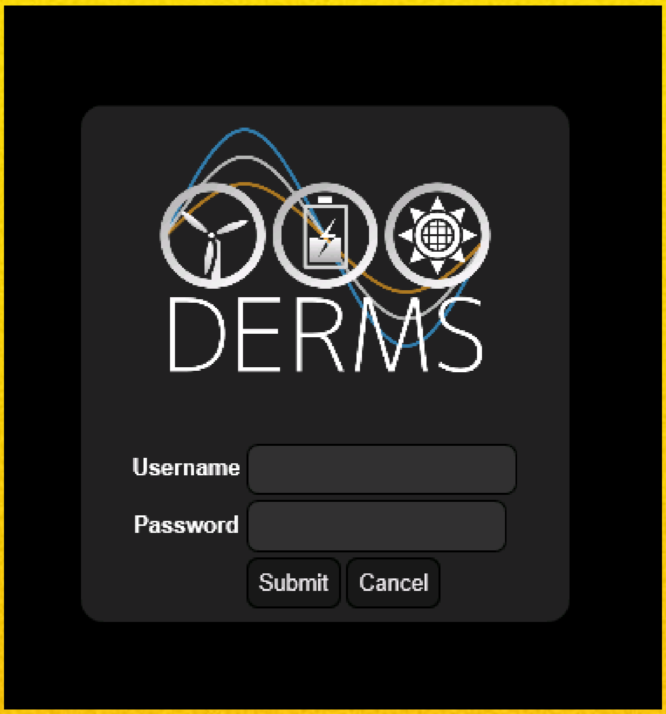
Customer Readiness Report and Performance of the Technical Solution in a Controlled Environment

SDRC 9.4

Power Potential (Transmission & Distribution Interface 2.0)

November 2019



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Executive Summary

Power Potential is a demonstration of using an automated solution to enable distributed energy resources (DER) connected to the UK Power Networks Southern Eastern network to provide reactive power services to National Grid ESO. To deliver this, the project is implementing a Distributed Energy Resources Management System (DERMS).

This report provides an update up to 19 November 2019 on the work conducted to prepare customers to take part in the Power Potential trial, the performance of the technical solution in a controlled environment and expected performance in the live environment. The report explains the state of readiness for the first stage of the trial (Mandatory Trials) and the development and testing of the technical solution for the later stages of the trial.

2000 customer interactions so far, to bring customers to trial

5 DER controllers passed laboratory integration test

20 components in the end-end system

Over 30 business processes developed for trial

From a technical perspective, the project completed acceptance testing of the DERMS software on a cloud environment, with simulated network and customer behaviour.

The DERMS software was then installed on a pre-production system of similar specification to the live production environment. Integration, functional, user-acceptance and non-functional testing on the pre-production system has been undertaken to support DER commissioning and the initial mandatory trials stage for each DER. Final checks before transfer to live were being completed as at 19 November. The live production system has been set up and connectivity tested, with penetration testing begun, and the DERMS system is expected to go-live in December subject to a final DERMS software release passing the final tests required to satisfy the go-live criteria.

On pre-production, functionality and integration testing has covered:

- a web-services link to National Grid's Platform for Ancillary Services (PAS),
- ICCP links from DERMS to the PowerOn network management system,
- a DERMS web interface for DER and UK Power Networks,
- new PowerOn screens for UK Power Networks' Control Engineers,
- DNP3 communication from DERMS and PowerOn to a test RTU and DER controller.

Significant challenges have been overcome in all these areas. A unit testing approach to functionality and integration has been taken, building up to demonstrate end-end integration and functionality scenarios.

From a customer's legal/commercial perspective, the contractual framework of a trial contract and variation to the UK Power Networks connection agreement have been developed and signed by customers. New processes and systems have been developed to pay DER customers for the service, and the customers have registered for this. Further information has been developed on the commercial procedures for reactive power procurement. The customer approach and learning is underpinned by continual engagement with participating DER and a Regional Market Advisory Panel.

From a technical perspective, the customer must meet defined technical requirements and integrate according to an interface schedule. Customer DER controllers have been integration tested in laboratory conditions with an upgraded UK Power Networks' Remote Terminal Unit (RTU) to ensure there will be end-end functionality with PowerOn and DERMS in the live environment.

Five customers have signed up for the trial and have been supported to pass through these stages of legal, commercial and technical preparation (laboratory and site). One customer has proceeded through a site pre-commissioning stage, proving integration in the field between an upgraded RTU and a DER controller. Site commissioning with DERMS is planned for all five customers once DERMS is live, their RTUs have been upgraded, and the customers have finished their site works.

There is a staged approach to trials: DER commissioning (currently scheduled for January), Mandatory Trials (currently scheduled for January), Optional Trials (currently scheduled for

February- April 2020) and then full technical and commercial trials with the DERMS Full Solution. To support the next Optional Trials stage, which will demonstrate up to 24/7 reactive power service delivery for eleven weeks, most of the system testing has already been completed on pre-production and is being deployed to production. The optional trials phase will use the link to PAS, more of the DER web interface and additional resilience features such as system backups and automatic failover between sites.

Key elements of the DERMS Full Solution have also been developed and are about to enter the formal test phase – commercial functionality, export of a CIM-compliant network model from PowerOn to be processed by DERMS, outage planning inputs, analogue data correction techniques, network security analysis, contingency analysis, and forecasting of load and generation from weather forecast inputs.

To support the preparation for trials and the trials themselves, new business processes have been developed by both National Grid ESO and UK Power Networks. The transfer to trials is subject to meeting defined “GO” criteria agreed with the project’s steering committee.

Power Potential takes a learning-by-doing approach to deliver a technical, commercial and business demonstration of a DSO enabling DER contribution to transmission services. The customer readiness and system delivery for such a complex project have been hugely challenging and forced the project to delay its trial start while these aspects were being resolved. We now look forward to our 2020 trials, final SDRCs and informing BAU service delivery.

Definitions

AWS	Amazon Web Services
BAU	Business as Usual (after the innovation-funded trials)
CIM	Common Information Model (IEC standard)
DER	Distributed Energy Resources
DERMS	Distributed Energy Resources Management System
DSO	Distribution System Operator
ICCP	Inter Control Centre Protocol (IEC standard)
FAT	Factory Acceptance Testing
IEC	International Electrotechnical Commission
GSP	Grid Supply Point
MW	Megawatts (unit of active power)
Mvar	Mega-var-amperes (unit of reactive power)
NFT	Non Functional Testing
NGESO	National Grid Electricity System Operator
OAT	Operational Acceptance Testing
P	Active Power
PAS	Platform for Ancillary Services
PQ	Active Power v Reactive Power, capability envelope or permitted range for a DER
PQM	Power Quality Meter
Q	Reactive Power
RTU	Remote Terminal Unit
SCADA	Supervisory Control and Data Acquisition
SDRC	Successful Delivery Reward Criteria
SGT	Super Grid Transformer, at a GSP
SIT	System Integration Testing
UAT	User Acceptance Testing
UKPN	UK Power Networks
V	Voltage
VPP	Virtual Power Plant

1. Introduction

SDRC 9.4 requirements and evidence

The purpose of this document is to provide evidence that the Power Potential project has delivered on the criteria required to successfully achieve the fourth reporting milestone for the project, known as SDRC 9.4. Consistent with the original bid and project direction for the Power Potential (TDI 2.0) project, this Successful Delivery Reward Criteria report covers the scope listed in Table 1 .

Table 1: Evidence related to the SDRC criteria

9.4 Customer Readiness Report and Performance of the Technical Solution in Controlled Environment	
Stage Gate 3 – Update on the effort required to ready customers to take part in the trial (technical, business processes, etc.) and the performance of the technical solution in a controlled environment and expected performances in the live environment.	☐ Test Report – End to End testing ☐ Business Change Implementation Report ☐ Customer Readiness Assessment ☐ Technical Solution – GO / NO-GO Criteria Results ☐ Customer and Business – GO / NO-GO Criteria Results

Table 2 below illustrates where each evidence item for Successful Delivery Reward Criterion 9.4 has been addressed in the report.

Table 2: Evidence related to the SDRC criteria

Evidence item	Relevant section of the report
Test report- End to End testing	*Chapter 2: System Technical Readiness including Test Report (end-end)* Evidence items: • Description of the components and system delivered for test • Report on the completed and in-progress FAT/SIT//UAT and NFT testing achieved for the DERMS Interim Solution on the Azure and pre-production environment • Readiness of the live production environment. for OAT
Business change implementation report	*Chapter 4: Business readiness at UK Power Networks and National Grid ESO*
Customer readiness assessment	*Chapter 3: Customer readiness* Evidence items • Five customers signed DER framework agreement and variation to their connection agreement • Lab testing complete on five DER controllers • RTU-DER integration at one customer site • DER site readiness outlined in this Chapter • Scheduled DER commissioning outlined in this Chapter • DER engagement – meetings and webinars including Regional Market Advisory Panel
Technical solution- GO/ NO-GO criteria results	***Chapter 5: Go No-Go criteria***

Trials Overview

Introduction

The Power Potential project aims to trial the provision of reactive and active power services in the south east of England. This is intended to explore the use of Distributed Energy Resources (DER) to provide dynamic voltage support and constraint management services to the Electricity System Operator (ESO).

The trial is exploring the provision of reactive and active power services while investigating both the technical and commercial aspects of DER participation. It is designed to mimic the real-world situation in which a change in reactive and/or active power flows are required on the distribution network in order to manage voltage or thermal constraints on the transmission network.

The trials are further intended to ensure that trial participants receive adequate compensation for their involvement, whilst also encouraging market bidding that mimics real-world behaviour.

DER have the option to participate in either or both the reactive and active power service trials. As part of the initial trial stage, there is an optional trial to analyse the response from DER without the commercial element of the project. The optional trial will use the Distributed Energy Resources Management System (DERMS) that is linked to NGESO systems. However, before taking part in the optional trials, all participants must complete a Mandatory Technical Trial, which is designed to assess and ensure their technical capability.

The DERMS Web Interface provides DER with a web portal to communicate its interest in participating. This system, hosted and operated by UK Power Networks, also acts as the intermediary between National Grid ESO (NGESO) and participating DER. The trials will provide evidence on the performance of DERMS and the link between PAS (Platform of Ancillary Services) that is used by NGESO.

Reactive Power Service Trials

The reactive power service trials will test the reactive power generated or absorbed by the participating DER plant. It is expected that this production/absorption of reactive power will allow more effective control of the voltage in the transmission system.

The reactive service is initiated by DERMS issuing instructions for DER to enter reactive (Q) mode at the start of each service window, for which the DER was contracted.

When in Q mode, DER will automatically respond to voltage changes measured at the DER connection point. In addition to this, a NGESO instruction (based on the requirement for response at 400kV) will be sent to the DERMS. This instruction would be translated by DERMS into a change of DER voltage set-point to achieve NGESO's request.

In order to test both the technical and commercial performance, the reactive service component of the trial will be split into three waves:

- Wave 1 is predominantly aiming to trial the technical aspects of the Power Potential services and through the trial, allow participants to recover most of their upgrade costs. The wave 1 trial covers a range of network configurations and operating conditions, both planned and unplanned.
- Wave 2 introduces competitive bidding between DER, with the volumes accepted by NGESO in line with actual system need. The volumes procured during this wave will not be used to secure the system, but will be evaluated against a counterfactual approach of investment in reactive equipment.
- Wave 3 will expose DER to competition with other market-based options available to NGESO to secure the system. DER will be competing with transmission-connected assets where multiple parties at multiple connection levels can fulfil a requirement. Therefore, only DER that are as cost-effective as other options will be accepted. As such, planning of wave 3 will consider periods of low demand (e.g. over public holiday periods) when the reactive power requirement is higher.

Active Power Service Trials

The active power service trials will dovetail with the reactive power service trials during waves 2 and 3 to explore the active power generated from the participating DER's unit. After receiving an instruction, the DER will need to be capable of responding by automatically ramping the active power generated in either direction according to the DERMS instruction and within the plant limitations. This service is expected to manage transmission constraints and to support technical and commercial optimisation and dispatch. It will be exercised on the day in real-time depending on the cost compared to other options available to National Grid ESO.

Trials Plan

Each wave is coordinated and timed to facilitate maximum learning potential from each DER and also to allow sufficient availability for DER to recover utilisation costs.

Wave 1 trials are scheduled for a duration of 11 weeks to gather sufficient experience of the reactive support provided by DER for planned outages and also maximise the potential for learning from unplanned outages during the trial. This allows 1,848 hours of availability for DER to recover initial outlay costs

Wave 2 is scheduled for a duration of 13 weeks (2,184 hours), which respects the project commitment to run the market for a minimum of 1,800 hours and is intended to explore the commercial competitiveness between participating DER.

Wave 3 trials are key to preparing DER for "business as usual" (BAU) operation and are initially scheduled for a duration of two weeks (subject to the performance of the previous waves).

System Architecture Overview

DERMS Interim Solution – system live from November 2019

Used for Wave 1 Technical Trials: 'Mandatory' trials and 'Optional' reactive power service trial

Used for full commissioning of DER

Demonstrates PAS-DERMS-PowerOn-RTU-DER integration to deliver services

UK Power Networks restricts output of specific DER in network outage conditions

Demonstrates both self-dispatch and enhanced control

No commercial functionality

DERMS Full Solution – system live from late spring 2020

Used for Wave 2 and Wave 3 trials

Includes full commercial functionality – regional reactive power market for reactive and active power services

Day-ahead and real-time network load flows to determine secure network capability

Day-ahead forecasting of active power flows and active/ reactive service availability

The Power Potential solution enables DER located on the distribution network to provide reactive and active power services to National Grid ESO for their use to operate and secure the transmission system. DERMS will provide the capability to handle the following services:

- Dynamic Voltage Service
  - for Low Voltage Management
  - for High Voltage Management
- Active Power Service
  - MW Re–Dispatch (Active Power) Service (for Thermal Constraints)

A simplified architecture for the Power Potential Solution is shown below in Figure 1, showing the combination of National Grid ESO, UK Power Networks and DER components interfacing with core DERMS application. The key components are:

- **DERMS** – Main core of the solution developed by ZIV Automation, implemented as a redundant server-based software product located within the UK Power Networks ICT network
- Platform Ancillary Services (**PAS**) – Developed by National Grid (NGESO)
- UK Power Networks' Distribution Management System (**DMS**) PowerOn – Existing system required the following changes:
  - Network Model export capabilities – **CIM Export** functionality developed by GE as part of a delivered upgrade to PowerOn Advantage (needed for Full Solution only)
  - SCADA data interface with DERMS – **ICCP Link** new data points to be mapped
  - DNP3/Field Protocols – Data points configuration to align with **DER RTU changes**
- RTU and DER DNP3.Field Protocols – **RTU logic change** to accommodate PP real time signals to and from DER
- **DERMS DER web interface** – Part of DERMS, developed by ZIV
- **Weather data** – interface via UK Power Networks' Enterprise Service Bus (needed for Full Solution only)

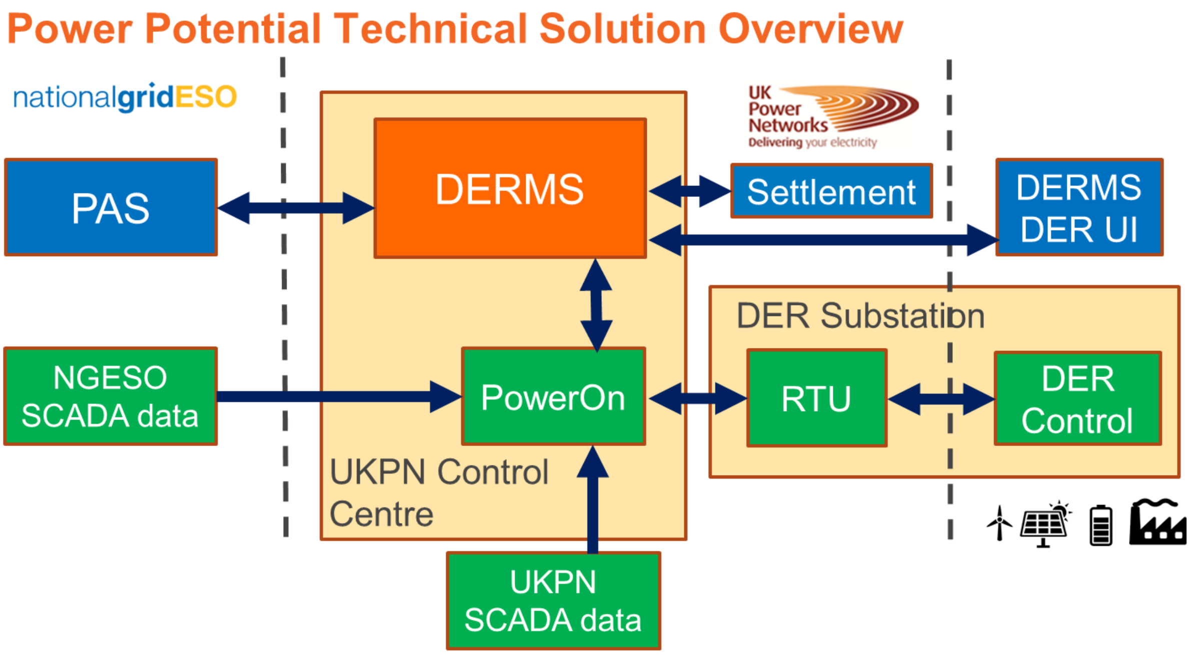


Figure 1: Simplified Power Potential system architecture

1.1 Overview of the DERMS Interim solution

The DERMS Interim Solution is an intermediate configuration of the DERMS Full Solution system, and is implemented earlier than the DERMS Full Solution. The DERMS Full Solution delivers the full scope of the project as per the original bid.

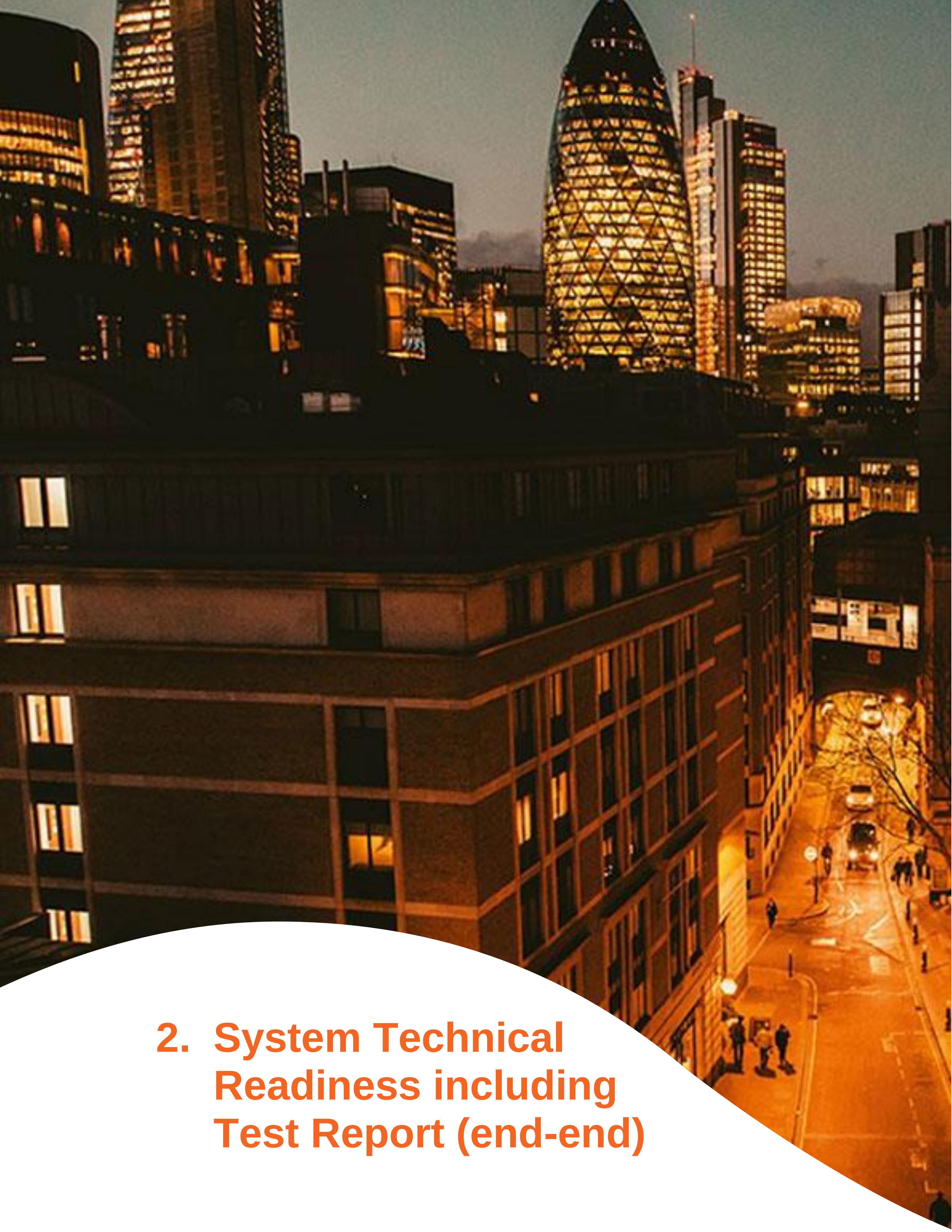
The simplified architecture diagram in Figure 1 represents the infrastructure for both DERMS Interim Solution and DERMS Full Solution.

The Interim DERMS solution demonstrates the same infrastructure, interfaces and despatch as in the Full DERMS solution, but without the network modelling in the DERMS or the wave 2 commercial functions. Thus in most but not all respects the detailed infrastructure design of the Full DERMS solution applies to the Interim solution. The minor exceptions are detailed in the next section.

The configuration of the DERMS Interim Solution was chosen to mitigate delays within the project schedule by reducing the scope of the first go-live deployment. It did this by eliminating the dependency on external factors, such as the availability of a network model consistent with Common Information Model (CIM) standard which provides an updated network model data to support a valid load-flow calculation. DERMS Interim Solution runs with a static simplified CIM-compliant network model, and does only requires UK Power Networks SCADA data from the DER sites rather than the whole network area.

The DERMS Interim Solution is used to support DER commissioning, Mandatory Trials and Optional Trials. It delivers Mandatory Trials for the active and reactive power service, and Optional Trials for the reactive power service. The project has completed

- all of the infrastructure build and integration testing on pre-production for DERMS Interim Solution
- functional testing required for DER commissioning and for Mandatory Trials, and
- a dress-rehearsal of connectivity checks for the ‘cut-over’ to the live system.



2. System Technical Readiness including Test Report (end-end)

System overview

This section provides an overview of the whole control system which will be used to offer active/ reactive power services to NGESO as part of the Power Potential project, including both DERMS and all associated systems and infrastructure. It covers an overview of the key components, test infrastructure, testing completed so far and technical readiness assessment. All components have been tested individually and in integration testing, up to end-end testing.

The key components of the Power Potential solution that have been or will be tested are shown in Figure 2 and are as follows:

1. PAS (Platform for Ancillary Services)
2. IIB (the interface between for example PAS and DERMS)
3. DERMS
    a. Service Mode Functionality
    b. Network Security Analysis inputs including Outage Planning inputs
    c. Mandatory Trial Interface
    d. Future Availability Functionality
4. PowerOn screens,RTU Logic and DER controller integration
5. NGESO to UK Power Networks ICCP link
6. DERMS Full Solution
    a. PowerOn CIM
    b. Forecaster
    c. Commercial Functionality

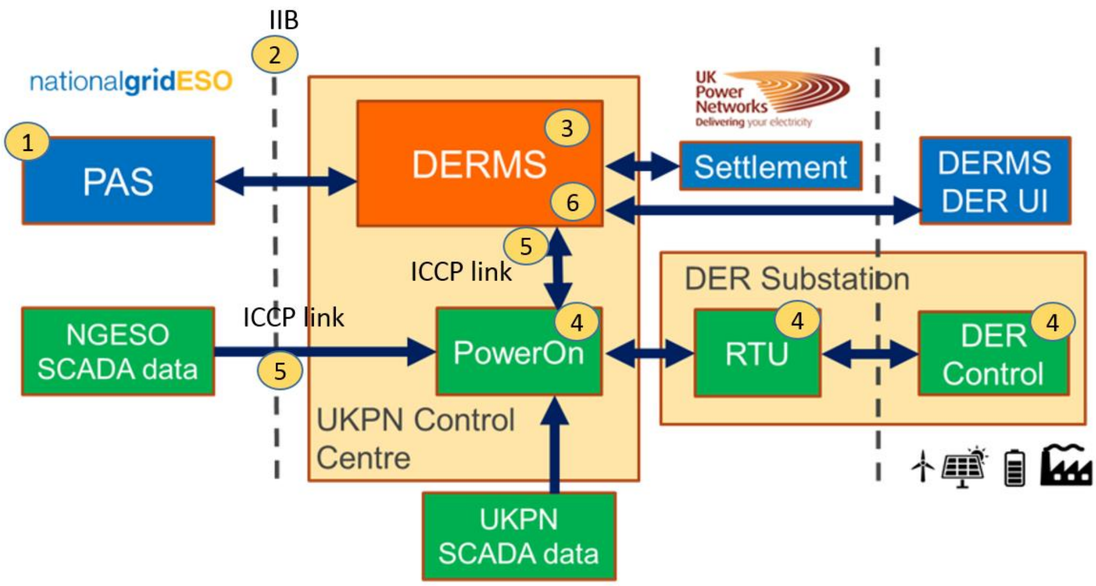


Figure 2: Overview of DERMS components

This chapter describes the system and components delivered for functional testing (both at component level and end-end), non-functional testing, and a test report on the initial system being delivered for DER commissioning and mandatory trials (including end-end scenarios). The final section is a look-ahead to the DERMS Full Solution.

The DERMS Web Interface for DER customers and the RTU-DER integration are described later in the Customer Readiness section of this document.

SDRC 9.2 in 2017 covered the system design – this report provides greater detail of what has been and will be implemented for test before the project moves into trial.

Power Potential uses three distinct environments – two for test and one live:

- Microsoft Azure Cloud – test bed, use mainly for FAT, DERMS controller latency evaluation, and any adhoc testing and

- Pre-Production – replica of Production but not connected to live electrical network. This environment will be used primarily for SIT, NFT and UAT to provide the test results and performance expected in the live environment.
- Production – this will be the live environment and is ready to be used for Operational Acceptance Testing and DER Commissioning tests prior to trials.

UK Power Networks hosts all the required environments on its premises, in associated data centres and/or Azure cloud. The structure of pre-production and production is shown in Figure 3, with the underlying Azure infrastructure supporting the on-premises pre-prod and prod implementation is shown in Figure 4.

The Azure system has a level of access security appropriate for test by the project team, increasing to full security on Production (live environment with externally-accessible interfaces, connected to the live network management system).

