio band	Time synchronisation can be maintained at lower cost than using GPS at all locations
IC8 - Network Islanding At present there cannot be islanded sections of the DNO network as statutory voltage / frequency cannot be maintained and safe trip on fault cannot be ensured (generator earthing)	The Constellation platform and wide area protection can allow sections of the DNO network to safely island and reconnect and can be deployed at scale	Reduced reinforcement and preserve customer supplies in more situations. Especially beneficial as more DG operates using voltage source inverters
IC9 - Black start from DG Due to the decreasing transmission connected generation it is more expensive to maintain current black start support	Use DER to start local islands within the DNO networks and bring these together to re-form the grid. This is feasible and scalable to deploy on the Constellation technology	Improved resilience to high impact low probability events at lower overall cost
IC10 - Thermal camera hot spot detection Occasionally loose or corroded connections within the power system heat up and cause faults	Limited movable thermal cameras and software on Constellation could use image processing to detect hot-spots on open bus-bar sites without having to send the data to be processed centrally	Reduction in fault volume and I&M cost due to online monitoring
IC11 - Thermal camera oil level detection As large transformers lose oil over time this of often noticed on the first cold night of the year when they trip on low oil	Use thermal camera and local image processing to provide an oil level indication and proactively top up before a trip is caused	Reduced network risk from trips and optimised field response to top up oil

Problem / use case	Method	Benefit
<u>IC12 - Security camera inspections</u> Major substation sites are inspected to determine if there are changes / issues requiring intervention. This costs time and results in subjective data	Image processing of security camera footage could identify many items an inspection would pick up – using change detection or picking up known signature visual elements. To do this at scale centrally would be unfeasible and costly	Improved response to issues on site enabling defects to be resolved more quickly at lower cost.
<u>IC13 - Accurate post fault maintenance scheduling</u> Older oil switchgear often needs maintenance after a number of fault operations due to contact wear	Monitor fault current flow and estimate wear on contacts. Where the fault current is low and contact wear reduced maintenance intervals can safely be increased	Reduced maintenance costs
<u>IC14 - Network fingerprinting</u> Limited records of the DER assets connected to our network due to low registration levels. This will become more of a problem as penetration increases	By monitoring changes on the networks at high frequency some parameters can be used to determine at a high level what assets are connected	Improved visibility of flexible assets ensuring better understanding of load / generation mix and not un-knowingly disconnecting generation
<u>IC15 - Low conductor detection</u> At present low conductors are often only detected when members of the public call in to inform us. This can leave safety hazards on the network for significant periods without us being aware	It is possible to detect low conductors from network impedance fingerprint changes. This is still in research as part of an ENWL / Kelvatek project but could be rolled out at scale on the Constellation platform	Low conductors (and other similar safety risks) can be detected and resolved quickly without waiting for a third party to inform us
<u>IC16 - Enable local markets for curtailment and flexibility trading</u> Currently there is little visibility of the distribution network, both around capacity and real time usage	Deploy constellation functionality to distribution substations to provide local intelligent control and calculation at a very low level. Some of this has been demonstrated in WPD's Open LV project	Additional functionality and equipment control is available at lower overall cost

Problem / use case	Method	Benefit
IC17 - Dynamic Low Frequency Disconnect The LFDD scheme is designed to disconnect demand in nine predetermined blocks with each block triggered at lower system frequency.	Dynamically update the disconnection blocks to ensure, as much as possible, that DER assets which can support the system stability are not disconnected by LFDD.	Improved LFDD performance and ability to reduce cascading effect of disconnecting DG during system instability events.

10.4.9 Testing and commissioning

Through learning from previous and on-going projects like FITNESS and Unified Protection, we believe testing of the Constellation platform and both Methods is critical. As such, we will subcontract OMICRON (vendor-independent testing of all elements) and RuggedCom (independent provider and testing of communication systems) to provide valuable expertise in the testing and commissioning of Constellation.

The main requirements of the required testing philosophy are as follows:

- Installation of a permanent protection and control testing, monitoring and cyber security device in the substation to enable continuous network monitoring and ensure cyber security;
- Simulation and Testing of local intelligent control over R-GOOSE and inter-substation communication over 5G WAN; and
- Enabling remote testing and simulation procedures without need for manual intervention;

The testing products and tools will be available as discrete hardware (HW) platforms and software licenses at the outset of the project, but the required tools for the permanent installation at the substation will be combined into a single platform as part of the project. It should also be noted that OMICRON currently does not support R-GOOSE testing and/or monitoring, however this capability will be developed during the Project.

Table 19 – Independent testing services for Constellation

Activity	Description	Tasks
Expert services for offsite testing with 3rd party suppliers and partners	• Participation in pre-factory acceptance tests (FATs) and FATs • Participation in PNDC testing for communication network devices • Non-Conformance testing on site	• Supply equipment • Provide expert knowledge and support • Preparation for each pre-FAT, FAT and PNDC tests • Execute all aforementioned tests
Preparation of test plans and procedures for off-site and on-site testing	• Preparation of test procedures and plans to enable automated testing using RelaySimTest, DANEO, StationScout and StationGuard • Implementation of review comments and finalisation of test plans • Adaptation of test plans as required once after each pre-FAT and FAT	• Supply of test plans • Guide vendors in production of automated intelligent protection and control testing
Supervision and guidance on-site during installation and commissioning of project setup	• Cold commissioning (commissioning offline) of OMICRON products as required • Supervise and guide execution of additional site acceptance test (SAT) procedures (in addition to non-conformance tests)	• Prepare for on-site SAT • Execute non-conformance tests • Supervise SAT • Prepare risk assessments and method statements for site access
Training for use of OMICRON products and tools	• Customise trainings based on project requirements and learning • Provide training	• Lead and provide training. • Customise training content

10.4.10 Trials

The aim of the Constellation trials is to ensure a sufficient level of de-risking is achieved for the project methods by advancing their TRL and successfully demonstrating operation of the methods. Full formal site selection will be carried out during the project but during the bid development we carried out initial trial site selection and selected two areas:

- Maidstone
  - Existing Unified Protection development
  - A suitable “hub” with a large generator connected and complex protection arrangements
- Lewes
  - Existing generation limitation
  - A suitable hub with a high penetration of medium scale DER

Demonstrating the solution across two unique areas will us allow to assess Methods 1 and 2 in complex running arrangements on locations with a high penetration of DER. It will enable us to understand Methods deployed independently and interactions between them. This would not be possible with a single trial area.

10.4.10.1 Maidstone area

This is a complex part of the network as Maidstone Grid is typically supplied through Kemsley GSP, but if the network is reconfigured it can be supplied through Northfleet East GSP or Canterbury North GSP. Furthermore, the physical site consists of one grid and two primary substations. Each primary site has transformers with dual secondary windings. Currently, there is a 40MW synchronous generator connected at 33kV and a number of smaller (<5MW) generators connected to the 11kV network. These sites are ideal for adaptive protection settings as the entire area is currently constrained due to DOC settings.

