Power Potential

(Transmission & Distribution Interface 2.0)

SDRC 9.6 Trials Report

30 April 2021

nationalgridESO

Contents

Executive summary

The purpose of this report is to provide evidence that the Power Potential project has delivered on the criteria required to successfully achieve the sixth reporting milestone for the project, known as *SDRC 9.6* or the *Trials Report*. It outlines the completion of the trials in line with the agreed contractual framework and reviews the trial performance and key learning for consideration of transition into a Business-as-Usual (BAU) service.

Through Power Potential, we have demonstrated a world-first regional reactive power market, and the principles of a transmission and a distribution system operator enabling Distributed Energy Resources (DER) on the distribution network to deliver dynamic voltage control for transmission constraints, integrated with operational systems.

After the individual DER commissioning and their mandatory trials, the end-end collective live technical and commercial trials ran for 20 weeks from October 2020 to March 2021. A Distributed Energy Resources Management System (DERMS) enabled day-ahead offer of services by DER, and NGESO procurement of those services against a budget. Based on that day-ahead procurement, we demonstrated automated delivery of dynamic voltage control by DER. DERMS was integrated with National Grid's Platform for Ancillary Services (PAS) and UK Power Networks' PowerOn network management system, providing visibility for both licensees' control engineers. We also successfully ran trials of simultaneous instruction from DERMS for both active and reactive power services.

By delivering within an agreed safe operational PQ envelope and compliance with statutory voltage limits for the distribution networks, this approach potentially enables a new source of voltage control.

NGESO, UK Power Networks and the DERMS developer, ZIV Automation, gained insight in how to deliver and operate the systems and processes to enable these services, integrated with other operational systems and processes. This included learning related to system availability, DER delivered response, commissioning processes, the contractual framework and settlements.

Participating DER gained important learning into operation in voltage droop control, how to interface for distribution network control, and how to deliver reactive power services alongside other services such as Firm Frequency Response, Enhanced Frequency Response, Dynamic Containment and any existing active power market obligations.

Based on trial experience, we delivered multiple DERMS improvements and PAS changes. We also identified multiple system and process improvements to facilitate any transition to BAU.

Power Potential was designed as a single dynamic service to meet the dynamic and steady-state use-cases in the bid. Through this project, we have identified that DERMS could enable both DER self-dispatch for a dynamic service and a subsequent enhanced or instructed dynamic service, i.e. each within 2-5s of initiation. However only one out of five DER showed they were capable of fast operation in voltage droop control i.e. to respond in 2-5s and to meet the dynamic service requirement. While noting that the Power Potential technical and commercial design was for a dynamic voltage response, the trial has also demonstrated technically that a steady state performance could be delivered by DER via DERMS.

The project has demonstrated the concept of end-to-end dynamic and steady-state voltage control from DER with a Virtual Power Plant (VPP). The project also provides relevant learning for the development of other future voltage control services from DER. The DERMS integration design, the use of a defined PQ envelope for each DER's service range, and the high-level procurement/market approach could be readily adapted for future reactive power services.

The market part of the Power Potential trial demonstrated the ability of DER to commercially tender and compete to provide a reactive power service within a VPP. It also demonstrated an ability to assess, nominate and instruct reactive power services through VPPs to meet a reactive power requirement. With the implementation of the identified key learnings, it is expected that this could be another option for NGESO to manage dynamic voltage support alongside traditional options (STATCOM/SVC) and transmission connected generators.

However, the project has also identified several areas for improvement and further considerations that will need to be addressed prior to accessing the benefits of DER reactive power capability through a comprehensive

Power Potential roll out. Utilising the outcomes of the Power Potential project, UK Power Networks and NGESO are now discussing the next steps to enable voltage-control services from DER to compete with transmission alternatives.

NGESO's and UK Power Networks' experience working together on delivering the Power Potential project has shown it is important that both parties understand each other's ways of working and IT infrastructure needs. The key learnings from Power Potential are being fed into future development work associated with NGESO's voltage Pathfinders and reactive market reform. Further details can be found in the Markets Roadmap to 2025 (https://www.nationalgrideso.com/research-publications/markets-roadmap-2025).

In addition to leveraging the technical and commercial learnings and solutions identified within the trial, we are keen to explore which elements of functionality and transferable processes from Power Potential can be further developed to fulfil the needs of the Regional Development Programme (RDP).

This trials report SDRC 9.6 is complemented by SDRC 9.5 (cost benefit analysis) and SDRC 9.7 (DSO risk-reward framework); these other SDRCs further explore the commercial and regulatory basis for the trials and any potential extension to a BAU solution.

ACRONYMS

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
ENCC	Electricity Network Control Centre
ESO	Electricity System Operator
FAT	Factory Acceptance Testing
ICCP	Inter Control Centre Protocol (IEC standard)
IEC	International Electrotechnical Commission
GSP	Grid Supply Point
MW	Megawatts (unit of active power)
Mvar	Mega-var-amperes (unit of reactive power)
Mvarh	Mega-var-ampere-hours
NFT	Non-Functional Testing
NGESO	National Grid Electricity System Operator
OAT	Operational Acceptance Testing
P	Active Power
PAS	Platform for Ancillary Services
PoC	Point of Connection (at DER, UK Power 'Networks' measurements)
PQ	Active Power vs Reactive Power, capability envelope or permitted range for a DER
PQM	Power Quality Meter
Q	Reactive Power
RDP	Regional Development Programme
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
TNUoS	Transmission and Use of System Charging
UAT	User Acceptance Testing
UI	User Interface
UKPN	UK Power Networks
V	Voltage
VPP	Virtual Power Plant

1. Introduction

1.1. SDRC 9.6 requirements and evidence

The project direction requires that this Trials report SDRC 9.6 outlines the '*completion of the trials in line with customer agreements and reviews the performance of the trial; and 'the closure of the project (potentially moving into BAU) in line with customer agreements*. Note this is interpreted here as the closure of the trials rather than the closure of the project – a separate closedown report will be issued in July 2021 in line with the governance requirements for NIC projects.

The evidence required as set out by the Power Potential bid document is:

- Trials Phase Report including adequacy of contracted volumes to meet requirement, availability/reliability of DER and control system, accuracy of sensitivity and accuracy forecasting, evidence of competitive bidding, evidence of conflicts
- Report summarising the financials of each party (subject to DER commercial confidentiality), and in particular, the costs incurred by the DNO, the uplift applied to DER bids, and hence the net revenue that the DNO receives
- Assessment of scheme design and operation to cover how well it worked, where conflicts arose, and how the governance arrangements performed
- Plan for transitioning trial participants into enduring solution

Table 1 SDRC evidence criteria by section

Evidence criteria for SDRC 9.6	**Section in this report**
Trials Phase Report including	
Adequacy of contracted volumes to meet requirement	1.1
Availability/reliability of DERs and control system	2.4
Accuracy of sensitivity (effectiveness)	3.1.1
Accuracy of forecasting	2.5
Evidence of competitive bidding	3.2
Evidence of conflicts (Simultaneous Active and Reactive Power)	2.6.2
Report summarises the financials of each party (subject to DER commercial confidentiality), and in particular the costs incurred by the DNO, the uplift applied to DER bids, and hence the net revenue that the DNO receives	4
Assessment of scheme design and operation to cover	
How well it worked, where conflicts arose	2, 3
How the governance arrangements performed	1.1
Plan for transitioning trial participants into enduring solution	6 7,7.3

The Power Potential project had two main governance processes, namely the Project Steering Group (SG) and the Regional Market Advisory Panel (RMAP).

The purpose of the SG was to provide strategic direction, decision making and issue resolution to the project, and to support the NGESO and UK Power Networks' Project Leads throughout the lifecycle of the project. The attendees to the SG included the Project Sponsors, Project Leads and associated senior managers within each organisation.

The Regional Market Advisory Panel was created to provide a forum for interested stakeholders and industry experts to help shape technical and commercial developments of the Power Potential project. This was done by stakeholders providing different perspectives and ways of thinking, support for the fundamental principles of the developed market solution in a coordinated and transparent manner that created a level playing field for all parties. The Panel was chaired independently, and its membership comprised representation from a cross section of interests in distributed flexibility services and market design, including Ofgem, BEIS, new and existing DER parties (directly connected customers and aggregators) and the Association of Decentralised Energy.

A key focus for decision making and consultation for SG and RMAP was regarding the number of DER participants and contracted Mvar that the project team were able to sign up to participate in the trials. Initially it was anticipated that 70Mvar volume of DER could be recruited, however it became clear during the project that this was not achievable, hence the SG set out clear expectations of the project's core objectives be satisfied to ensure sufficient learning can be demonstrated. These were

1. Sufficient participation, defined as having at least five participants signed up to the project with at least one DER commissioned prior to the Mandatory Technical Trial (this milestone was met on 16 March 2020) and a total of four having completed these Mandatory Technical Trials before the start of Optional Trial.
2. Sufficient effect, defined as expecting to see at least 40 Mvar of reactive power availability across the GSPs.

These objectives were also discussed and agreed at RMAP, with stakeholders' keen to see the progression of the project into live trials. In practice due to challenges at the commissioning stage related to COVID-19, as described in the next section, the SG approved starting the Optional Trial with three DER having completed their Mandatory Trial, with four participating by the end of the Optional Trial. These criteria were met for four DER.

The governance structure put in place during Potential Power was important to shape the decisions of the project team during the trials.

1.2. Project overview including changes

The project progressed in stages with significant activities being delivered within the technical, commercial, business process and trials workstreams, all supported by project management activity.

As notified to Ofgem in April 2020, project delivery was significantly affected by COVID-19 restrictions, with a material impact on Power Potential trials, particularly affecting site commissioning. One DER was commissioned in February 2020 (before lockdown restrictions) with commissioning activities for the rest of DER being re-started at the end of July.

This had an impact on the SDRC reports and the project end date. Therefore, the project changed the planned delivery timelines (but not the delivery scope) to manage this situation. In order to preserve the duration of Wave 1 Optional and Wave 2 Market trials, in April 2020, the start of Optional and Market trials were frozen until at least 1 September 2020, and the trial timescales were extended to March 2021, with the project end date extended to July 2021. According to this new timeline, testing and integration activities were refocused and it was decided to conduct Wave 1 Optional and Wave 2 Market trials with a single version of the DERMS software, in order to minimise disruption. (In practice, further DERMS upgrades were required to respond to trial learning, but the core functionality was available in the live system in September 2020).

The Wave 1 Optional Technical Trials began on 14 October 2020 – this was six weeks later than the 1 September date envisaged as reasonable endeavours in April 2020 during our COVID-19 re-plan. As a result of the six-week delay, the project adjusted the duration of the Wave 1 Technical Trials from 12 to eight weeks. The project team, partners and participating DER have shown great commitment to deliver the learning from this project and bring us into the end-end trials stage.

1.2.1. Design Overview

To provide context for the explanation of the trial, this section provides an overview of the implemented technical design for DER to deliver voltage control services for transmission based on instructions from DERMS. Section 3 includes an equivalent commercial overview.

The approach implemented for Power Potential's end-end trials uses the high-level architecture shown in Figure 1. Each DER participant (bottom right) operates in voltage (droop) control to deliver the services. The DER receives instructions and reports its status to UK Power Networks' systems. This is an integration from DERMS to the PowerOn Network Management System to the site Remote Terminal Unit (RTU) to the customer's local control system or DER controller. Monitoring data is obtained from the site RTU. Further information on this integration across ~20 secure systems and links was provided in SDRC 9.4 (Customer Readiness Report and Performance of the Technical Solution in a Controlled Environment). In SDRC 9.4 we referred to the DERMS Interim and DERMS Full Solution. In SDRC 9.6 for simplicity, we refer to the DERMS solution and a specific upgrade. This is because there were multiple incremental improvements in DERMS informed by trial experience which were not known at the time of writing the SDRC 9.4 report. In addition, the commercial aspects of the DERMS Full Solution were delivered for live trials, but other aspects designed relating to network model import, load-flows and active power dispatch from PAS were developed and partially tested, but not taken to live trial. This is described further in section 6 of this report.