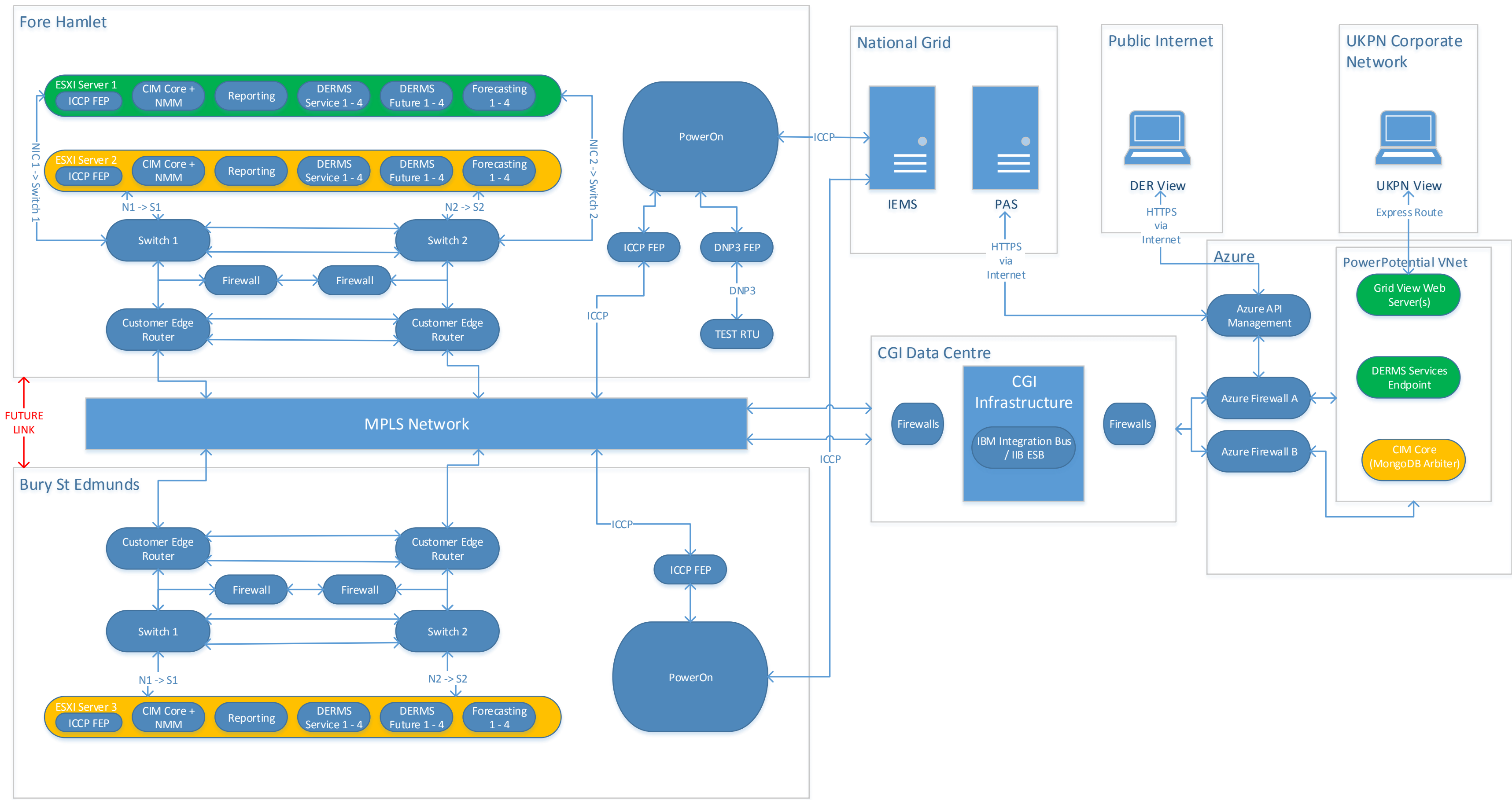


Figure 3: Power Potential Prod and Pre/Prod Environments – IS structure diagram

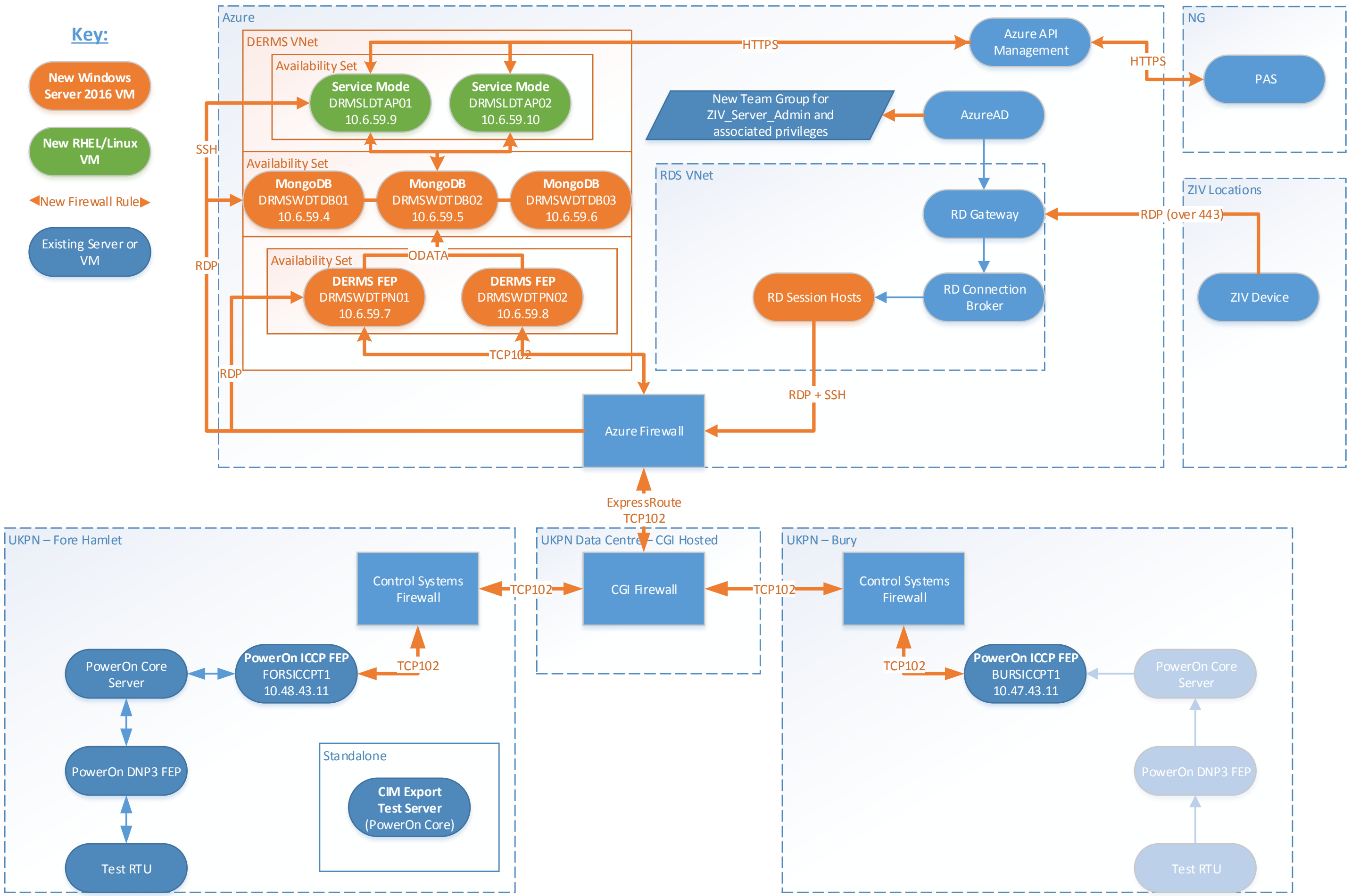


Figure 4: Azure hosting to support the pre-prod and prod environments

Testing stages and approach

Testing Overview – Strategy and Scope

The overall test approach was defined in a test strategy and subsequent test plans for SAT/SIT/UAT, NFT, OAT and cutover to live plans Power Potential testing has followed a risk-based test approach which entails both static and dynamic testing:

Static testing means evaluating a source document such as requirements or acceptance criteria without execution of a particular test script (such as in a demonstration), whereas dynamic testing involves evaluating an application or service based on its behaviour during execution of a particular test script. Static testing occurs during reviews and walkthroughs of source (approved) documents such as Power Potential requirements, test scripts execution results or other acceptance criteria.

Within dynamic testing, various factors such as operational capability, accuracy, business risk, and performance criticality will be analysed to make a decision on which of the test phases will be performed and how much testing will be done (coverage).

Figure 5 overleaf represents the Power Potential solution and all its components and interfaces, providing more detail of the sub-components of DERMS than previously in Figure 1.

Except for DERMS, all the integrating components existed within the respective organisations prior to the project; however, each component required software and/or hardware change and a new interface defined with DERMS.

The testing strategy defines the testing processes, procedures and phases for each component before it is ready for integration for Power Potential. It also, identifies roles and responsibilities of each actor/organisation and the environments on which each test phase will be conducted.

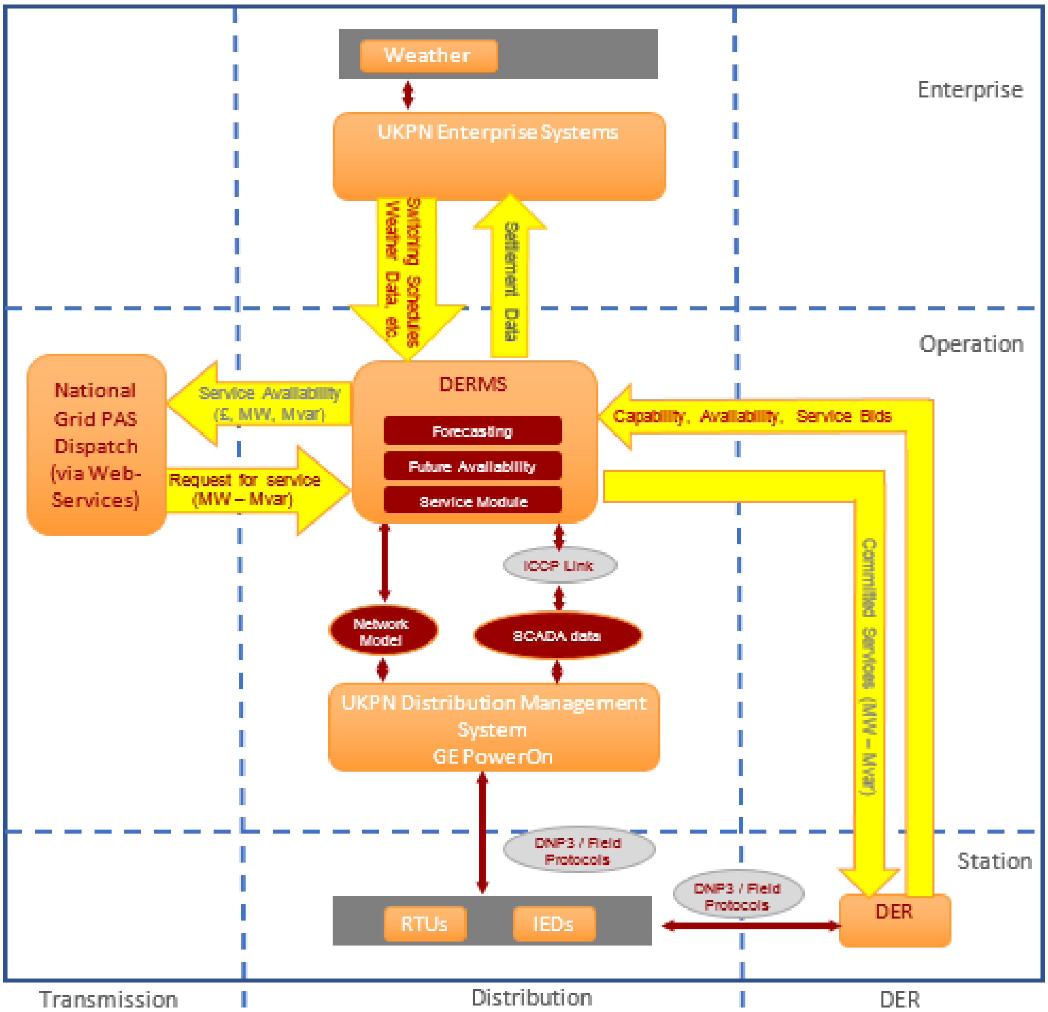


Figure 5: Solution data flow diagram

Testing Definitions

In general, the following process is applied. Any deviations from this process are documented and justified within this document.

There are a number of test phases coordinated and managed by the nominated test lead and executed by relevant testing team(s). The test teams comprised of resources from multiple organisations or external third party organisations. During the testing phases all defects identified are registered in a JIRA defect management system, available to all relevant parties. The defect log was maintained across all testing phases to ensure defects do not reappear during later software releases and for audit capability.

Test phases used for Power Potential are:

- **Static Testing**
    - Validate Requirements definition and agree
    - Define test scenarios and test cases for each requirement
    - Agree the logical flow of dynamic testing
    - Agree datasets to be used
    - Agree exit entry criteria for each test

- **Dynamic Testing**
    - Pre-release System Testing – ZIV Automation's testing on its AWS environment, prior to releasing the software to the project
    - Factory Acceptance Testing (FAT) – Supplier's own testing of software, but installed on the UK Power Networks Azure cloud environment with simulation of network load and DER response
    - System Integration Testing (SIT) – Validating the Power Potential End to End functionality (Functional and Commercial) with full integration of all supporting systems
    - User Acceptance testing (UAT) – Verification of Power Potential solution against existing output from systems. Note: SIT and UAT are run as a combined phase
    - Non Functional testing (NFT) – To validate server/application related functions like backup & restore, data storage, user access, penetration/security, performance, resilience, and scheduled housekeeping tasks
    - Operational Acceptance Testing (OAT) – Validation of processes to support Power Potential in live production including all interfaces with other systems. Where live connection/running is not possible e.g. iEMS, the pre-prod environment or live snapshot simulations are considered/adopted.
    - Regression Testing throughout – To ensure that no errors or problems have been introduced and existing unchanged areas of the application/service still function as they did prior to the changes. This test is not a specific phase and will be conducted on Supplier's recommendation or at any time during the project lifecycle. Typically run after a major release.

Details of environments

Testing will be carried out in the following test environments in NGESO and UK Power Networks

Table 3: Test phases and environments

Test Phase	National Grid	UK Power Networks
Informal Testing	UAT	Azure/Test lab – Nelson Street
Site Acceptance Testing	UAT	Pre-prod
System Integration Testing	UAT	Pre-prod
User Acceptance Testing	UAT	Pre-prod
NFT/OAT	UAT	To- Be-Prod

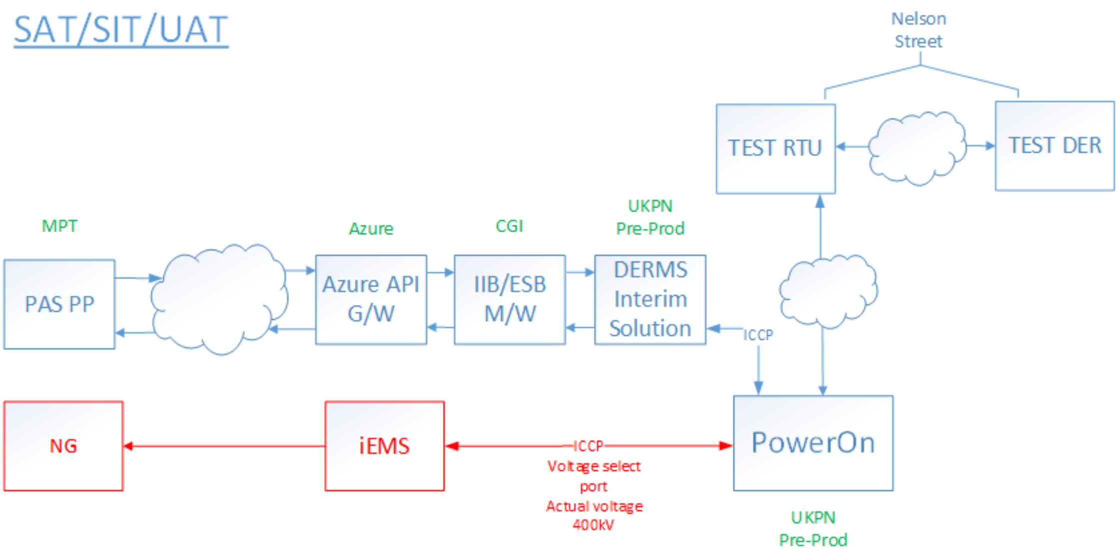


Figure 6: Testing environments

PAS (Platform for Ancillary Services)

PAS – Platform for Ancillary Services

The NGESO main interface with DERMS is the Platform for Ancillary Services (or PAS). PAS is a new NGESO control and monitoring solution to support and enhance existing and future reserve and frequency services. It sits in NGESO control room and has been designed for a range of ancillary services and not only for the Power Potential ones. PAS will receive from DERMS volume availability and cost for each Power Potential service at the GSP level. It will also allow NGESO control room engineers to provide instructions for the different services, in real-time.

There is no change between DERMS Interim Solution and Full Solution for the PAS design, architecture and message exchange. The PAS solution has been developed and tested ready for Optional Trials.

PAS processes for the Reactive Power Service

This section covers the PAS main processes for the Power Potential reactive power service, before describing the development and testing activities for this interface.

We can distinguish two main time scales in PAS: day-ahead and delivery/current day. Activities related to day-ahead correspond to all the commercial processes and those related to the delivery/current day correspond to the dispatch and use of the service in real-time. It is important to note that Power Potential follows a day-ahead market procurement to accommodate variability of DER generation. Associated to these time scales, DERMS has two different functional modules (future availability mode and service mode) whose details are covered elsewhere in this report.

The PAS day-ahead, commercial processes will become available for the DERMS Full Solution. For the DERMS Interim Solution, PAS has the same logic embedded, but it will follow an automatic nomination process (i.e. acceptance of all available volumes) as there is no commercial procurement during the trial validation of the Interim Solution.

From day-ahead to in-day commercial processes

The main steps of the Power Potential commercial process for the reactive power service are:

- Gate Closure: 14:00.
- Post-gate and pre-nomination: 14:00 – 17:00.
- Nomination: 17:00.

Day-ahead, DER submit availability and prices through a web platform/user interface to offer services for the different commercial windows. Gate closes at 14:00, DERMS gathers this information and presents the aggregated data to PAS in the form of cost curves (i.e. bands). Between 14:00 and 17:00, NGESO makes a procurement decision, identifying an economic solution and in line with transmission system requirements. The procurement decision is communicated to DER by 17:00 and the service delivery starts at 23:00.

This day-ahead commercial process only applies to the Full Solution. The Interim Solution follows an automatic nomination of available volumes after gate closure (14:00).

For in-day real-time and dispatch processes, the service delivery starts at 23:00 and, for the declared availability intervals, DER are armed to provide the service. PAS acts as a control room tool from which to visualise and instruct the service at the GSP. PAS will show availability of the service at each GSP (lead/lag) in real-time as well as total instructed volumes.

PAS development and testing for Reactive Power service

Details of the development and testing activities of the PAS system for the reactive power service, according to the process specified above, are described in this section.

Day-ahead: availability & nomination process

DERMS sends day-ahead availability together for all four GSPs in scope after gate closes at 14:00. This is done in the form of cost curves (bands) in 48 windows of 30 minutes for the Interim Solution (Wave 1 trials) and in six windows of four hours for the Full Solution (Wave 2 and 3 trials). The structure of these cost curves is the same for the Interim Solution and Full Solution. The information is presented in 10 bands containing different service parameters such as volumes (lead/lag), prices (availability and utilisation), and maximums.

A screenshot of the PAS nomination interface can be seen in Figure 7. Three different tabs enable this process and have been tested against the project specifications:

- **Nominate tab:** on this screen, a Trader/Ancillary Services Analyst can nominate volumes during the Full Solution trials. During the Interim Solution trials, an auto-nomination process is trigged by the PAS system. This nominates the highest band from the available Q from the received cost curve. This interface also allows to download the cost curves from the download button.
- **Current tab:** this screen will keep the nominated values until the next day gate closes.
- **History tab:** this screen will hold last seven days of data.

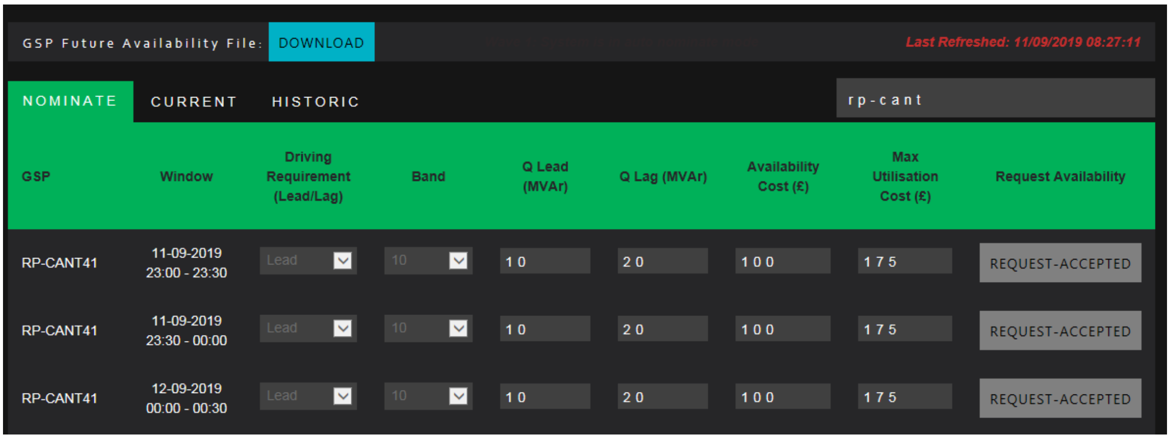


Figure 7: PAS nomination and availability screen

In-day/current day availability

The nominated values will be available for dispatch the next day. These can be visualised on a dispatch screen, as seen in Figure 8.

Reactive power Q volumes (lead and lag) will be displayed on the graphs upon mouse hover. Any change in Q volume (i.e. re-declaration) from DERMS will get reflected on the graphs instantly.

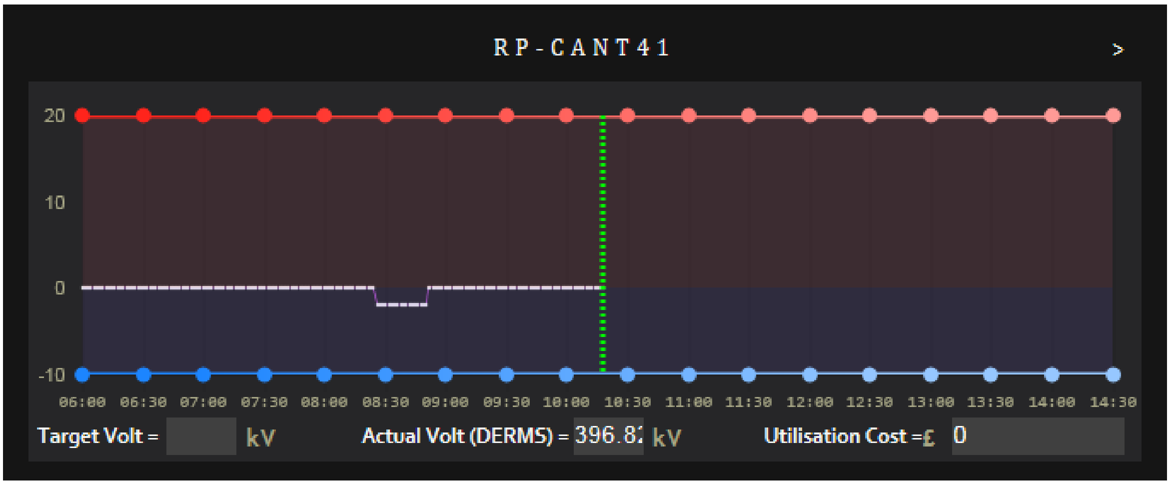


Figure 8: PAS current day availability screen

Dispatch

The actual PAS dispatch instruction for the reactive power service is shown in Figure 9. The NGESO control room user can dispatch or request a volume of Mvar from the below screen by issuing a GSP voltage set-point instruction.

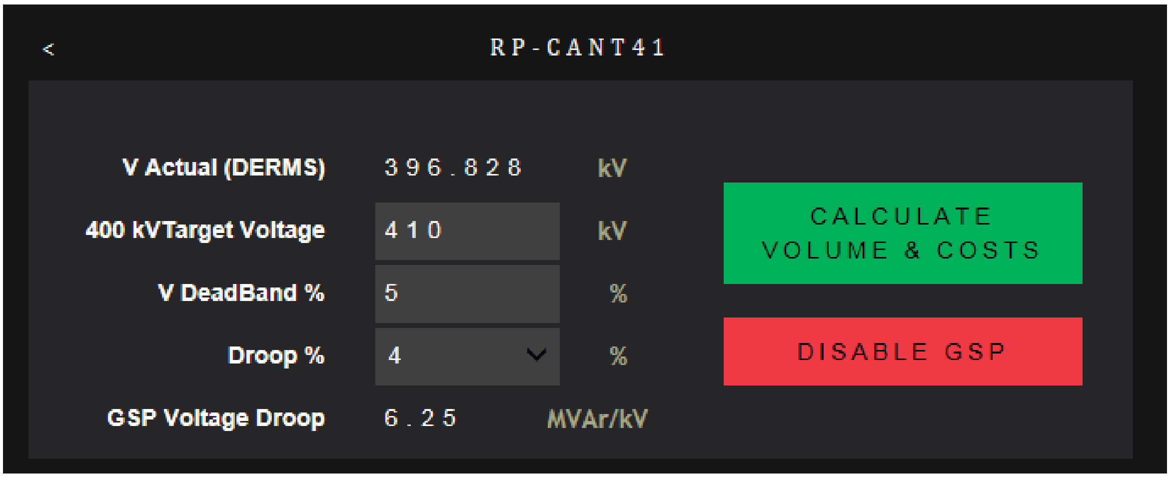


Figure 9: PAS dispatch screen

The parameters that affect the instruction are:

- **400kVTarget Voltage:** Target voltage at the GSP.
- **VActual (DERMS):** Actual GSP voltage as recorded by DERMS.
- **Deadband %:** band to keep the voltage within certain predetermined limits.
- **Droop %:** voltage droop is the intentional loss in output voltage. The **GSP Voltage Droop displays the** droop value in Mvar/kV units.

When the NGESO control room user clicks on *Calculate Volume and Costs* button a new dispatch instruction window opens, which gives details about the cost and the Q volume available for dispatch. A screenshot is presented in Figure 10.

All the dispatches in last 36 hrs can be seen on the 'Dispatched' page.

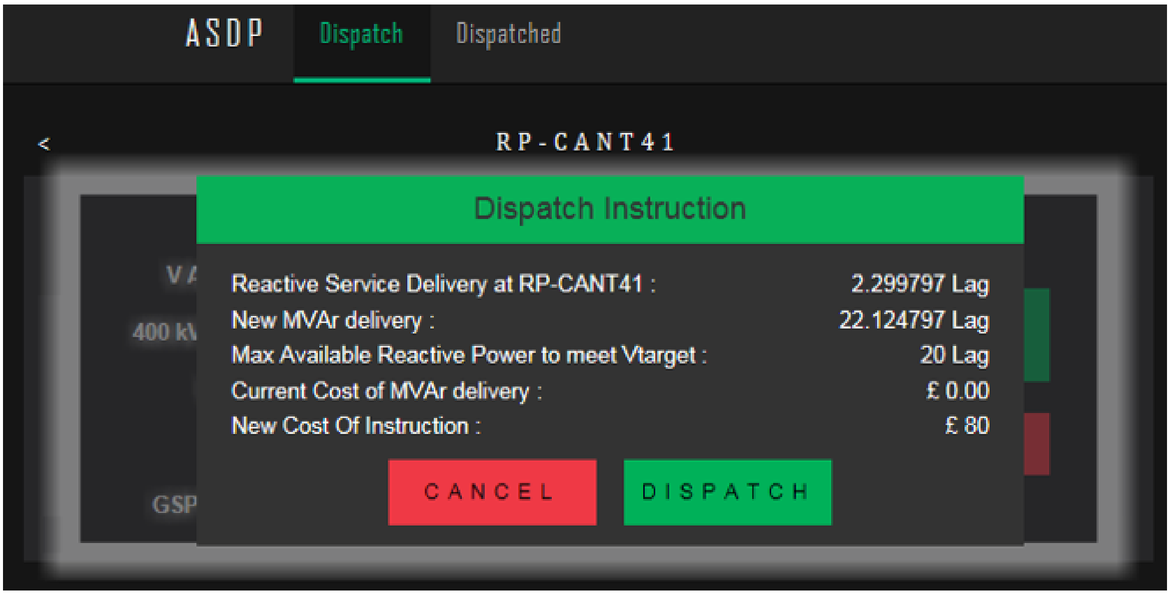


Figure 10: PAS dispatch instruction info screen

The main parameters that are visualised in this screen are:

- **Reactive Service Delivery at GSP:** Mvar or Q volume delivered at each GSP.
- **New Mvar delivery** calculates value of Mvar based on target voltage instruction.
- **Max Available Reactive Power to meet Vtarget:** Q volume available for dispatch.
- **Current Cost of Mvar delivery:** cost of Mvar delivered at each GSP.
- **New Cost of instruction:** cost of instruction from the cost curve.

Disable instruction

A final screen has been developed from which the NGESO control room user can send a "disable" instruction to stop the reactive power service. Figure 11 shows this display.