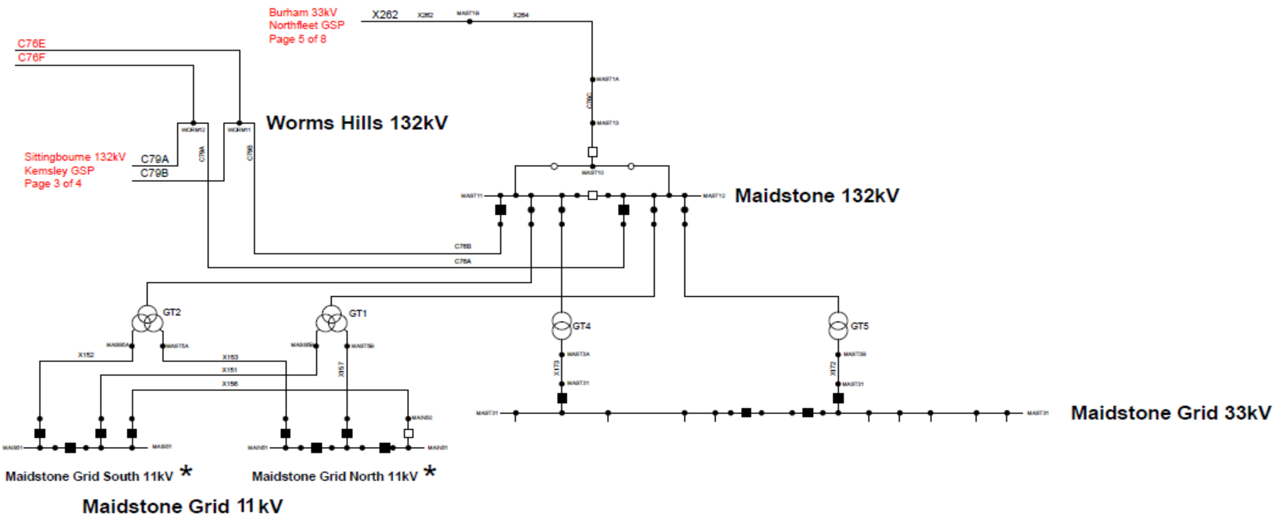


Figure 43 – Maidstone area overview as per the Long Term Development Statement (LTDS)

The Maidstone trial area will consist of one grid site, one primary site and one 33kV DER site. In total, there are 30 circuit breakers (CBs) which require 60 IEDs. The rest of the equipment is listed in

Table .

Table 19 – Maidstone trial area equipment requirements

Full (grid) intelligence	# for Maidstone area	Partial (DER site) intelligence	# for Maidstone area
PAC IEDs	58	PAC IEDs	2
Welotec RSAPC Computers (IEC61850-3 compliant)	4	Welotec RSAEC Computer (IEC61850-3 compliant)	1
Ruggedcom RST2228 (Layer 2 Managed switches)	6	Ruggedcom RX1480T (Layer 3 Managed switch/5G Router/PTP/NTP)	1
Ruggedcom RX1536 (Layer 3 Managed switch/5G Router)	2	Omicron MBX1 (Substation simulator/Test system)	1
CMC 356 platform (RelaySimTest)	1	OMTC-100 (GPS Clocks)	1
DANEO 400 platform	2	FortiNet cyber security solution	1
Omicron RBX1 (Substation simulator/Test system)	2	Substation protection and control cubicle (To house these items)	1
Meinberg M1000 (NTP & PTP Server)	2		
OMTC-100 (GPS Clocks)	2		
FortiNet cyber security solution	2		
Substation protection and control cubicle (To house these items)	2		

10.4.10.2 Lewes area

The Lewes area is saturated with DG. Lewes Grid is typically supplied from Ninfield GSP and connected to Bolney GSP as a “loose couple”. Looking at two of the 33kV network feeders there are three 33kV connected DER on the same ring. This circuit can be reconfigured and supplied from another two grid sites. These sites are ideal for adaptive protection settings due to the number of possible supply arrangements and as the entire area is currently constrained due to DOC settings. Additionally, due to the many running arrangements possible on the 33kV ring, it is ideal for wide area protection and control.

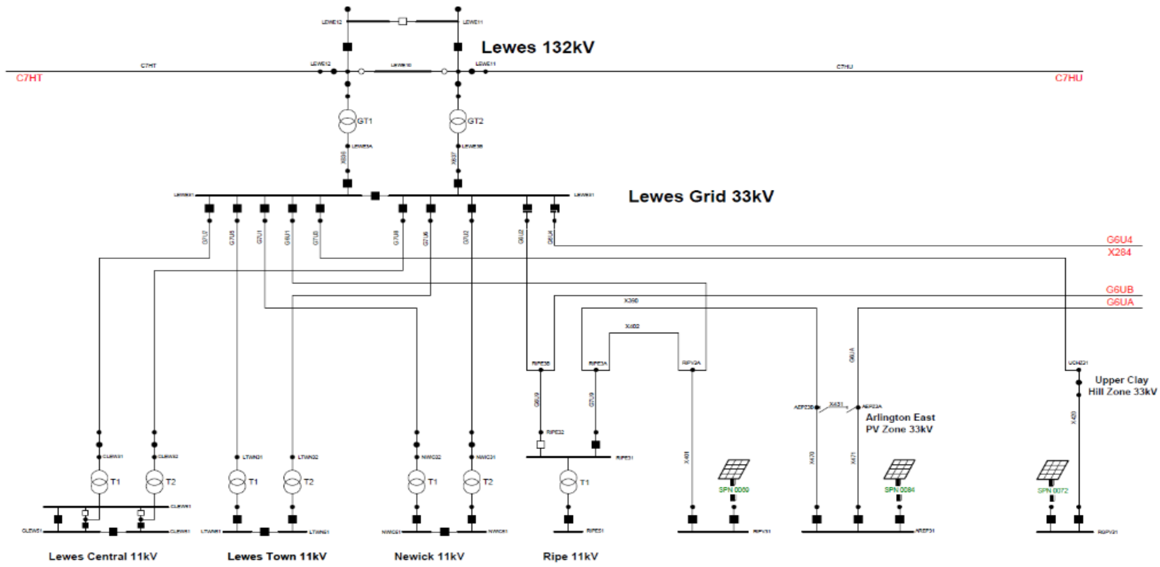


Figure 44 – Lewes 33kV network overview from LTDS

The Lewes trial area will consist of one grid site, one primary site and one 33kV DER site. In total, there are 37 CBs which require 72 IEDs. The rest of the equipment is listed in *Table* .

Table 20 – Lewes trial area equipment requirements

Full (Grid) intelligence	# for Lewes area	Partial (DER site & Primary) intelligence	# for Lewes area
PAC IEDs	46	PAC IEDs	26
Welotec RSAPC Computers (IEC61850-3 compliant)	4	Welotec RSAEC Computer (IEC61850-3 compliant)	7
Ruggedcom RST2228 (Layer 2 Managed switches)	6	Ruggedcom RX1480T (Layer 3 Managed switch/5G Router/PTP/NTP)	7
Ruggedcom RX1536 (Layer 3 Managed switch/5G Router)	2	Omicron MBX1 (Substation simulator/Test system)	7
CMC 356 platform (RelaySimTest)	1	OMTC-100 (GPS Clocks)	7
DANEO 400 platform	2	FortiNet cyber security solution	7
Omicron RBX1 (Substation simulator/Test system)	2	Substation protection and control cubicle (To house these items)	7
Meinberg M1000 (NTP & PTP Server)	2		
OMTC-100 (GPS Clocks)	2		
FortiNet cyber security solution	2		
Substation protection and control cubicle (to house these items)	2		

10.4.10.3 Design of trials

The first stage of trials will initially be carried out in a controlled environment using the PNDC real-time simulation and HV/LV testing facilities. The virtualisation of the Constellation platform and deployment of Methods 1 and 2 as applications in this platform necessitate a software-oriented validation methodology that ensures performance of the critical functions such protection is maintained by the software architecture and is not adversely impacted by non-critical functions (e.g. environmental monitoring). Therefore, the PNDC trials stage focuses on rigorous testing of the software functionality in a realistic operational environment.

This testing environment also allows for more accelerated testing and exposing the Constellation platform to conditions that are not easily or practically replicable in a live network trial.