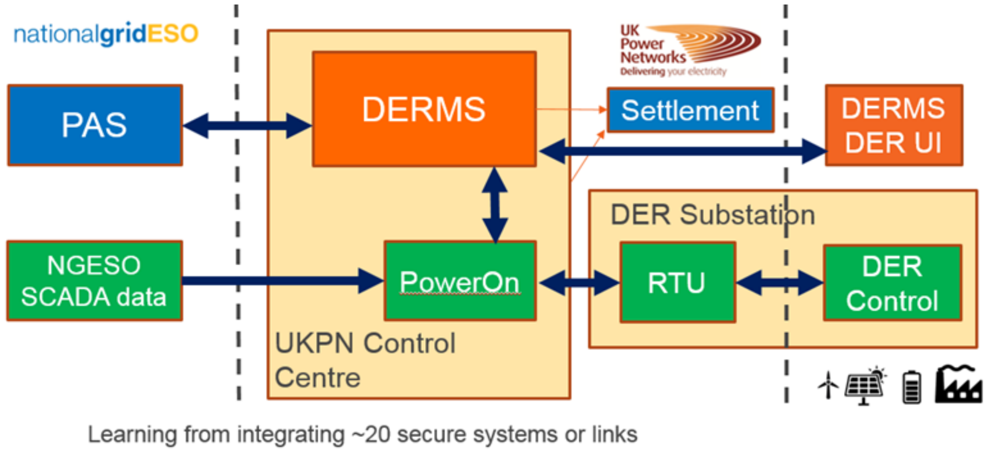


Figure 1 Power Potential – Simplified Technical Solution overview

DER will provide the voltage service based on when they have offered availability via the DERMS Web Interface (DER UI) and when they are accepted for service by NGESO – this acceptance is communicated day-ahead of service from the Platform for Ancillary Services (PAS) system to DERMS and shown on the DERMS Web Interface. The PAS-DERMS data exchange is per Grid Supply Point (GSP), representing a VPP of DER.

When a DER is accepted to deliver service in a 'service window', DERMS instructs the DER to operate in voltage (droop) control, and sends a voltage set point to the DER. Any difference between the set point and local measured voltage will cause a reactive power output at the DER which can affect network voltage to deliver the voltage control service (see Appendix 1 for further the details of the droop relationship, based on 4% of nominal voltage and the contracted lag Mvar of the DER).

DERMS' instructions to DER in the VPP for response are based on the difference between the target voltage and actual voltage at the Grid Supply Point. DERMS then monitors and adjusts the issued set points based the transmission requirement and the metering data from the DER site. Further detail of the GSP requirement is provided in section 2.4.2 and the overall design for the control in Appendix 1. Instructions from DERMS respect agreed ranges for each DER for the combination of active power (P) and reactive power (Q) for the site, and statutory voltage limits. These are pre-agreed in the contractual agreement for each site during the trial (as described in SDRC 9.4), and which maintain a safe and secure distribution network during service delivery.

1.3. Trials Recap

After commissioning, the original trial design that was developed by the project team was split into three main stages (or waves) as summarised in Figure 2 Trial Design below.

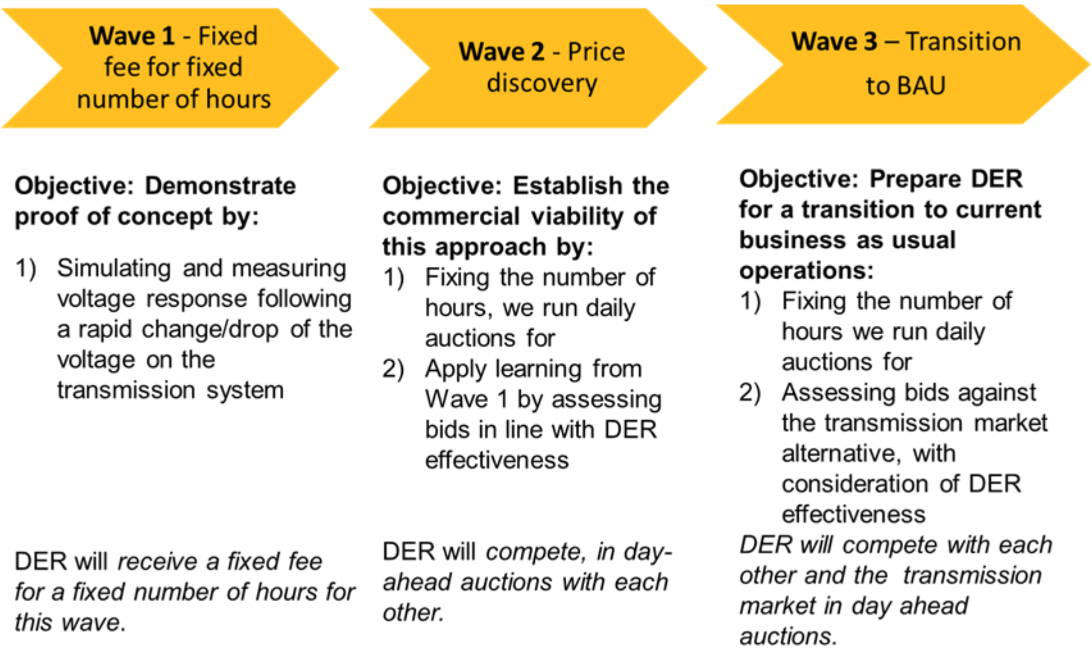


Figure 2 Trial Design

The delivered trial schedule is provided for reference in Appendix 5.

1.3.1. Commissioning to DERMS and Capability Testing of DER

The first element of functional verification of the live system was the commissioning of each DER to DERMS (verifying all signal integration DERMS-PowerOn-RTU-DER on site, dispatch functionality and fail-safes). The second element was a capability test of each DER, in which its operation in voltage droop control to the expected voltage range and speed of response was reviewed.

Further information regarding the criteria and associated outcomes is in section 2.2 of this report.

1.3.2. Wave 1 Mandatory Technical Trials

The aim of the Wave 1 Mandatory Technical Trials was to demonstrate that DER are technically capable of delivering reactive power services when instructed by the DERMS. DER were only allowed to participate in the other waves of the project and therefore the provision the service, once they successfully completed the Mandatory Technical Trial.

Detailed guidance and test procedure were developed that outlined three reactive power tests:

1. Response to simulated signals; step change in 400kV voltage
2. Response to simulated signals; ramp changes in 400kV voltage
3. Response to 400kV voltage set point changes

Further information regarding the criteria and associated outcomes are in section 2.3 of this report.

1.3.3. Wave 1 Optional Technical Trials

The aim of Wave 1 Optional Trials was to analyse the DER responses under DERMS following different changes in network conditions directed from NGESO instructions sent from PAS instructions. This part of the trials only applied to the reactive power service, with additional learning potentially driven by system events (unplanned and planned) and not by specific test methods. An allowance was allocated from the project budget to pay DER to take part to develop the technical learning.

During this stage of the trials, network security was not assessed against a network model as originally planned at project inception. There were significant data challenges with validating and integrating a complex network into DERMS during the project, hence UK Power Networks developed a manual off-line process whereby network running constraints were entered (day ahead) by 14:00 to set the running arrangement (i.e. revised P-Q envelope) for a given time-period, aligning with the commercial service window.

There were additional challenges in delivering DERMS to the required quality and in DER readiness, hence the project team reduction in the duration of the trials to run over an 8-week period (instead of 15 weeks) between 15 October to 10 December 2020. The availability hours were modified to still ensure DER could earn up to £45k by being available for a minimum of 987 of the 1345 hours in the trial, and £36k by being available in voltage control for at least 373 hours. Participation payments were made based on the number of hours DER were available across the total number of hours in the trial.

The technical analysis and learning outcomes captured during Wave 1 Optional and Wave 2 trials are described in section 2.4 of this report.

1.3.4. Wave 2 Commercial Trials

The purpose of Wave 2 Commercial Trials was to facilitate “price discovery” from DER by allowing DER to freely bid on both utilisation and availability under a competitive environment, allowing them to reflect any risk or cost associated with the provision of the reactive power service in the most efficient way. The schedule to provide the reactive power service was from 23:00 on the previous day, to 22:59 on the next day for each day of the trials, according to the Electricity Forward Agreement (EFA) calendar that is used when trading on the electricity market. The EFA calendar is split into 4-hour windows (or blocks) starting at 23:00.

DER resource procured during Wave 2 was not considered as contributing to securing the reactive power requirement for the system as per other balancing services but was essentially surplus to test the price discovery principle, given the unproven nature of the service.

Payments to DER came from the project budget, so it was important to develop a process to monitor the budget allowance as well as create price discovery.

Further information on the process developed for Wave 2 trials and the associated commercial outcomes is described in section 3 of this report.

1.3.5. Wave 3 Commercial Trials

The concept of the Wave 3 trials was to utilise participating DER to secure the system reactive power requirement. DER would submit availability and utilisation prices (as during Wave 2), and these prices would be compared against alternative actions available to NGESO (including large transmission connected generation that are obliged to provide reactive power services as set out in the Connection and Use of System Code (CUSC). In this case, the budget for Wave 3 payments would be made directly from NGESO’s balancing services, as per other balancing services and included in BSUoS (Balancing Services Use of System) charges.

This stage of the trials was considered beneficial to provide additional learning to assist with transitioning the outcomes of the Power Potential project into BAU. However, significant delays in starting the trials meant that Wave 3 could did not go ahead to ensure that the project retained its focus on the key objectives of the original bid which could be delivered through the Wave 1 (technical) and Wave 2 (commercial) trials.

1.3.6. DER trial participants

This trial would not have been possible without the commitment of the five DER operators who signed the trial contracts and then worked with the project team to prepare and deliver the trials. In alphabetical order, these were Gresham House, Lightsource BP, RWE, Vattenfall and Zenobe. Each one made a material contribution to the learning of this project. We have included their feedback on specific areas of the trial throughout the document, including on potential changes for the future (section 6), and their general perspective on participating in the trial in section 7.

This report has been written without specifically naming the five DER sites involved in the commissioning, capability test and trials. Instead, we mention learning from a DER or all DER. On occasion, we refer to DER by number (1-5), technology type (battery, wind, PV), their associated Grid Supply Point or some other characteristic such as connection voltage, where this helps us describe the project learning. This approach to the reporting was developed after discussion with the participating DER, to enable us to publicly share as much trial learning as possible.

2. Technical Learning (Commissioning, Capability Test, Wave 1 and 2)

2.1. DERMS changes delivered in trial to support technical learning

Over the Power Potential Trials period, the live DERMS solution was upgraded with additional functionality and defect fixes. This approach was taken in order to minimise delay to the live system learning, by focusing development, test and defect resolution and additional functionality required for the next trial stage (or to resolve issues identified in the previous trial stage). The project team developed a strategy and plan to test and release a number of versions of DERMS on the production environment with each version satisfying the needs and readiness for each trial phase. The deployment followed the process and criteria described in Appendix 2.

The initial live deployment was in December 2019 (an information systems infrastructure go-live), with a further upgrade in February 2020. This enabled the full integration to PowerOn for DER commissioning. Further upgrades were made in summer 2020 to address issues arising in Mandatory Trial (e.g. assumed voltage droop calculation for DER), then in September 2020 before the end-end trials began with PAS. An upgrade was made in December 2020 based on learning from the Wave 1 technical trials (Design Overview) and a final upgrade in February 2021 reflecting learning from the Wave 2 commercial trials and addressing trial interruptions due to repeated temporary loss of connectivity between the PAS and DERMS systems.

Mandatory Technical Trials

The Mandatory Technical trials spanned a number of months (July to December) with the five participating DER. Three versions of DERMS were used for Mandatory Technical Trials – 16.7, 18.2.4 and 18.2.6. Release 16.7 addressed an ambiguity in the design in the definition of the voltage droop calculation, so that DER were sent appropriate voltage set points in response to a GSP requirement.

As different DER underwent Mandatory Technical trials at different times, it spanned more than one release of DERMS. Mandatory Technical trial defects logged underwent triage and resolution for the next release, following the prioritisation and readiness criteria for each version for the trials.