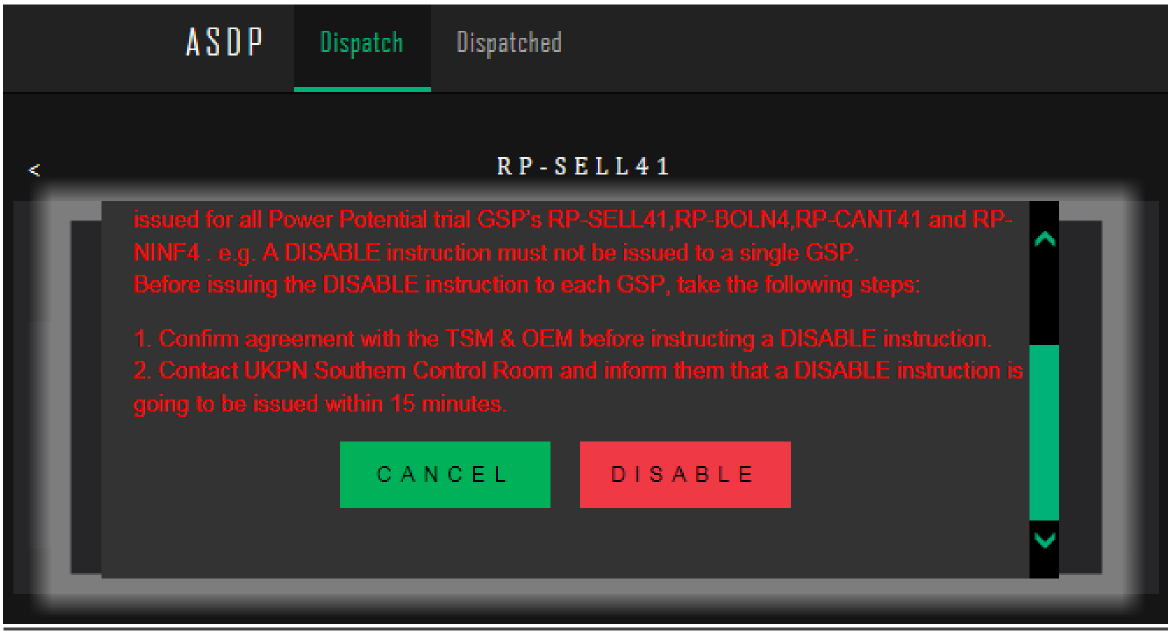


Figure 11: PAS dispatch disable instruction screen

The PAS development team has created and tested these new interfaces for the Power Potential reactive Power service.

PAS processes for the Active Power service

The Power Potential active power service has no procurement decision associated to it. This real-time service can be used if DER are available. Accordingly, it only has dispatch screens associated to it.

The PAS system is currently developed and will be tested for the Power Potential reactive power service but not for the active power service, which will be implemented for the Full Solution.

PAS-IIB-DERMS

IIB and Azure hosting of the solution (for Azure test, pre-production and live)

The IIB and Azure aspects of the Power Potential solution are supporting elements – tested with the associated PAS-DERMS and DERMS web interface functions detailed later in this document, rather than tested as individual components.

UK Power Networks' Enterprise Service Bus (ESB) tool – IBM Integration Bus (IIB) is used as the messaging platform to provide the integration services in Power Potential project. IIB is a proprietary software tool from IBM and is a middleware product. The capabilities of IIB have been used to develop the scalable and robust integration solution required in Power Potential.

Azure API Management (APIM) Gateway is a cloud based API Gateway service and is show in Figure 12 below. It can be configured with security policies like Restricted Caller IPs (IP Filtering), Rate Limit, Validating Authorisation tokens etc., which will be executed to validate the incoming requests before forwarding them to DERMS through IIB.

These IS hosting functionalities are relevant to two parts of the DERMS architecture.

1. The NGESO PAS – DERMS web services communication goes through the Azure API Management Gateway and IIB.
2. Both the DERMS Pre-production and Production UK Power Networks Gridview (Dashboard) and DER Dashboard applications are hosted within the App Service environments on Azure cloud. Dashboard applications fetch the data using Azure Gateway service end points which are configured to retrieve the data from DERMS backend systems.

All the DERMS Test Environment services hosting the Dashboards (UK Power Networks/DER) Applications, CIM Core, Service Modules, Simulator and Future Availability Modules are deployed on Azure Virtual Machines within the UK Power Networks Azure cloud infrastructure.

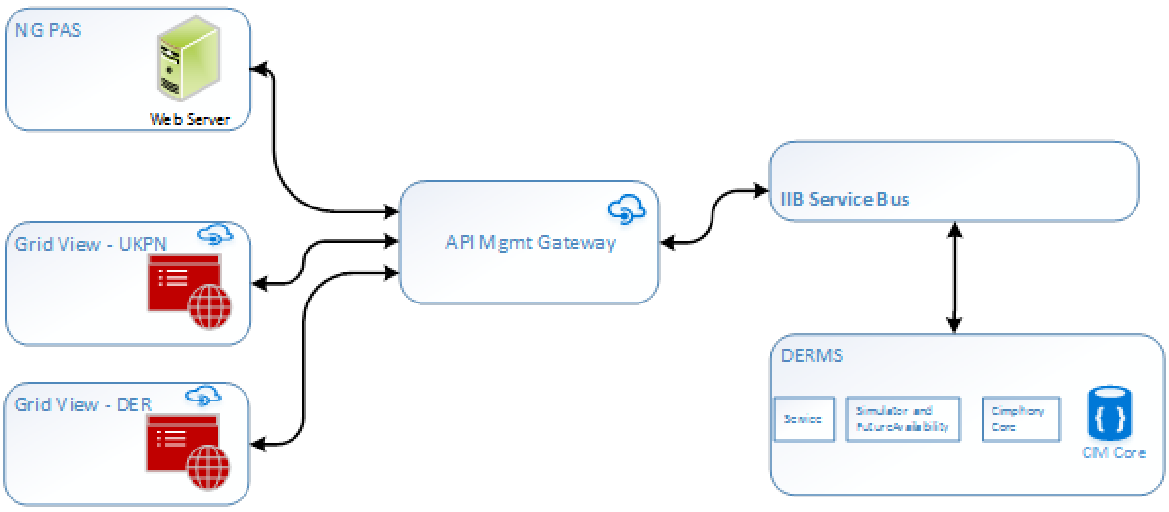


Figure 12: the Azure APIM Gateway and IIB architecture

Below there is an overview of the Power Potential User Acceptance Testing (UAT) scenarios which are being tested as part of the PAS to DERMS interface. This is the foundation of UAT for PAS.

In preparation for the Optional trials which use PAS, NFT for the whole system is conducted once that stage of SIT/UAT is complete.

Table 4: Integration and functionality tests for PAS-IIB-DERMS

Functionality	Description
Availability	DERMS sends Day Ahead Availability File with PRE flag before 14:00 (Gate Closure)
	DERMS sends Day Ahead Availability File with PRE flag after 14:00(Gate Closure)
	DERMS sends Day Ahead Availability File with POST flag before 14:00 (Gate Closure)
	DERMS sends Day Ahead Availability File with POST flag after 14:00 (Gate Closure)
	DERMS Sends Day Ahead Availability for all four GSPs together to NG
	DERMS sends Second Day Ahead Availability File with POST flag after 14:00 (Gate Closure)
	DERMS sends availability at the GSP level to NG
Nomination	Nomination file from PAS to DERMS is not correct
	DERMS to send new COST Curve after Auto nomination
	Re-dec Sent after Nomination Gate Closure
Real-time meter (RTM)	DERMS send realtime-meter for the contract (when time is between contract start and end)
	DERMS should receive the NACK (acknowledgement) and send back the confirmation to NG
In-Day availability	DERMS sends IN-Day Re-dec changing Q values
	PAS to display Actual Volt and Current Cost as Not Available
Dispatch	DERMS Should accept the dispatch request and confirmation sent back to NG
	DERMS Should have ability to reject the dispatch and send back confirmation to NG

DERMS Service Functionality

DERMS Service Mode Functionalities in Interim and Full Solution

The DERMS Service Mode functionalities apply to the dispatch algorithms and instructions, in real-time, for the two Power Potential services: 'Q service mode' for the reactive power service and 'P service mode' for the active power service.

The entire 'Q service mode' dispatch process remains unchanged between Interim and Full solution. The only exception is that, in the Interim solution, the real-time DER merit stack is only based on DER effectiveness, as other commercial inputs are disabled. Therefore, the FAT testing of this 'Q service mode' algorithm for the Interim solution proves valid for the Full solution as well. This includes stability of the control system for DER dispatch, following a NGESO instruction at the GSP.

Overview of Service Mode dispatch instructions

The DERMS Service Mode functionalities apply to the dispatch algorithms and instructions, in real-time, for the two Power Potential services: 'Q service mode' for the reactive power service and 'P service mode' for the active power service.

Instructions from National Grid ESO to DERMS for the different services are defined at the interface points with the distribution network (i.e.400 kV level, GSP). For the active power service, National Grid ESO will instruct a MW volume. For the reactive power service, National Grid ESO will instruct a voltage target set point with a droop characteristic and a dead-band to be delivered at each GSP. DERMS service mode algorithm continuously calculates free capacity in the DER and the distribution network and adjusts local DER set points to achieve National Grid ESO instructions, at the lowest cost, without violating distribution network constraints. In addition, in post-fault conditions, DER under the reactive power service will automatically deliver voltage support after a large transmission voltage change and will adjust their response to help the voltage recovery following an enhanced signal.

The following sections describe the functional testing carried out to validate these dispatch functionalities for each Power Potential service.

Testing of 'Q service mode' functionalities

The testing of 'Q service mode' functionalities include all the functional testing to validate the reactive power service dispatch instructions during real-time.

There are several interfaces linked to the 'Q service mode' to input data that enables this testing. These are:

- DER user interfaces – These interfaces are used to input the DER technical data, PQ capability curves and to define time intervals in which DER are available to provide the service as well as for visualisation purposes.
- PAS Q service mode mock interface – A 'mock' PAS interface has been developed for the testing of the Q service mode algorithm, which replicates the PAS behaviour and allows modifying of the main input parameters that DERMS will be receiving from this system. It also enables in depth testing by having the possibility to override the transmission voltages at the different GSPs.
- UK Power Networks' management interfaces – This interface is used to set user access, enter DER technical details such as the contractual PQ envelope, outage planning restrictions to the PQ envelopes and effectiveness calculations for the Interim solution, as network security and load flow functionalities are de-scoped from this initial release. The outage planning and effectiveness aspects of this interface will be disabled for the Full solution when all the DERMS functionalities are in service.

In addition, a simulation engine has been developed by ZIV to generate network data and isolate this functional testing from other integration activities. Furthermore, a time management feature has been made available within DERMS to simulate different times of the day in which different conditions and DER may be present.

The set of tests for the Q service mode have covered the validation of the different GSP instruction parameters and correct DER response within limits, for different combination of DER, at different times of the delivery day. In particular, DERMS will use the following parameters to calculate the volume of Q required to be delivered by DER:

- GSP Voltage set-point (kV)
- GSP Voltage dead-band (kV)
- GSP Voltage droop (kV/100Mvar)
- GSP Real time voltage (kV)

A screenshot of these Q instruction parameters can be seen in the upper right part of Figure 13:

Figure 13: DERMS PAS Q service mode mock interface

These parameters will determine the volume of Q to be delivered at the GSP and to be distributed between the participating DER. The Q service mode controller will ensure that the total volume of Q delivered at the GSP equals this quantity, according to the droop curve and the GSP actual real-time voltage. In the absence of an instruction, changes of GSP real-time voltage will also trigger the response of DER that are armed to provide the service, offering dynamic support.

Tests to validate the correct system response when changing these parameters and values have been run in an AWS (Amazon Web Services) environment (tested by the developer) and in an Azure environment (tested by the project team), together with the simulation engine. This has validated the FAT acceptance criteria for the Q service mode. In addition, testing has been extended to a pre-production environment, to pick up any remaining defects in the service functionalities. A non-exhaustive summary of main tests and validations carried out successfully and witnessed by UK Power Networks and National Grid ESO during FAT for the Q service mode can be found below:

Creation of Droop Slope Chart
- Voltage set-point change
- Deadband change
- Droop slope change

Calculation of Delta Q Requested
- Within Deadband
- Above Deadband
- Below Deadband

Q Mode Module Closed Loop Control
- Zero Delta Q Request
- Non Zero Delta Q Request

Q baseline and Q GSP availability calculations

Q Required Distribution to Each ‘armed’ DER
- Zero Delta Q Requested
- Positive Delta Q Requested (Lagging)

- Negative Delta Q Requested (Leading)
- Positive Delta Q Requested (Lagging) Different DER Q Max
- Positive Delta Q Requested (Lagging) Different DER Q Max

DER Response Limits

- PQ Envelope
- DER Technical Q Limit
- UK Power Networks Outage Planning Interface: Day Ahead Q Limits

Initially, a 'dummy' GSP has been setup for testing purposes with five DER under it. Testing has then been extended to the GSPs and DER that will form part of the final DERMS release for production:

- GSP Bolney
- GSP Ninfield
- GSP Sellindge (N/A)
- GSP Canterbury North

Stability of control scheme of 'Q service mode'

The validation and commissioning of the stability of the DERMS controller for the Q service mode is an important aspect that has gone under separate testing. Being a closed-loop controller, the feedback coming from system measurements will have an impact on the stability of the overall solution.

The high-level structure of the DERMS Q service mode control system is presented in Figure 14 and Figure 15.

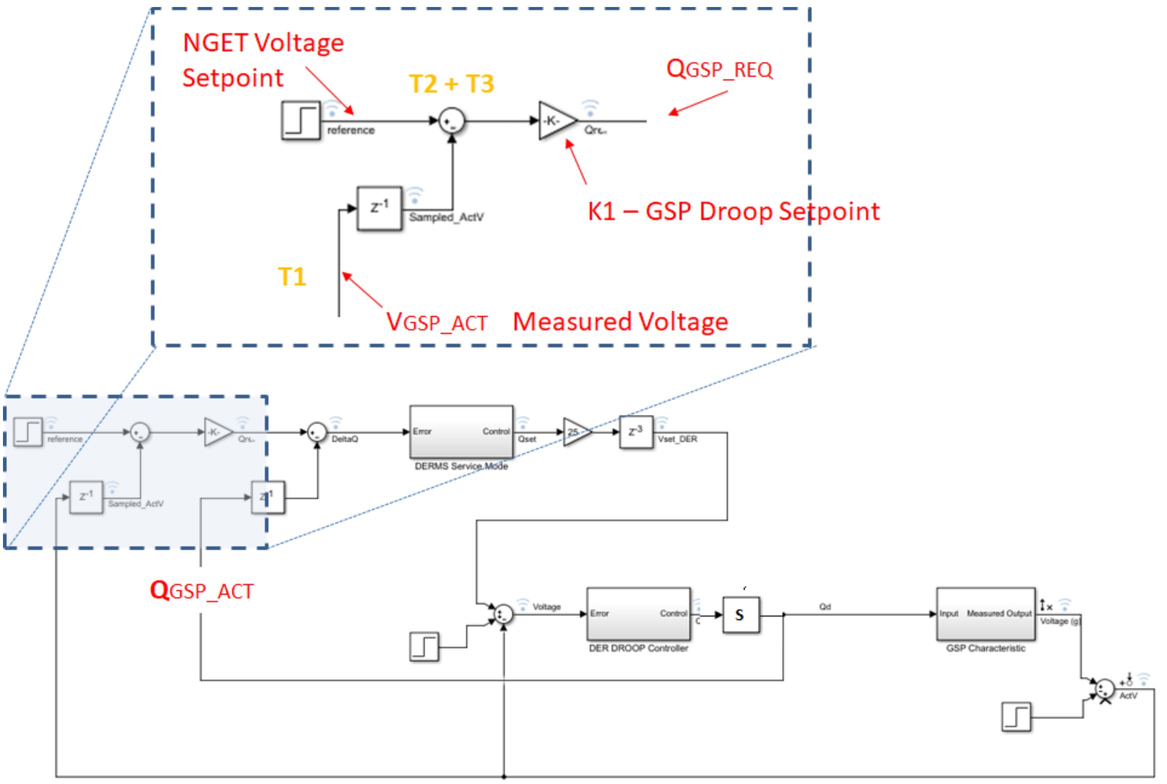


Figure 14: DERMS Q service mode control system (view 1/2).

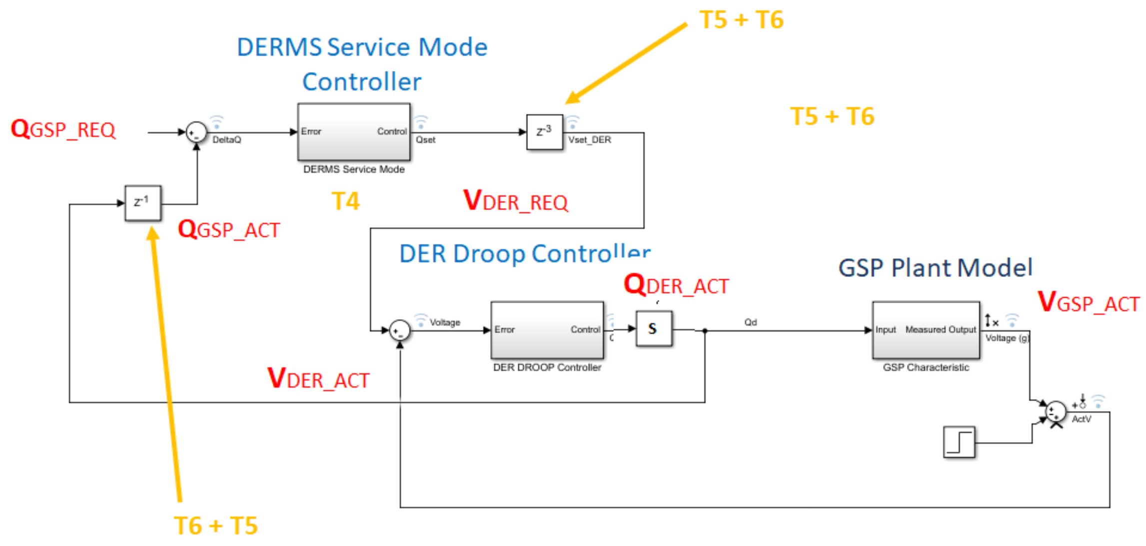


Figure 15: DERMS Q service mode control system view (2/2).

There is a fast acting continuous controller, implemented for each DER, and a slower acting integral controller to achieve the Q response required at the GSP.

The continuous controller is located in each DER and is able to respond quickly to changes in its terminal voltage. This allows the system to provide fast and responsive operation for system faults and disturbances. The response of each DER is based on the voltage droop for that DER and the voltage set point which is calculated by the DERMS system and updated at least every 10 seconds.

The integral controller is located in the DERMS system and provides a slower acting response to NGESO set point changes and system voltage changes. It effectively calculates new voltage set points for the individual DER based on the system operation since the last SCADA data update was received. This data update typically occurs every 10 seconds and therefore any set point changes or DER dispatch commands are only generated at the same time resolution, i.e. every 10 seconds. This period is too long to respond to system faults and disturbances which may be returning to pre-fault values before the DERMS can respond. The inherent delays in the communication paths of this control scheme, together with the controller parameters, have an impact on the DERMS performance and behaviour. The main elements that can affect the system stability can be classified as follows:

- Communication delays:
  - T1: Delay between NGESO[1] and PowerOn
  - T3: Delay between PowerOn and DERMS
  - T4: Delay in DERMS calculations
  - T5: Delay between DERMS and PowerOn
  - T6: Delay between PowerOn and RTU of each DER
- Internal controller gains:
  - K1 (integrator gain)
  - K_{GSP} (stiffness of the GSP)

The final commissioning of the DERMS control system will happen upon SIT testing completion.

To initially tune the controller, communication delays have been grouped into a single time constant that can be set in the simulation environment, by altering the simulator calculations time cycle.

The initial testing in Azure has provided valuable insights of the range of allowable values that the controller can operate with. The following tests have been carried out:

- Changing simulator calculation cycle time

[1] This refers to NGESO SCADA network measurements for DERMS calculations and not to PAS. Delays in the data communicated from PAS (T2) do not have an impact on the DERMS stability behaviour.

- Changing integral control parameters (K1)
- Changing grid strength (K_{GSP})

This testing has determined the need to balance between time constant delays and integrator gain for a controller stable response. In addition, realistic grid strength values at the relevant GSPs have been provided for this tuning.

An example of the stable controller response to a voltage increase instruction can be seen in Figure 16 in terms of DER and GSP flows.

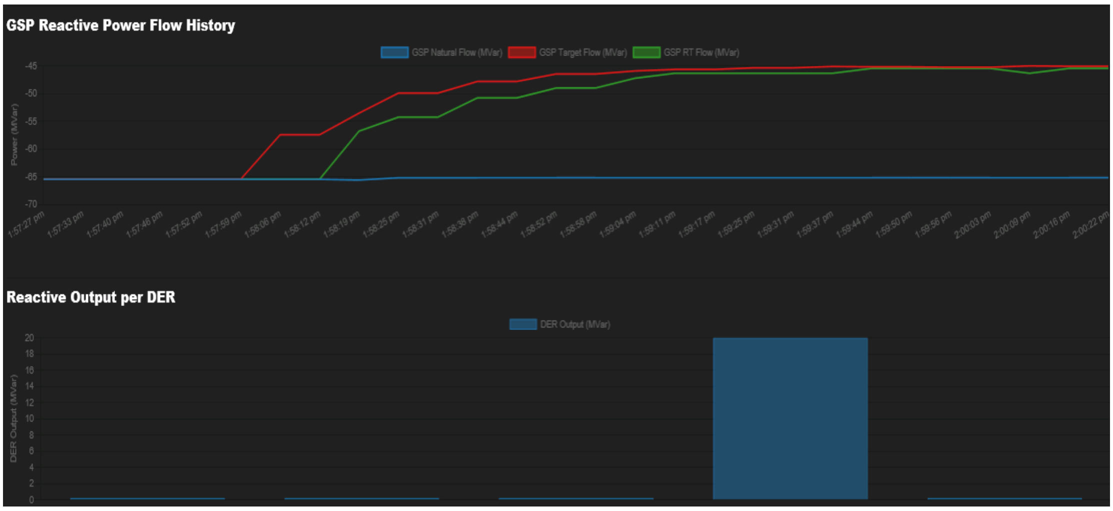


Figure 16: Example of stable testing result. One DER available: Q actual tracks (green) Q requested (red) for the following instruction: voltage set point of 405kV, dead-band = 2kV, 4% drop.

Testing of ‘P service mode’ functionalities

The testing of ‘P service mode’ functionalities include all the functional testing to validate the active power service dispatch instructions during real-time.

There are several interfaces linked to the ‘P service mode’ to input data that enables this FAT testing, together with ZIV’s simulation and time management engines:

- DER user interfaces
  - As described above for the Q service mode, these are used to input the DER technical data, PQ capability curves and to define time intervals in which DER are available to provide the service as well as for visualisation purposes.
- PAS P service mode mock interface
  - Similarly to the Q service mode algorithm, a mock PAS interface for the P service has been developed, which replicates the PAS behaviour and allows to modify the main input parameters that DERMS will be receiving from the PAS system.

The ‘P service mode’ dispatch mode is only available for the Full solution. There are no stability tests associated to this algorithm as ‘P service mode’ consists of open instructions, with no feedback from system measurements.

DERMS Mandatory Trial Interfaces

Mandatory Trials

Distributed Energy Resources (DER) will only be allowed to participate in the provision of either active or reactive power services in Wave 1, Wave 2 or Wave 3 once they have undertaken Mandatory Trials. The aim of the Mandatory Trials is to demonstrate that DER are technically capable of delivering both reactive and active power services when instructed by DERMS.

Mandatory Trials interfaces for the reactive and active power services have been developed in DERMS to carry out these trials in which specific test cases will be driving the DER response. For this part of the trial, the Platform for Ancillary Services (PAS) interface is not expected to be used and instructions are envisaged to come directly from DERMS.

The Mandatory Trials interfaces for each GSP/DER have been validated and tested in a simulation (Azure) and pre-prod environment, by running the specific test cases and the trial DER.

Overview of Mandatory Trials scope for Q reactive power service

The reactive power service tests in the Mandatory Trials aim to validate the DER's reactive power responses to simulated 400kV voltage signals in DERMS. Initially, three different tests[2] are expected to be run with an approximate duration of 15 minutes each. Each test needs to be carried out individually for each DER participating in the reactive power service.

In addition to the individual tests, collective tests are also to be run considering a group of DER to prove the virtual power plant (VPP) concept. The collective DER tests are required to assess that the DERMS distributes the total reactive power required at the GSP correctly between a DER's reactive stack.

Testing Mandatory Trials interface for Q service

Mandatory Trials interfaces for each GSP (Ninfield, Sellindge, Bolney and Canterbury North) have been developed in DERMS to carry out the Mandatory Trials for the Q service participants.

DERMS will use the existing 'PAS Q service mode mock interface' with a few adjustments to accommodate these tests. This interface mimics the PAS behaviour and allows the project control over the service activation, creating different system events to study.

The Mandatory Trials for reactive power have been structured around three main test cases:

1. Fixed GSP voltage set-point instruction vs. sudden change in 'fictitious/test' GSP voltage input (Test 1).
2. Fixed GSP voltage set-point instruction vs. slow change in 'fictitious/test' GSP voltage input (Test 2).
3. Change in GSP voltage set-point instruction vs. actual GSP voltage measurement (Test 3).

The main feature of the Mandatory Trial interfaces is a 'switch' button that allows to override actual voltage values by a 'fictitious/test' signal. This enables to carry Test 1 and 2. Test 3 is focused on smoothing the transition to trials and further validation of the stability of the solution.

Figure 17 shows the Mandatory Trial interface for the reactive power service for one of the GSPs configured for Test 1 and Test 2.

[2] Test scripts for each of the Q service test cases can be found in: https://www.nationalgrideso.com/document/143346/download

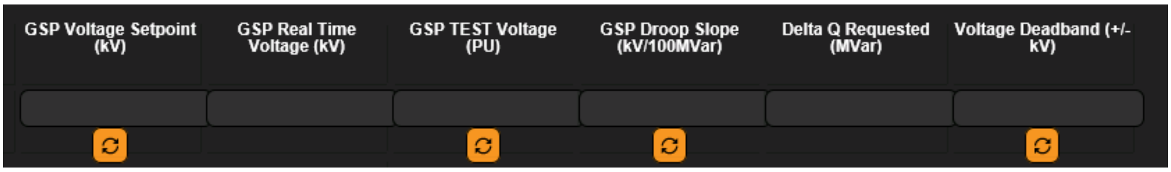


Figure 17: Mandatory Trials interface for one GSP for Q service (configured for tests 1 and 2).

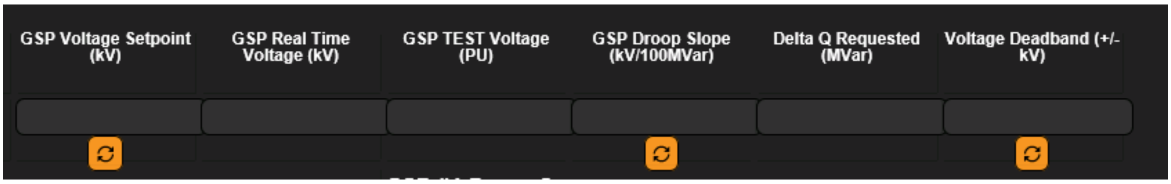


Figure 18: Mandatory Trials interface for one GSP for Q service (configured for test 3).

The main inputs and variables in this interface are:

- **GSP Voltage set-point (kV):** target voltage set-point at the GSP.
- **GSP Real Time Voltage (kV):** actual GSP voltage as received by DERMS.
- **GSP Test Voltage (pu):** 'fictitious/test' voltage to override the GSP Real Time Voltage (only for tests 1 and 2).
- **GSP Droop Slope (kV/100Mvar):** droop gain associated to the voltage instruction.
- **Delta Q Requested (Mvar):** reactive power requested derived from the voltage instruction (internal parameter, cannot be edited).
- **Voltage Dead-band (+-kV):** dead-band around the target voltage set-point.