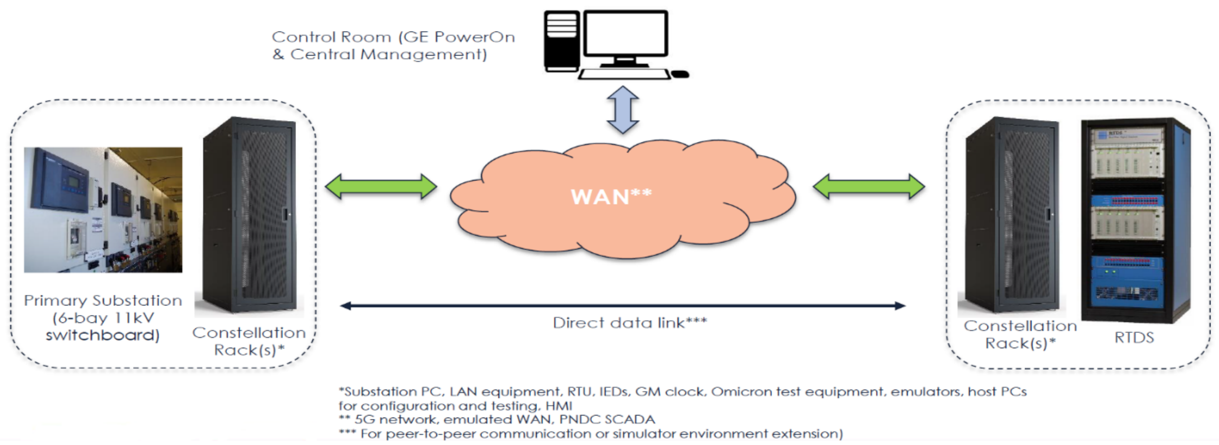


Figure 45 – PNDC trial set up

The PNDC trials lead into two distinct trials phases carried out in selected UK Power Networks sites. PNDC testing however will remain active in parallel with network trials to ensure continuous support and validation of any changes that occur in the field. Table summarises each of the trial stages, their focus and approach.

Table 21 – Trial stages with focus and approach for each stage

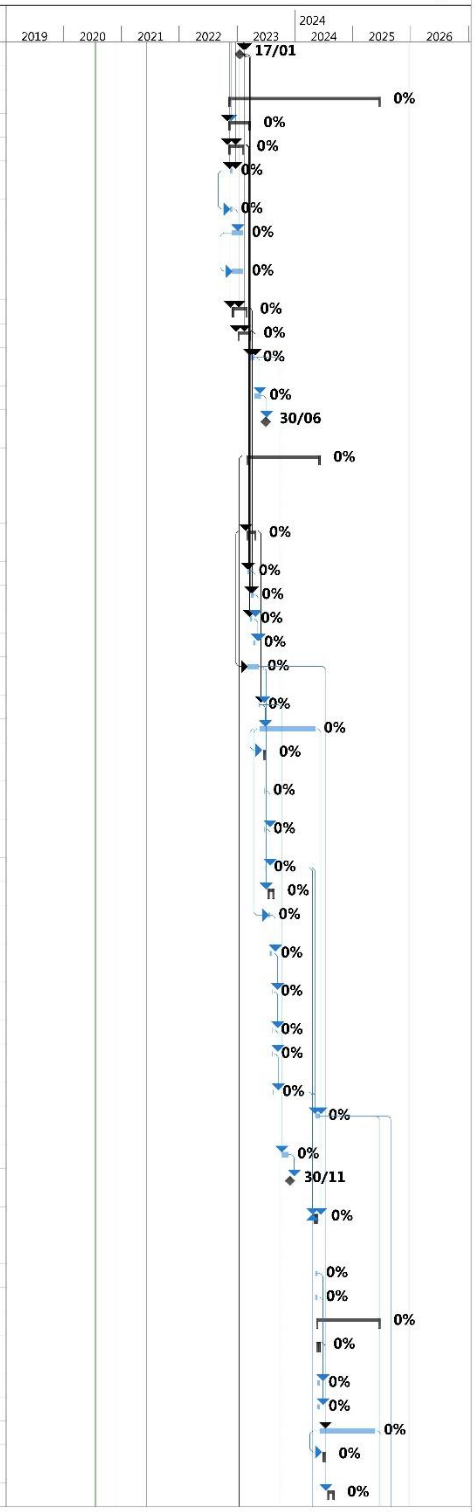
Trial	Focus	Approach
Off-network trials at the PNDC	• Verification of Methods functionality and performance (local and communications enabled) • Interoperability testing • Hardware and architecture resilience assessment	• Implementing and test a replica of trial site equipment and configurations using PNDC hardware in the loop test setup • Simulation of operational scenarios with the Real Time Digital Simulator (RTDS) • Retrofit of PNDC 11kV substation
Network trials – Phase 1 (shadow/passive operation)	• Integration within UK Power Networks systems and interaction with central ANM and ADMS • Testing the central management of settings, on-site hardware and Methods 1 and 2 software • Passive functional performance assessment for Methods 1 and 2	• Development of performance scenarios for each Constellation element • Commissioning the Constellation system on the trial locations • Method 1 functional testing • Method 2 functional testing
Network trials – Phase 2 (live operation)	• Full functional performance and assessment of the Constellation system including Methods 1&2, comms, central management and OIC successful use-cases	• Live testing all Constellation elements during network events which normally occur, such as topology reconfiguration, faults, loss of comms, demand changes, voltage fluctuations • Assessment of coordination between central ANM and ADMS and local Constellation systems

Appendix 10.5 Project plan – detailed project plan

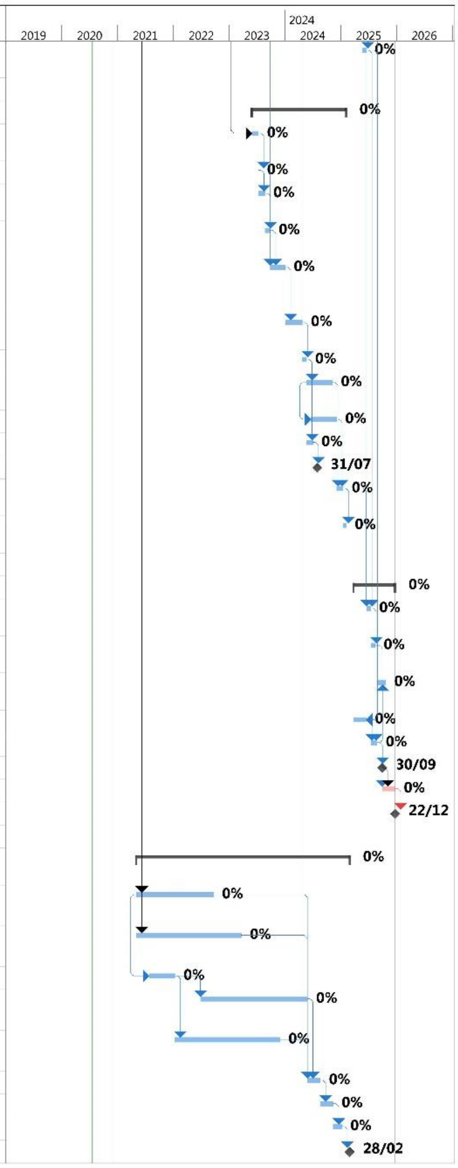
Version 1.9 | Constellation - Project Plan | Page 1