Wave 1 Optional Trials

The DERMS 18.2.4 upgrade on 12 September 2020 addressed all the end-end functionality requirements following the Wave 2 FAT (Factory Acceptance Test), and also delivered the final aspects required for PAS-DERMS integration required for Wave 1 operation. DERMS 18.2.4 release was used in production to complete Wave 1 Optional trials between 14 October and 10 December 2020.

The start of Wave 1 Optional trials was delayed due to a communications issue between DERMS and PAS on the Azure API management layer. To minimise any further delay, 14 October 2020 a ‘fall-back’ option was agreed for NGESO to liaise with UK Power Networks to instruct DERMS without the PAS system. However, the connectivity issue was resolved and tested prior to the trials starting.

DERMS 18.2.4 went into Wave 1 Optional trials on Wednesday 14 October, with the service delivery beginning on Thursday 15 October for an eight-week period of 24/7 operation. We had an initial issue with enabling the voltage service, which was resolved on the same day with support ZIV Automation.

However due to a planned outage of NGESO PAS system on Wednesday 14 October, trials started with just UK Power Networks and DER systems (DERMS<>PowerOn<>RTU<>DER) and applied the fall-back to implement instructions from NGESO for the first day of delivery on Thursday. The live PAS system reverification completed on 15 October instructing DERMS for the rest of trials (apart from during planned PAS outages).

Wave 2 Market Trials (with continued technical learning)

Just after completion of the Wave 1 trials, DERMS 18.2.6 was deployed on the live production environment on the 10 of December replacing 18.2.4. This was not the official start of trials but DERMS was put into Wave 2 mode in readiness for January 2021.

DERMS 18.2.6 included the changes in integration design arising from learning from the Wave 1 trials (see section 2.1 involving changes to reduce data volumes, reduce service interruptions, restore service recalculation frequency). It also resolved defects affecting Wave 2 — active power services and integration issues affecting Wave 2 settlements.

At the time of the start of Wave 2 trials, there were no P1 defects. However, a daily manual workaround was required by the UK Power Networks team to reject DER availability in the case that there was 'no nomination' by the NGESO commercial team via the PAS system. The default 'accept' behaviour had been suitable for test and Wave 1 trials but was incorrect for Wave 2.

All other known defects including cosmetic improvements to the DERMS Web Interface were triaged for the last planned upgrade of DERMS in February. Based on trial experience in Wave 2, that upgrade also made DERMS less sensitive to trial interruptions due to loss of PAS-DERMS connectivity (see section 2.3.3).

DERMS 18.2.7 failed UK Power Networks' testing to qualify as the last patch for Power Potential. This was due to functional dashboard issues arising from data model duplication within the DERMS MongoDB database. The production deployment was cancelled, and an updated version of the patch was agreed with ZIV Automation.

DERMS 18.2.8 was retested thoroughly and then deployed on Production on 12 February. This was the version of DERMS delivering the final six weeks of the Power Potential Wave 2 trials.

2.2. Commissioning & Capability

Before participating in the Power Potential Wave 1 Mandatory Technical Trials, each DER had to be commissioned to prove that it can provide this service safely and securely on the UK Power Networks network, in accordance with the DER Framework Agreement e.g. the DER Interface Schedule and the operational envelope defined in the Variation to the Connection Agreement.

Additionally, each DER had to undergo technical capability tests to assess reactive power range and speed of response to changes in voltage set point sent from DERMS, against DER Technical Requirements, referenced in the DER Framework Agreement.

Whilst there were similarities between commissioning and capability tests and they could be carried out at the same site visit, the purpose and process behind the two assessments were very different.

2.2.1. Commissioning

Commissioning includes manual instruction of the DER via the DERMS RTU Test UI, PowerOn and RTU, for Power Potential signal verification and for observation of dispatch and failure modes. This is carried out by UK Power Networks as depicted in Figure 3 below and evidenced by ECP 11-0702a Commissioning Test Form , signed by the commissioning engineer. This approach was developed specifically for the project, as the first example of integrated visibility and control DERMS-PowerOn-RTU-DER. Figure 3 shows the relationship and point of collaboration between the key stakeholders during commissioning.

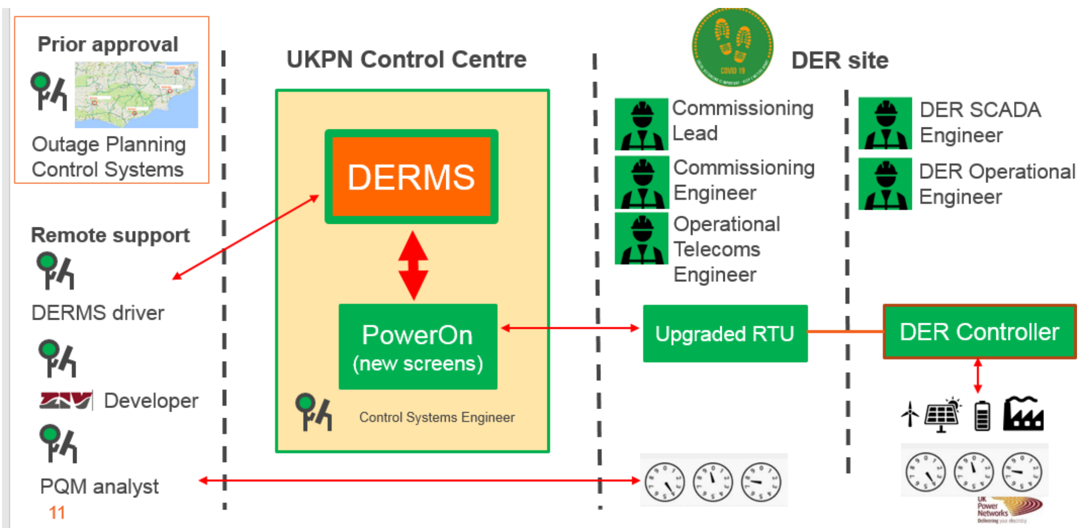


Figure 3 Participants co-ordinated to deliver each DER commissioning

The minimum requirement for all DER before participation in the Mandatory Technical Trial was to pass the commissioning test to DERMS for voltage service. However, those DER who chose to also participate in the active power service in Wave 2, must also have passed the specific tests for P service to DERMS (including combination of P and V service).

UK Power Networks successfully commissioned five DER on site. The first DER was fully commissioned in March 2020 and the final DER's full commissioning was completed in December 2020.

UK Power Networks documented the end-to-end process for full commissioning of DER to the DERMS in a DER commissioning test procedure to be carried out and verified on site prior to energisation of the participating DER. The procedure includes the associated tele-control pre-commissioning tests, on-site commissioning tests, and post-energisation checks. The commissioning process was carried out in two phases:

1. Bench testing in the UK Power Networks laboratory test environment (optional but recommended)
2. On-site testing and commissioning in the live production environment (required).

   This involved pre-requisite checking and testing, including the end-to-end integration testing between DERMS – PowerOn – Remote Terminal Unit (RTU) and customer's Local Control System (LCS) on the live environment, before moving on to final commissioning.

Experience from the first DER, highlighted the need for considerable work on the initial part of commissioning the customer's LCS to the UK Power Networks RTU and PowerOn. This prompted a review of the procedure, which then divided the on-site element into two further stages:

1. Pre-Commissioning — focussed on commissioning the customer's LCS to the UK Power Networks RTU and PowerOn
2. Full commissioning – confirmed DER operational services, communications loss and Failsafe actions.

For subsequent DER, the commissioning stages were scheduled, such that the second stage of full commissioning would only go ahead once pre-commissioning was completed. This helped progressing the commissioning procedure as well as identifying potential risks and learning, prior to connecting DER to the live DERMS. Appendix 6 provides further detail of the commissioning approach.

Key Observations from Commissioning

Effort involved in RTU Scaling – leading to new approach to RTU logic

Based on the learning outcomes from the testing, UK Power Networks considered developments on the RTU logic to support 'Float data' type for measurements (P, Q, V). This was due to the fact that there was low resolution of analogue data i.e. measurements at the point of connection (PoC) or set point instructions. The UK Power Networks RTU and customer's LCS needed to be scaled appropriately which was a complicated time-consuming task. The updates, which were made on the RTU logic, significantly simplified the end-to-end systems' integration on site, by keeping the resolution of end-to-end data exchange, resulting in a smoother commissioning procedure for DER, addressed customer concerns and improved E2E system performance. Prior to developing the RTU logic, all DER were consulted and agreed to apply those changes and re-sent their simulation results to be reviewed and confirmed by the project technical integration lead, prior to on-site testing. The final Interface schedule was published to the website on 10 June 2020.

Reactive Power Service (Q) at Night – responding to customer needs

Since the early stages of the project, it was apparent that the participating solar technology would only be capable of providing reactive power services at night. This is because solar farms need to maximise active power service during daylight hours and then use their invertors to deliver Q service during the hours of darkness. This required greater emphasis on planning of out-of-hours resource during the testing and commissioning phase, but DER feedback (participants and prospective participants) was that this restriction could be lifted by technical changes once familiarity was gained with the control system.

Power Quality Metering (PQM) Polarity – standardisation

The metering sign convention for import v. export at the PoC follows the UK Power Networks standard; the DERMS solution was also implemented accordingly.

Part of the commissioning process is to check that the PQM polarity is in line with UK Power Networks' standards. This is to ensure that the Control Engineers can determine in which direction power is flowing. At one of the sites however, it was found that the PQM meter was connected to the metering CTs on the customer side of the point of connection. In this case, UK Power Networks' standards dictate that when the customer is generating (exporting) active/reactive power onto the UK Power Networks network, the analogue metering should read negative values, as per the PowerOn analogues. Unfortunately, DERMS is configured to read a positive value for export, which caused a significant issue for the limits in DERMS. To get around this issue, it was agreed with UK Power Networks' Asset Management to invert the PQM signage on site, to provide the polarities as per DERMS' requirements. However, this was only a temporary solution during the trials, as it provided the wrong polarity within PowerOn.

Disabling the DERMS Service Module during commissioning

To commission using DERMS requires the Service Module to be disabled, so that manual instructions could be sent, without being overwritten by the service module. This in turn required the DERMS Simulator refresh rate for the associated Grid Supply Point to be increased to a maximum of 7,000 seconds (1.9hours). This was feasible for commissioning the customers for trial, but section 6 notes this is an area for post-trial improvement.

Interaction with original Connection Agreement

An observation during commissioning was the conflict between contracts and operating limits. For some DER, contractual limits in the Power Potential Framework Agreement (during reactive service delivery) could differ greatly from those in the Customer Connection Agreement (when no reactive service delivery). This became significant during commissioning, when a DER was transitioning between 'Contractual' mode and Power Potential (ANM) mode. For instance, under the Power Potential Framework Agreement, a DER could export and import reactive power in line with its PQ capability curve. Under the Customer Connection Agreement (contractual mode) however, the DER may not have been permitted to export. Therefore, if the DER was exporting under ANM mode and was switched to contractual mode, this would cause a breach of contractual limits and lead to failsafe actions, preventing the progress of the commissioning programme.

Interactions with other DER services

An important observation, during the commissioning and capability testing phase, was that Power Potential participants were also engaged in other services, such as Fast Frequency Response (FFR) and the ability to stack services to maximise revenue opportunity. During commissioning, the Power Potential project needed to liaise carefully with customers to coordinate Power Potential activities with those other services.

2.2.2. DER Capability/Performance Testing

Each DER participating in the Power Potential trials, was required to undergo technical capability tests to assess reactive power range and speed of response to changes in voltage set point sent from DERMS. The full extent of the tests is covered in the DER Technical Requirements document on the Power Potential website. A summary of the minimum performance expectations, agreed within the project were as follows:

1. DER speed of reactive response in Mvar/s (measured at the DER Point of Connection) is consistent with delivering at least 90% of the maximum reactive range in 2-5 seconds.
2. The DER will provide a stable response (within ±5% of delivered response, consistent with the criteria above) from 5s after receiving an instruction i.e. settling to stable value with no oscillation.
3. Reactive response to be assessed from the time the DER receives a voltage set point instruction

4. Maximum reactive range defined as in the Power Potential DER Framework Agreement (summed across both lead and lag directions, determined by reference to the P-Q capability curve specified in Schedule 3)
5. DER reactive response will follow the 4% voltage droop characteristic consistent with the following equation, with voltages in kV and reactive response Q in Mvar.