The Mandatory Trials interfaces for the reactive power service was initially tested for a 'dummy' GSP with several 'dummy' DER under it, in a simulation (Azure) environment as proof of concept.

In readiness for Mandatory trials, testing is being carried out to GSPs listed below and DER in the GSP area in a pre-prod environment:

- GSP Bolney
- GSP Ninfield
- GSP Sellindge (N/A)
- GSP Canterbury North

As part of testing, the following were tested: RTU logic, PowerOn interface and DER simulators individually to ensure readiness and then integration testing.

This validates the use of these interfaces to carry out the Power Potential Mandatory Trials for the Q service.

Overview of Mandatory Trials scope for P active power service

The active power service tests in the Mandatory Trials aim to validate the DER' active power response to simulated active power signal requests in DERMS. One test[3] is expected to be run with an approximate duration of 15 minutes. This test needs to be carried out individually for each DER participating in the active power service.

Testing of Mandatory Trials interface for P service

The Mandatory Trials for active power have been structured around one individual test case to verify that the DER working with DERMS responds correctly to changes in the requested active power volume. The tests require the variation of the DERMS MW request at the DER level.

[3] A test script for the P service test case can be found in: https://www.nationalgrideso.com/document/143346/download

The RTU DER Test signal interface in DERMS will be used to issue MW instructions to the DER to conduct these tests. A screenshot of this interface for one DER for the active power service Mandatory Trials is shown in Figure 19.

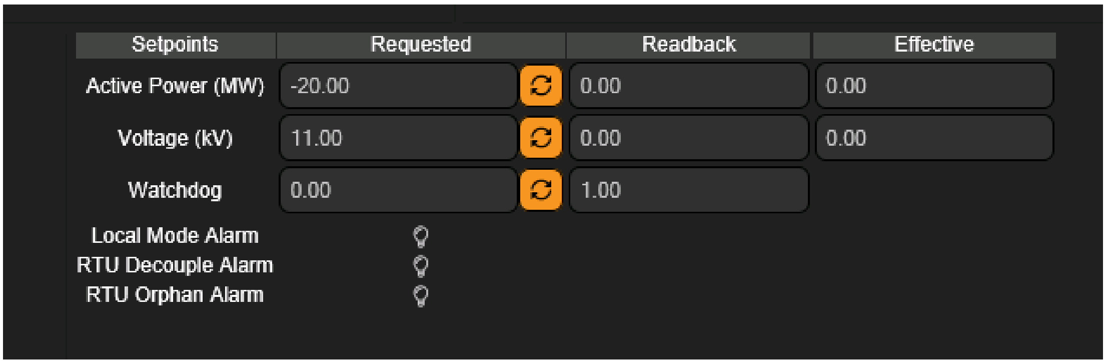


Figure 19: Mandatory Trials interface for one DER for P service

Through varying the requested active power (MW) value, the mandatory test for the active power service can be executed.

Network Security Assessment – Inputs to DERMS

In order to secure the distribution network, when the DERMS interim solution is trialled, UK Power Networks engaged Moeller & Poeller Engineering (MPE) to undertake an assessment to determine the necessary limitations that should be applied to each DER to prevent overloading or out-of-range voltages on the distribution network. In executing this engagement, MPE has performed the following tasks:

- Assessment of equipment thermal loading, operating voltages and step voltage changes when the distribution network is in its fully intact configuration
- Development of PQ and VQ capability curves for each DER included in the Power Potential trial to prevent loading and voltage limits being exceeded in the distribution network

This assessment was completed using a model of the UK Power Networks' South Eastern network in DigSILENT PowerFactory. The high-level methodology used for the assessment was as follows:

- Replace each DER in the existing PowerFactory model with a static generator set up with the maximum capability curve for that DER
- Operate each DER individually to the limits of their reactive capability curves and then reduce the capability until it does not cause any voltage or loading violations in the network
- Operate all DER concurrently at the limits of their reactive capability curves and then reduce their capabilities until they do cause any voltage or loading violations in the network
- Generate PQ and VQ curves for each DER

Note that there are a considerable number of uncertainties in undertaking this assessment. Examples of these uncertainties include the suitability of the PowerFactory model used and the considerable range of possible operating arrangements, DER dispatches and network loading conditions.

Therefore, a conservative approach was used in the methodology to give confidence that the network will be operated safely during the Power Potential trials. This conservative approach was applied as follows:

- The largest (reasonable) reactive capability for each DER is initially assumed. This has the benefit of ensuring that DER do not end up with 'stranded' capability (that is, capability that a DER has available but was not assessed and therefore cannot be accessed), and that their actual operating points will be less than the assessed network capacity.
- Conservative limits are applied for voltage tolerances, equipment ratings and other limitations throughout the assessment.
- Extreme operating conditions (e.g., maximum and minimum recorded load conditions) are used; actual operating conditions should typically be more favourable.

Two capability curves were prepared for each DER—one showing the reactive power capability of the DER against its real power output ('PQ' curve), the other showing the reactive power capability against its terminal voltage ('VQ' curve). Examples are shown in Figure 20 and Figure 21.

The Customer Readiness chapter of this report provides more context on the customer engagement to agree the PQ curves and implement them in the contracts.

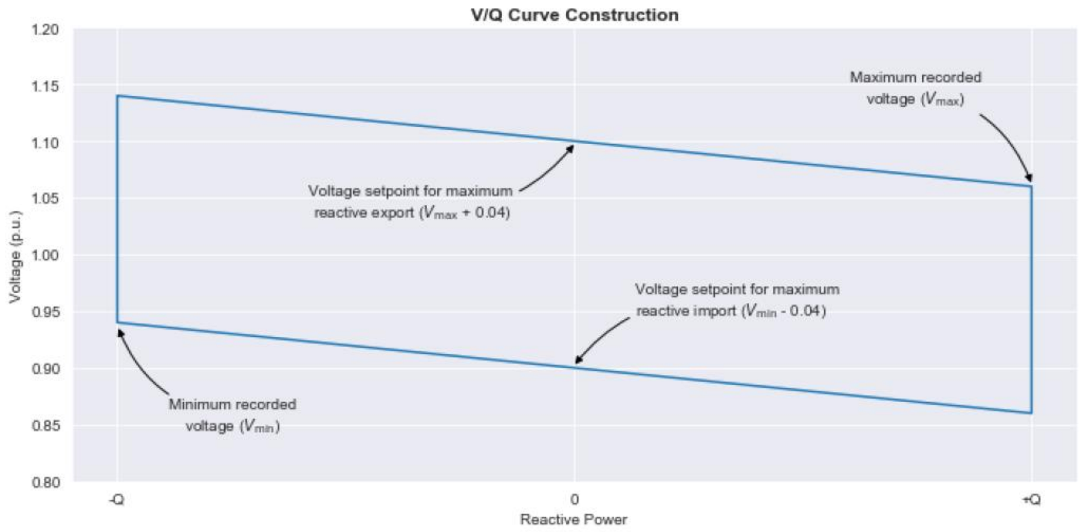


Figure 20: An example V/Q curve

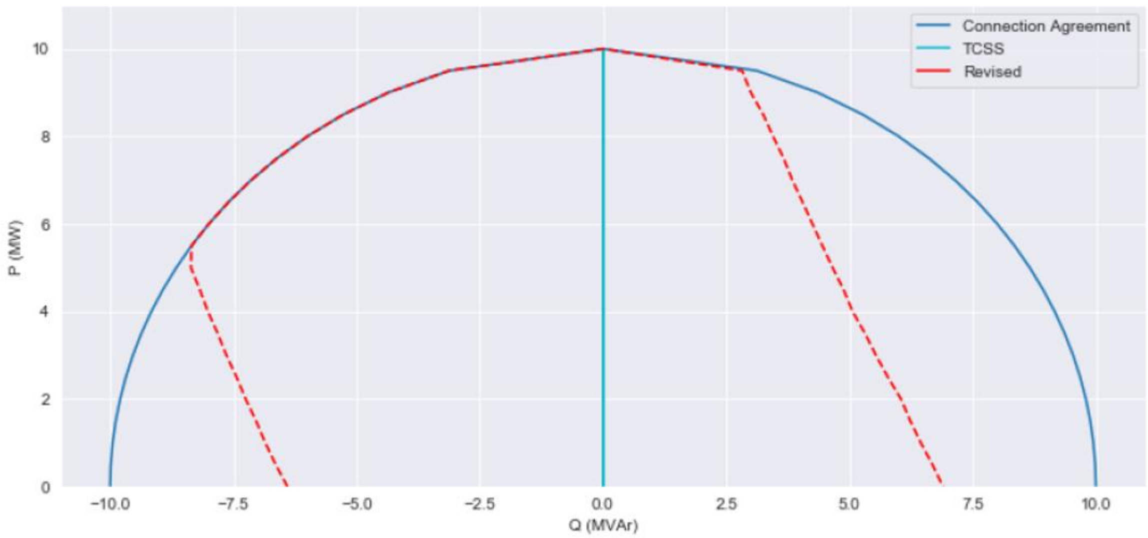


Figure 21: An example PQ capability curve

The combination of the PQ curves described above with DERMS outage planning inputs described in the next section secures the distribution network during Wave 1.

The VQ capability curves are derived from the load flow calculations carried out as part of the assessment. They are based on the voltage setpoint necessary to achieve maximum reactive export at the highest voltage recorded at the DER terminals during the assessment (across all load steps and operating scenarios), and to achieve the maximum reactive import at the lowest voltage recorded.

Since the Power Potential scheme will be using a 4% voltage droop characteristic, this results in a required voltage setpoint range for each DER from 0.04 p.u. below the minimum-recorded voltage at its terminals through to 0.04 p.u. above the maximum-recorded voltage.

Modelling

The DigSILENT PowerFactory model contained a representation of the distribution network from the 400kV grid supply points through to the 11kV and 6.6kV distribution substation busbars. It also contained a representation of the National Grid Electricity Transmission network.

For the assessment, minimum and maximum load cases are considered on the assumption that these will be the worst-case scenarios for the distribution network. Furthermore, some of the DER units interested in participating are only offering services during the day or at night; separate day and night cases are also considered (DERs not offering services during a time period are placed out of service while assessing that case). This gives a total of four study cases to be included in the assessment – minimum and maximum load during the day, and minimum and maximum load during the night.

In some cases, the operating scenario selected is unlikely to be coincident with the extreme operating cases for the DER unit. The day minimum scenario is a good example of this – it occurs at 15:00, when PV output is likely below its peak. This adds some conservatism to the assessment.

Assessment

The assessment of reactive capability consisted of the following steps:

1. Checking the step voltage change after a trip
2. Checking the effect on steady-state voltage and equipment loading (thermal limits)

Wherever these checks showed that the DER caused a limit to be exceeded, the reactive capability of the DER was reduced until no limits were exceeded.

Step voltage change

Engineering Recommendation (ER) P28 from the Energy Networks Association provides guidance on the assessment of power quality. It gives a general limitation for the magnitude of voltage changes of 3% of nominal, a limit that has been adopted by UK Power Networks. An updated version of ER P28 is expected shortly, but based on the present draft looks likely to retain the 3% limit.

The most significant step voltage change caused by a DER unit is typically when it is tripped offline. The magnitude of the voltage change is dependent on the network characteristics (system strength and XR ratio) and the real and reactive output of the DER unit at the time of trip. Since the Power Potential scheme will change the reactive output of the DER unit, it will have an effect on the voltage step change when the DER is tripped and therefore must be reassessed against the 3% limit.

Steady state busbar voltages and equipment loading

The Power Potential scheme will affect voltages throughout the distribution network and therefore bus voltages must be checked to ensure that this does not cause any of these voltages to exceed the allowable limits.

UK Power Networks operates its distribution network with the voltages in the range of ±0.06p.u. of nominal for voltage levels 33kV and below, and +0.10/-0.06p.u. of nominal for the 132kV voltage level. These levels were generally already applied in the PowerFactory model, and were therefore retained. Some busbars – typically those entered in PowerFactory as 'terminals' rather than 'busbars' – did not have any existing voltage limits. In these cases, the default voltage limits were applied when processing the results of the assessment.

Thermal limits

Reactive power flows throughout the network will also be affected by the Power Potential project. Line and transformer loading must therefore be checked to ensure that the Power Potential project does not cause any equipment ratings to be exceeded. For the purposes of the assessment, the line and transformer ratings in the model were retained. Since these ratings are seasonal, the 'summer' ratings were used to ensure that the results are conservative. The assessment of equipment thermal loading was against the thermal limits of assets in the PowerFactory model. For some DER, at higher P levels, the allowed Q was constrained to stay within the Maximum Permitted Export Capacity of the site (defined in MVA).

Pq cuFor Wave 2, a full load flow in the loop will be running on a CIM model in real-time and network thermal limits are checked constantly to ensure the distribution network is safe.

DNO Outage Planning Inputs (Interim Solution)

Under intact network conditions, DERMS will be freely instructing DERs within their available PQ capability ranges, restricted only by their contractual PQ envelopes, as entered into DERMS at the outset. At times of network outages however, DERMS may need to restrict the DER's PQ capability range further, in order to secure the network. Due to the design limitations of the DERMS Interim Solution, network security will not be assessed against a network model during the Wave 1 Optional Trials. Instead, network security will be assessed by a manual, offline process performed by the UK Power Networks Outage Planning Team. To facilitate this, a UK Power Networks Management User Interface (UI) has been provided in DERMS to allow network running constraints to be entered at day ahead, to set the running arrangement (revised P-Q envelope) for a given time-period, matching the commercial service window.

The UI takes the form of two dashboards in the DERMS UI:

1. DNO Outage Planning Interface: Current Day
2. DNO Outage Planning Interface: Day Ahead

Active and reactive (PQ) values for each participating DER, for each settlement period, are entered by 14:00 at day-ahead in the Day Ahead view, as shown below. Note that unless the values are changed, they will default to those values entered in the DER PQ capability envelope.

Given the volume of data entries (five parameters, over 48 periods per DER), a bulk upload facility is available for the Outage Planning team to upload PQ availabilities and curtailments for multiple future days. This will over-write/update all existing values in DERMS. Note that all values will remain unchanged until the next update.

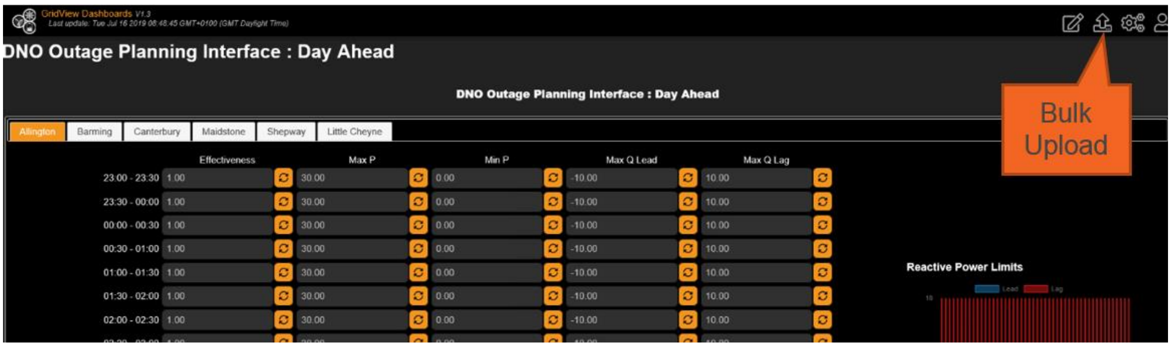


Figure 22: Example of DNO Outage Planning Day Ahead Interface

Additionally, the Outage Planning team can enter amendments manually for individual participating DER per settlement period up to 14:00 at day ahead.

DER outputs will be restricted to those P and Q capabilities entered into this UI.

Testing of this functionality was carried out on the pre-production DERMS version 14.5 in September 2019, where Reactive Power restrictions, entered into the UI, were proven to have the anticipated response on DER output. This is evidenced in the DNO Outage Planning Inputs (Interim Solution) evidence file. Note however that further regression testing will be carried out on the final release of DERMS.

Integration between PowerOn, RTU and DER controller

DER Interface schedule

The DER Interface schedule list (https://www.nationalgrideso .com/document/119536/download) documents and explains the signals between the UK Power Networks RTU and DER controller, including an additional information on how to set up the DNP3 Protocol configuration for each signal. These signals are needed to integrate the DER controller with the Power Potential solution via an RTU device.

The DER Interface Schedule has been revised several times to take into account customer feedback and business preferences. Working closely alongside the Active Network Management rollout, the communications route is being future-proofed to aid transition to multiple service functionality.

Remote Terminal Unit (RTU) with Power Potential logic

A RTU is a microprocessor-controlled electronic device that interfaces objects in the physical world to a distributed control system or SCADA system by transmitting telemetry data to a master system, and by using messages from the master supervisory system to control connected DER. The RTU monitors the field digital and analogue parameters and transmits data to the UK Power Networks NMS (PowerOn) via the satellite SCADA communications route. This information is used by the UK Power Networks control centre to ensure the network is within safe operating limits. The standard for connections to UK Power Networks for voltages above 33kV includes the requirement for an RTU. The RTU is located within the UK Power Networks switchroom.

To support Power Potential, a software upgrade was specified and developed by UK Power Networks for application to the standard RTU type at UK Power Networks 33kV and 132kV DER sites. This logic facilitates the exchange of controls, limits and setpoints to deliver the voltage and active power services. The Power Potential logic functionality enables the list of signals listed in the DER Interface Schedule and additionally the integration of the signals required to integrate with the UK Power Networks PowerOn system, with the application of failsafes in case of any loss of communications or non-compliance RTU-DER or PowerOn-RTU. The developed RTU logic passed a FAT at the GE site, and was then deployed to a UK Power Networks RTU for acceptance testing

Lab testing environment

There are two stages for the DER commissioning -- lab integration and on-site commissioning testing.

The purpose of this laboratory environment is to bench test the integration between the RTU and the DER controller as shown in Figure 23, with extension to integration test with PowerOn for later customers. The integrated system test was performed at a UK Power Networks operational telecoms test environment and validated the signal list mentioned before.

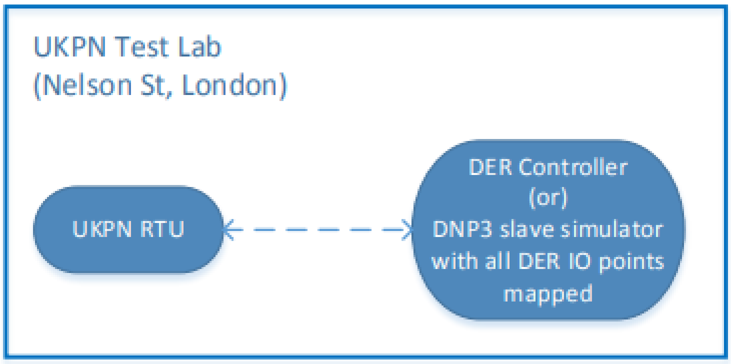


Figure 23: Lab testing environment

Summary of laboratory bench testing

- IP configuration and settings for DNP over Transmission Control Protocol/Internet Protocol (TCP/IP) through cyber security/firewalls
- Analogue inputs/outputs
- Digital inputs/outputs
- Analogue/digital readbacks
- Functional behaviour including change of mode
    - P, Q, V and Power Factor
    - Contractual
    - Enable/Disable service
    - Decouple
    - Failsafes
    - Limit breaches
- Voltage setpoints

On site testing environment

This is the operational testing environment where all the functional and site commissioning tests will be performed. On-site commissioning testing is a combination of integration testing (repeated from the lab) and capability testing as detailed in the DER Test Specification. The live environment, as shown in Figure 24 includes the site RTU and the customer DER control system connected via PowerOn to DERMS.

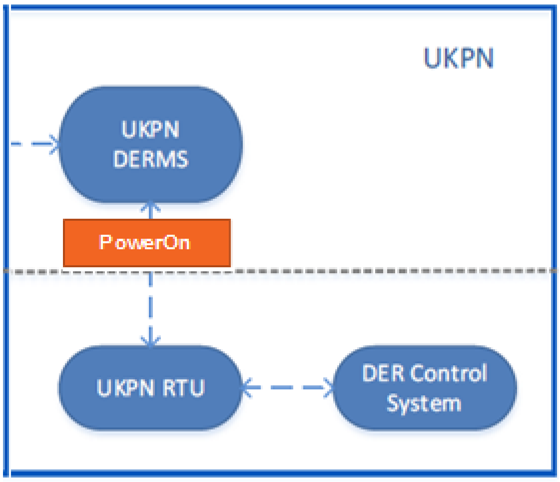


Figure 24: On-site testing environment

Prior to scheduling site-based commissioning for each DER (see Chapter 4 on Customer Readiness), UK Power Networks needed to update the logic on the RTU located at the DER site. RTUs below a set specification also required a hardware change. Of the five RTUs participating in the trial, only one required a hardware change.

The logic is delivered to the RTU remotely from the UK Power Networks Operational Telecoms department. An Operational Telecoms Engineer is also required to be at site to ensure the delivery of the logic is received correctly and business as usual activity is not impacted. The RTU logic update does not disturb the DER from normal operation.

One customer chose to adopt a staged approach to commissioning – completing initial integration testing RTU-DER controller on 14 November 2019, with full commissioning to be scheduled in January 2020 when both DERMS is live and the customer is ready for capability testing.

Note that a test for time synchronisation between the UK Power Networks RTU and DER controller will also be performed as part of site-commissioning test.

RTU to DER Integration tests on site

This section covers the test cases associated to the UK Power Networks RTU to DER control system integration. This is achieved using DNP3 protocol where the UK Power Networks RTU acts as the master and DER control system acts as the slave. Tests are to be carried in both lab integration (not compulsory) and on-site (compulsory) environments.

RTU DER installation

This test is to confirm if the RTU to DER integration gets back to its normal status after an initialisation routine. This can happen during a power loss situation or an RTU restart scenario.

RTU DER Digital input map

This test is to confirm if the RTU gets all the digital inputs correctly from the DER control system. These inputs inform the UK Power Networks RTU on whether the various conditions requested by UK Power Networks for DER control were successfully received and executed by DER control system.

RTU DER Digital output map

This test is to confirm if the RTU can send binary output commands to DER control system. The commands drive the DER to different conditions of operation that is desired by the UK Power Networks DERMS system. In addition, these commands include signals that tell the DER about compliance to the active and reactive power services.

RTU DER Analogue input map

This test is to confirm if the RTU gets all the analogue inputs correctly from DER control system. These inputs inform the UK Power Networks RTU on whether the various set points requested by UK Power Networks for DER control were successfully received and executed by DER control system.

RTU DER Analogue output map

This test is to confirm if the RTU can send analogue output commands to DER control systems. These commands are basically operational setpoints that are desired by the UK Power Networks DERMS system. These commands are very important for the P/Q services.

Facilitating visibility of service delivery and end-end testing

New dedicated screens have been created for the UK Power Networks control engineer’s visibiltiy of the service operation on PowerOn. Figure 25 provides an example indicating the actual active and reactive power level, and the voltage and power factor at each DER site, alongside the target value (setpoint) and upper and lower allowed limits. It also indicates whehter the RTU/DER is in the control of the DERMS(ANM) system, PowerOn (NMS) or the RTU is not communicating (in orphan mode), returned to its contractual mode and the RTU is in local mode. The PowerOn screens also enable Control Engineers to return specific DER to their pre-trial contractual mode, or via a group telecontrol to return all DER to their contractual mode of operation.

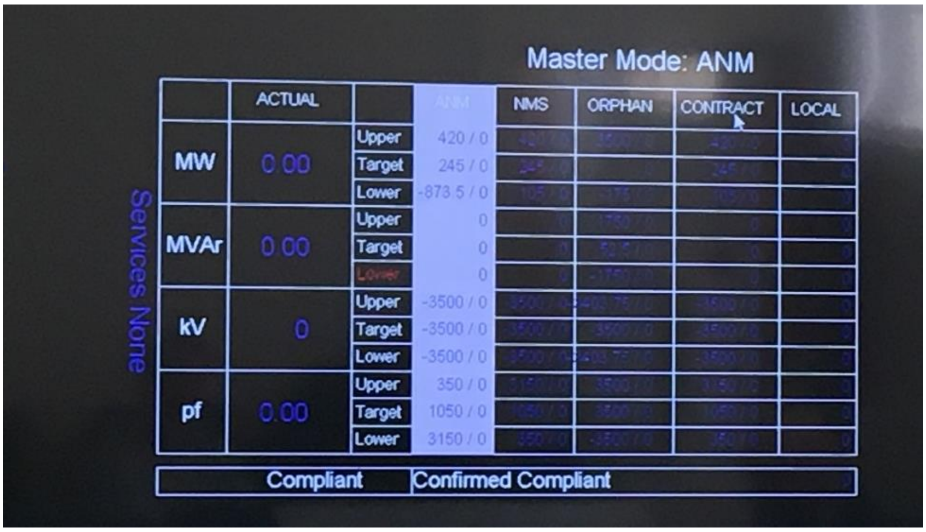


Figure 25: PowerOn screen developed for the project for Control Engineer visibility

These PowerOn screens were also vital to the end-end integration and functionality testing of the pre-production system as a pre-requisite to deployment to live of DERMS, new PowerOn functionality and upgrade of the RTUs. As part of that end—end testing, signal exchange was verified across a DERMS RTU test user interface screen, the PowerOn screen, the RTU mimic screen shown in Figure 26 and customer DER controller.

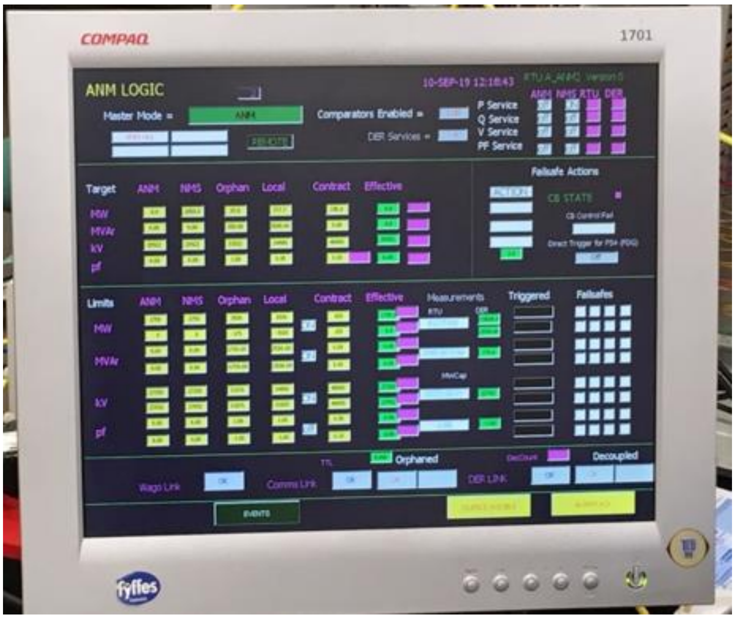


Figure 26: RTU mimic

NGESO measurements provided to UK Power Networks via ICCP links

DERMS is receiving 400kV transmission SCADA data from NGESO. This data for DERMS' calculations passed through an existing ICCP (Inter Control Centre Protocol) link that directly connects the UK Power Networks and NGESO SCADA systems, then through a second ICCP link to DERMS.

ICCP link connection between NGESO and UK Power Networks

The Power Potential project has set up real-time metering data to be sent to UK Power Netoworks. Data includes all voltage metering for every circuit, transformer and busbar (where available) within an agreed area of the South East of England.

It is also sent the "most trusted" voltage signal at each selected site. This signal is the one agreed to be used as actual voltage 400kV input for each GSP in DERMS, ensuring alignment between NGESO control room and DERMS calculations.

Sites from which measurements are received range from West Weybridge, Barking and Tilbury in the North down to the South coast, and from Lovedean/Fleet and Bramley in the west across to the East coast. Within the project scope, only the measurements associated to Bolney, Ninfield, Sellindge and Canterbury North will be relevant to DERMS. In particular, voltage and flows (active and reactive power) through the super grid transformers at these four locations.

Testing of ICCP link

All database configurations have been tested on pre-production servers on both the ends of the links between UK Power Networks and NGESO.

UK Power Networks have production systems containing two ICCP Servers connected to two NGESO ICCP Servers for resilience. NGESO network communications are maintained and supported by Vodafone. NGESO applications and database are configured on the GE product.