ID	Task Name	Duration	Start	2019–2026
1	Funding award	0 days	Tue 01/12/20	01/12
2	**Project duration**	**1120 days**	**Mon 03/05/21**	0%
3	Project start	0 days	Mon 03/05/21	03/05
4	Project end	0 days	Tue 30/09/25	30/09
5				
6	Finalise legal	120 days	Tue 01/12/20	0%
7	Assemble project team	120 days	Tue 01/12/20	0%
8	Kick-off meeting	0 days	Fri 14/05/21	14/05
9				
10	**Detailed design of Methods & trials**	**255 days**	**Mon 17/05/21**	0%
11	Identify relevent standards	25 days	Mon 17/05/21	0%
12	Develop non-functional requirements - performance, reliability, comms, security	40 days	Mon 21/06/21	0%
13	Functional requirements for each part (M1,M2, 5G comms, etc)	40 days	Mon 21/06/21	0%
14	Functional requirements for central management of apps & devices	40 days	Mon 21/06/21	0%
15	Specify system architecture	20 days	Mon 16/08/21	0%
16	Functionality virtualisation specification	25 days	Mon 13/09/21	0%
17	Consult on proposed approach and standards	6 wks	Mon 18/10/21	0%
18	Baseline architectures and standards	2 wks	Mon 29/11/21	0%
19	Detailed systems design	3 mons	Mon 18/10/21	0%
20	Select demonstration sites	60 days	Mon 31/05/21	0%
21	Specify hardware	25 days	Tue 11/01/22	0%
22	Detailed site design	2 mons	Tue 15/02/22	0%
23	Request revised price from Partners	2 wks	Tue 11/01/22	0%
24	Go to market for second supplier for M1 and M2	6 wks	Mon 13/12/21	0%
25	Internal Stage Gate - revised provider / scope / cost	2 wks	Tue 25/01/22	0%
26	Overarching trial design (performance criteria, trial objectives)	60 days	Tue 15/02/22	0%
27	Prepare Ofgem deliverable	6 wks	Mon 13/12/21	0%
28	Deliverable 1: System design & Architecture	0 days	Mon 28/02/22	28/02
29				
30	**Develop & Build Phase**	**280 days**	**Mon 13/12/21**	0%
31	Development of M1, M2 & Central management	8 mons	Tue 08/02/22	0%
32	Development of testing functionality & hardware	8 mons	Tue 08/02/22	0%
33	Integration with existing UKPN systems	80 days	Tue 20/09/22	0%
34	Virtualise functionality & software build	9 mons	Tue 08/02/22	0%
35	5G slicing development	150 days	Mon 13/12/21	0%
36	Specify test plan / approach for each element to be demonstrated	40 days	Tue 10/05/22	0%
37	Specify test scenarios for each element to be demonstrated	40 days	Tue 10/05/22	0%
38	Prepare ofgem deliverable	6 wks	Tue 05/07/22	0%
39	Deliverable 2: Trial Design & sites	0 days	Mon 29/08/22	29/08
40	**ABB Factory Assessment Test (FAT)**	**20 days**	**Tue 18/10/22**	0%
41	Pre-FAT checks	10 days	Tue 18/10/22	0%
42	FAT	5 days	Tue 01/11/22	0%
43	Report on results	5 days	Tue 08/11/22	0%
44	**GE Factory Assessment Test (FAT)**	**20 days**	**Tue 08/11/22**	0%
48	**Siemens Factory Assessment Test (FAT)**	**20 days**	**Tue 29/11/22**	0%
52	M1 FAT complete	0 days	Mon 14/11/22	14/11
53	M2 FAT complete	0 days	Mon 05/12/22	05/12
54	Central systems FAT complete	0 days	Mon 09/01/23	09/01
55	**PNDC build**	**130 days**	**Tue 15/02/22**	0%
67	**Maidstone area build**	**221 days**	**Tue 15/02/22**	0%
87	**Lewes area build**	**231 days**	**Tue 15/02/22**	0%

ID	Task Name	Duration	Start
107	UKPN site build complete	0 days	Tue 17/01/23
108			
109	**Demonstration Phase**	**645 days**	**Tue 15/11/22**
110	**PNDC trials**	**80 days**	**Tue 15/11/22**
111	**Method 1**	**50 days**	**Tue 15/11/22**
112	Deploy functionality to PNDC RTDS setup	2 wks	Tue 15/11/22
113	SAT on PNDC RTDS	2 wks	Tue 15/11/22
114	Perform trial testing a variety of situations	2 mons	Tue 29/11/22
115	Review results and iterate as required	2 mons	Tue 29/11/22
116	**Method 2**	**50 days**	**Tue 06/12/22**
121	**Central Management**	**50 days**	**Tue 10/01/23**
126	Review results, revise & validate design and operation	1 mon	Tue 21/03/23
127	Prepare Ofgem deliverable	6 wks	Tue 18/04/23
128	Deliverable 3: Method development & PNDC trial learning	0 days	Fri 30/06/23
129	**Network trials - shadow / passive operation (functionality, central management & interoperability testing)**	**315 days**	**Tue 07/03/23**
130	**Deploy & SAT constellation to trial sites in passive operation**	**35 days**	**Tue 07/03/23**
131	M1 at Maidstone	2 wks	Tue 07/03/23
132	M2 at Maidstone	2 wks	Tue 28/03/23
133	M1 at Lewes	2 wks	Tue 21/03/23
134	M2 at Lewes	2 wks	Tue 11/04/23
135	Set up Central Management functionality within UKPN estate	10 wks	Tue 07/03/23
136	Confirm site trials start	1 wk	Tue 16/05/23
137	Monitor performance during trial	48 wks	Tue 23/05/23
138	**Review network incident or comms failure as they occur**	**5 days**	**Tue 20/06/23**
139	Gather data on event / trial testing variety of scenarios	1 day	Tue 20/06/23
140	Assess performance against expectation	2 days	Wed 21/06/23
141	Write report	2 days	Fri 23/06/23
142	**Central Management testing**	**24 days**	**Tue 18/07/23**
143	Agree firmware / config uprades to use to test deployment	1 wk	Tue 18/07/23
144	Prepare materials for update, agree test dates	2 wks	Tue 25/07/23
145	Set up performance monitoring to verify operation during test	1 day	Tue 08/08/23
146	Carry out updates	1 day	Wed 09/08/23
147	Review results & roll back if unsucessful	2 days	Thu 10/08/23
148	Report results	5 days	Mon 14/08/23
149	Review results, summarise final learnings and outputs	4 wks	Tue 07/05/24
150	Prepare Ofgem deliverable	6 wks	Tue 10/10/23
151	Deliverable 4: Site installation learning	0 days	Thu 30/11/23
152	**Performance review and confirmation to proceed to active trial**	**10 days**	**Tue 07/05/24**
153	M1 Local ANM	2 wks	Tue 07/05/24
154	M2 Protection	2 wks	Tue 07/05/24
155	**Network trials - active operation**	**270 days**	**Tue 21/05/24**
156	**Transition Constellation functionality to active control**	**10 days**	**Tue 21/05/24**
157	M1 Local ANM	2 wks	Tue 21/05/24
158	M2 Protection	2 wks	Tue 21/05/24
159	Monitor performance during trial	48 wks	Tue 04/06/24
160	**Review network incident or comms failure as they occur**	**5 days**	**Tue 02/07/24**
164	**Central Management testing**	**24 days**	**Tue 30/07/24**