Equation 1

DER Voltage set point = Real Time Voltage + Reactive Response/ Maximum Q lag x 0.04 x Nominal voltage

Capability test results varied considerably for each DER and it is notable that only one of the five DER commissioned fully met the above requirements for dynamic response, however Steering Group decided to progress with the trials in order to allow to generate key learnings from other aspects of the project.

One of the key learning outcomes identified in the original bid document (Page 73 – Learning Outcomes) was the ability of the solution to accurately estimate the response at GSP level (dynamic and steady-state).

Steady state voltage control is the management of system voltages for slow changes such as the normal daily variations in demand. Steady state voltage control is provided by periodic dispatching constant reactive power resources such as shunt capacitors, shunt reactors or contracted providers in constant reactive power control assisted by dynamic reactive power providers such as generators or Static Var Compensators automatically responding to slow changes in system voltage. Transient voltage control is the management of sudden changes resulting from network faults or plant losses and is provided by dynamic reactive power providers rapidly responding to the change in voltage.

In general, the DER participating in the Power Potential trials had been designed to meet distribution system requirements limiting reactive power to remain within set power factor limits. In contrast all plant required to meet the Grid Code is designed to modulate reactive power to contribute to system voltage control. This includes many relatively small-scale generation projects (6MW upwards) mainly connected at 33kV and encompassing a large variety of converter based renewable technology including wind farms, tidal turbines and batteries. All have successfully demonstrated the capability to deliver a change of 90% of their reactive power capability within one second.

Measured DER Response Times

One of the main issues faced, in terms of measuring the fast response times, is the rate at which network data can be captured. UK Power Networks has two mechanisms in place to measure network parameters, both of which pass data through on-site Remote Terminal Units (RTU) to a data historian called ‘PI’.

1. Analogue metering – widespread existing mechanism feeding into the current Network Management Systems.
2. Power Quality Metering (PQM) – high accuracy metering installed as specific sites (most recent large generation connections) for network performance assessment but not fed back to the Network Management System.

Power Potential employed the PQM system, due its greater accuracy and perceived fast sampling rate. However, following capability testing of the first DER, it was found that although the data was sampled at one second intervals (or less) at the meter, by the time the data reached the ‘PI’ database, sampling was down to 15 second intervals. Therefore, this proved insufficient for the purposes of the capability test, which required sampling rates of one second to verify the dynamic response.

To overcome this challenge, two alternative methods were used to capture data during subsequent capability tests.

1. UK Power Networks was able to extract the data at one second intervals directly from the PQM servers on site and downloaded to Excel files. This approach was used when the appropriate UK Power Networks engineers were available.

2. Wireshark – Operational data was recorded directly from the DERMS Front End Processors (FEP) at one second intervals by ZIV. Once again, the data was made available in Excel spreadsheets.

Given the requirement for each DER to deliver at least 90% of the maximum reactive range in 2 – 5 seconds, it is significant that all DER came very close to achieving the requirements, with DER 2, a Battery Storage unit, achieving full compliance.

Although DER had raised concerns on their ability to meet the response requirement at the recruitment and contract signature stage, participants declared their willingness to carry out further work in order to determine full compliance. In particular, UK Power Networks facilitated testing on DER 1 to test their response time and tune their controller, arranging times for this with network control engineers and outage planners. This resulted in a reduced reactive power range for that customer but allowed the DER to participate in the trials.

The project team agreed to progress DER through the remainder of the trials and continue to monitor performance, in order to provide bid learning in terms of both 'dynamic' and 'steady state' response, as well as wider learning for the project.

Table 2 Typical DER response times during capability test

	Time to achieve 90% of full reactive power range (seconds)
DER 1	<6.5s (noting limitations in data capture for first customer as described above)
DER 2	2-5s* (see note below)
DER 3	<21s
DER 4	7s
DER 5	Not fully verified as capability test did not achieve full range; speed of response then reduced as part of investigation of site trip and oscillation of this 132kV customer (see further explanation at end of this section)

*Note that DER 2 identified issues with their invertor operation in the latter part of the Wave 2 trials, which hampered delivery of Power Potential and Dynamic Containment services simultaneously. A temporary workaround was implemented by the customer, to allow continuation of the trials for that participant, albeit the DER response time was increased from two seconds to approximately five seconds (from customer) for the remaining week of the trials. If an enduring solution is developed by the customer for BAU, which changes the invertor control system, a further capability test will be required to confirm dynamic response times and reactive power range.

Mvar Range and direction of response

The reactive power response of a DER to voltage instructions sent from DERMS varied considerably depending on active power on the day and as we later learned from the capability testing of some customers, transformer tap position affecting local voltage. Hence each DER revealed different types of technical response, which can be characterised as follows.

Whilst one DER was able to achieve its declared reactive power range at the stated lead and lag values, it was more common to see DER achieving their declared reactive power range but at skewed lead and lag values. For example, if a DER had a rated capacity of 35Mvar from +20Mvar to -15Mvar, the reality may be +18Mvar to -17Mvar, so still 35Mvar but with maximum lead and maximum lag slightly offset. This was because of tap position. In most cases, this was accommodated within the PQ envelope at different active power (P) levels. However, in some cases this caused the DER to operate outside contracted limits, which would lead to a breach of limits and subsequent failsafe action by DERMS to stop the services.

Only one DER was unable to achieve its rated reactive power range. Response in the leading direction was accurate but in the lagging direction, response was consistently 21% below the rated capacity. This prompted a change in the Framework Agreement and the DERMS technical settings were revised accordingly.

One of the more significant observations, was the delivery of reactive power prior to any instruction or when the DER was being instructed for zero response (termed 'spilling'). In Figure 4, the DER provided Mvar output without any request, i.e. response should have been zero in line with the requested output from DERMS.

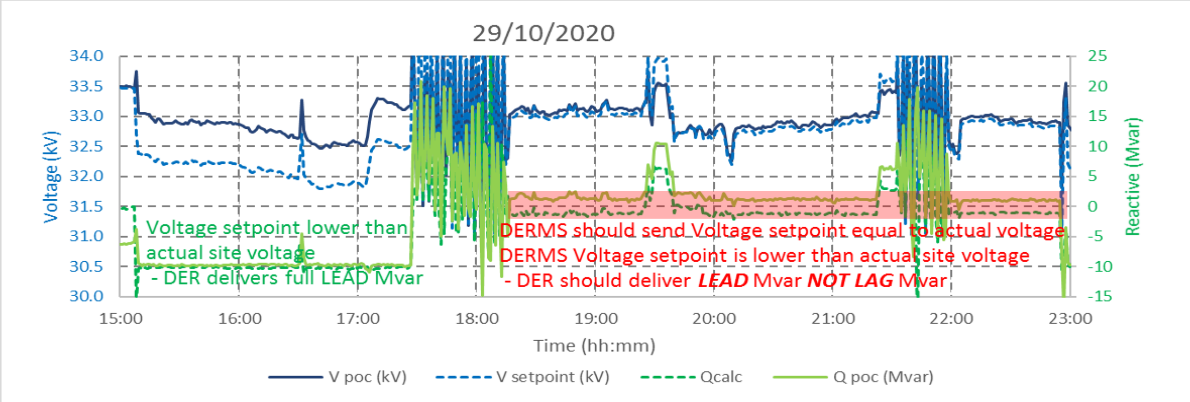


Figure 4 29 October 2020

Figure 5 shows the result of this spill, where DERMS sent a set point requesting a leading Mvar. Although the DER responded in the correct direction, the DER started off in the wrong position, so ultimately delivered a lagging Mvar response, which may require additional compensation to be purchased elsewhere if this was a BAU situation.

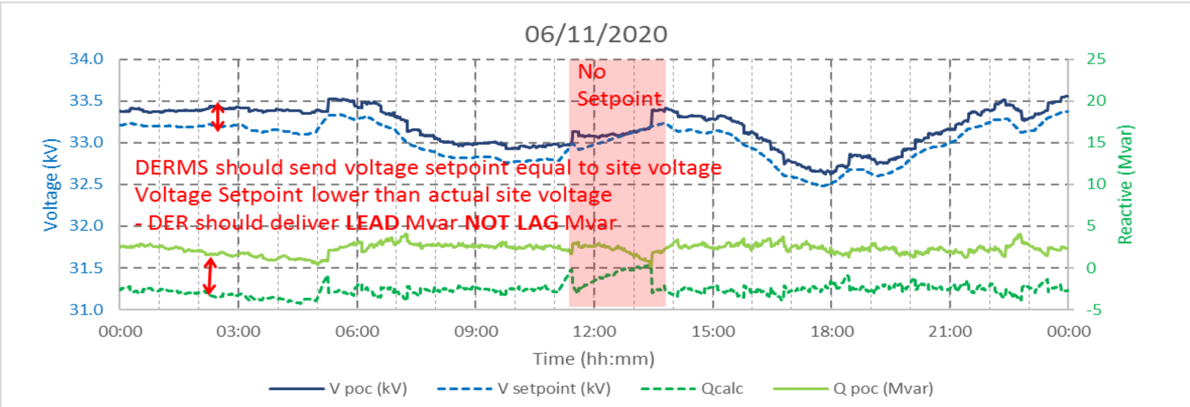


Figure 5 6 November 2020

Subsequent investigations by the customer have concluded that transformer AVC action and tap position were contributing factors to the 'spill', in addition to the set point being sent to control part of the site against its local voltage, while Mvar from the rest of the site cable network could still vary with active power levels. This theory was supported by the capability test that was done along with adjustments to the local grid transformer's tap position. This initial tapping done in exploration to get the DER Mvar output as close to 0 Mvar as possible, as the generator was 'spilling' Mvars onto the distribution network. Although reactions were improved, the spill element remained and DER Mvar output was up to six Mvars away from what was predicted. Note also that there was a supergrid-level tap change during the test, which showed the DER responding in the correct direction.

Challenges with capability test of our 132kV DER participant

Unfortunately, the fifth DER did not meet the technical standards required in the capability test and therefore while successfully commissioned and the customer attempted a Mandatory Trial, it was not able to participate in the Wave 1 or Wave 2 trials. UK Power Networks however worked diligently with the customer to resolve a number of issues.

Commissioning had been delayed during 2020 due to an active power ‘readback’ issue, where the customer was unable to configure their site controller to provide active power upper and lower limit ‘readbacks’ to DERMS. This was eventually resolved by UK Power Networks through the introduction of a simulated ‘readback’ at the RTU, thus negating the need for the customer to do this. Hence, commissioning was completed successfully in December 2020, to verify end to end signal behaviour.

During the capability test however, whilst testing speed of response over the full reactive power range, the site invertors tripped twice on over-voltage. This was traced to the transformer tap changers not reacting fast enough to bring the voltage under control, which was exacerbated by the size of voltage and rate of change required by DERMS during the test.

A further test was agreed at a reduced reactive power range with the customer that would help to restrict the size of voltage change required, thereby minimising the risk of the invertors tripping. Upon testing however, it was noticed that the DER response oscillated, something that had not been experienced during the previous tests, and some aspects of the site configuration may have been changed since the initial dispatch test during commissioning due to other works at site. Testing was therefore recommenced, initially with transformer taps in fixed position, as advised by the customer and oscillations were eventually brought under control when the customer reduced the reactive power ramp rates from 4.0Mvar/s down to 0.2Mvar/s. However, this meant that the site controller response time was unacceptably slow.

Although the issues were not resolved in time for the trials, discussions between the customer and UK Power Networks continued.

The site has a 33kV board to which the inverters connect, and the 33kV board feeds the 132kV transformer which is in turn connected to the UK Power Networks network. The tap changer sits between the 132kV transformer and the 33kV board, and its function is to manage the 33kV voltage within safe (stable) operational limits. It does this by reacting to changes of the 33kV voltage and adjusting the transformer ratio to increase or decrease the 33kV voltage. It is fully autonomous, and is not connected to the site control system, nor is it connected to any of UK Power Networks’ equipment or data connections. The reactive power service operates by adjusting the inverter voltage, which in turn adjusts the 33kV voltage, and the effect of this can be seen at 132kV and on UK Power Networks’ network.