The ICCP connection between NGESO and UK Power Networks is working in a pre-prod environment and in a production environment, ready for trials start. Testing in September 2019 confirmed that the servers and clients at both ends (UK Power Networks and NGESO) could communicate with each other successfully.

Power Potential is funded by Ofgem to generate learning within the industry. Since the success of the UK Power Networks KASM project – which set up an ICCP link with National Grid as part of its scope – the ICCP link has been identified by the UK industry as the "de facto standard" for DNOs to interface to NG for SCADA data exchange.

Power Potential has however identified that an issue with using two ICCP links in series to pass data from NGESO to UK Power Networks' PowerOn and then on to DERMS, as shown in Figure 27 below.

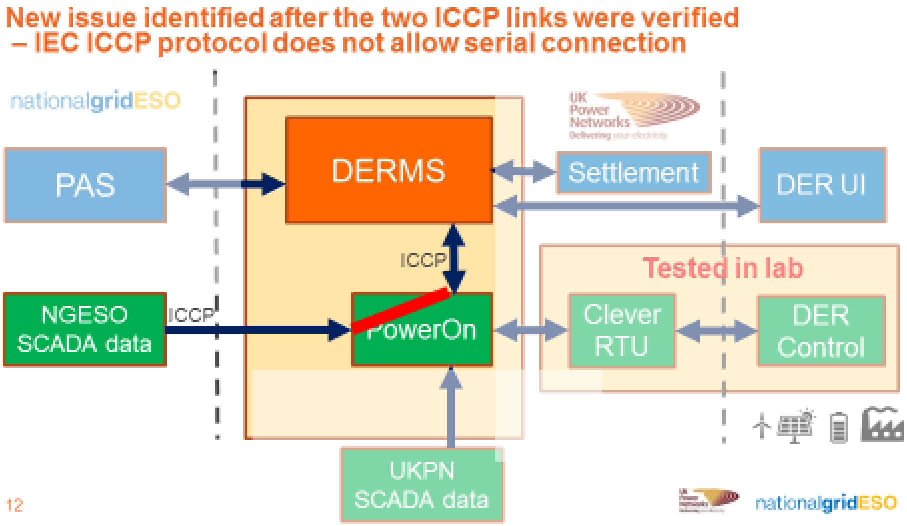


Figure 27: Serial ICCP links

ICCP is an IEC point-point protocol, so there are limitations with using ICCP as a bus to pass signals from NGESO-PowerOn over ICCP, then over PowerOn-DERMS ICCP. This arrangement has been part of Power Potential's agreed design since 2018, and re-uses the existing ICCP link set up for the KASM project. However the protocol limitation was only just identified as a barrier at final integration stage. Originally identified this was for passing to DERMS National Grid's selected voltage references at the four GSP voltages, then identified this would also be required for Q flows at SGTs since these are not monitored on the UK Power Networks network. NGESO has added P and Q to the V points being shared over ICCP.

Identifying this limitation is a significant learning to the wider industry and the project will be expected to provide detailed engineering rationale and may lead to engagement/feedback to the IEC standardisation body responsible for ICCP standard.

A manual workaround was developed by the project to be able to pass the signals, and successfully verified on 17 October 2019 to pass the Ninfield 400kV voltage from NGESO's SCADA to PowerOn to DERMS in around 1ms (below the timescale resolution of the timestamp). This was then extended to other voltage, active and reactive power analogue data which needed to be sent across the link.

However this manual workaround is not scalable or supportable into BAU, and the project is currently analysing the technical solution to provide this data after trials within the NIC project, when the service moves to a BAU deployment.

Non-Functional Testing (NFT)

The previous sections have covered integration and functionality testing as demonstrated in the FAT, SIT and UAT test stages. This final section of the test report covers non-functional testing, to ensures that the DERMS and associated integrated systems continue to function if any part of the IT infrastructure fails or stops. NFT is conducted on the pre-production environment. The tests are linked to the non-functional requirements in the following areas

- No data loss
- Data integrity
- Application recoverability
- Server and Communication Failure recoverability
- Backup restore of the environment and application
- Data volume capacity
- User privileges (Admin, Super User)
- Schedule housekeeping – automated jobs, error logs, audit logs.
- Penetration Testing
- Performance

A detailed NFT test schedule was developed with the specific NFT tests and the responsible owners is detailed below.

Table 5: List of NFT Tests

NFT TESTS	Responsible partner/contractor
Application Recoverability	CGI, UKPN, ZIV
Backup Restore of PP environment and application	CGI, UKPN, ZIV
Configuration Management	CGI, UKPN, ZIV
Compatibility	CGI, UKPN, ZIV, NGESO
Compliance	CGI, UKPN, ZIV, NGESO
Data Integrity	CGI, UKPN, ZIV, NGESO
Data volume capacity	CGI, UKPN, ZIV
Disaster Recovery	CGI, UKPN, ZIV
Latency	CGI, UKPN, ZIV
No data loss	CGI, UKPN, ZIV
Penetration testing	iOActive
Performance – stress & load	CGI, UKPN, ZIV
Reliability	CGI, UKPN, ZIV
Repeatability	CGI, UKPN, ZIV, NGESO
Scalability	CGI, UKPN, ZIV
Security	CGI, UKPN, ZIV
Server and Communication Failure	UKPN, ZIV
Supportability	CGI, UKPN, ZIV
Usability	CGI, UKPN, ZIV
User privileges	CGI, UKPN, ZIV

The project has different NFT requirements for the different trial stages – for example the initial deployment of DERMS for commissioning and mandatory trials has reduced NFT requirements, not including the automatic failover described in the next section. The DERMS Interim Solution also has lower thresholds for data volume and performance stress testing.

Failover capability – for optional trials and for DERMS Full Solution.

As an example of the additional NFT requirements being delivered later in the project, there will be automatic failover of DERMS, PowerOn and the associated ICCP links. This means that DERMS may failover between the primary control room site in Ipswich, the backup site in Bury St Edmunds, or even for DERMS and PowerOn to continue operating on different sites. Manual failover was demonstrated at the end of September 2019, and since then a 'node health indicator' has been implemented to monitor which DERMS and PowerOn node (site) is active at any time, to manage the failover and backups.

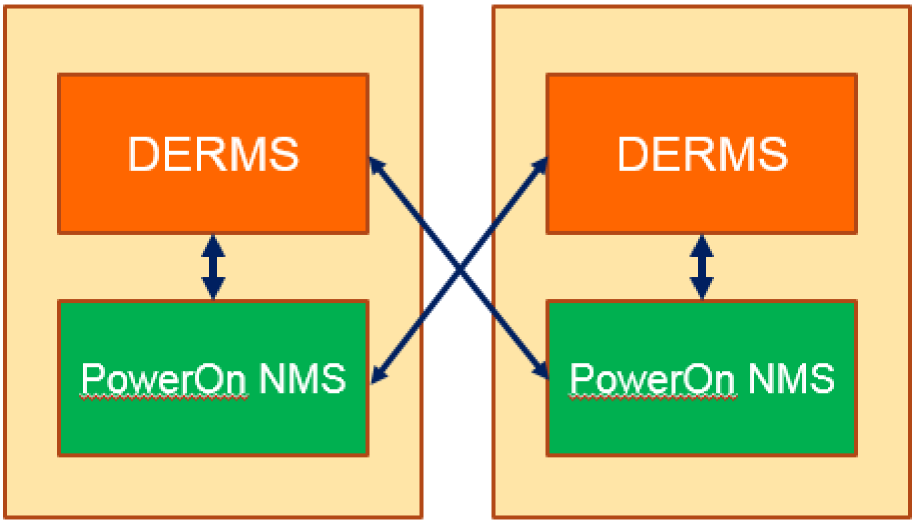


Figure 28: DERMS Failover arrangement

Test report as at 18 November 2019

In Autumn 2019, the project decided to focus successively on delivery of three levels of requirements – to support DER commissioning/ Mandatory trials (Interim Solution), to support Optional trials (Interim Solution) and finally to support the Full Solution trials. The test effort was thus refocused to support system delivery from that perspective.

Testing milestones achieved are shown below (see final section of this report for how they link to the project GO criteria for Mandatory Trials).

Table 6: Key test milestones

Environment	Test type	Test
Completed (passed)		
Azure	FAT	DERMS Interim Solution
Laboratory	FAT	RTU logic FAT – GE site, Rugby
Laboratory/ pre-prod	SIT	PowerOn-RTU-DER controller –UK Power Networks Nelson St and pre-prod – five controllers
Pre-prod	SIT	NGIEMS-PowerOn-DERMS – voltage signal for Ninfield GSP
Pre-prod	SIT/UAT	Connectivity test - PAS-IIB-DERMS
In progress		
Laboratory	SAT	RTU logic acceptance testing – UK Power Networks Nelson St (bench test)
Laboratory/ pre-prod	UAT	NGESO-DERMS-ICCP-PowerOn-RTU-DER controller – functionality test demonstrating Mandatory Trial
Pre-prod	SIT/UAT	DERMS Interim solution functionality on multiple DERMS Releases
Laboratory/ pre-prod	SIT/UAT	DERMS-ICCP-PowerOn-RTU-DER controller – end-end integration testing and with DERMS' PAS simulator
Pre-prod	SIT/UAT	Business logic test – PAS-IIB-DERMS
Pre-prod	SIT/UAT	PAS-IIB-DERMS for Interim Solution (optional) – SIT/functional/UAT
Pre-prod	SIT/UAT	Control Engineer acceptance test and alarm verification
Pre-prod	NFT	End-end DERMS-DER controller system for commissioning and Mandatory Trials
Prod	Cutover/OAT	End-end connectivity checks
Prod	NFT	Penetration test (cybersecurity)
Forthcoming		
Prod	Cutover/OAT	Connectivity PAS-IIB-DERMS
Pre-prod	SIT/UAT	Business logic for active power service PAS-IIB-DERMS

Pre-prod	NFT	NFT for Optional trials (Interim Solution) and Full Solution
ZIV's AWS environment then UK Power Networks' Azure	Pre-FAT and FAT	DERMS Full Solution
Pre-prod	SIT/UAT	DERMS Interim Solution (optional trials) and Full Solution
Pre-prod	**NFT**	**DERMS Full Solution**

The detailed SIT/UAT test cases were set out in the SIT/UAT plan, and are repeated in Appendix A of this document. Table 7 indicates outstanding cases which must be run and passed (in additional to the cyber security penetration test) to meet the GO criteria for taking DERMS live for mandatory trials.

Table 7: Progress at 18 November 2019 through the SIT/UAT/NFT test cases for initial DERMS go-live for Mandatory Trials.

	Test cases	Passed/Not needed for Mandatory	Outstanding /Partially Tested/Failed
SIT/UAT	19	11	8
Signals Test	51	42	9
NFT	69	35	34
Total	**139**	**88**	**51**

Completion of NFT requires completion of SIT for the appropriate trial stage, as a pre-requisite. The final stage of NFT is penetration testing, and this test started on 18 November 2019.

DERMS defect status

As at 18 November 2019, extensive testing had identified 227 defects of which 173 had been closed and 52 were still to be resolved, as shown in Figure 29. Of those remaining, there are 13 DERMS defects relevant to the initial deployment of DERMS for DER commissioning and Mandatory trials. A further DERMS release is due to be delivered to UK Power Networks at the end of November to resolve those defects.

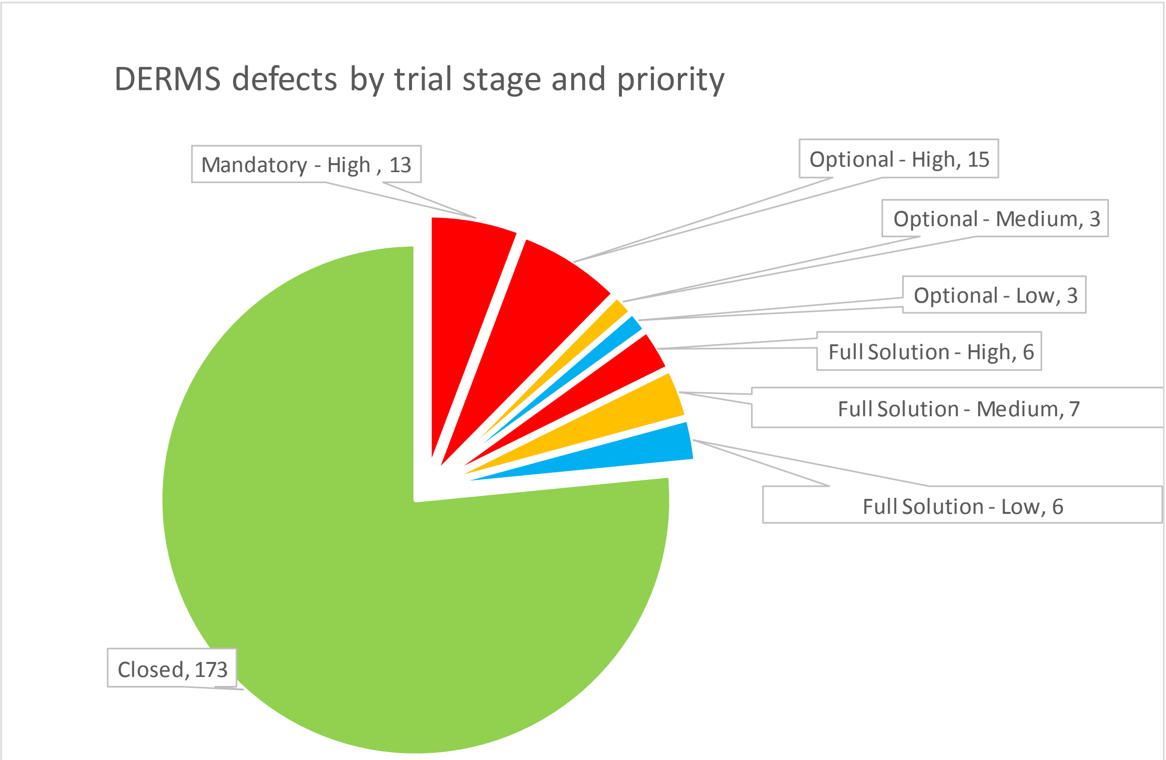


Figure 29: Pie chart of all defects – open and closed

DERMS Full Solution – look ahead

Development has begun on the incremental upgrades to the DERMS Interim Solution which form the DERMS Full Solution.

To date delivery has been demonstrated via workshops and demonstrations in the developers' testing environment. The key components will enter their pre-FAT stage in December 2019, followed by a FAT stage with the software being demonstrated on the UK Power Networks Azure cloud environment.

DERMS Commercial Functionality

DERMS is an automated technical solution developed to support the technical and commercial optimisation and dispatch of DER for Power Potential. This system helps UK Power Networks and NGESO to implement the commercial arrangements agreed for Power Potential and create a new reactive power market for DER including renewable generators.

For the reactive power service, the data submission required from DER will vary across Wave 1 (DERMS interim solution), Wave 2 and Wave 3 (DERMS full solution). Specifically, during Wave 1, DER will only be required to declare their availability and their expected operating level (in MW) per settlement period on a day-ahead basis. No price input is required at this stage.

However, during Wave 2 and Wave 3, DER will be required to submit additional data, as indicated below:

- Availability (Yes/No) per service window,
- Expected operating level (in MW) per settlement period of the window in which the DER is available,
- Availability price (£/Mvar/h) and utilisation price (£/Mvarh) per service window, and
- Maximum reactive range (in Mvar) per service window.

Evidently, this payment structure includes Availability and Utilisation payments and is completely different to the existing current practice implemented through the Obligatory Reactive Power Service (ORPS). The ORPS is a mandatory service for large generators with a utilisation-only payment structure, and therefore there is no tender process.

As for the active power service, the data submission requirements are similar to the ones during Wave 2 and Wave 3 of the reactive power service. To be more precise, DER will need to submit:

- Availability (Yes/No) per service window,
- Maximum Active Power and Minimum Active Power parameters per service window,
- Expected operating level (in MW) per settlement period of the window in which the DER is available, and for the two settlement periods prior to the service window,
  Utilisation price (£/MWh) per service window.

This section focuses on the commercial functionality agreed for the DERMS Full Solution. DERMS calculates an effectiveness score at the GSP for each provider, which is unique to a service window. DERMS also determines the expected reactive range using the expected active power output provided by the DER according to the PQ capabilities chart in schedule 3 of the DER Framework Agreement. The expected reactive range for each settlement period of a service window is subsequently converted into an average expected reactive power range for the service window.

DERMS then collates the information from all DER for each GSP taking into account the effectiveness factors and costs, as well as forecast utilisation of the reactive power service and distribution network safety considerations. Then, DERMS passes the combined information of the VPP (virtual power plant) per GSP to NGESO for bid assessment in the form of a stacked order.

NGESO does not receive DER specific information such as its technical capabilities or individual prices, because DERMS calculates the total cost of the service per GSP and presents it to NGESO as a VPP.

These functionalities are expected to be tested in the pre-FAT stage, but we have closely worked with ZIV through technical queries and worked examples to ensure deliverability.

NGESO procures based on its technical requirement for reactive power service in each service window and assesses the cost of the VPP against the alternative cost to NGESO (i.e. counterfactual cost) of delivering the equivalent service.

With regard to service delivery, DERMS will send a signal to move nominated DER to voltage control mode (i.e. arming) at the start of the designated service window. NGESO according to its technical requirements for reactive power service will issue voltage set-point instructions at the transmission level to DERMS. After receiving these instructions, DERMS will translate them into set-point instructions at the relevant connection voltage level.

DER will be required to inject or absorb reactive power throughout the designated service window, and DERMS will optimise the utilisation of reactive capability on the nominated DER based on their effectiveness factors, utilisation price and available reactive range. NGESO cannot see which individual DER are being dispatched, only the net effect at the distribution – transmission interface[4].

Forecaster

The forecaster was developed by ZIV Automation as part of DERMS. The purpose of the forecaster is to produce forecast results for both demand and DER output, using a combination of historical demand/output data and historical forecast weather data, combined with latest weather forecasts.

The Forecaster Module takes data from the CIM Core Database within DERMS, including the current network configuration, historical data and other data such as weather forecast information (temperature, wind and irradiance data), to generate a forecast for all DER (wind/solar etc.), as well as load and demand on the system. The forecast is generated periodically for the forecast interval and stored in the CIM Core Database, where it can be used by the Future Availability Module for planning, scheduling purposes and for visualisation and reporting by Grid View.

The forecaster module bases its forecasts for demands and generation predominantly on:

- Forecast Weather data received from the MET Office. The weather forecast data is extracted by UK Power Networks via DERMS and stored in the central database.

- Calendar-related variables, such as clock-change, public holidays, seasons etc., which have a significant impact on the forecast profile of demands and of solar DER, e.g. available daylight hours at different times of the year.

- Historical data – Forecaster uses historical data in a training phase, during which the Forecast model is trained to build a predictive model based on a wide range of input parameters. For new DER resources, the CIM Core Database is configured with initial values, which are used by default until real-time data becomes available. As soon as a DER comes online, the Forecaster begins learning from the real-time data that is collected and stored in the CIM Core database. Quickly the default values are modified and the solution becomes more and more accurate.

For example, the Forecaster integrates real-time weather and forecast weather updates with current network loading and historical data to build a forecast for both load and demands that used a mix of actual and historical data to build a reliable forecast. The historical dataset is stored locally within DERMS in the CIM Core database. This dataset is extended over time to provide more data supporting forecasts that are more accurate.

The forecast module does not include planned outage and contingencies in its calculations. Data such as switching schedules and DER plant availability are also integrated into the CIM Data model and are combined with the forecast data in the Future Availability to produce a forecast production schedule.

[4] For further details, please see Market Procedures - https://www.nationalgrideso.com/document/140746/download and Reactive Power Commercial Procedure Wave 2 and Wave 3 – https://www.nationalgrideso.com/document/140786/download

Testing of the forecaster functionality will begin in December 2019 as part of the full solution pre-FAT by ZIV Automation, and will later be confirmed by UK Power Networks and NGESO during on-site FAT testing.

PowerON CIM

The Power Potential project requires an accurate network connectivity model with asset electrical parameters as well as SCADA data that need to resemble the as-built and operational live network for the relevant parts of the UK Power Networks and National Grid networks. The timely availability of all of these data types will allow the Power Potential application to carry out accurate real-time power flow analysis to dispatch active and reactive power services to NGESO.

The GE PowerOn DMS application was selected by UK Power Networks' project design review team as the most suitable source to fulfil this requirement as it already holds the most accurate network connectivity data and real time SCADA data. However, currently there is no supported mechanism in PowerOn to export this data to other applications. An interim solution of XML file export was used by KASM which involves an interface which is no longer supported by GE.

A requirement of the project was for GE to develop the model and SCADA export functionality and to have this exported data be compliant with the IEC CIM standard.

The solution is in two parts

- Develop an automated export functionality in GE PowerOn to export the model and SCADA data to any external applications such as the Power Potential solution.
- The data exchange format is proposed to be based on open standard IEC CIM which will be used to carry out data integration with the Power Potential application.

During the bidding process, several options were considered to cater to the requirement of having a real time model to be used in the Power Potential solution as well as other ANM types of developments. From lessons learned and further investigations, it was decided that PowerOn was the source of the latest updated data of UK Power Networks' network. This information needs to flow to Power Potential automatically without manual intervention from the users to achieve the timings of each service.

The solution selected will adopt an open standard data exchange approach to reduce dependencies on vendors and individual experts with the use of IEC CIM. The IEC CIM is the most widely-adopted standard in the world promoting interoperability within the scope of electricity power systems.

The following high-level work flow depicts how the CIM export functionality will be used to export the network model.

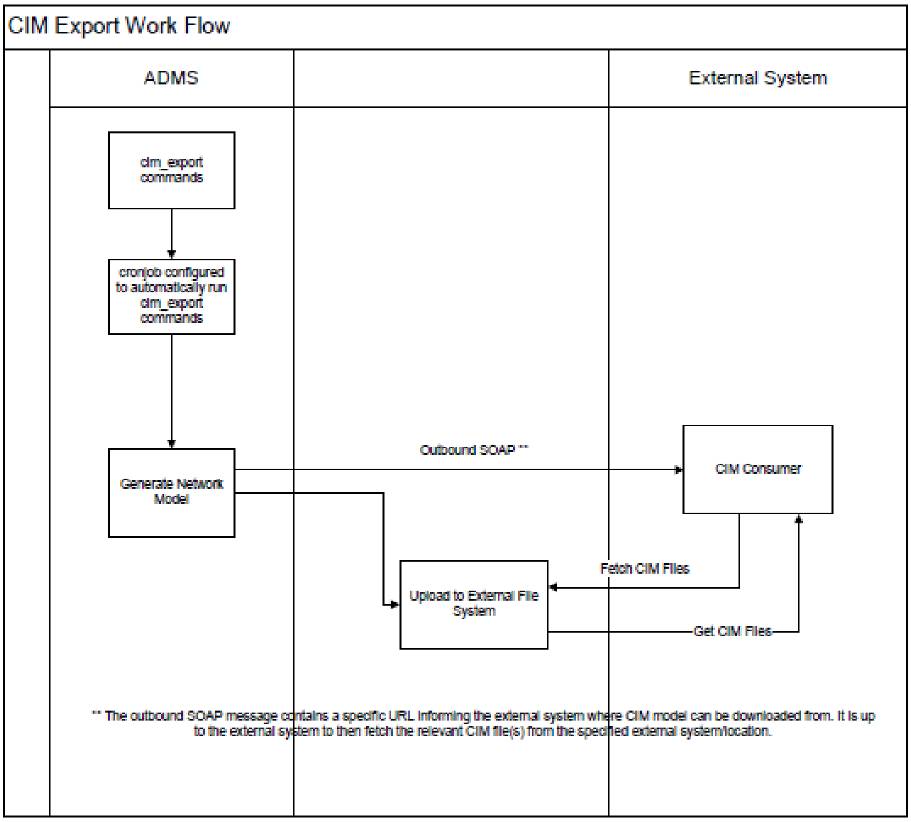


Figure 30: CIM Export work flow

An in-depth analysis and issue resolution process was conducted to identify issues/errors in the CIM extract between GE, UK Power Networks, ZIV and CGI (CIM consultant). The issues were prioritised into those that were critical and needed to be fixed for ZIV consumption and those either not required or for which a workaround could be implemented.

All of the high priority defects/issues were resolved and ZIV were able to confirm:

- that ZIV could use the CIM extract in the DERMS system and
- that the transformed CIM file would provide a convergent loadflow which could be used with the DERMS system.

DNO Outage Planning Inputs (Full Solution)

Unlike the Interim solution, the DERMS full solution is able to assess network security against a network model. The Service Module within DERMS, takes real-time inputs from the SCADA network and other network data to calculate the optimal technical running arrangement for generators and demands which respects network constraints.

The Service Module within DERMS is based on an integrated loadflow engine and optimisation algorithm. Based on the Day Ahead (30 min) production forecast, NGESO will instruct either a MW volume reduction or Voltage target set-point and droop characteristic to be delivered at the 400kV delivery point.

The Service Module will calculate the optimum DER production dispatch that satisfies the service request at the lowest cost. The algorithm issues setpoints to DER and other control equipment required to achieve the stated service level required by NGESO and transmits these to the relevant equipment without breaching any network constraints or breaching DNO system security and quality of supply standards.

Testing of the full solution functionality is planned to start in December 2019 at the pre-factory acceptance test (Pre-FAT) by ZIV Automation and later confirmed by UK Power Networks and NGESO during on-site FAT testing.

3. Customer Readiness

Customer Journey and Technical Readiness Assessment

Power Potential recruitment to date – customer journey

To date, the project team are actively engaging and assisting five companies who are keen to participate. Each customer is a different step of the journey to readiness for trials. Below is a roadmap setting out the journey:

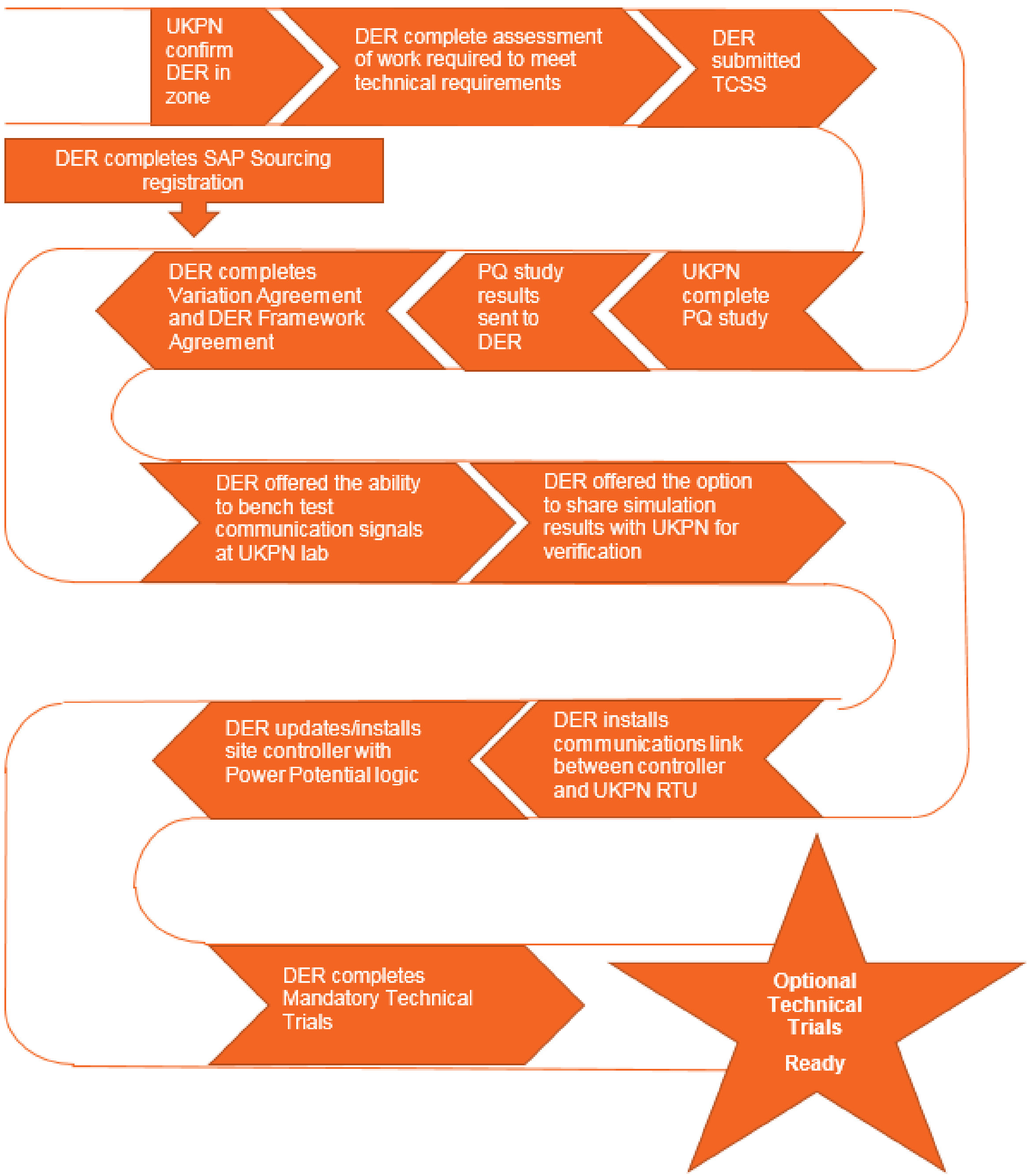


Figure 31: Customer journey to participation

Project resource

UK Power Networks recruited a DER Relationship Manager in January 2018 to assist Workstream 2 (Commercial) with recruitment and help DER prepare for their journey to trials. The role provides interested parties with a single point of contact to respond to email enquiries, arrange meetings and own the relationship with the customer. Including emails and meetings, there have been more than 2000 customer interactions on the project so far.