ID	Task Name	Duration	Start
171	Review results, summarise final learnings and outputs	4 wks	Wed 21/05/25
172			
173	**Innovation competition**	**421 days**	**Tue 30/05/23**
174	Plan competition - prep info pack, target areas and requirements	30 days	Tue 30/05/23
175	Launch competition	1 day	Tue 11/07/23
176	Publicise and engage to drive competition interest	30 days	Wed 12/07/23
177	Receive proposals & select use cases to be tested	25 days	Wed 23/08/23
178	Incubate and engage to ensure functionality can be demonstrated, write operational documentation	3 mons	Wed 27/09/23
179	Test (functionality & interoperability) at PNDC	4 mons	Wed 03/01/24
180	Deploy to UKPN trial sites	20 days	Wed 24/04/24
181	Trial solution (functionality & interoperability)	6 mons	Wed 22/05/24
182	Review results, performance	6 mons	Wed 19/06/24
183	Prepare Ofgem deliverable	6 wks	Wed 22/05/24
184	Deliverable 5: OIC learning	0 days	Wed 31/07/24
185	Review BAU transition suitability and arrangements	20 days	Wed 04/12/24
186	Remove elements not to the retained post project	15 days	Thu 16/01/25
187			
188	**Closedown & BAU roll out**	**194 days**	**Wed 26/03/25**
189	Closedown documentation for BAU transition	1 mon	Wed 18/06/25
190	Remove / hand over project equipment / software	1 mon	Wed 16/07/25
191	Dissemination event and data publishing	2 mons	Wed 27/08/25
192	Preparation for BAU roll out	3 mons	Wed 26/03/25
193	Prepare Ofgem deliverable	6 wks	Wed 16/07/25
194	Deliverable 7: Full trial learning	0 days	Tue 30/09/25
195	Post-project close out activities	3 mons	Tue 30/09/25
196	Publish close-down report	0 days	Mon 22/12/25
197			
198	**Academic Insight & Future Governance**	**968 days**	**Mon 03/05/21**
199	Communication and data architecture - Strathclyde	18 mons	Mon 03/05/21
200	Adaptive and wide area protection - Strathclyde	24 mons	Mon 03/05/21
201	Procure remaining research themes	6 mons	Mon 26/07/21
202	System reliability & distributed control - TBC	24 mons	Tue 28/06/22
203	Future Governance for multivendor operation - TBC	24 mons	Tue 11/01/22
204	Review and summarise research themes	3 mons	Tue 28/05/24
205	Include input from live experience	3 mons	Tue 20/08/24
206	Prepare Ofgem deliverable	6 wks	Tue 12/11/24
207	Deliverable 6: Academic Insights	0 days	Fri 28/02/25



Appendix 10.6 Risk Register & Contingency plan – tables of risk and mitigations

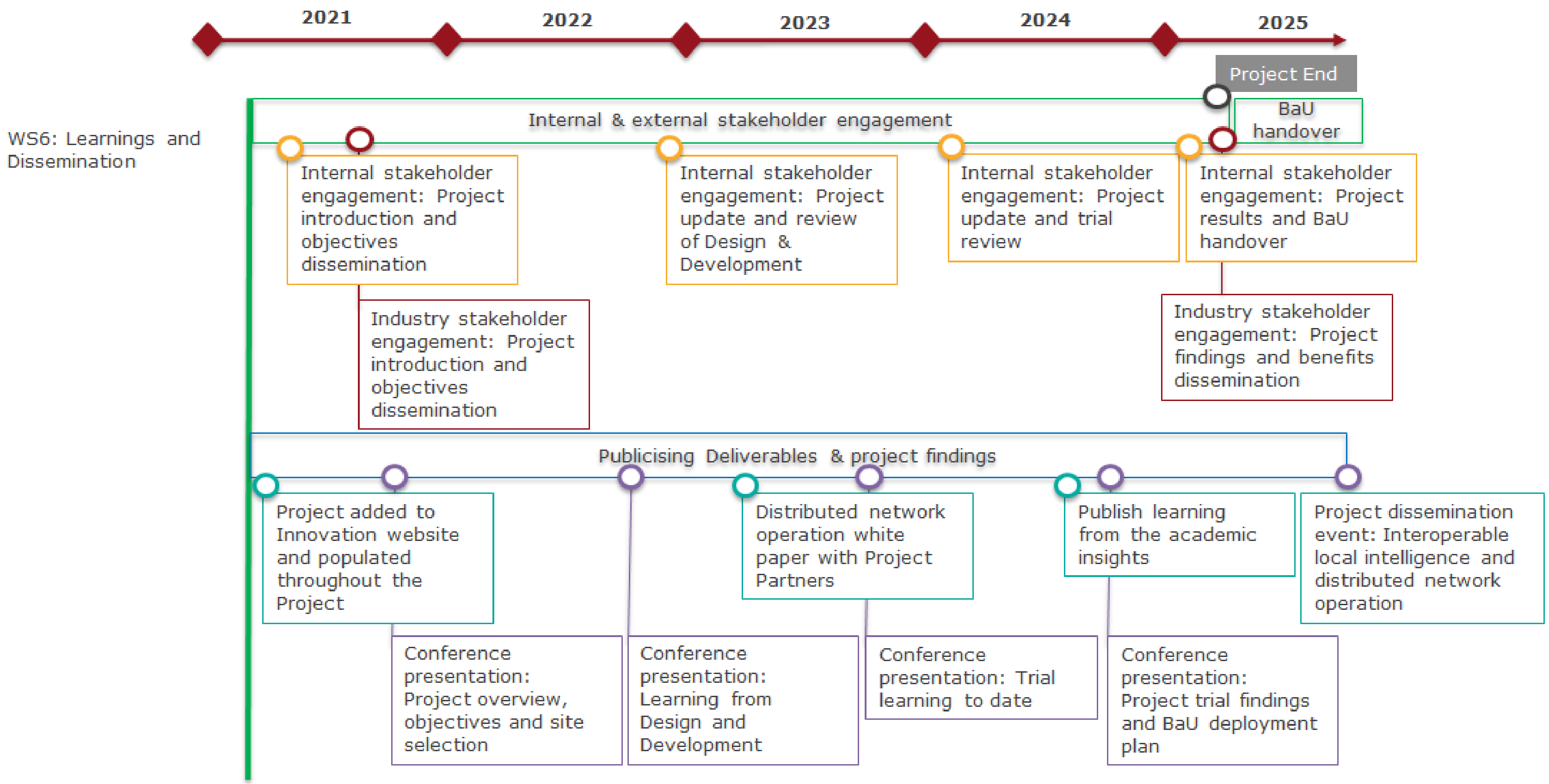
RISK & ISSUE LOG

ID	Risk / Issue	Status	Description	Impact	Risk Probability	Risk Impact	Risk Score	Mitigation / Planned Actions	Mitigated Probability	Mitigated Impact	Mitigated Score	Owner	Last updated	Date Closed
R1	Risk	Open	COVID-19 restrictions continue and impact project activities	Cannot hold face-face meetings slowing down bid development and design process and de-prioritised site work (non-essential)	3	5	15	- Contingency built in and a price review stage gate included at the end of detail design. This will allow costs to be re-negotiated after the architecture and design has completed. - Engage provider on fixed priced contract rather than time and materials	2	3	6	Project Manager	06/07/2020	
R2	Risk	Open	Architecture and system build costs are significantly higher than anticipated at FSP costing stage	Project overspend requiring additional partner contributions and/or change request for reduction in project scope	3	5	15	- Contingency built in and a price review stage gate included at the end of detail design. This will allow costs to be re-negotiated after the architecture and design has completed. - Engage provider on fixed priced contract rather than time and materials	2	4	8	Project Manager	06/07/2020	
R3	Risk	Open	Some elements of the technical solution are not achievable to the desired specification within the project timescale and budget	The project will not deliver all of the intended outcomes	3	4	12	- Ensure requirements and solution design is realistic after the detail design stage. - Continuously and quickly adapt to changing requirements, with iteration loops built into the project plan throughout the development. - Regularly progress following UKPN established project control methods	3	3	9	Project Manager	06/07/2020	
R4	Risk	Open	Methods do not deliver the anticipated benefits	Lower than anticipated value delivered	3	4	12	- Structure project such that there is no critical dependency of the most complex parts of the project on other parts - Regularly revise business case to update expected method costs and expected benefits	3	3	9	Project Manager	06/07/2020	
R5	Risk	Open	Development partner/supplier performance is not adequate	Outcomes are delayed, with potential overspend. This may also require a change in partner/supplier as an interim step.	3	4	12	- Ensure shared responsibility for deliverables - Incentivise partner/supplier for success - Ensure tendering/onboarding process focuses on critical project elements	2	3	6	Procurement	06/07/2020	
R6	Risk	Open	Suitable innovation competition entrants cannot be found	Project is delayed and/or requires re-scoping	3	5	15	- Leverage PNDC core research programme contacts - Leverage the R&D connections and experience of all partners	3	3	9	Procurement	06/07/2020	
R7	Risk	Open	Failure to agree project contracts between UKPN and project partners	Project cannot proceed	3	5	15	- All partners have agreed in principle to NIC terms - Negotiation of collaboration agreement between all partners to begin after FSP submission - long lead in between project award and work start to allow time for negotiations	1	4	4	Project Manager	06/07/2020	
R8	Risk	Open	A partner/supplier may withdraw from the project	Partner/supplier must be replaced or project descoped	2	5	10	- Ensure all partners/suppliers are engaged and involved throughout the project - Previous engagement with wider industry provides confidence there are a number of potential organisations who can deliver some project aspects	2	4	8	Project Manager	06/07/2020	
R9	Risk	Open	Suitable sites for the demonstration of the solution are not available	Trials cannot proceed	2	5	10	- Undertook early research and identified two potential network areas, of which two are proposed in the bid - Ensure value can be derived from the off-network testing	2	2	4	WS3 Lead	06/07/2020	
R10	Risk	Open	Unavoidable changes are made to key personnel on the project	Possible delays to the project	4	4	16	- Comprehensive project documentation is maintained to reduce the impact of any staff changes that may occur. - Ensure knowledge sharing is undertaken across the project team to avoid single point of failure	3	3	9	Project Manager	06/07/2020	
R11	Risk	Open	The specification and build of the equipment takes longer than expected	Possible delays to the project	3	3	9	- Ensure timescales on the project are realistic and have built-in contingency for high risk elements - Undertake regular reviews during high risk and critical project activities	3	2	6	Project Manager	06/07/2020	