The tap changer installed at the site was not been properly considered in the design of the scheme – as its specification was not clear to either UK Power Networks or the current owner of the site. The crux of the issue at the site was that the tap changer may fight the reactive power service, and/or cause unstable or unexpected operating characteristics. We observed this during testing when the reactive power output of the site did not change as expected, and the site tripped out on high inverter voltage during testing. Both of these symptoms can be explained by the tap changer (and site operatives reported very rapid operation of the tap changer during the testing).

In terms of progressing the design and site setup to deliver services in any future version, there is a potential technical solution available to deliver reactive power, i.e. to turn off the tap changer, or actively manage the tap position as part of the DER service.

This would require network stability studies, and a detailed analysis by an engineer competent and experienced in this area (and also taking into account the unusual operational characteristics of the DER service). Once this study is completed, it should indicate a new operational range within which the site should be stable and be capable of reliable DER service provision.

The study would also need to determine any consequences arising from the revised tap changer controls and would need review and approval by UK Power Networks, potentially also variations to the grid connection agreement.

For the purpose of the trial, the inclusion of this 132kV customer ensured that the DERMS was built and tested to accommodate DER at different voltage levels rather than just 33kV. However, it highlighted particular changes on-boarding a customer with a transformer and tap-changer within their site.

2.3. Individual DER Mandatory Trials with DERMS

2.3.1. Introduction

The aim of the Wave 1 Mandatory Technical Trials was to demonstrate that DER were technically capable of delivering reactive power services when instructed by the DER Management System (DERMS). DER were only able to participate in the provision of either active or reactive power services once the Mandatory Technical Trials were undertaken successfully.

Outlined below is a common set of objectives that were evaluated for Mandatory trials

- Verify that the DERMS' response to fast change in simulated 400kV voltage is correct and it issues the correct voltage set points to DER i.e. DERMS successfully instructs generators (functionality and communications between DERMS and DER work)
- Verify that a DER responds to the DERMS' voltage set point change and delivers expected reactive power output change. The correct lead/lag action by the DER is demonstrated
- Verify that the DERMS calculates settings for each DER within their operating limits
- Verify that DERMS operates within limits

2.3.2. Minimum performance expectations

In the project technical requirements, we set up the minimum performance expectation from DERs. The major points are presented below:

- Reactive response measured at the DER Point of Connection
- Reactive response to be assessed from the time the DER receives a voltage set point instruction
- Maximum reactive range delivered as in the Power Potential DER Framework Agreement (summed across both lead and lag directions)
- DER reactive response will follow the 4% voltage droop characteristic consistent (2.4.3)
- The DER will provide a stable response (within +/- 5% of delivered response consistent with the performance criteria outlined above) from 5s after receiving an instruction i.e. the output settles to a stable value with no oscillation.

2.3.3. Tests

Test 1 and Test 2

- Changes were made to the simulated 400kV GSP voltage input signal to the DERMS. The DERMS's 400kV target voltage set point, 400kV dead band and 400kV GSP droop setting remain fixed at 2% and 16kV/100Mvar respectively.

Test 1

- The simulated signals voltages used were 420kV and 380kV

Test 2

- The simulated signal voltage used were progressively ramped between 420kV and 380kV, with the steps individually calculated according to the Mvar size of the DER being tested

Test 3

- The evaluation of the test objectives and criteria using the actual 400kV measured voltage on the transmission system
- The test validated the stability of the solution using NGESO measured signals and required the use of the real 400kV voltage signal input and variation of the DERMS 400kV target voltage set point.
- The settings for Test 1 were used

Detailed test guidelines and procedure were developed – the external version of these can be found on the project website.

2.3.4. Results

DER 1 Solar PV plant

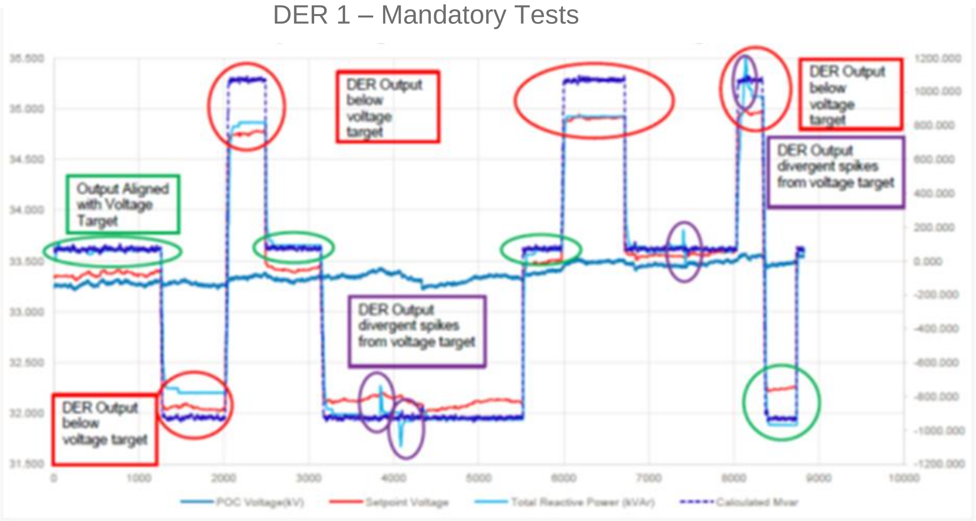


Figure 6 DER 1 Mandatory Trials

Test 1

- Involved the application of a step change to the simulated 400kV voltage input signal to the DERMS; The DERMS' 400kV target voltage set point is fixed as well as the 400kV dead band and the 400kV GSP voltage droop setting.
- At 2307 the voltage set point sent by DERMS was reduced corresponding to a voltage set point of 420kV at the GSP level. The reactive power requested was -0.925Mvar, though the DER delivered -0.75Mvar. The voltage set point sent by DERMS then increased as a 380kV set point in DERMS was entered. The delivered reactive power delivered by the DER did not meet the calculated value i.e. 0.82Mvar and 1.07Mvar respectively.
- The DER response to the voltage target was shown to be approximately 4s.

Test 2

- This involved the application of a progressively increasing ramp to the simulate 400kV GSP voltage in DERMS; target voltage set point, dead band and droop settings are fixed (2% and 4% respectively).
- From 23:38 small voltage set point changes were sent by DERMS that corresponded to increasing voltage at the GSP. A 402.06kV voltage at the GSP corresponded to a calculated value of --0.93Mvar, though the DER delivered -0.873Mvar. With a further increase in 400kV voltage, the DER was able to achieve the calculated Mvar expected which remained at -0.93Mvar.
- At 00.25, the voltage set point in DERMS was increased corresponding to a reduction in GSP level voltage. It was found that a GSP voltage of 397.9kV requested the maximum calculated Mvar for the DER capability (1.07Mvar), though the DER was not able to meet this and delivered 0.855Mvar. Further reductions in voltage at the GSP did not increase the magnitude of the Mvar delivered by the DER.

Test 3

- To evaluate the DER working with DERMS, responds correctly to the actual 400kV measured voltage using NGESO measured signals.

- At 01.02 the voltage set point sent by DERMS increased to 34.96kV; a 420kV at the GSP level was entered in DERMS. The delivered reactive power by the DER did not quite meet the calculated value by approximately 0.1Mvar. However, when the voltage set point sent by DERMS was decreased to 33.23kV, a 380kV at the GSP level was entered in DERMS. In this case, the measured reactive power delivered by the DER slightly exceeded that requested. Though the magnitude of the over and under delivery is small, due to the small size of the DER, the relative proportions are to be noted.

DER 2 Battery storage plant

Test 1

- Involved the application of a step change to the simulated 400kV voltage input signal to the DERMS; The DERMS' 400kV target voltage set point is fixed as well as the 400kV dead band and the 400kV GSP voltage droop setting.

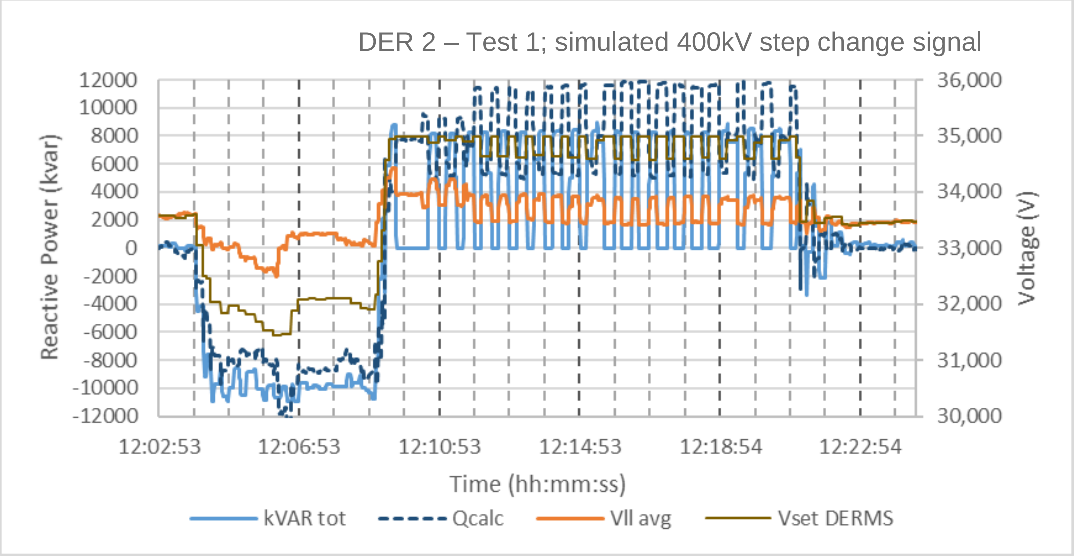


Figure 7 DER 2 Test 1; simulated 400kV step change 1202 to 1223

- At 1203 the voltage set point sent by DERMS was decreased over a period of 30s, this corresponds to the voltage step point in DERMS being set to 420kV at the GSP level. The reactive power output from DER 2 changed to approximately 10Mvar in the leading direction. With the measured voltage change the calculated reactive power requirement was around 1.5Mvar less than the delivered reactive power. The reactive capability of 10Mvar in the leading direction looks to be demonstrated at 1205 when the calculated reactive requirement hits 12Mvar though the actual plant output stays at 12Mvar.
- At 1208 the voltage set point sent by DERMS was increased from 32kV to 35kV over a period of approximately 30s, corresponding to the voltage set point in DERMS being set to 380kV at the GSP level. The reactive power output from DER 2 changed to approximately 9Mvar lagging. However, after 15s the reactive output dropped to zero and the proceeded to hunt between zero and 8Mvars lagging until 1220 when the voltage set point sent by DERMS was reset to track measured voltage. The Figure 8 shows the reactive power ramp in more detail.