The project team produced a contact sheet to introduce the team and respective roles. The sheet helps steer DER to the project's account managers to ensure the relevant team member addresses enquiries.

DER meetings

To date, the project team have hosted 123 DER meetings, talking with 208 interested participants.

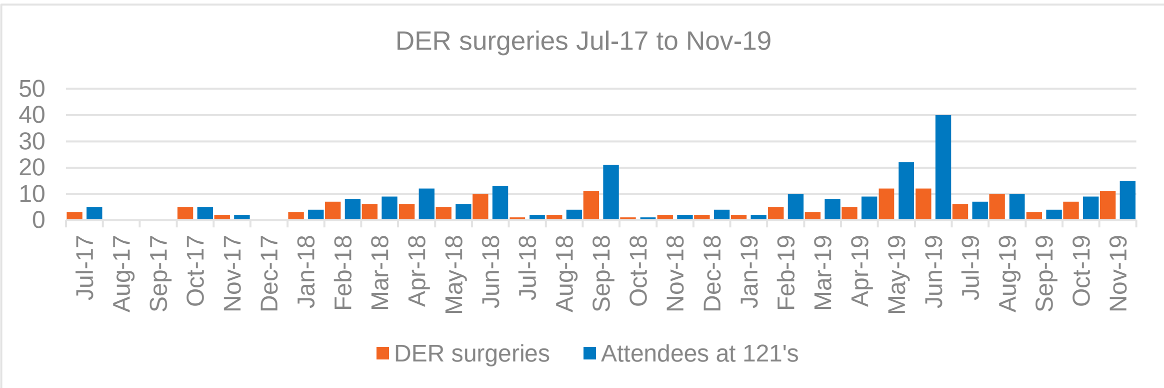


Figure 32: DER meetings Jul-17 to Nov-19

DER webinars

The project team hosted four webinars to provide DER with an opportunity to hear how the service will be run from a technical and commercial perspective:

- 21 September 2017, 171 registered
- 29 January 2018, 166 registered, 30 joined 18% take up
- 26 March 2018, 83 registered, 37 joined 22% take up
- 16 May 2018, 49 registered, 15 joined 30% take up

The presentations and transcripts from the webinars were published to the project website to allow those who were unable to join the webinar the opportunity to review the slides and contact the project team with any questions.

Regional Market Advisory Panel (RMAP)

The RMAP was formed in February 2018 to provide a conduit for DER (both trial participants and those interested in future development of the service), government (BEIS), regulator (Ofgem) and consists of an independent chair. The panel's Terms of Reference and meeting minutes are on the project's website. The RMAP has met eight times.

DER Framework Agreement & Market Procedures

The initial DER Framework Agreement along with the Market Procedures document were published in May 2018 for consultation by the DER. The project team were keen to hear DER views on the contractual terms, payment structures and the appropriate £/MWh payment for the active power service for the Mandatory Technical Trial. Four formal responses were received and the consultation responses[5] were shared with the project's mailing list 5 July 2018 and published on the project's website. The following action was noted by the project team:

- DER wanted the opportunity to review the terms of the contract following completion of Wave 1 trials to allow them to consider previously unforeseen factors
- The project team agreed with this approach as it would aid project learning and help steer the future waves

UK Power Networks' project mailbox

Whilst the initial project mailbox (box.powerpotential1@nationalgrid.com) was created at the beginning of the project, this was hosted on the National Grid ESO server. To enable UK Power Networks to receive the DER enquiries at the same time, a new mailbox was created. This ensured enquiries were captured, tracked and handled in a smooth manner.

Criteria for participation

The criteria for participation was set as:

- Electrically connected to one of four Grid Supply Points (GSPs) with the South Eastern region of UK Power Networks: Bolney, Ninfield, Sellindge & Canterbury North
- Ideally, connected at 33kV or above for most effectiveness
- With a capacity of ≥ 1MW
- A requirement to be able to shift 90% from full lead to full lag <2s, 100% in 5s

The project team produced the document 'A Guide to Participating' to assist DER in determining the initial technical requirements.

Eligibility to participate

The first step of the customer journey was for UK Power Networks' DER Relationship Manager to check if the interested DER was electrically connected to one of the four GSPs. DER provided UK Power Networks with their export Meter Point Administration Number (MPAN) which was checked against the Income Services database to establish the DER Point of Connection. The next step was to review the UK Power Networks PowerOn system (the network management system) configuration, to check the flow of electricity under intact network conditions had some effectiveness at one of the four GSPs.

[5] https://www.nationalgrideso.com/document/118821/download

Technical Characteristics Submission Spreadsheet (TCSS)

The next step was for DER to understand the capability of their plant to deliver and absorb additional reactive power beyond their current daily plant operations.

The project team created a Technical Characteristics Submission Spreadsheet to understand the plants present capabilities.

The project team began direct discussion with four types of generators:

- Energy storage
- Photovoltaic
- Wind
- Synchronous

The technical members of the team assisted DER to complete the submission and reviewed the contents, identifying any limitations and providing suggestions to overcome any barriers.

UK Power Networks' Connection Agreement

The DER Connection Agreement stipulates the characteristics of supply, connection point(s), MPANs, commencement date of agreement, Maximum Import Capacity (kVA) and Maximum Export Capacity (kVA) to UK Power Networks' South Eastern network.

The DER Engagement Manager liaised with the UK Power Networks Income Services team to obtain a copy of the DER Connection Agreement so that safe operating limits could be considered when completing the P-Q desktop study.

PQ study

UK Power Networks performed the steps outlined in the found in the Network Security Assessment section for each DER who was confirmed as electrically-connected to one of the trial GSPs, met the criteria to participation and submitted a TCSS.

UK Power Networks completed assessments to determine the necessary limitations that should be applied to a DER unit to prevent overloading or out-of-range voltages on the distribution network. The following tasks were performed:

1. Assessment of equipment's thermal loading, operating voltages and step voltage changes when the distribution network is in its fully intact configuration
2. Development of PQ capability curves for each DER unit to prevent loading and voltage limits being exceeded on the distribution network

As part of their registration for the Power Potential project, DER needed to submit their PQ capabilities charts. These charts indicate for a given active power output (expressed in MW) the range of reactive power that will be made available (expressed in Mvar). PQ capabilities charts have to be defined at the point of connection for non-synchronous DER and at the generator terminals for synchronous DER.

UK Power Networks reviewed these submissions and discussed with DER any limitations on these charts related to their Connection Agreement for the relevant sites. UK Power Networks is committed to operate a safe, reliable and cost-effective network and, therefore, it needs to assess any potential impact on its network because of the new operational circumstances of the participating sites.

The assessment undertaken by UK Power Networks combined the PQ capabilities charts offered by DER, the limitations of their Connection Agreement, and a sensitivity analysis on forecast load conditions with the requirement to keep the network intact. UK Power Networks also sought independent review of its assessment from experienced technical consultants who verified the outputs of the PQ capabilities charts' analysis.

As a result, the combined PQ capabilities charts were included in Schedule 3 of the DER Framework Agreement and will be verified through commissioning testing.

In case of PQ capabilities charts' restrictions, DERMS will be provided with what DER offered as their max PQ range. In this way, DERMS will be able to quantify as a project learning the potential service lost by these restrictions, which will enable UK Power Networks and NGESO to further develop and improve future reactive power services.

Variation Agreement relating to a Connection Agreement

The DERs' Connection Agreement limited the amount of reactive power the DER was allowed to import and export to the UK Power Networks network. Upon completion of the P-Q study, where safe operating limits were established, UK Power Networks was able to extend the reactive power range on offer to the DER. A variation to the DERs' existing Connection Agreement was created to formally allow the DER to extend their reactive power capability for the duration of the Power Potential trials.

Technical Readiness – communication with the DER controller

One of the Power Potential project's technical requirements is for DER to communicate to UK Power Networks via Distribution Network Protocol (DNP3). This protocol is widely used within the utilities industry and is also used by UK Power Networks for its SCADA system. Upon speaking to potential participants it was soon realised that all DER, where a controller was already in use, were currently using the Modbus protocol at their site. This meant that in order to participate DER needed to check if their current site controller was compatible with DNP3. Some DER were required to purchase a DNP3 module, whilst others had bespoke equipment which required coding. More information can be found in the PowerOn and RTU Logic Integration section – this section covers the customer readiness perspective

Lab testing

Early on, UK Power Networks recognised the need for DER to be offered additional help with configuring their controllers with DNP3. There are multiple controllers available for generators to choose from, some of which are not compatible with DNP3, unless a converter is purchased. Prior to scheduling a lab test with DER, assessment calls were arranged with the project's Technical Integration Lead. The assessment provided UK Power Networks with specification details relating to DER controllers and the DER an opportunity to ask questions in preparation for bench testing.

DER were advised to use software to simulate the signal of the master (RTU) to the slave (DER controller). The Technical Integration Lead offered to review the DER simulation results prior to the lab visit. This step proved invaluable, saving both the DER and UK Power Networks time and effort and identify potential code errors which could be resolved in advance of bench testing.

UK Power Networks hosted four DER and tested five controllers at its laboratory in London. The first DER visited in April 2019 and the final test was completed 14 August 2019. This was a key activity to de-risk the integration testing as part on site commissioning.

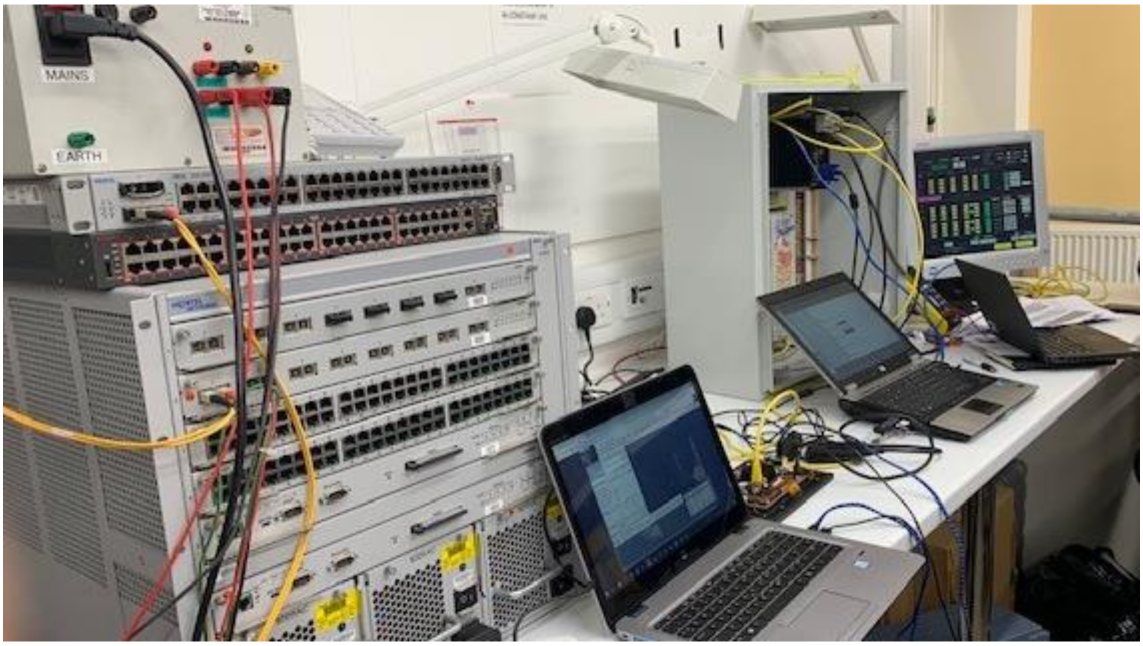


Figure 33: Laboratory testing environment

Communications link

It is the DERs' responsibility to procure and install the communications link between their controller and the UK Power Networks RTU, see Figure 34 below. The communication path differed between running internally within one building (building shared between DER and UK Power Networks) to between buildings. Whilst it was the DER responsibility to install the cable, UK Power Networks were required to witness delivery of the communication end into the UK Power Networks switchroom.

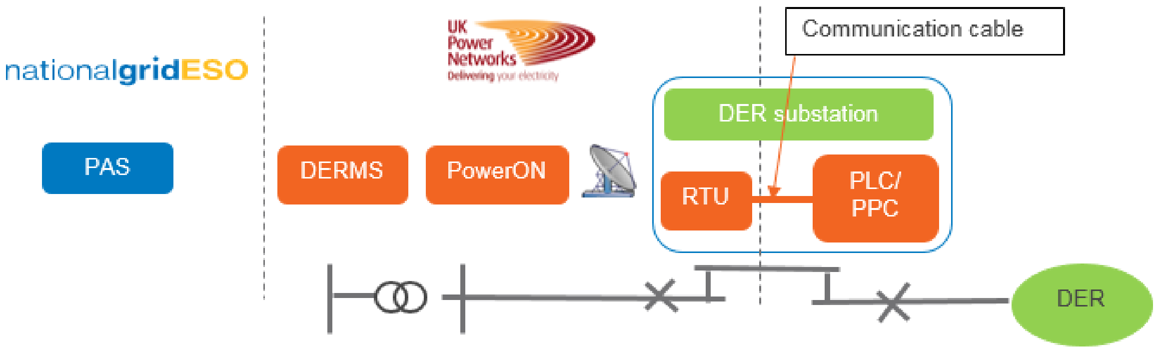


Figure 34: Communications link focussing on DER substation

Power Quality Meter (PQM) data

Currently UK Power Networks' parameters (voltage, active and reactive power, current etc.) are measured using analogue transducers, which feed the data to PowerOn for control engineers to monitor the status of the network.

As part of continuous improvement, Power Quality Meters (PQM) are being trialled at selected sites across UK Power Networks, including at the DER points of connection associated with Power Potential participants. These meters are able to provide greater accuracy and faster sample rates than the existing analogue units, as required by DERMS, therefore, during the RTU update work the

PQMs will be configured to send data to PowerOn in place of the existing units for the purposes of the trials.

Site-based pre commissioning

The project has taken a staged approach to commissioning.

- Stage 1 – Pre Commissioning involves testing between RTU-DER, then PowerOn-RTU-DER, but not including DERMS.

- Stage 2 – Full Commissioning involves DERMS-PowerOn-RTU-DER, and can only happen once DERMS is live – this may involve a second visit for those DER that have already undergone pre-commissioning.

The final site sign-off will be with the second stage, although the project team consider that the vast majority of the work will be in the PowerOn-RTU-DER stage, and DERMS-PowerOn integration will already have been proven in the test system. Therefore once Stage 1 has successfully completed, Stage 2 should be rapidly delivered.

Proceeding with Stage 1 would allow UK Power Networks and the DER to move forward off the starting blocks, and progress through the commissioning process (and identify any early issues) while DERMS completes its remaining non-functional tests and goes through its cutover process to a live operational system. However, some DER customers have expressed a preference to complete commissioning in one visit.

Site-based pre-commissioning (Stage 1) began 13-14 November with one customer site, and successfully demonstrated RTU-DER integration. However due to RTU hardware issues at the site, full PowerOn-RTU integration was not proven, and a return visit is required to complete integration with PowerOn.

The Full DER commissioning approach is documented in a DER commissioning test procedure (UK Power Networks internal) and DER Test Specification. Full commissioning is being scheduled for customers in December 2019 and January 2020.

DER recruitment journey and service readiness

The project team has actively encouraged participation from varied technology types. This included PV power plants, wind farms, synchronous generators, and battery storage. This will ensure sufficient learning from each technology type is captured to determine their contribution to providing voltage support to the transmission system operator. The project's ambition is to access new sources of reactive power for system services and learning from the trials to see how to translate into a business as usual approach, which needs to be aligned with NGESO reactive market development.

Figure 39 details the number of sites actively engaging across various technology types during the project. Not all of them will go on to participate in the project trials however their contribution to date has allowed the project team to capture valuable learning on the process to participation, technical and commercial challenges. Although the figure highlights that the engagement and interest received from solar providers have been significant, this does not translate into a direct project participation of many solar players. The project reached an important milestone with one solar provider who demonstrate technical capability to provide voltage control. The test was coordinated with UK Power Networks control engineers who monitored to ensure network safety and reliability with no adverse customer impact. National Grid ESO confirmed this is the first night time grid support service from a solar asset in the UK. Battery storage systems have, in general, showed a strong commercial appetite to deliver reactive power, getting ready for future system needs.

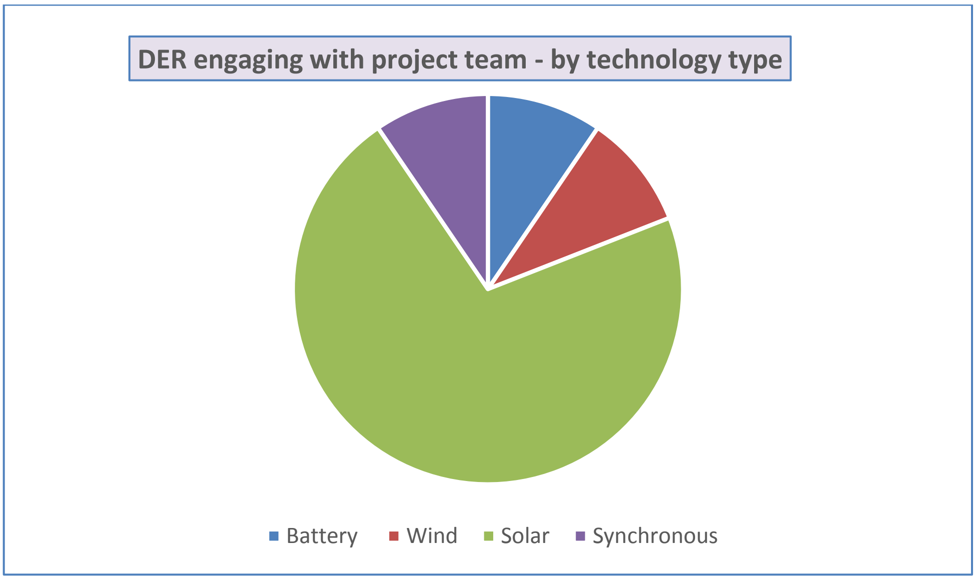


Figure 35 – Overview of DER engagement by technology type – not representative of final DER participants

During the engagement process to date, the project team has discovered that the complexity of integration is dependent of technology type, age and the existing monitoring and control systems. In the following section the team has captured some of the challenges, concerns and areas that require further consideration specific to the various technology types and their readiness to provide a reactive power service.

Learning and challenges for each technology type: DER feedback

Table 8 captures the main learning gathered from DER discussions and the main challenges associated to each technology type to participate in the Power Potential reactive power service.

As a recap, the DER technical requirements (functional and non-functional) have been established in the DER Technical Requirements.

This highlights both communication requirements and control performance requirements for DER. From a functional perspective, the main aspect for the DER to fulfil is to be able to provide dynamic voltage support by being controlled in voltage droop control mode. This will allow them to provide reactive power in line with local voltage variations and received voltage setpoints from the DERMS control system. Non-synchronous participants (inverter based) have proven able to meet this requirement, but concerns have been highlighted for synchronous participants when following this approach as it might affect the plant stability and security. Specific details are captured below:

Table 8: Key participation issues identified for different technology types

	Notes/issues/concerns highlighted	Comments
Battery/ Storage	• Battery technology is technically ready to deliver a reactive service and has the capability to do so (inverters able to operate in the full PQ quadrant). • There is a concern around degradation while providing a reactive power service.	• It was expected that degradation could become a stronger concern in providing a reactive service over the long term. • It was considered essential that the DER monitor those factors which drive degradation during the trial to support project learning.

	Notes/issues/concerns highlighted	Comments
Wind	• Technology has proven to be ready for the service, especially when reactive equipment is already in place at site but also with the reactive power being produced directly at the wind turbine level. • This technology raised a concern about exceeding MVA limits when providing active and reactive power simultaneously (in the Connection Agreement MVA limit is equal to MW limit). This is applicable to other technology types. • Technology has raised a concern around potential losses when providing reactive power.	• DERMS only send signals to the DER for them to operate within secure PQ limits, in line with their connection agreement (see the variation to the connection for the duration of the trials). • While higher currents can lead to higher losses, these are not expected to be significant. In addition, DER will be compensated for their production at their point of connection.
STATCOM	• This equipment can directly meet Power Potential service requirements with minor control upgrades. • It has been pointed that the interaction of STATCOM with transformer tap changers is something to monitor during trials. • There is a concern that their operation may create network voltages to go outside statutory limits. This is applicable to other technology types.	• It has been proposed to operate part of the trials at a fixed tap position to better understand and capture the interaction between schemes. • It is DERMS task to ensure that the DER operate within secure limits and without detriment to the distribution network.
Solar	• Some providers are not able to provide reactive power during the night due to inverter restrictions. However, some others have the capability to do so and provide reactive power at zero active power output. • There is a concern related to this technology about overload of transformer while operating with high reactive currents (operation close to zero power factor can lead to higher currents, which in turn lead to higher losses and heat). • In general, there is uncertainty about the plant reactive power capabilities as usually operated at unity power factor. • Changes in inverters to enable further reactive power capabilities proves to be expensive.	• There is a big link between the inverter technology and their capability to provide reactive power at different active power outputs. The project has no barrier in accommodating DER participation for certain times of the day only. Ultimately, solar DER capabilities to provide the service will be validated during the trials. • On the transformer overload concern, it has been agreed to limit the reactive power outputs to operate between secure reactive levels if this is a concern for the DER.

	Notes/issues/concerns highlighted	Comments
Synchronous Plant	• It is not certain that this technology can provide reactive response by the generator AVR and how that interacts with taps of generator step-down transformer. • There is a concern of the impact of sudden voltage changes on specific plant equipment (trip of inductive loads). • There is a concern of not being operated to maintain a certain power factor and how receiving voltage set-point signals can affect the plant operation. • Synchronous plants are technically more complicated than other providers due to the need for plant upgrades (AVR, PLC, controller) to accept dynamic setpoints for the AVR. • The operating instruction under Power Potential is different to the one received by transmission connected generators to provide Mvars.	• The existing Power Potential voltage control approach is not suitable for synchronous plant as it compromises security of the AVR control system; risks stability of the generator if target set point is too low and an upgrade to the AVR is required, at significant costs, to receive voltage set point. • Alternative approaches continue to be investigated to determine an appropriate approach to facilitate a safe and economic despatch of synchronous plant.
Other Issues Identified	• Technical difficulties to integrate sites connected at 11kV were identified • Impact/warranty on the inverters and transformers and other equipment while providing reactive power services concerns participants. • The cyber security of IT solution is a concern.	• The DNO identified a cheaper alternative solution for the equipment required to integrate site at 11kV if a participant at this connection level comes along. • Strong security measures have been established around the DERMS solution as it is connected to critical network infrastructure and system. • Cyber security assurance was provided along with UK Power Networks information security standard

DERMS DER Web interface

Each DER participating in the Power Potential services will have access to a DERMS Web Interface in which it can place bid prices for the active and/or reactive power services and monitor technical data and parameters.

Different DER user screens have been developed in DERMS for each wave of the trial to gather and display DER data. These interfaces can be grouped as: DER day-ahead data submission screens (for Wave 1 and for Wave 2), DER current day monitoring screens and DER technical parameter screens.

The DER dashboards have been fully tested in the simulation (Azure) environment, apart from the DER day-ahead data submission screens needed for Wave 2, which only come into service with the DERMS Full Solution.

DERMS includes specific Web Interfaces to DER that will provide each of them with a web portal to communicate its interest in participating in the Power Potential services. The DERMS, which will be hosted and operated by UK Power Networks, acts as the intermediary between National Grid ESO and participating DER.

The DERMS Web Interface is a web-based user interface that will allow DER to submit data indicating their service parameters and availability to participate in the various waves of the trial. Several dashboards have been developed to allow for DER day-ahead data submission (including bulk data upload for Wave 1), DER current day monitoring and capture of DER technical parameters.

Figure 36 outlines the interactions for the reactive and active power service through DERMS. This process is the same for Wave 1 trials with the DERMS Interim Solution and for Wave 2 trials with the DERMS Full Solution. The only difference is that the DER commercial parameters inputs are deactivated in Wave 1 and the NGESO procurement is automatic. The active power service only comes into play in Wave 2.

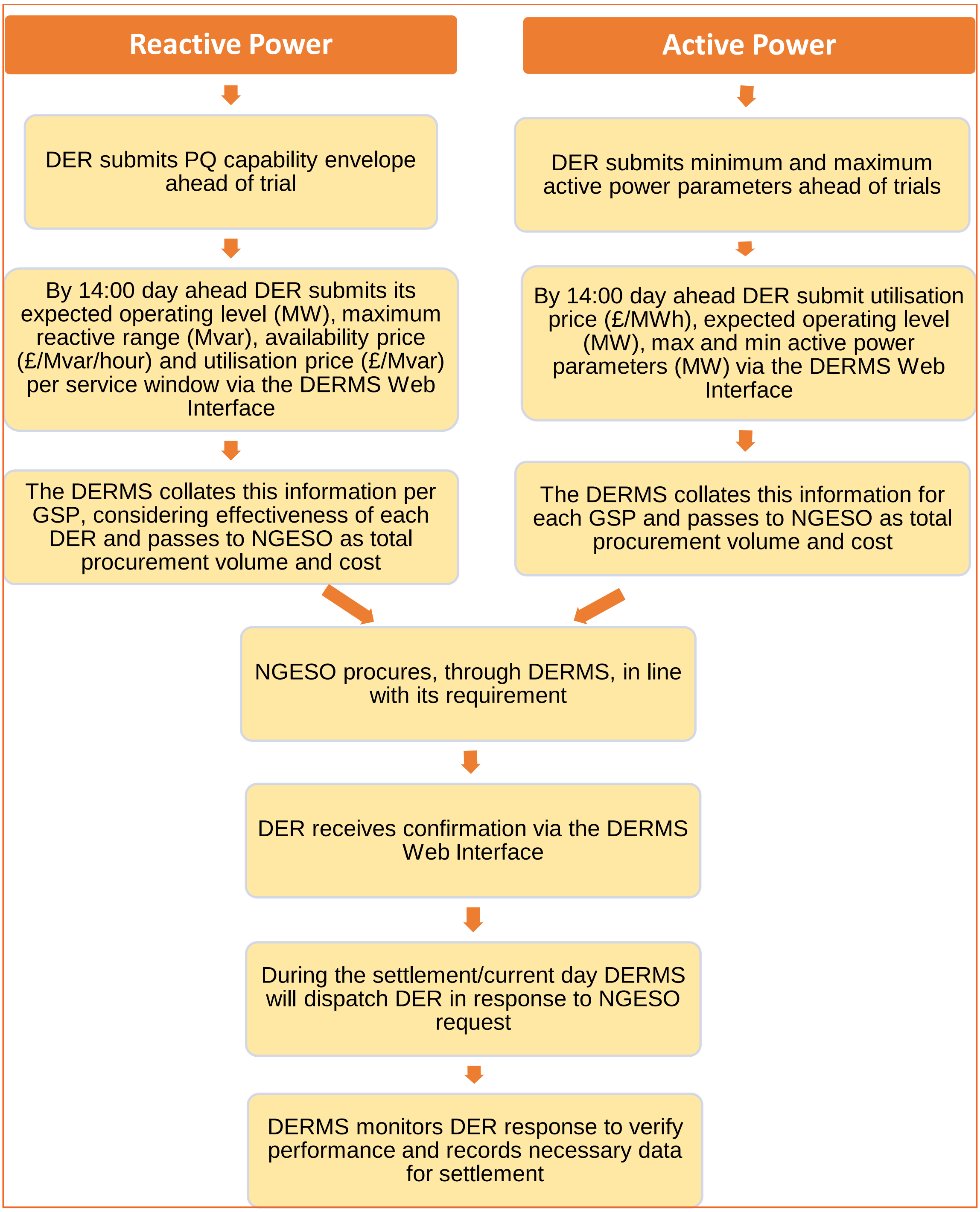


Figure 36: DER process to participate in the Power Potential services

DER Data submission screens (Day-Ahead)

For the reactive power service, the data submission required from DER will vary across Wave 1 (technical learning) and Wave 2 trials (technical and commercial learning). During Wave 1 DER will only be required to input their expected operating level (in MW) and availability (Yes/No) per settlement period on a day-ahead basis. A DER Mvar range will be automatically generated from the information they submitted in the reactive power capability table. No price input is required at this stage. However, during the Wave 2 commercial trials (which are more geared towards commercial learning), DER will be required to submit additional data, as indicated below:

- Availability (Yes/No) per settlement window.
- Expected operating level (in MW) per settlement period of the window in which the DER is available.
- Availability price (£/Mvar/h) and utilisation price (£/Mvarh) per service window.
- Maximum reactive range (in Mvar) per service window.