RISK & ISSUE LOG

ID	Risk / Issue	Status	Description	Impact	Risk Probability	Risk Impact	Risk Score	Mitigation / Planned Actions	Mitigated Probability	Mitigated Impact	Mitigated Score	Owner	Last updated	Date Closed
R12	Risk	Open	IPR requirements deter some innovation competition entrants	Limited outcomes from innovation competition element	4	4	16	- Ensure early publication and full explanation of IPR requirements to ensure entrant buy-in to project requirements	2	3	6	Project Manager	06/07/2020	
R13	Risk	Open	Integration of equipment and systems is not achievable or is more difficult/takes longer than expected	Project incurs delays or cannot proceed	4	5	20	- Collaborative requirements gathering and design process is undertaken to ensure integration elements are understood - Prepare key systems to be ready for integration, while detail design is taking place	3	3	9	WS1 Lead	06/07/2020	
R14	Risk	Open	Solution has unintended impact on the network causing failure, underperformance, and/or customer equipment failure	Loss of supply, damage to customers' equipment	2	5	10	- Equipment is fully tested off-network - Sufficient time is included in project plan to resolve any issues fully and re-test - No equipment will be deployed on the network into an active trial before it has successfully passed FAT and SAT	1	5	5	Project Manager	06/07/2020	
R15	Risk	Open	Catastrophic failure of equipment causes network damage and/or injury	Network equipment is damaged, injury is caused	2	5	10	- Solution consists of mainly software components and the hardware ones cannot fail explosively (substation PC, routers & switches) - Failure Mode and Effects Analysis is undertaken to ensure such failures are anticipated and designed out	1	4	4	Project Manager	06/07/2020	
R16	Risk	Open	IT security standards are not met	Network is rendered open to cyber attack	2	5	10	- OT integration testing is included in the PNDC trial scope - Ensure full engagement with IT security team throughout the project - Key UKPN security requirements need to be fulfilled before the system is commissioned to our network - Ensure test plan encompasses all relevant IT security tests	2	4	8	WS1 Lead	06/07/2020	
R17	Risk	Open	Insufficient innovation competition entrants who meet the entry/procurement requirements	Project is delayed and/or requires re-scoping, limited outcomes from innovation competition	3	4	12	- Leverage partner experience in R&D incubation - Identified over 15 use-cases for participants to work on	2	3	6	WS4 Lead	06/07/2020	
R18	Risk	Open	Insufficient availability of quality training data for machine learning to enable solution to be accurate and effective on the network	Accuracy of algorithm decision making is not assured	4	3	12	- Using simulation early, and ramp up level of autonomous operation throughout the duration of the tests as data is built up	3	3	9	WS3 Lead	06/07/2020	
R19	Risk	Open	Length of trial period is not sufficient to collate all representative data	Trial is insufficiently representative of potential scenarios with which the solution may be required to cope	3	3	9	- Significant time allocated for testing on the network - Off-network testing to simulate various network scenarios	1	3	3	WS4 Lead	06/07/2020	
R20	Risk	Open	The selected hardware is not suitable for the time-critical operation of Methods 1 and 2	The project will not deliver all of the intended outcomes	3	4	12	- Equipment was selected based on its ability to perform the required functionality - Sufficient risk budget to ensure equipment scope change can be absorbed	2	3	6	WS2 Lead	06/07/2020	
R21	Risk	Open	5G coverage is not available in the trial areas in time for the trials	Project is delayed and/or requires re-scoping	3	4	12	- Contingency budget to account for the installation of small 5G cells in the trial areas - Vodafone to leverage relationship with infrastructure operator (Telefonica) in the trial areas to ensure coverage is delivered in time for the trials	2	2	4	WS1 Lead	06/07/2020	
R22	Risk	Open	The virtualisation approach is not suitable for real time protection & control applications	Project is delayed and/or requires re-scoping	3	4	12	- Carried out investigation to select a flexible approach which can deliver the capabilities - Included in project risk budget which will be governed with a stage gate at the end of detail design (Jan 2022)	3	3	9	Project Manager	06/07/2020	
R23	Risk	Open	The DER operators in the trial areas do not wish to participate in trials	Trial results are of lower quality and potentially insufficient to inform BaU roll-out	2	4	8	- Engaged with DER operators in the provisional trial areas - Ensured minimal effort and impact on DER operation during trial	1	3	3	Project Manager	06/07/2020	