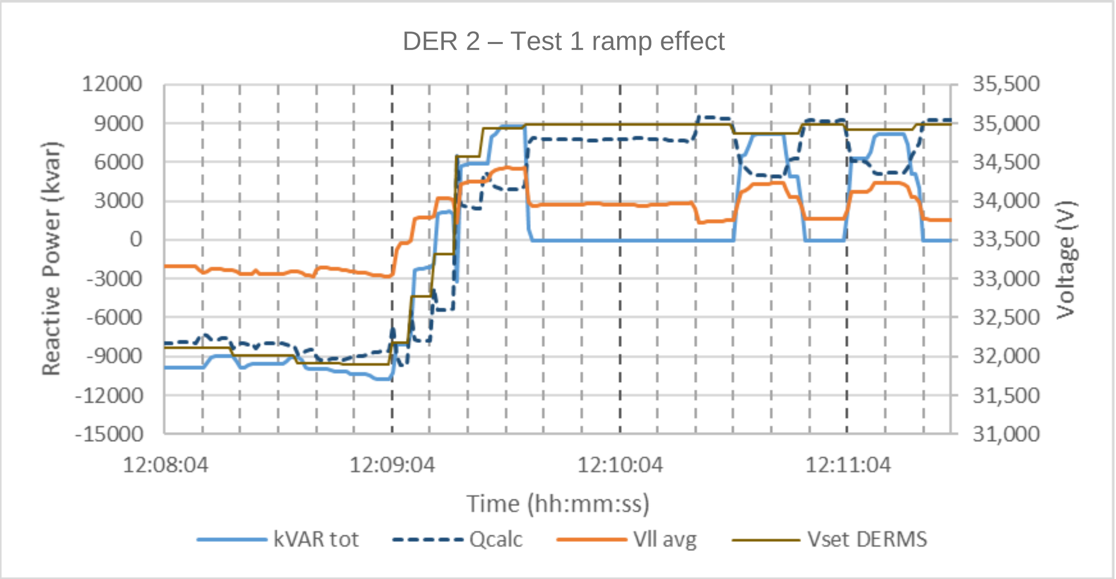


Figure 8 DER 2 Ramp Effect during Test 1 1209

- The DER voltage limit set in DERMS was not exceeded (34.98kV), though it was reaching the limit which could be causing the oscillations if the DER controller is not interpreting this correctly.
- The GSP voltage in DERMS was returned to 400kV around 12:20.

Test 2

- This involved the application of a progressively increasing ramp to the simulate 400kV GSP voltage in DERMS; target voltage set point, dead band and droop settings are fixed (2% and 4% respectively).
- The first instruction for Test 2 was a 403.2kV set point which resulted in more negative Q response form the DER (approximately 10Mvar) compared to the set point request (-8.7Mvar). It was decided not to increase the voltage further as required by the procedure as the DER was already over responding. At the time it was unclear if the over response was due to DERMS or the DER.

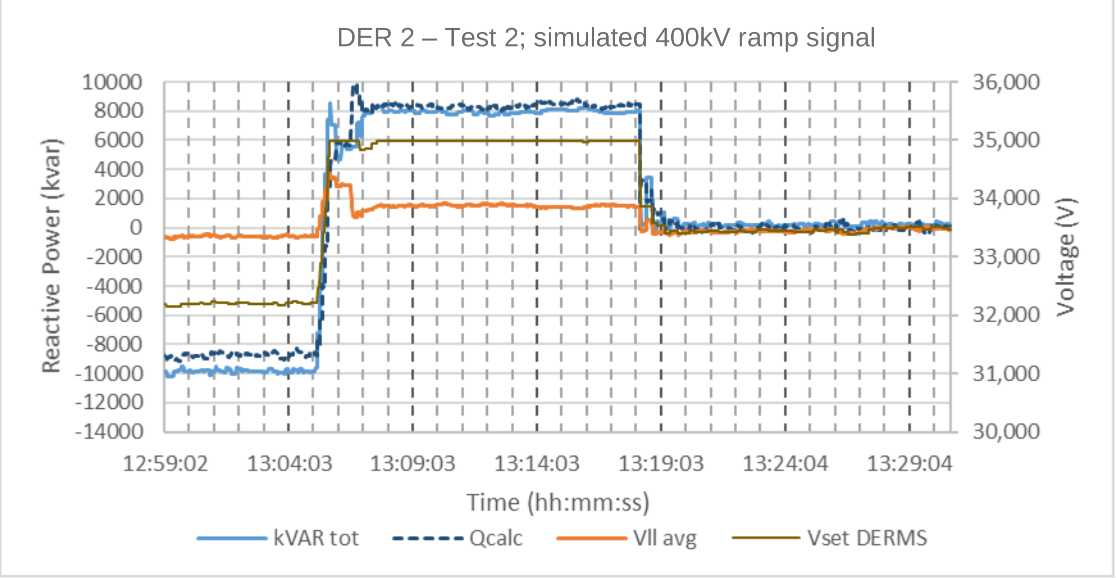


Figure 9 DER 2 Test 2; simulated 400kV ramp 1259 to 1330

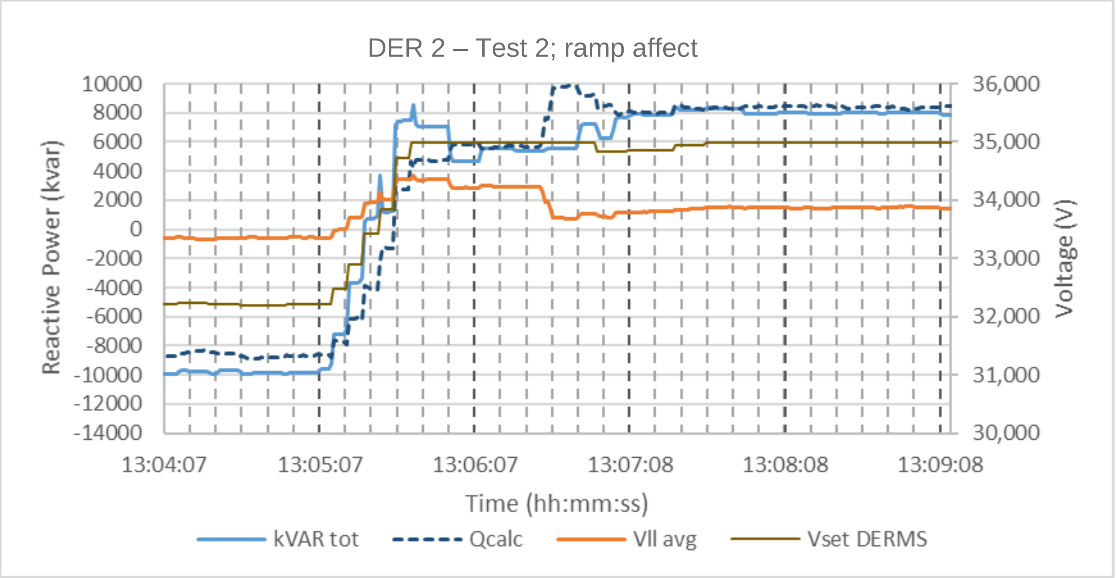


Figure 10 DER 2 Ramp Effect during Test 2 1305

- At 1305 the voltage set point sent by DERMS was increased from 32.2kV to 35kV over a period of approximately 30s corresponding to a GSP voltage set point of 396.8kV applied in DERMS. The reactive power output from DER 2 changed over a similar time although the change exceeds the calculated reactive power required. However, after increasing to 7.5Mvar lagging the reactive output dropped closer to the calculated reactive requirement of 6Mvar and the proceeded to hunt to get to a steady state.
- At 13:06:30 there was a small drop in the local voltage (orange) and reflected in the calculated reactive power (dark blue dash). There is an apparent delay of around 15s before the measured reactive power starts to respond at 13:06:47 increasing from 5.5Mvar to 8Mvar achieving steady state after 30s.
- Further changes in the 400kV set point happened around 13.10 (396kV) and 13:15 (396.8kV) which resulted in the same Q set point request from DERMS of 8.7Mvar.

Test 3

- To evaluate the DER working with DERMS, responds correctly to the actual 400kV measured voltage using NGESO measured signals.
- An initial set point of 420kV was entered in DERMS.

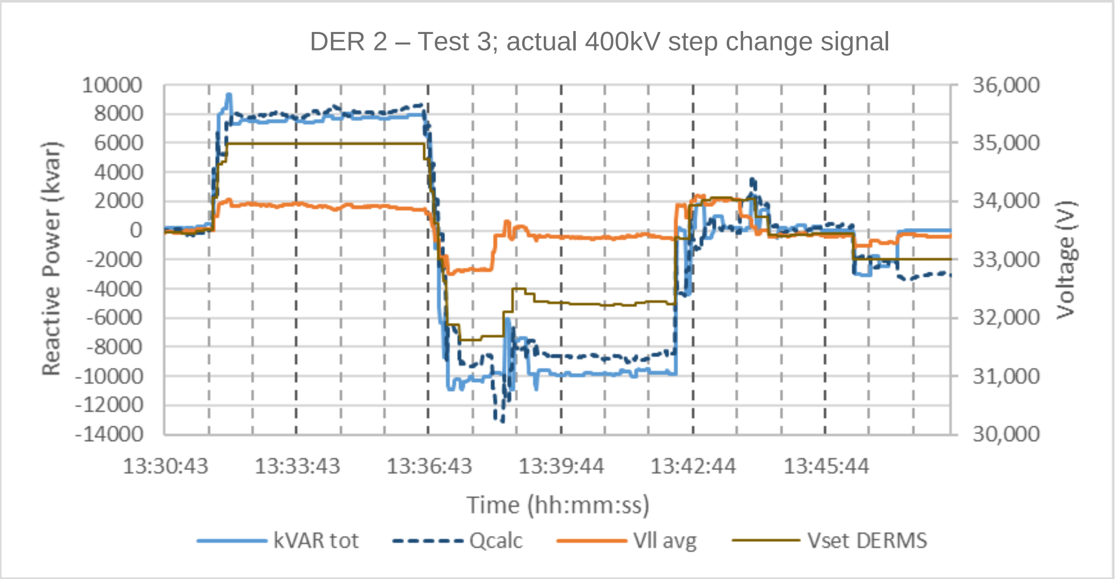


Figure 11 DER 2 Test 3 actual 400kV step change signal 1330 to 1348

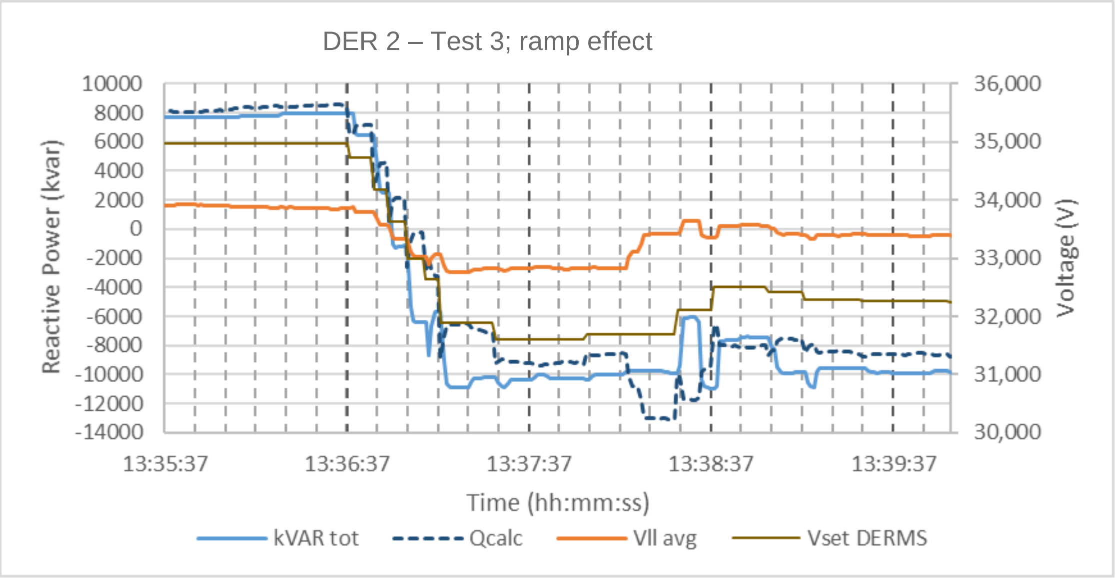


Figure 12 DER 2 1336 Test 3 Ramp Effect

- Generally, the delivered lagging reactive capability agrees with calculated reactive requirement but there appears to be over delivery of approximately 1Mvar in the leading direction.
- At 13:36 the voltage set point sent by DERMS was decreased over a period of 30s; GSP voltage set point was changed to 380kV. The reactive power output from DER 2 changed to approximately 10Mvar leading over a similar time. With the measured voltage change the calculated reactive power requirement was around 1.5Mvar less than the delivered reactive power. The reactive capability of 10Mvar leading looks to be demonstrated at 1338 when calculated reactive requirement hits 13Mvar leading as a result of a small measure voltage rise but actual plant output stays at 10Mvar.