For the active power service, the data submission required from DER only applies to Wave 2. DER will need to submit the following parameters:

- Availability (Yes/No) per service window.
- Expected operating level (in MW) per settlement period of the window in which the DER is available, and for the two settlement periods prior to that window.
- Utilisation price (£/MWh) per service window.
- Maximum active power and minimum active power (in MW) per service window.

DERMS Web Interface for DER submissions in Wave 1 (Day-Ahead)

Figure 37 shows the DER user interface for Wave 1 future day submissions, for a generic DER. This interface also allows a bulk data upload for the whole duration of the Wave 1 trials.

Figure 37: DER user interface for participation and data submission in Wave 1.

Data entry at different periods have been tested and validated for different DER in a simulation (Azure) environment. Data entries are disabled after 14:00 and re-opened at 23:00 for the next day.

DERMS Web Interface for DER submissions in Wave 2 (Day-Ahead)

This screen enables the 'hidden' commercial features of the Wave 1 data submission screens to allow DER to submit commercial values in relation with their service participation in Wave 2, as described above.

The DER data submission screen is fully developed and tested for Wave 1 but not for Wave 2, which will only be tested and put in service for the Full Solution.

DER Real-time monitoring screens (Current Day)

The DERMS will also provide the ability to monitor the DER performance during the delivery day (current day). This provides a view of current day activities in terms DER declared availability, scheduled production and the real time active and reactive power of the plant.

Figure 38 shows the different displays available for this current day screen.

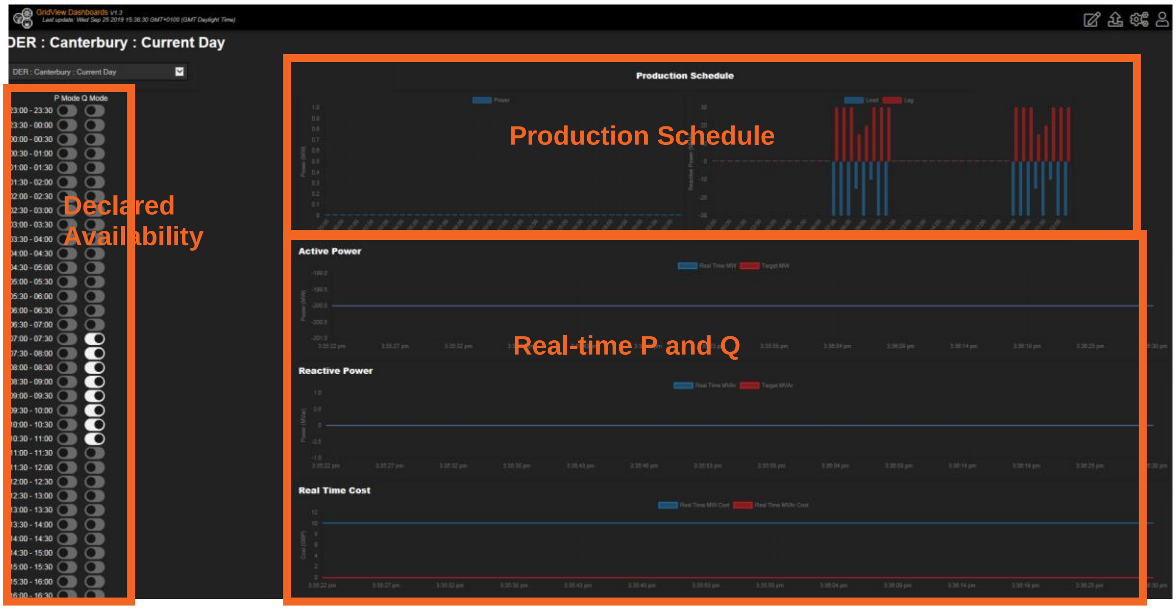


Figure 38: DER current-day user interface

Data visualisation at different periods has been tested and validated for different DER in a simulation (Azure) environment.

DER Technical data screen

These screens will contain the technical capability data of the plant as captured in Schedule 3 of the DER Framework Agreement, Figure 39 as shown in for a generic DER. These parameters are agreed as part of the contractual arrangements with the DER and will be visible but not editable via this screen. However, in Wave 2 and 3, DER have the option to reduce the reactive range they offer at the 'day ahead' stage.

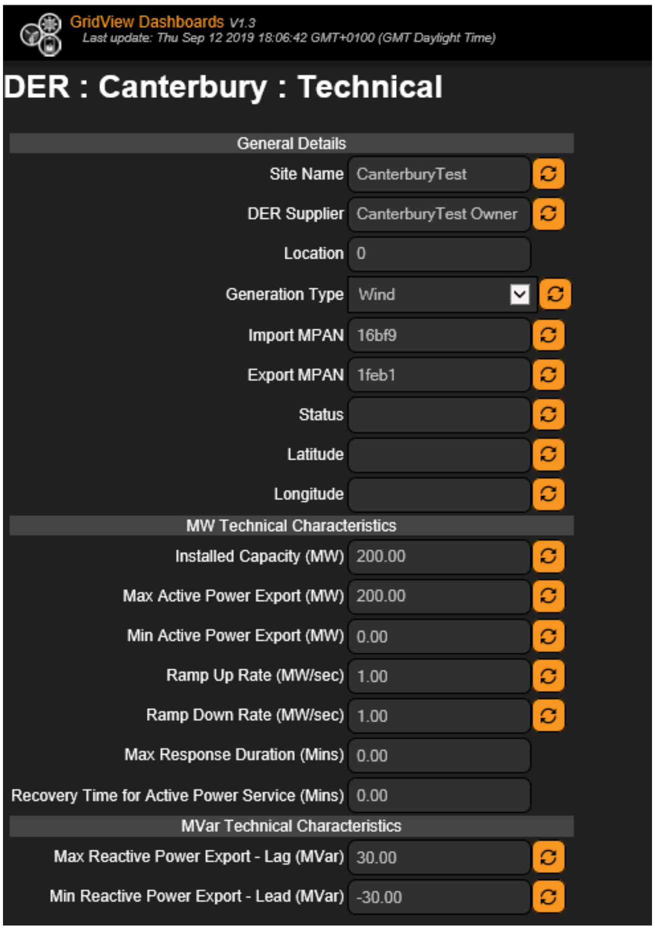


Figure 39: DER Technical parameters interface

Data entry has been tested and validated for the potential DER participants in a simulation (Azure) and then pre-prod environment. This data is input into DERMS by the project team based on the DER Framework Agreement and cannot be edited by the DER.

These technical parameters are evaluated together with the DER active and reactive power limits reflected by their PQ capability curves, as shown in Figure 40 for a generic DER. The table on the left shows the data entry which generates the PQ capability curve on the right. PQ curves are restricted to ensure network security as described earlier in this chapter.

Creation of PQ curves using this interface have been tested and validated for the potential DER participants in a simulation (Azure) environment. This data is input into DERMS by the project team and cannot be edited by the DER.

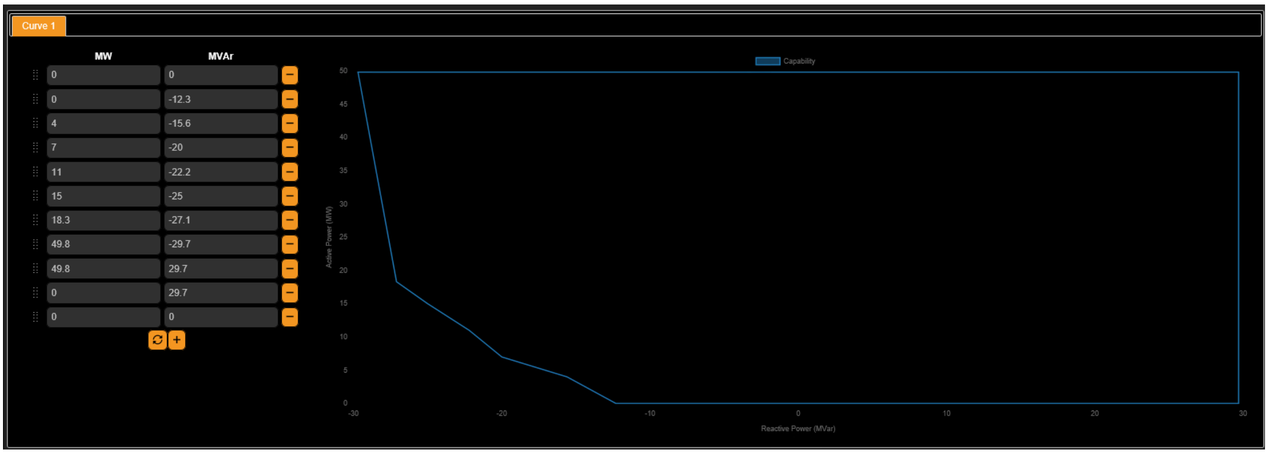


Figure 40: Simplistic DER PQ technical capability curve

DER Commercial Readiness

DER Framework Agreement – Summary of changes

The project team has closely engaged and is still engaging with all DER that expressed their interest for the Power Potential project by using multiple ways to facilitate their understanding and participation in this new market.

In order to achieve this, UK Power Networks and NGESO produced a summary that acts as an informal introduction to the DER Framework Agreement. This includes the main parts of the Agreement and helps DER gain a good insight into the participation requirements.

As part of the project team's engagement with DER and interested stakeholder, it identified that some clauses of the DER Framework Agreement required amendment and/or further clarification. Specifically:

- the "DER Technical Requirements" document has been updated and the relevant reference has been incorporated into the DER Framework Agreement,
- UK Power Networks and NGESO have agreed that UK Power Networks may pay the participating DER any reasonable third party costs and expenses incurred in connection with the commissioning testing even if these tests are not complete,
- the project team has clarified that during the Mandatory Technical Trials and/or the Optional Technical Trials, any reference to issuing a Voltage Arming Instruction, an Active Power Instruction, and Voltage Set Point Instruction can take place not only through DERMS, but also through any other automated system available to UK Power Networks,
- outdated deadlines and references to specific dates have been updated to reflect the revised trial start date and the updated trials calendar,
- UK Power Networks has clarified that it will act reasonably when exercising its powers for retesting DER or investigating their compliance to the DER Framework Agreement,
- the reference to 2,520 hours of opportunity during wave 1 Optional Technical Trials has been changed to a reference to 1,358 hours. The table that explains the participation payments per range of availability hours has also been updated,
- the definition of "Available" has changed to accommodate that a DER unit is capable of providing Reactive Power Response over the Maximum Reactive Range at the Expected Operating Level in one or more Settlement Periods in a Service Window,
- a definition for Permitted Third Parties to the DER Framework Agreement has been added.

Through this continuous engagement with DER and the wider industry, UK Power Networks and NGESO can achieve their ambition to create a new market for reactive power and access new sources for these services, while learning from the trials and implementing the identified changes to the DER Framework Agreement as part of the BAU transition.

DER Connection Agreement

In addition to the Framework Agreement, DER have been asked sign a Variation Agreement to their existing Connection Agreement. This Variation Agreement was required to ensure consistency with Schedule 3 of the DER Framework Agreement and the new PQ capability parameters under which participating DER will be operating during the Power Potential trials.

This was necessary as all users of the distribution network are subject to Distribution Use of System Charges (DUoS), and UK Power Networks have confirmed that the reactive power and excess capacity charges will not be applied to DER when they are providing service under Power Potential. For example, an instruction from DERMS to operate with a power factor less than 0.95 or to exceed the maximum import capacity would be typical examples of circumstances where these charges will not be applied.

Reactive Power Commercial Procedure Wave 2 and 3

This document was published in March 2019 and provides an overview of how Wave 2 and Wave 3 of the Power Potential trial of the commercial reactive power service will work. The document is intended to help potential trial participants understand their potential revenue from the trial and beyond.

It is a commercial procedure document which:

- Sets out the principles that National Grid Electricity System Operator utilises when assessing reactive capability delivered throughout the trial.
- Describes how the Distributed Energy Resources Management System (DERMS) calculation will work and the impact of effectiveness on a provider's cost to National Grid ESO.National Grid ESO commitments.

In Wave 2, the counterfactual cost is based on the long-run cost of investing in alternative transmission network infrastructure to address reactive power requirements. In Wave 3, the counterfactual cost is based on the total cost of other system actions available immediately to NGESO (not including alternative transmission network infrastructure).

Thus, if the total cost of the VPP per service window is lower than the counterfactual cost, it will be accepted and the relevant DER that make up the VPP will be nominated for service delivery up to the defined technical capabilities (i.e. PQ capabilities chart, or a more limited range as defined by DERs during the nomination process). Otherwise, if the total cost of the VPP is more than the counterfactual cost, it will be rejected and DER will not be nominated for service delivery. DERMS will provide unsuccessful DER with a brief explanation for the rejection.

For context of National Grid ESO's recent reactive power requirement, historic utilisation charts had previously been published. Whilst availability may be flat across the day, utilisation volumes will fluctuate. To support DER in assessing their participation in the trial, historic utilisation charts were published on the project website in May 2018.

National Grid ESO's Forward Plan, Product Roadmap for Reactive Power and System Balancing Reports[6] have committed to publishing historic spend by region by Q3 2019. This will allow greater visibility of the cost of managing reactive requirements and the spend on voltage constraints in all regions. The Power Potential project region will be included in this, but it is not expected to be a distinct region.

Finance – settlements

Settlement architecture

When designing a service, a fair and transparent compensation mechanism for the service provider is a key to its attractiveness and success. A settlement methodology for active and reactive power service had been developed in 2018 and can be found in Appendix 2 of the DER Framework Agreement which is available on the project website.

However, in addition to having the methodology, it is critical to deliver the payments on time. Service Level Agreements (SLAs) set out in the DER Framework Agreement require UK Power Networks to produce a Monthly Statement (both for DER and National Grid ESO) on a monthly basis, but not later than eight business days after the end of the Relevant Month (month for which settlement calculations need to be carried out). Even though in the Power Potential trials the number of participants is limited, and, in theory, settlement calculations could have been carried out manually,

[6] Page 17 > Stage 2: Simplification & P18
We will separate out the costs within the MBSS and make it clear when we are procuring active power to access Reactive Power. We will complete this work by the end of Q4 2018/19.

the process needed to be robust enough to be applicable in the future. Therefore, automation of the settlement process is key to the project replicability and business readiness.

It was decided that a settlement solution would be developed in-house by UK Power Networks using Microsoft Warehouse (backend of the Microsoft Power BI tool). The scope of the solution is to produce Monthly Statements which then could be used by designated UK Power Networks employees in the DER payment process. In parallel, National Grid ESO and UK Power Networks jointly developed the format of the Monthly Statement that settlement solution would need to produce. High-level architecture of the solution is shown on the Figure 41:

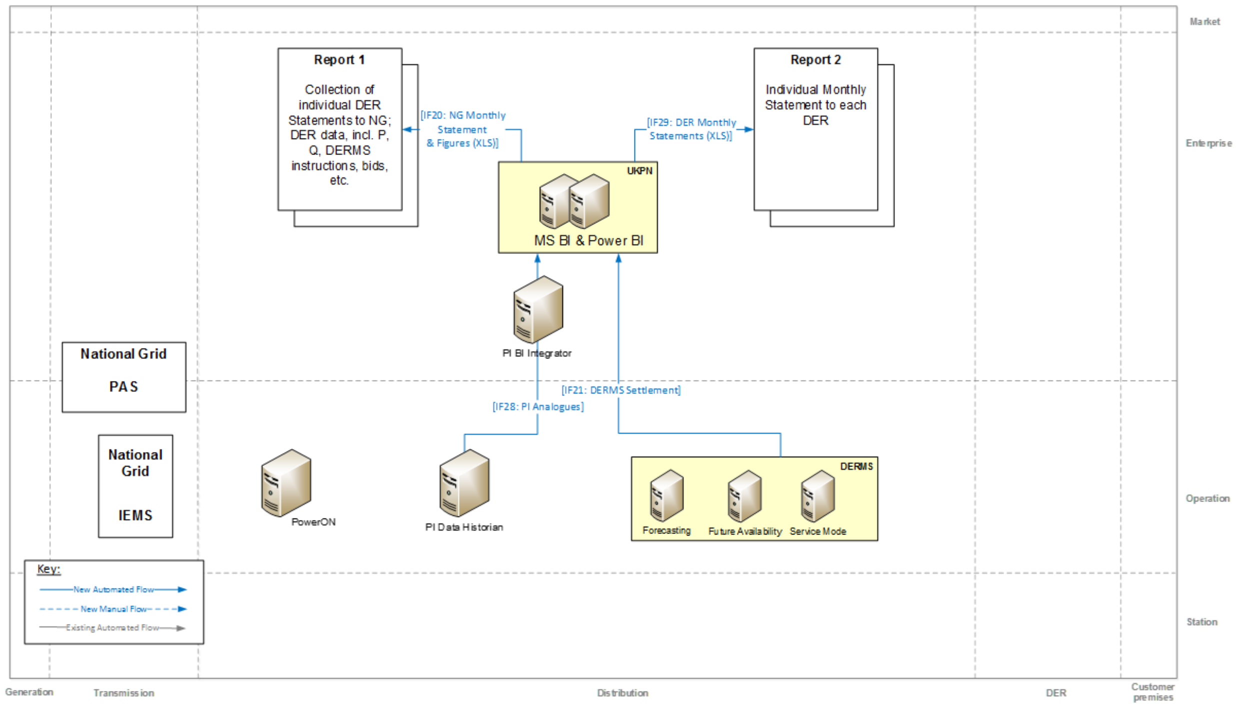


Figure 41: Settlement solution- Data interfaces and communication protocols

As can be seen in Figure 41 above, settlement solution has the following interfaces:

1. PI Historian
2. DERMS
3. Dual output of the Monthly Statements for UK Power Networks and NGESO (physically it is one interface: export of the Monthly Statements in Excel format into pre-defined folder)

The settlement solution operates in the following way:

1. Once a month (on the first day of the month following the Relevant Month) it imports data from PI Historian and DERMS:
   a) Data from PI Historian includes Active and Reactive power readings from UK Power Networks' RTUs (measured in MW and Mvar respectively) installed at DER substations.
   b) Data from DERMS includes DER technical characteristics relevant to settlement, DER bid information, DER actual availability and DERMS instructions to DER.
2. The settlement solution processes imported data by applying equations from the Appendix 2 in the DER Framework Agreement.
3. The settlement solution populates DER Monthly Statements (in a pre-defined template) and uploads them into the agreed location on one of the UK Power Networks servers.

The settlement engine uses DER reference numbers from DERMS in its generation of Monthly Statements. A UK Power Networks resource will populate the front page of the Monthly Statement with the customer details. This arrangement was made to avoid the settlement engine either containing personal data or connecting to the UK Power Networks systems that contain that data and further IT security arrangements needed in that case.

Developing the business solution

In addition to developing the technical interface of the settlement solution, the team has further engaged with Tax Finance, Innovation Project Management Office and Procurement teams in order to inform, consult and collaborate on the design of the settlement solution. A dry run exercise mapping exact roles and responsibilities of each party involved in the process took place in June 2019.

The UK Power Networks business change lead has been also assisting with the DER engagement activities, in particular the supplier registration in SAP Sourcing (see screenshot below), issuing the Variation to the Connection Agreement and ensuring self-billing compliance.

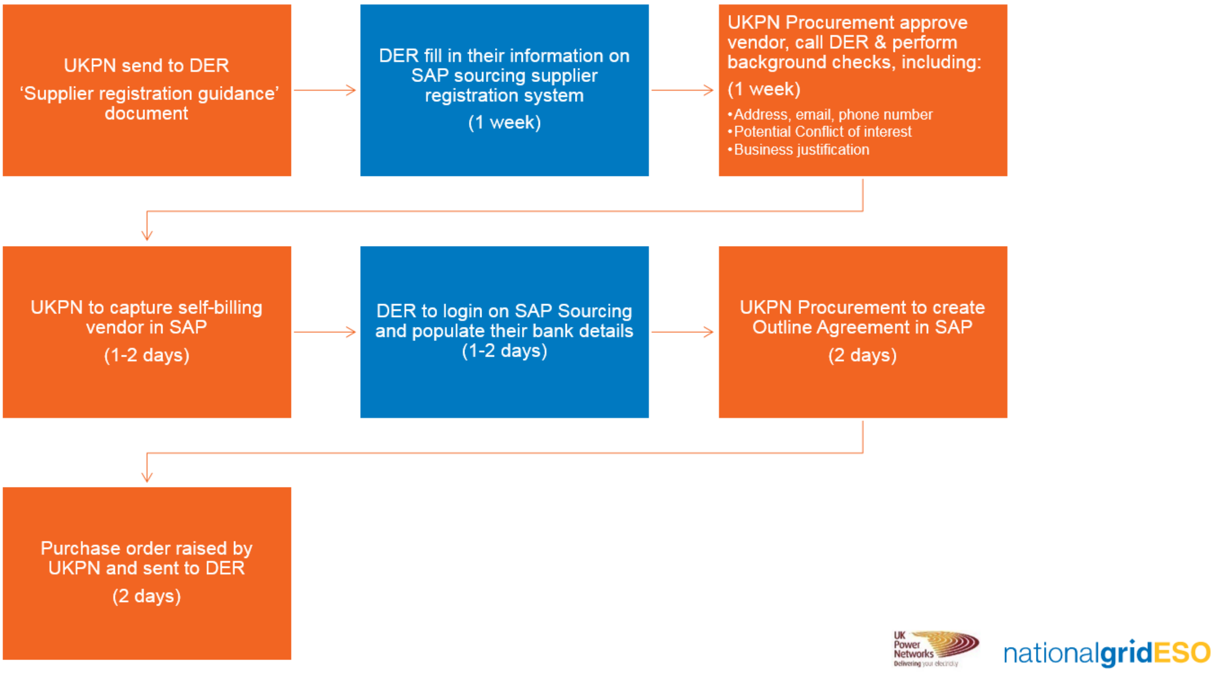


Figure 42: SAP Sourcing setup process

To date (15 November 2019), UK Power Networks' Procurement have set up all five DER in SAP Sourcing, approved the vendors in the system (including background checks) and started creating the Outline Agreement in SAP for three DER. Following this, a Purchase Order can be raised by the PMO desk.

4. Business Readiness

Business Change by UK Power Networks

This section provides a description of how UK Power Networks have organised their business change strategy in response to the TDI 2.0 service. It presents the strategy, its key objectives and activities to support the project throughout delivery, trial and transition into Business as Usual. The business change workstream encompasses activities pertaining to business readiness, process mapping, communications and training to prepare and adapt to the new processes and roles.

The project team has engaged with over fifteen teams from the business, including Outage Planning, Control Systems Automation, Network Control, Capital Programme, Finance, Legal, Procurement, PowerBI, Income Services and others. Business engagement will be essential in terms of proactively understanding the criteria of a successful trial and requirements for the business sign-off.

UK Power Networks' business change strategy

The business change strategy aims to ensure a seamless transition from delivery into trials into Business as Usual and encompasses business readiness, process mapping, communications, organisational changes and training needs in the organisation (see Figure 43 below).

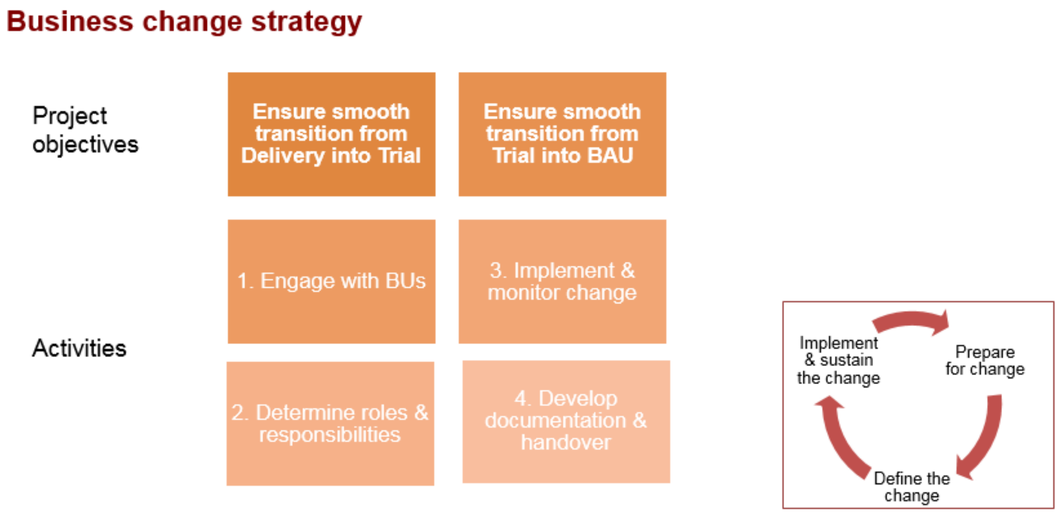


Figure 43: Business change strategy

As described in SDRC 9.2, the key focus for WS3 has been the engagement with diverse business units whose role has been fundamental in terms of informing the strategy, understanding the current situation, defining new roles and tasks and ultimately leading the business towards a successful project delivery.

Early communication, ongoing engagement via face to face meetings, ad-hoc workshops, regular working groups, newsletters and teleconferences have been deployed to ensure all key stakeholders are being informed. Senior managers from UK Power Networks and members of the project team have been actively sharing project news through internal and external fora. Stakeholders are in full understanding of the process and what the implications are for their day-to-day role. Overall internal stakeholder have been proactive and positive in terms of supporting the project delivery and preparation for trials.

Figure 44 shows an example of a recent project newsletter to inform key stakeholders.

UK Power Networks
Delivering your electricity

Power Potential: a world's first collaboration with National Grid

What is Power Potential?

The Power Potential project, a joint partnership between UK Power Networks and National Grid, is a world first whole-system innovation project, examining the future of dynamic voltage control by Distributed Energy Resources (DERs).

The Power Potential project is being delivered by the Innovation team and we are working across the business with a number of different teams including Outage Planning, Infrastructure Planning, Control Systems, Smart Grid Development and Income Pricing.

The project is looking at the technical and commercial aspects of procuring and absorbing reactive power from DERs connected to the distribution network to help manage voltage constraints on the transmission network.

Power Potential will procure the following services:

1. Dynamic voltage support (Mvar for low and high volts)
2. Active power support for constraint management and system balancing

Figure 44: A snapshot from an internal UK Power Networks' newsletter

Business engagement example- settlement dry-run June 2019

Historically, there was no settlement function in UK Power Networks so the project team had to prepare and test a settlement process from the beginning. The objective of the settlement dry-run which took place in June 2019 was to capture the process end-to-end, understand the business involvement and communicate key dates and milestones during the trial.