Appendix 10.7 Knowledge Dissemination Roadmap



Appendix 10.8 Organogram & Partners

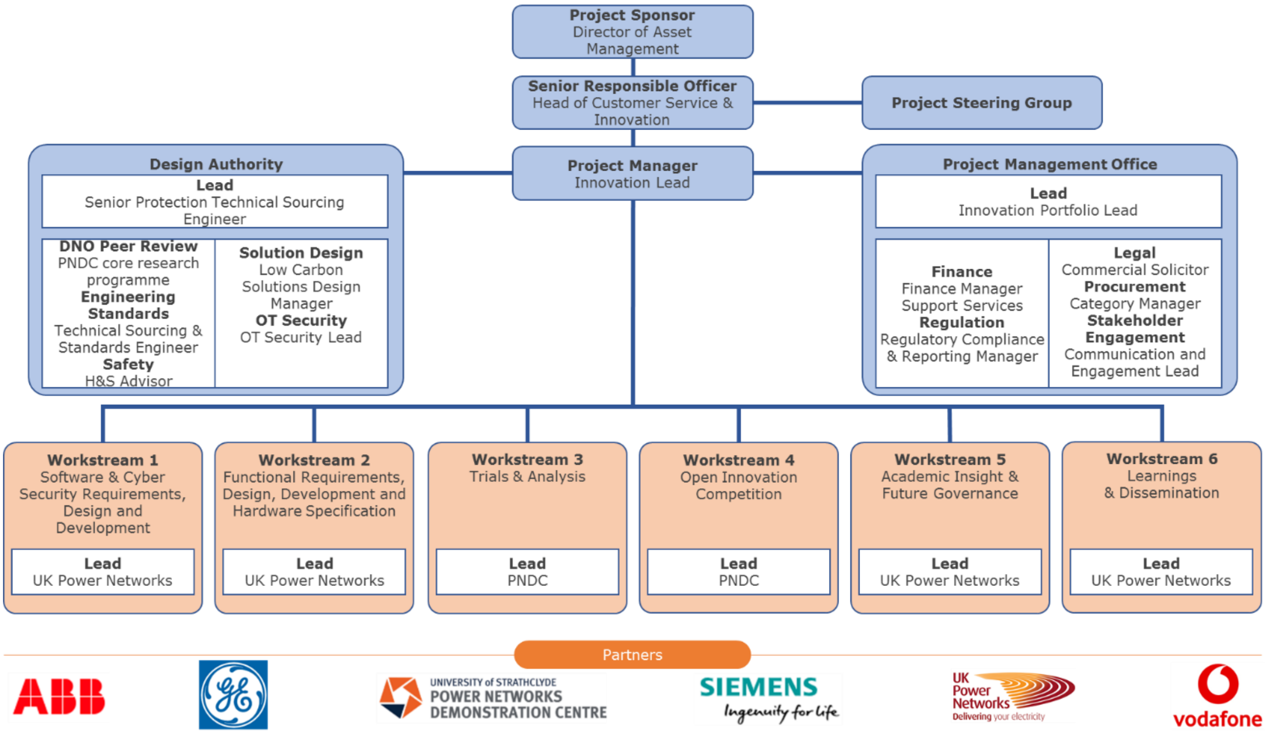


Figure 46 – Project organogram

Leading the Constellation consortium is UK Power Networks. The consortium includes a diverse set of partners, each with the ambition to innovate and improve the current distribution system.

UK Power Networks – South Eastern Power Networks plc is the Funding Licensee for this Project, it will be working with the other UK Power Networks licensees, Eastern Power Networks plc and London Power Networks plc. DNOs must deliver value to network users and must compare the costs and benefits of smart energy management solutions, such as demand response, to traditional grid reinforcement. UK Power Networks will lead the running and governance of the Project, guiding the Project to ensure that it delivers the required benefits to the distribution network. UK Power Networks will also provide DNO services throughout all the workstreams, which will also include consultancy services and feasibility studies for sites and connections, engineering and support knowledge dissemination.

ABB Ltd – ABB is at the forefront of digitalisation technologies and new software-oriented protection and control solutions and believe that they will be important enablers for a zero-emission future. We want to constantly push for the borders of technology, together with our customers. Virtualisation of protection functionality is a next innovation step, and the possibility to research it together with a forward-looking utility customer provoked us to apply for this innovation project.

GE – A wholly owned division of General Electric, GE Digital is one of the largest industrial software companies in the market. With a footprint in 100 countries, GE Digital comprises several software businesses: Grid Software, Power Digital, Oil and Gas digital, and Digital

Plant, which serves the manufacturing sector, water utilities and economy scale digital transformation projects.

“Transforming how industry solves its toughest challenges by Putting Industrial Data to Work.” Their customers are on the front line of the world’s toughest industrial challenges: enabling more renewable energy on the grid; reducing emissions; increasing plant productivity; adapting to demand and keeping their teams safe. Software is mission critical to achieving these goals. GE’s years of hard-won insights in power generation, utilities, oil & gas and manufacturing mean they are uniquely positioned to help their customers better operate, optimise and analyse their work to deliver greater results today – and in the future.
GE is involved in the Constellation project as it is a great fit to their purpose and mission. The project will enable their customers manage the uptake of DER and maximise the generation capacity available by developing and testing software solutions that can managed DER even if central communications are interrupted. GE will support the Constellation project by delivering expertise in project management, consultancy and technical delivery of ADMS software solutions and enhancements.

University of Strathclyde - PNDC – The PNDC is a smart grid innovation acceleration centre, which brings together academics, engineers and technologists to define and execute research, development, and demonstration projects with the aim of shaping and optimising smart electricity networks of the future. The facility contains a unique 11kV and LV distribution network able to represent various network configurations (i.e. urban, rural and hybrid), secure test bays, a MW-scale MG Set, a dedicated SCADA control room and a real-time simulation suite. This affords the pre-commercial development, testing and demonstration of HV and LV equipment and secondary control, protection, communications and measurement systems. As such, the ‘real life’ distribution network at the PNDC provides a unique platform for researching, developing and demonstrating innovative solutions as they apply to electric networks. Working with industry partners, the facility has achieved a significant track record of success in fast tracking innovative solutions for electrical network application. The PNDC has facilitated projects for UK wide application and has leveraged international project developments for UK adoption.

Siemens – Siemens’ technical expertise, comprehensive portfolio and long-standing experience are helping to pioneer a sustainable future across the globe. They embody their ethos of Ingenuity for Life with the creation of benefits for customers and society through the power of innovation and entrepreneurial spirit within the frames of electrification, automation and digitalisation. As a result, supporting the advancement of industry thinking with the application and demonstration of innovative solutions which meet the needs of an increasingly distributed and digitally enabled world, Siemens see the Constellation project as a key demonstrator. The solution and approach highlight how the requirements of tomorrows network will be addressed, offering a pathway for DSOs to increase connectivity and capability throughout their existing estates. With the integration of both regional and headquarters competency, Siemens will support the design and implementation of the concept, working with the consortium of partners, to develop considerations for scale and growth post Constellation. Siemens bring not only exceptional domain knowledge and system integration capability, but also offer the opportunity to build upon existing UK Power Networks platform investments in the form of Siemens EnergyIP. As part of the proposed Constellation solution, Siemens will leverage existing infrastructure to support the advancement of these technologies.

Vodafone – Vodafone is a leader in technology communications through mobile, fixed, broadband and TV. They have extensive experience in connectivity, convergence and the Internet of Things, as well as championing mobile financial services and digital transformation in emerging markets. Since making the first mobile call in the UK on 1 January 1985, Vodafone has grown into an international business and one of the most valuable brands in the world. Vodafone is at the forefront of 5G development and deployment, having already launched networks in the UK, Ireland, Italy, Germany and Spain, with more to follow. Our scale allows us to learn rapidly from different operating environments and vendor mixes, and to support significant R&D resources in multiple regions. Our wide regional presence is recognised by board representation at the GSMA, representing the interests of mobile operators worldwide.

The goals of the project, shared learnings and potential future benefits to the sector and society as a whole are well aligned to our purpose led business strategy, and coupled with one of our primary focus sectors makes this a natural fit.

Appendix 10.9 Technology Readiness Level (TRL) for key Constellation elements

Constellation consists of a number of unique Project elements (described in Section 2.2. Technical description of Project), which poses a challenge in assessing the start and end technology levels. We have therefore, assessed each one individually to determine that the core Methods (1 and 2) are TRL 5 (rounded up). We acknowledge that the enabling elements, in the central management and the hardware, require less development and are higher starting TRL.

Overall, we believe the enabling technology for Constellation is developed suitably well to enable demonstration on our network after the design and development phases of the Project.