DER 3 Wind plant

Test 1

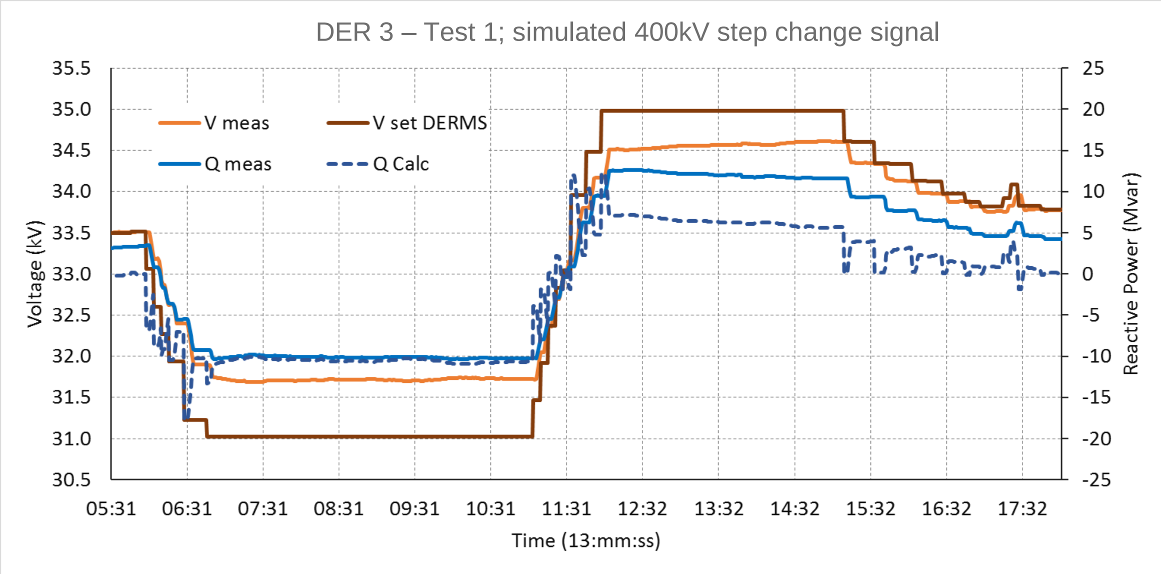


Figure 13 DER 3 Test 1 Simulated Voltage Step Change

- At 13:06 the voltage set point sent by DERMS reduced to 31kV corresponding to a voltage set point of 420kV at the GSP level. From 1307 to 1311 the reactive output matched the calculated requirement. The voltage set point sent by DERMS then increased to 35kV at 13:11; 380kV set point in DERMS. The delivered reactive power then exceeded the calculated value by approximately 5Mvar.
- The change from leading to lagging reactive power took approximately one minute. The DER appears to track the change in voltage set point sent by DERMS. Plot below indicates shows 400kV instruction and set point change sent to the generator.

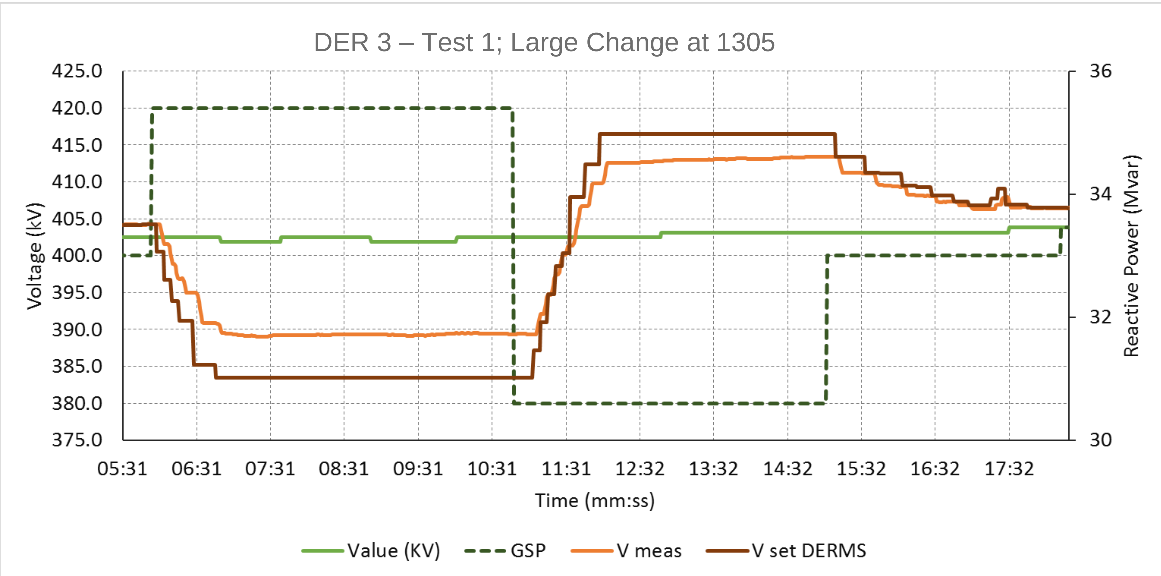


Figure 14DER 3 Large Change 1305

Test 2 – Ramp Voltage

- Test 2 involves the application of a progressively increasing ramp to the simulate 400kV GSP voltage in DERMS; target voltage set point, dead band and droop settings are fixed (2% and 4% respectively).

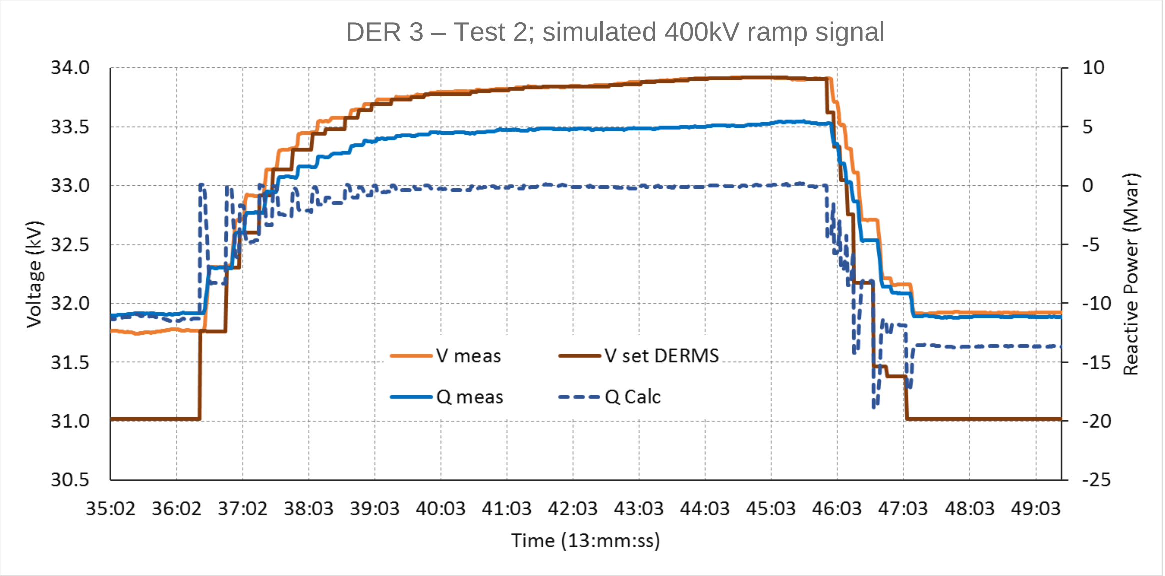


Figure 15 DER 3 Test 2 Simulated 400kV Ramp

- At 1336 the voltage set point sent by DERMS was increased as a ramp. The measured reactive power responded. Once in steady state the delivered lagging reactive power then exceeded the calculated value by approximately 5Mvar.
- At 1346 the voltage set point sent by DERMS was then decreased to 31kV in approximately one minute suggesting a step input to the DERMS controller; an initial instruction of 404kV was entered in DERMS at this time. In steady state the measured reactive power output looks to be limited at 13Mvar as indicated in the morning capability tests. A further increase in voltage set point was outlined in the procedure, however as the DER “limit” was already reached it was not increased further.
- Around 1350, the voltage set point was changed to 402.5kV, though this did not result in an appreciable difference in the Mvar requested nor the DER Mvar output.

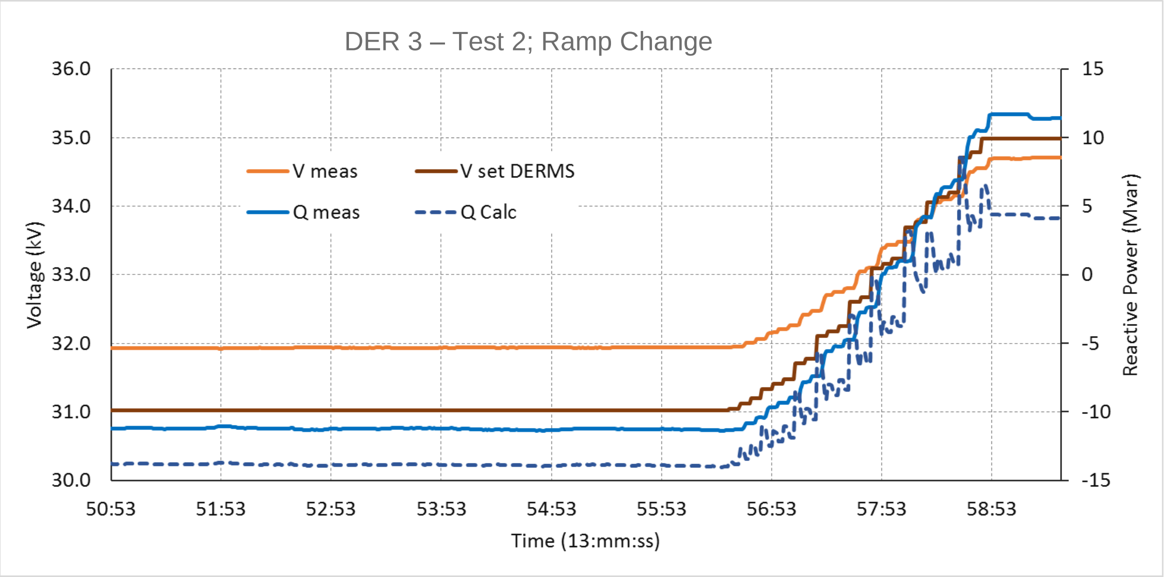


Figure 16 DER 3 Test 2 Ramp Change

- At 1356 the voltage set point sent by DERMS increased to 35kV as a ramp over approximately two minutes. This corresponds to a 397.5kV set point entered in DERMS. The measured reactive power responded but at no point aligned with the calculated value. Once in steady state the delivered lagging reactive power then exceeded the calculated value by approximately 7Mvar.

Test 3

- Test 3 is to evaluate the DER working with DERMS, responds correctly to the actual 400kV measured voltage using NGESO measured signals.

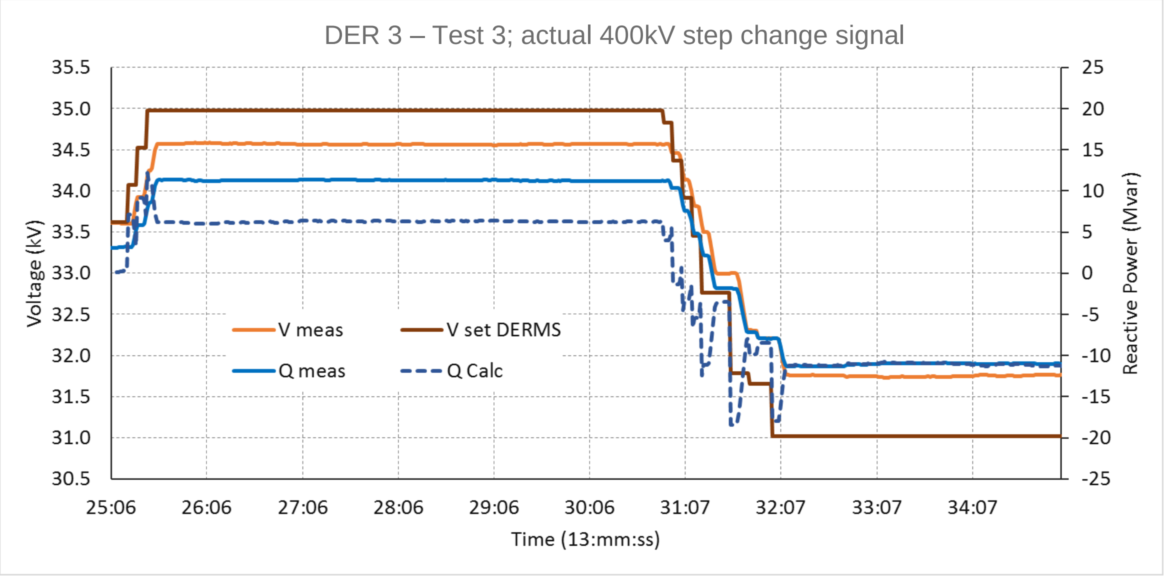


Figure 17 DER 3 Test 3 Actual 400kV Step Change Signal

- At 1325 the voltage set point sent by DERMS increased to 35kV; a 420kV at the GSP level was entered in DERMS. The delivered reactive power then exceeded the calculated value by approximately 5Mvar.