A broad team from UK Power Networks was involved including: the PMO desk, Procurement, Finance and Tax and PowerBI teams.

A number of bilateral meetings were held and the discussion was focused on post-dispatch and reporting periods. The business change lead presented the step-by-step process over the course of the trial and outlined the specific requirements for each team. A detailed checklist of requirements and summary of risks was also discussed.

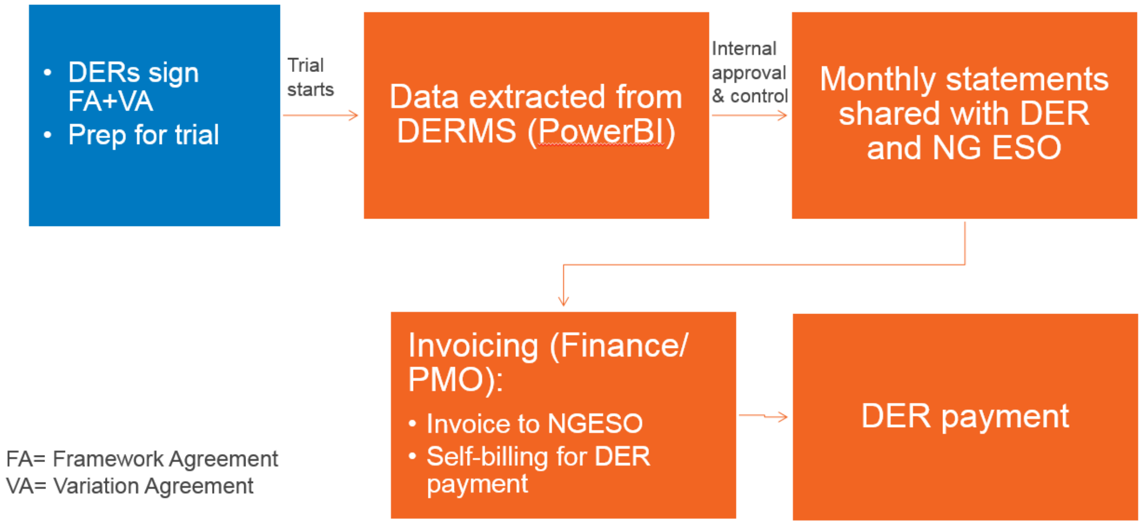


Figure 45: Settlements High Level Monthly Process

Organisational Impact Assessment

A preliminary Organisation Impact Assessment was completed in Q2 2019 which assessed the impact of the Power Potential project on UK Power Networks' operations in the near term. The assessment provided a general overview of the impacted business units and helped the team understand potential overlaps and interdependencies with other ongoing programs, such the Active Network Management (ANM) and Flexible Distributed Generation (FDG).

Project Stakeholder Engagement plan

Over the course of the project, the project team has been engaging with a number of business units to inform, consult and collaborate to deliver project outcomes. The Project Stakeholder Engagement plan helped outline the way in which stakeholder engagement should be structured and tracked over the course of the project. It supported the project team to monitor and control communication across the project and assess the progression of relationships across project delivery.

The plan provides an overview of business contacts, including their function, organisation, key interests in project, level of influence and level of interest (or level of resistance). It summarises the rationale why a stakeholder has been involved in the project, the key messages and methods the project team will use to engage with them. A copy is available to Ofgem on request.

Business process log

A business process log was created to keep track of the progress of the business change activities and assess readiness before the trial.

The activities were largely grouped into four categories: those which are related to DERMS delivery, those related to PowerOn, those related to NGESO/UK Power Networks operations and those related to UK Power Networks' operations only. Approximately forty processes were defined, with most of them required for the trial setup, for example change control activities such as DER contract management, DER Lab testing, DER commissioning, RTU logic upgrade.

The business process log has assisted the project team to identify required changes to existing business policies, processes and procedures and helped organise the definition and documentation of these processes with input from the different stakeholder.

To date (15 November 2019), 44% of the defined processes for the interim solution were Green with the remaining part (56%) were Yellow (on track but not delivered or fully documented yet).

Settlement

UK Power Networks' PowerBI team have been tasked with the design and delivery of the settlement software, assisted by the project team and experts from the IS team. The WS3 Lead has further engaged with Tax Finance, PMO and Procurement teams in order to inform, consult and collaborate on the design of the settlement solution. A dry run exercise mapping exact roles and responsibilities of each party involved in the process took place in June 2019.

The WS3 Lead has been assisting with the DER engagement activities, in particular the supplier registration process), variation to the Connection Agreement and self-billing compliance.

In terms of delivering the settlement solution, the biggest risks identified were:

- The PowerBI/DERMS systems interface and communication
- Procurement change in terms of setting up self-billing vendors in SAP Sourcing

Readiness assessment

Part of the business change activity is to assess how big the change from Power Potential will be on the organisation, the number of impacted business units in the near and longer term. So far, all impacted business units have been supportive, engaged and keen to understand the impact on their day-to-day operations. It is important to note that some of these are already required and underway as part of other programmes (e.g. ANM) which fit under the DSO transition and a closer collaboration with these teams has been advised and initiated.

Business Change by National Grid ESO

This section describes the business change implementation activity undertaken at National Grid ESO.

Teams and key individuals throughout National Grid ESO have been engaged to explore, identify and implement changes to systems and procedures in readiness for the Power Potential active and reactive power trials.

As described in the SDRC9.2 report, procurement of reactive power services during the commercial trials (Wave 2) takes place on a day-ahead basis. During the technical trials (Wave 1) there are no procurement activities and all available volumes will be accepted for dispatch. The active power service has no associated procurement process as it is a real-time service that will be used if volumes are available.

No change to the organisation structure and no recruitment of additional resources are required to deliver the services during the trial as the work is within the capacity of existing operational roles albeit with some changes and supported by the project delivery team. New processes and systems are required while some existing processes and systems have been adapted to accommodate the project as described in Table 9 and Table 10.

Within National Grid ESO, the Network Access Planning (NAP) team in the Network Capability team will continue giving advice to the Electricity Network Control Centre (ENCC) on system access and outages, engaging with the project to highlight particular running arrangements that affect the splitting of the GSPs in scope. The introduction of the combined service availability and commercial data from DERs will be added by the Structuring and Optimising Team to the list of options available to ENCC users to resolve voltage and thermal constraints in real-time.

In Wave 2, and in collaboration with the ENCC Strategy team and NAP planners, National Grid ESO Traders in the Commercial Operations function will review the DER market options once a day by 17:00 presented through the PAS. Traders will review the available reactive power services offered by DERMS and procure the required services according to system scenarios. System requirements will be calculated by the project team, reducing the need for additional inputs from the NGESO Voltage Strategy teams.

DERMS supports an interactive commercial process which allows DERs participating in DERMS to offer active power services and reactive power services for each service period for the day ahead (Wave 2). DER offers made in the form of bids are aggregated by DERMS and sent to National Grid ESO's PAS. DERMS will be responsible for arming units that have successfully secured reactive power tenders and dispatching contracted active power services through DERMS as required. In accordance with contracted windows, DERMS will put the contracted DERs into the voltage droop mode and assign respective setpoints to deliver the instructed reactive power service. For the instructed active power service, DERMS will give an active power set point to the contracted DERs.

Reactive and active power bids will be evaluated through the GUI incorporated within the PAS with data transferred from DERMS. The responsibility for contracting services through the project will lie with Commercial Operations function (weekdays) and ENCC (weekends). New PAS screens have been developed to interface National Grid ESO with DERMS, to receive commercial availability and data (day-ahead activities) and for sending instructions to DERMS (current day activities).

Table 9: NGESO Process changes adopted for the Power Potential trials

Theme	Purpose	Process
Requirements	Providing initial advice for the Control Room on system needs	Business process agreed for the Wave 1 technical trials including Network Access Planning input for planned GSP splitting.
Service request per GSP	To create Mvar instruction on VPP in PAS	Main information exchange through PAS connection. Additionally, 400kV measurements exchange occurs through the existing ICCP connection between NGESO iEMS and UK Power Networks' PowerOn.
Nomination	Establishes the approach to nominate the service required in response to the system need	Commercial procedure in place for Structuring and Optimisation Team to undertake nomination process.
Dispatch	To define Control Room responsibilities	Business procedure has been established for the Wave 1 reactive power technical trials.
Settlements	To establish how payments for services delivered will be reconciled with the service accepted by NGESO and the service delivered.	High level process agreed and detailed Standard Operating Procedure on track

Table 10: NGESO Systems Changes adopted for Power Potential trials

Change	Key Impact & Risks	Training Requirements	Dependency
PAS	An internal National Grid ESO system, it focuses on procurement of Ancillary services for the System Operator. PAS will connect to DERMS systems to allow for additional procurement of the project's services.	Training for Commercial, National Control Electricity and Operate The System Electricity teams on the use of PAS has begun and is already completed for Wave 1. It will continue and will finish for Wave 2/3 immediately before trial start. PAS project has independent timeline for training which needs to align with this project and ensure all roles are trained on additional usage, access and support for this project.	PAS project team, EBS
Electricity Balancing System (EBS)	The PAS-EBS link was identified in SDRC9.2 but following further detailed development of the solution, it has been established that there will be no link between PAS and EBS during the Power Potential trials.	Not applicable	
Trading system	Commercial process not clear and training not well delivered.	User documentation, training and testing to be carried out before the Wave 2/3 commercial trials start. Engagement with Senior Constraint Analyst in place and procurement process established.	-
Obligatory Reactive Power Service (ORPS)	Risk is low as this is used to store obligatory reactive power information on contracts and settlements. If used, then level of detail would have to be agreed.	Training requirements are low as the team already have an existing process that can be followed depending on the level of data required	-

Change	Key Impact & Risks	Training Requirements	Dependency
GENVARS	GENVARS was identified in SDRC9.2, but this system will no longer be in use at the time of the trial.	None	-
Web Interface TOGA/OLTA	Interface already exists to provide outages to UK Power Networks/DERMS	No changes in the existing process	SCADA ICCP links, Grid Code rules

5. GO – NO GO Criteria

Technical Go Criteria

The following items were identified as the technical criteria to judge readiness for the DERMS system to go live for DER commissioning and Mandatory trial:

- Interim Solution Factory Acceptance Test
- Interim Solution for Mandatory Trials System Integration Test and User Acceptance Test
- Interim Solution for Mandatory Trials Non-Functional Tests
- DERMS defect status (no priority defects outstanding)

This was an additional criterion set by the Project Steering Committee:

- Full Solution Common Information Model (CIM) convergence on one GSP (met in March 2019)

The following are additional criteria for Go live for Optional trial (and similar criteria will follow for Full solution)

- Interim Solution for Optional Trials System Integration Test and User Acceptance Tests
- Interim Solution for Optional Trials Non-Functional Tests
- Interim Solution Operational Acceptance Test
- Interim Solution Cutover complete and implementation checks

Customer Go Criteria

The following items were identified as the customer criteria to judge readiness to trial:

- DER Framework Agreement and Variation Agreement relating to a Connection Agreement signed by five DER with combined capability of at least 40Mvar (met on the 11 of November 2019).
- At least three DER sites commissioned before Mandatory Trial start (expected to be met in January 2020)

Business Go Criteria

National Grid ESO readiness to trial confirmed:

- Requirements: providing initial advice for the Control Room. Business process agreed for Wave 1 technical trials.
- Nomination: Established the approach to nominate the service required in response to the system need. Procedure in place for Structuring and Optimisation Team to undertake nomination process.
- Dispatch: Responsibilities within the Control Room established. Business Procedure developed and training provided for the Wave 1 reactive power technical trials.
- Settlement: Established how payments for services will be reconciled with the service accepted by NGESO and the service delivered. High-level process agreed and detailed Standard Operating Procedure on track for trials.
- PAS – Interfaces to DERMS established and testing scheduled. Agreed content, format and user interface for NGESO functions, such as Settlements, that will access information from PAS. This is required for optional trials, but not for mandatory trials go-live.

UK Power Networks readiness to trial confirmed

- Settlement including Procurement, PMO and PowerBi solution (including manual approach) – on track for delivery by mid December 2019
- Control room acceptance (Network Operations procedure) – on track for delivery by mid December 2019
- Service Definition Document with Enzen and Control System Infrastructure team (for IS support both confirmed in OAT acceptance test) – on track for delivery by end November 2019
- Dress rehearsal for cutover to live completed

Appendix A

SIT/UAT Test items

The following table contains the major functionality or proposed "must have" items that will be tested during Informal, SAT/SIT and UAT Test Phases.

Tests 1-12 are validated as part of DER Integration testing within the commissioning of each DER (and have been verified in laboratory testing so far) with the remaining points specifically addressed in SAT/SIT/UAT.

Table 11: SIT/UAT tests

	Test No.	Description	Functionality to be tested
1.	RTU_DER_1A	Access rights and Permissions for User/ Roles	Validate Access rights and Permissions for the following: **1.** Administrator • Verifying role with access to all functions, adding/removing Users and information **2.** Super User • Verifying read/write access to organisation and all information **3.** User • Verifying read access to all information **4.** Unauthenticated(Anonymous User) • Verifying a user not yet authenticated against the system **5.** Authenticated User • Verifying a user successfully authenticated and identity known to system but not authorised to access information
2.	RTU_DER_1	RTU – DER Initialisation	Validate RTU to DER integration gets back to its normal status after an initialisation routine. • Power loss situation or • RTU restart scenario.
3.	RTU_DER_2	RTU – DER digital input map	Validate RTU gets all the digital inputs correctly from DER control system. These inputs inform the UK Power Networks RTU on whether the various conditions requested by UK Power Networks for DER control were successfully received and executed by DER control system.
4.	RTU_DER_3	RTU – DER digital output map	Validate the RTU can send binary output commands to DER control system. These commands include signals that tell the DER about compliance to the active and reactive power services.
5.	RTU_DER_4	RTU – DER digital output map	Validate the RTU gets all the analogue inputs correctly from DER control system. These inputs basically inform the UK Power Networks RTU on whether the various setpoints requested by UK Power Networks for DER control were successfully received and executed by DER control system.
6.	RTU_DER_5	RTU – DER analogue output map	Validate the RTU can send analogue output commands to DER control systems, operational setpoints required by the UK Power Networks DERMS system for the P/Q services.
7.	RTU_DER_6	DER capability reactive power 1	Validate the following: • DER can generate the max allowable leading and lagging 'Reactive' power at maximum and minimum "Active Power Setpoint" possible for the generator at the time • Verify the 'Voltage Reference' and system voltage at point of connection and see if there is any violation (e.g., ± 6%).

	Test No.	Description	Functionality to be tested
8.	RTU_DER_7	DER capability active power 1	Validate the following: • DER responds to “Active Power Setpoints” • Note the time response from setpoint change to the final value • Note the reactive power and PF • Note the connection point voltages.
9.	RTU_DER_8	DER capability active power 2	Validate the following data, record and submitted to UK Power Networks. • kW – ‘Active’ power at the applicable measurement point. • kvar – ‘Reactive’ power at the applicable measurement point. • Time response of the DER control system • Initial reaction time to make an ‘Active’ power response to a change in setpoint • Total time taken to get a settled response
10.	RTU_DER_9	DER capability voltage 1	Validate that the DER is equipped with a continuously-acting automatic voltage control that meets the requirements
11.	RTU_DER_10	DER capability voltage 2 – tap changer	Validate that the DER is equipped with a continuously-acting automatic voltage control that meets the requirements through tapping of an external upstream tap changer
12.	RTU_DER_11	DER capability voltage 3 – voltage setpoint	Validate that the DER is equipped with a continuously-acting automatic voltage control that meets the requirements by the application of a voltage step to the DER reference voltage target
13.	DERMS_DER_01_a	DERMS receives availability from DER	Validate that DERMS can receive availability from DER
14.	DERMS_DER_02_a	MW setpoint DERMS dispatch to DER	Validate that based on MW set-point DERMS can dispatch to DER
15.	DER_DERMS_01_r	DER submit/change availability	• Data should be validated against contract (Schedule 3) • Validate data is received correctly and input into DERMS • Validate that DER can submit 13 weeks availability • Validate that DER can change availability up to 14:00 day-ahead
16.	DER_DERMS_01_r1	DER submit/change availability	• File is not correct [less/more availability, missing data, wrong data, right settlement resolution, wrong format] • 2. [Exception] DERMS has not successfully received the data for all the DER
17.	DERMS_DER_03	DERMS validate/availability from DER	DERMS validates data and saves it
18.	DERMS_DER_04	DERMS instructs DER to change reactive power output	Validate that DERMS can send instruction to DER to change reactive power output
19.	DERMS_DER_05	DERMS validates and accepts the availability from DER	Validate that DERMS receives and accepts the availability from DER

	Test No.	Description	Functionality to be tested
20.	DERMS_DER_05a	DERMS validates and accepts the availability from DER	Validate that trying to save incorrect data file/data format, it should throw exception
21.	DERMS_DER_06	DERMS to send instruction to DER to change reactive power output	Validate that DER receives instruction from DERMS to change from PF mode to voltage control mode
22.	DERMS_DER_07	DER changes operating mode	• Validate that DER changes operating mode
23.	DERMS_PAS_01a	DERMS sends availability at the GSP level to PAS	• [Exception] Send incorrect confirmation (e.g. service type, contract ID), it should get rejected • [Exception] DERMS does not send ok message after receiving confirmation from PAS, PAS should send an error to DERMS
24.	DERMS_PAS_02	DERMS send Day-Ahead availability to NG	• Validate for gate closure (14:00) • Pre/Post flag in availability file • Availability Cost Curve
25.	DERMS_PAS_03	DERMS to send instruction to nominated DER to change reactive power output	• Validate DERMS sends individual voltage set-point dispatch instruction to DER • Validate DER receives confirmation that is instructed
26.	DERMS_PAS_04	PAS to display delivery of service	• Validate DERMS sends to PAS live utilisation, actual voltage and costs • Validate PAS displays information received
27.	DERMS_PAS_04a	PAS to display delivery of service	• PAS is not receiving RTM for two minutes (SLA), PAS will send NAC (negative acknowledgement) message to DERMS via web services
28.	PAS_01	PAS receives, validates and displays availability at GSP	Validate availability for individual GSPs are in PAS with a post-flag and after gate closure
29.	PAS_01a	PAS receives, validates and displays availability at GSP	• [Exception] GSP level post-flag/gate closure is sending blank, PAS should send an error to DERMS • [Exception] GSP level post-flag is not a number, PAS should send an error to DERMS
30.	PAS_02	PAS auto-nominate availability at GSP by 16:45 and after 14:00	Validate that at 16:45 nomination request goes from PAS to DERMS on the availability file received in PAS_01
31.	PAS_02a	PAS auto-nominate availability at GSP by 16:45 and after 14:00	• [Exception] Nomination file from PAS is not correct, DERMS should send an error to PAS • [Exception] PAS sends (correct) nomination request, but DERMS does not confirm, PAS will ignore nomination for the entire window (30 min)
32.	PAS_03	Send Auto-Nomination	• Validate checks for Nomination/Auto-Nomination Gate Closure (16:30) • Validate Nomination Change (Re-Dec) from DERMS • Validate Nominated data for PAS user • DERMS send a re-dec to further breakdown nominated Mvar in 10 bands

	Test No.	Description	Functionality to be tested
33.	PAS_04	In-Day Availability	• Validate NG user has all 48 windows available to Dispatch from 23:00 • Validate In-day Re-Dec to Power factor mode (Re-dec from VC Mode to PF Mode) • Validate In-day Re-Dec to Value other than 0 (Re-Dec from VC-1 Mode to VC-2 Mode)
34.	NG_01	NG User (TSE User) View Current Day Availability	• Validate all In-Day availability for dispatch in In-Day • Validate DERMS has sent Actual Voltage, Utilisation Cost and Current Utilisation from RTM Service in-line with Web-Services Specification_PAS_v4.1.docx • Validate DERMS goes from VC Mode to PF Mode
35.	NG_02	Calculate Cost and Volume – Send Dispatch Instruction	• Transmission System Engineer (TSE) user sets target Voltage and Calculate Cost and Volume • TSE user to set Voltage Deadband and Voltage Droop • TSE user calculate Cost and Volume before dispatch and verify values align with the cost curve *Reactive Service Delivery at <GSP Name>* *Max available Reactive Power to meet Vtarget* *Current Cost of Mvar delivery* *New Cost of Instruction* • TSE user can send Dispatch Instruction to DERMS • Verify TSE user cannot dispatch when availability Re-dec to Zero (PF Mode)
36.	NG_03	Utilisation and V actual	• TSE user to verify Current Utilisation and Actual voltage sent by DERMS through RTM service • Validate Re-Dec from DERMS from VC mode t PF mode and TSE user can verify Current Utilisation • Verify Re-Dec from DERMS changes from VC1 Mode to VC2 Mode
37.	NG_04	Cease /Abort GSP	• Validate NG can send Abort instructions to DERMS and DERMS to send new Cost Curve with zero availability within 1 minute • Validate NG can request DERMS to come to VC mode from PF mode and DERMS can send new Cost Curve • Validate DERMS can send Abort instructions to NG in case DER has emergency and DERMS to send Re-Dec with zero availability
38.	PAS_DERMS_01	DERMS accepts nomination from PAS	• Validate DERMS receives PAS nomination • Validate. DERMS sends nomination confirmation to PA
39.	PAS_DERMS_01 a	DERMS accepts nomination from PAS	• [Exception] Nomination file from PAS is not correct, DERMS should send an error to PAS • 2. [Exception] PAS sends (correct) nomination request, but DERMS does not confirm, PAS will ignore nomination for the entire window (30 min)
40.	PAS-DERMS_02	PAS sends voltage set-point (per GSP) to DERMS	• Validate PAS displays DERMS initial settings (400kV voltage reading and voltage set-point for each GSP) • Confirm PAS sends dispatch instruction request • Validate DERMS sends dispatch confirmation to PAS

	Test No.	Description	Functionality to be tested
41.	PAS-DERMS_02a	PAS sends voltage set-point (per GSP) to DERMS	• [Exception] PAS sends a dispatch request and DERMS ignores it/rejects it, follow up action agreed between control rooms • [Exception] PAS sends an incorrect dispatch request (e.g. contract ID, service type, etc.), DERMS should reject request with an error code
42.	DERMS_DER_05	DERMS send nomination to DER	Validate DER receives nomination
43.	DERMS_DER_06	DERMS sends arming instruction to all nominated DER	• Validate DERMS instruct DER to change from PF mode to voltage control mode for the window in which a DER has been nominated • Validate DER receives confirmation that it is armed
44.	UKPN_01	UK Power Networks to ensure DER operation range is safe	Validate UK Power Networks revise PQ curve for each DER and adjust if needed for security reasons
45.	UKPN_02	Monitor network	UK Power Networks monitors the network in PowerOn

Appendix B

Data quality improvements for Full Solution

This section addresses the question of whether poor data quality will prevent DERMS from meeting those objectives. DERMS will base its control actions on real-time power flow assessments, using real time SCADA data from UK Power Networks.

The purpose of this section is to:

- Assess the quality of the SCADA data that will be used by DERMS
- Predict the impact of data quality issues on DERMS operations
- Develop recommended methods to improve data quality for the DERMS system

UK Power Networks and ZIV have analysed historical SCADA data in the Canterbury North network, received in the form of Process Information (PI) snapshot.

The issues and risks that were identified are set out in Table 12.

Table 12: Categorisation of data quality issues

High impact	Medium Impact	Lower impact
Poor granularity of data due to wide deadbands	Periods of data unavailability with simultaneous failure of data points	Data unavailability of individual data points
Zero crossing errors (where the power can flow in either direction but the meter only records positive values)	Gross errors – e.g. 'stuck' meter	
Lack of information on power flow direction	Measurement points with a linear offset from the real value	
Inconsistent configuration of reactive power measurements		

In order for DERMS to run, the realtime loadflows must reliably converge (i.e. reliably produce a coherent modelled set of voltages and flows on the network). The quality of data input to the loadflow engine affects both the capability of the model to converge and the accuracy of the result.

We have found that after resolving several errors, such as missing data and incorrect directionality, convergence can be improved from approx. 98% convergence rate to very close to 100%. Therefore, the risk of non-convergence is low. However, the accuracy of the loadflow model will be impacted by data quality issues.

The Q services are based on closed loop control architectures and use measurements that are derived from transducers installed at the GSP. From a commercial point of view, settlement is carried out using meter data directly and not the transducer readings and is therefore unaffected by the SCADA data inaccuracy.

When the DERMS scheme is applied to existing generators, SCADA data inaccuracy will not impact network safety. This is based on two assumptions: firstly, that the network planners have designed all existing connections such that a generator exporting within their MW and MVar limits cannot cause voltage issues or thermal overloads; secondly, as a back-up, that network protection mechanisms are already in place and that DERMS is not responsible for safety curtailment.

Poor data quality may however lead to inefficient decisions by DERMS in the deployment of DER. In particular, inaccurate data on the direction of Mvar flows may hamper the DERMS system in choosing the most efficient DER to respond to requests. We have separately documented a range of actions that can be (and in some cases already have been) taken to improve data quality – a mix of points to address for trial and for BAU.

The first mitigation is to apply a rating factor to each circuit based on the expected inaccuracy of the SCADA data. The rating factor should encompass linear offsets on specific feeders and deadbanding issues. In GSPs where new generators are connecting, a study of data quality should be carried out to recommend an appropriate rating factor. This will ensure network safety. However, this will lower the power carrying capacity of the network and lead to unnecessary curtailment of generators. Applying the data quality improvement techniques outlined in this report would allow the rating factor to be minimised and therefore maximise the available network capacity.

Secondly, the system needs to remain within limits during periods of data unavailability. A strategy to achieve this is discussed below.

Both software and hardware fixes should be considered to improve data quality.

High priority actions on data quality actions were identified as:

- Reliably establish the direction of real and reactive power flows at all times (i.e. identify measurement points with inconsistent configuration and/or zero-crossings). Clearly errors in the power flow direction could have a significant impact on DERMS' accuracy. Software based methods can help confirm MW direction and identify feeders with zero-crossing. Feeders with zero-crossing may then require installation of new metering.
- Address the effect of wide deadbands. Much of the data has poor granularity, and the impact is cumulative at the grid level, leading to the measured power flows lagging behind the actual power flows. This could be resolved either by replacing hardware for the worst measurement points, or by applying a derating to the system. For example, out of thirty-two 33kV feeders, the average feeder would require a derating of 0.8MVA, and the worst case would require a derating of 2.4MVA. A cumulative derating would need to be applied upstream. We also note that the current measurements typically have much better granularity than the MW and MVar measurements, but do not have directionality. In circumstances with no zero-crossings and a fairly constant power factor, it should be discussed whether DERMS should use current rather than MW and Mvar measurements.

The following issues have a lower impact but should also be addressed:

- Address measurement points with a linear offset from the real value. 10% of feeders have a significant linear offset. The offsets occur in different directions at different measurement points, so the cumulative effect will be low, but the impact on individual feeders is high. UK Power Networks can either:
  - Use the Data Quality Tool or a State Estimator (see below) to find and fix these data points (The issue can be fixed using a simple software-based correction factor, or by repairing the erroneous hardware);
  - De-rate all feeders to give a safety factor for the worst 10%. For three studied 33kV feeders with a significant linear offset, deratings of 6.5MVA, 2.3MVA and 1.8 MVA would be needed.

Following from the analysis of data quality issues, a Data Quality Tool has was developed by ZIV Automation to automatically fetch several months of UK Power Networks input data from the PI database, and then compare the flows at the two ends of a feeder. This has been identified as a suitable approach for trial, but would need update as network configuration and metering is updated.

Thus for transition of the solution to BAU, a 'state estimator' approach to data correction will be applied, which will automatically update for those configuration and metering changes over time. Within the project, a GE state estimator for the UK Power Networks licence area covering the trial area

- State Estimator installed, configured and tested on pre-production.
- State Estimator proven to work by GE's distribution power flow expert utilising "fake telemetry" to demonstrate to UK Power Networks.

- Summary of issues found on trial area that prevented State Estimator from working accurately (not achieving minimum level of transmission and distribution data) with recommendations to resolve.
- Instructions have been provided on how to implement State Estimator configuration into Production.

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