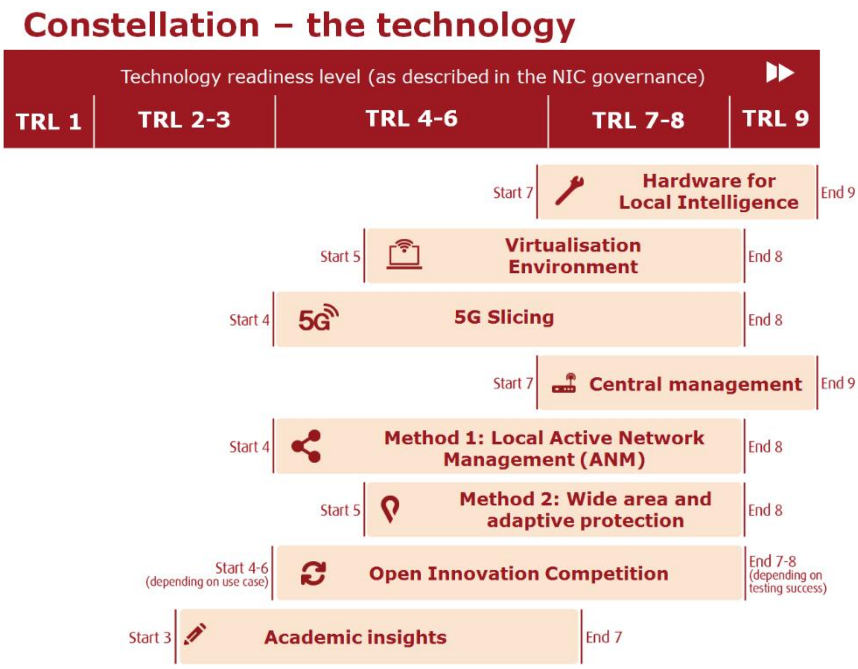


Figure 47 – TRL for key Constellation elements

Appendix 10.10 Changes from Constellation 2019

Constellation was submitted to the Network Innovation Competition in 2019 and was not awarded funding. Ofgem and the expert panel believed that the project was innovative, timely, developed new knowledge and delivered good value for money. The main challenges identified were the breadth of the expertise within the partnership, the clarity of the project scope, and the readiness to deliver the project. As such a number of changes have been made to the bid to address these concerns raised and secure funding this year.

Table 22 – Changes since Constellation bid in 2019

Change Description	Rationale
Improved clarity of scope and use cases. We have described two clear Methods deployed that are underpinned by the constellation platform.	At its core local intelligence within substations is taking over protection, control and monitoring functionality from existing hardware-based systems. A detailed business review identified that this could be broken out as two main Methods that could be developed today and deliver benefits to customers, demonstrating the capabilities of the local intelligence. This has helped to clearly communicate the project scope and objectives. There are many other use cases, as demonstrated by Appendix 10.4.8 Open Innovation Competition (OIC), which we would like to trial solutions for but have kept out of the Project Methods. This will enable us to publicise these use cases as part of the Open Innovation Competition and provide further benefits to our customers through the Constellation system.
Changed the interoperability approach from an "open source" model to a "multi-vendor" model	The 2019 submission intended to develop a single, potentially open source platform and functionality to demonstrate many use cases. Roll out would be easy as the solution is open source, but it would not prove the existence of a market to purchase other solutions. In this submission we are procuring a hardware platform and VM solution from the market with design input from all our partners. We are requiring the partners to deploy their proprietary virtualised software solution onto our platform, with one partner and one supplier for each Method deployed on the platform (we are only proposing one partner to provide the central management system). This will both prove the interoperability of the platform and the existence of a market by having two solutions for each Method.
Strengthened the project partnership	In order to clearly demonstrate that we have the right expertise to deliver the project we have brought strong partners on board. We have several of the global leaders in electricity network protection and control providing the technical development for the Methods. We have a global leader in mobile telecoms ensuring our site-to-site comms will deliver the cutting edge functionality required. Finally we have expanded the scope of University of Strathclyde's partnership to including globally leading academic input as well as the research and testing provided by PNDC.
Add further academic input and focus on governance of the solution to the project scope	Reviewing the feedback from the expert panel we realised that this was a key risk area that needed development within the project. As such we have included further areas of academic input to the project scope with some being procured within the projects to supplement the partnership with University of Strathclyde. One of these areas is to assess how this technology is governed and risk and liability managed

	within a deployment should a safety critical element not function in the way intended.
Expanded testing requirements	Since the 2019 submission SPEN's FITNESS project had completed and our Unified Protection project has delivered significant learning. Both identified the importance of testing and commissioning and the significant effort involved in getting multi-vendor IEC 61850 systems operational for the first time. As such we have significantly increased the specialist equipment, effort and time associated with testing and commissioning, including bringing in a specialist independent testing organisation to supplement our and PNDC's capabilities.
Increased number of network trial sites from 7 to 12	As discussed in 2019 many of the benefits of the Constellation platform and Methods arise from the interaction and data exchange between sites, and deployment across an area. In order to prove these benefits on the live network it requires us to install Constellation at more locations within defined areas rather than proving the concept at a single site. The two chosen areas, verified during the project, will each provide distinct new learning: Maidstone trial will demonstrate the operation of a single generator in a complex protection environment; Lewes trial will demonstrate the coordination between multiple generators. It will also enable us to trial Methods from two suppliers independently as we as in co-operation at the same site. Together this will deliver more learning, reducing the time from successful project completion to BAU roll out.

Appendix 10.11 Letters of Support – letters from project supporters

UNIVERSITY of STRATHCLYDE
POWER NETWORKS
DEMONSTRATION CENTRE

Mr Ian Cooper
Innovation Lead
UK Power Networks

Ref: **PNDC Technical Board support for Constellation NIC project**

10th July 2020

Dear Ian,

We are writing to you today on behalf of the Power Networks Demonstration Centre (PNDC) and the industry members of its Technical Board: SP Energy Networks; Scottish & Southern Energy Networks; UK Power Networks; Vodafone; and Fundamentals. This letter confirms our support and our commitment to collaborate with UKPN in the Constellation NIC project.

As you know, PNDC was formed as a partnership between government, industry and academia with the purpose of accelerating the maturation and adoption of innovative research and technology into business as usual deployment by the electricity industry. Collaborating on and supporting Constellation NIC project strongly aligns with this goal.

The PNDC and wider University of Strathclyde team has grown an extensive track record of innovative protection and control research and development (R&D), such that PNDC now has "Digital Substation" as one of its Board-approved Focus Areas. The associated project portfolio includes: Design and Demonstration of Distribution Digital Substation Architectures utilising Real-time Measurements; vRTU Requirements for Achieving Distributed Automation and Remote Configuration; and Evaluation of Digital Substation Architectures and Life Cycle Reliability. The PNDC Technical Board plans to invest between £400k and £600k in the Digital Substation work programme over the next four years to support aligned research and development activities.

This body of prior work provides a strong foundation for the Constellation project to now bridge the gap between innovation and roll out to business as usual. We also believe Constellation will be foundational in the journey towards autonomous distribution networks, which our analysis estimates will be ready for roll out from around 2030.

The signatories to this letter commit to supporting Constellation in two ways.

1. Project design authority – commitment to providing approximately three days per year input as network operators and technology innovators into the designs, standards and practices developed within Constellation. This will ensure interoperability of the solutions and suitability for deployment to multiple DNO networks.
2. Maximising the interaction and alignment with the PNDC's Digital Substation Focus Area– commitment to ensuring continuous interaction and knowledge exchange between the PNDC Digital Substation Focus Area project portfolio and Constellation. This includes, where possible, providing state of the art insight and additional new innovative functions arising from the Digital Substation programme which can be demonstrated on the Constellation platform.

The PNDC and its Technical Board members are looking forward to working with UK Power Networks on this exciting project and participating in the delivery of its highly innovative programme.

Yours sincerely,

Dr Federico Coffele

Federico Coffele

PNDC R&D Director

UNIVERSITY of STRATHCLYDE
POWER NETWORKS
DEMONSTRATION CENTRE

SP ENERGY NETWORKS

Nicol Gray

Senior Project Manager

Date: 14th July 2020

Scottish & Southern Electricity Networks

Frank Clifton

Innovation Strategy Manager

Date: 14/07/2020

UK Power Networks
Delivering your electricity

Zain Habib

Innovation Programme Delivery Manager

Date: 13/07/2020

vodafone

Liam Beard

Energy & Utilities Development Manager

Liam Beard

Date: 13/07/2020

FUNDAMENTALS

Vincent Thornley

Business Development Director

Date: 10th July 2020