- The voltage set point sent by DERMS then decreased to 31kV at 13:31; a 380kV at the GSP level was entered in DERMS. The measured reactive power output then matched the calculated requirement.

DER 4 Wind plant

Test 1 – simulated voltage step change

- Involved the application of a step change to the simulated 400kV voltage input signal to the DERMS; The DERMS' 400kV target voltage set point is fixed as well as the 400kV dead band and the 400kV GSP voltage droop setting.

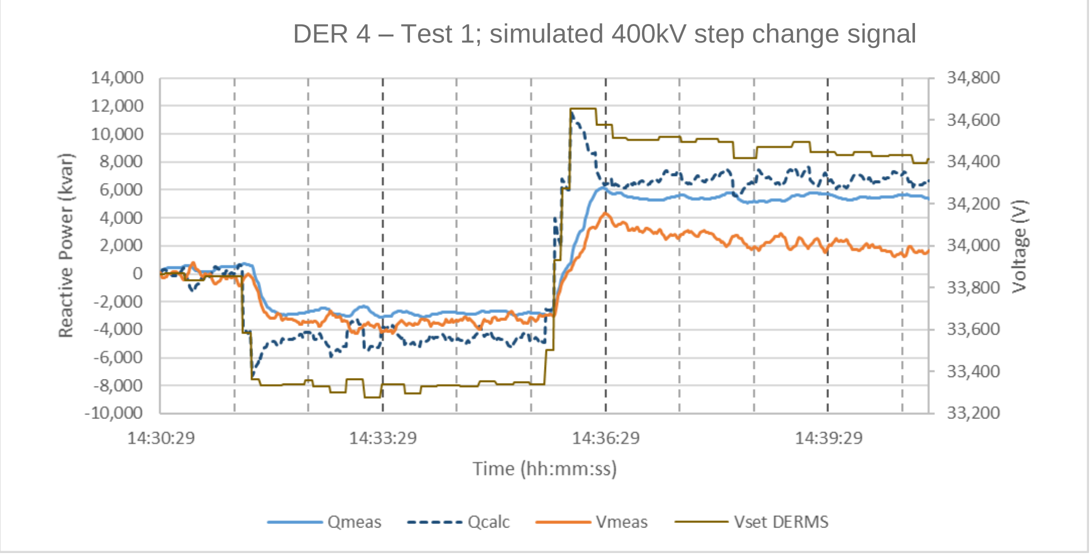


Figure 18 DER 4 simulated voltage step change

- At 14.32 the voltage setpoint was increased to 420kV at the GSP level was entered in DERMS. The delivered reactive power did not achieve the calculated value by approximately 4Mvar.
- The voltage setpoint sent by DERMS then decreased as a 380kV at the GSP level was entered in DERMS. Similarly, the measured reactive power output did not match the calculated requirement.

Test 2 – simulated ramp voltage

- Test 2 involves the application of a progressively increasing ramp to the simulate 400kV GSP voltage in DERMS; target voltage setpoint, dead band and droop settings are fixed (2% and 4% respectively).

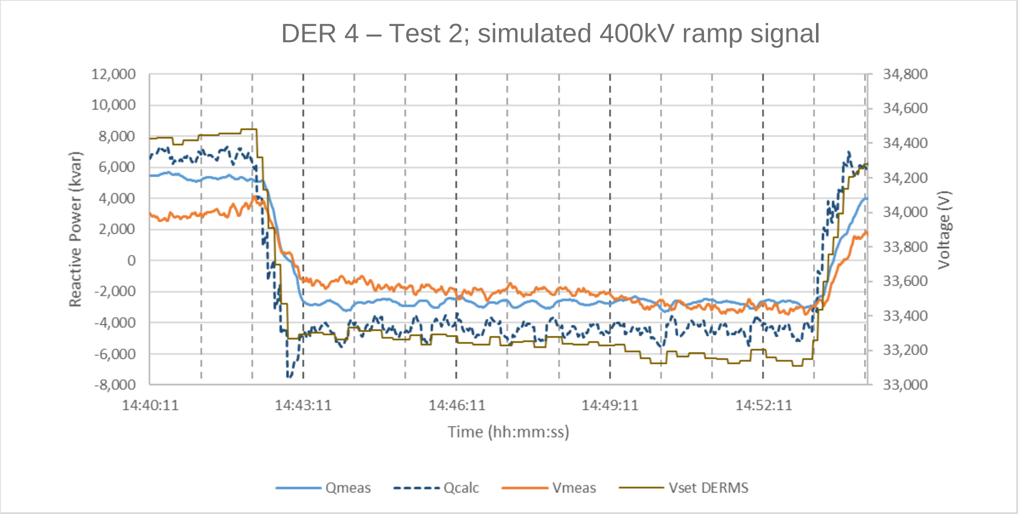


Figure 19 DER 4 Simulated ramp voltage signal

- At 14.42 the voltage set point was increased from 404kV to 406kV at the GSP level in DERMS. The delivered reactive power did not achieve the calculated value by approximately 2Mvar. In addition, there is a minimal change in the DER reactive power response though the voltage set point was changed by 2kV. The GSP voltage set point was then changed to 402.5kV at 14.49 to see if the DER response would be different, though the reactive power remained relatively consistent at around -2.8Mvar.

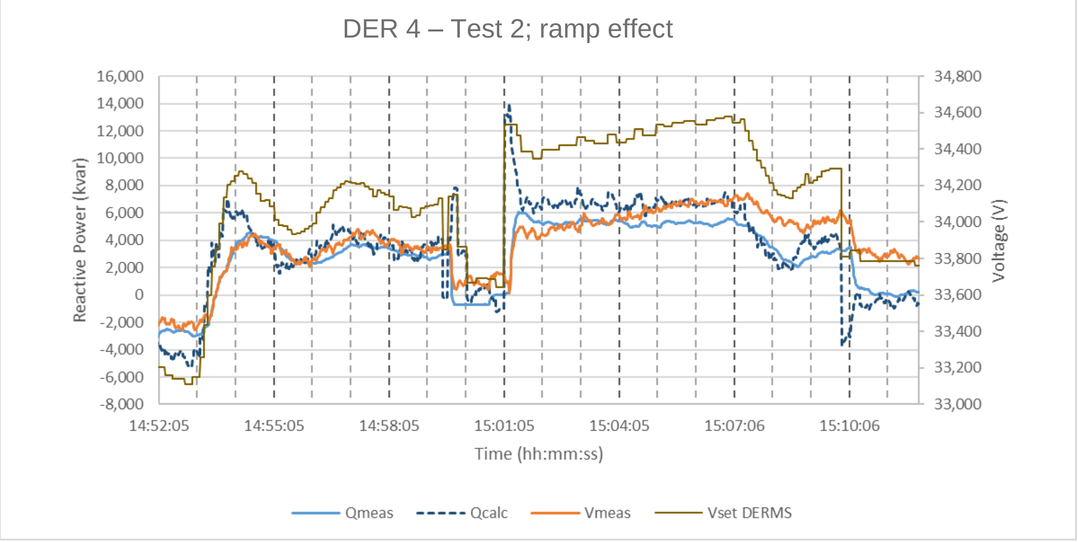


Figure 20 DER 4 Test 2 ramp effect

- At 14.52 the voltage setpoint was decreased to 397.5kV at the GSP level in DERMS to produce an injection of reactive power from the DER. Again, the delivered reactive power did not achieve the calculated value by approximately 3Mvar. The voltage was then reduced to 394kV at 15.03 and the shortfall in reactive power from the DER was approximately 7Mvar. Over the period since the beginning of the test, it's possible to see that the reactive power response does not increase in a ramp characteristic.
- At 15.05 the 400kV setpoint was changed to 397.5kV before returning to 400kV a few minutes later. In a similar way, DER does not produce the expected Mvar volume, though a better ramp response is shown.

Test 3 – voltage step change (real signal)

- Test 3 is to evaluate the DER working with DERMS, responds correctly to the actual 400kV measured voltage using NGESO measured signals.

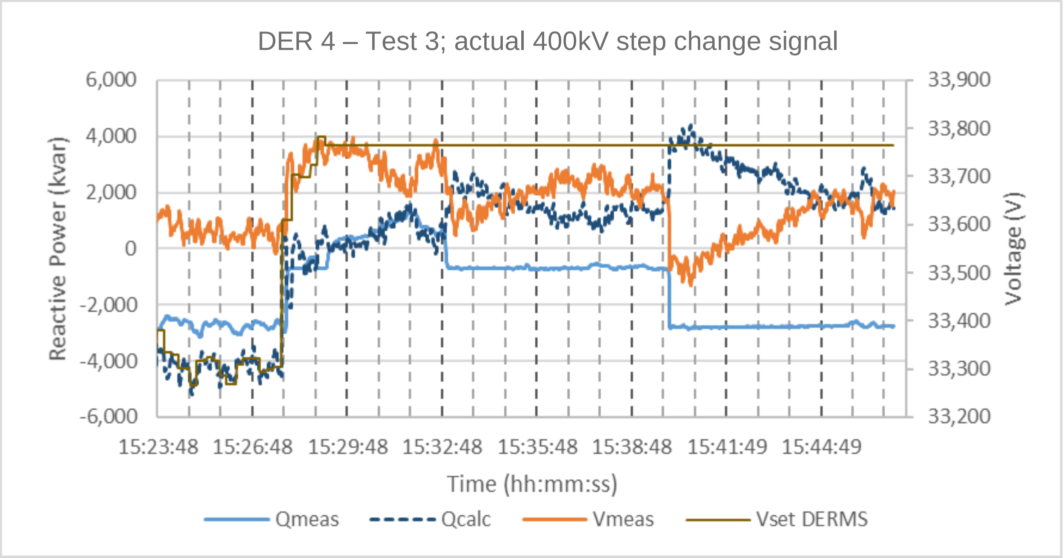


Figure 21 DER 4 Voltage step change

- As previously seen in the simulated voltage tests, the DER is not able to achieve either the required leading or lagging Mvar requested

2.4. Collective end-to-end trials

Wave 1 Optional Trials commenced at 11:00 on 15 October 2020 and ran continuously 24/7 for eight weeks until 10 December 2020.

Wave 2 trials commenced at 11:00 on 6 January 2021 and ran for 12 weeks until 27 March 2021 with two pauses for review of the nomination process (24/25 January) and for a DERMS upgrade (12 to 15 February).

A total of four out of five contracted DER participated in both Wave 1 and Wave 2 trials, with the fifth DER commissioned during Wave 1 having not satisfactorily completed its capability test and Mandatory Trial to be able to participate in the collective trials.

During the eight weeks of Wave 1 Optional Trials and 12 weeks of the Wave 2 Market Trials, the NGESO control room sent instructions to the DERMS via PAS. The instructions were based on setting specific inputs at each GSP e.g. voltage target, voltage dead band and percentage droop characteristic. These settings were altered on a weekly basis to investigate the DER response to providing leading and lagging reactive power during different times of the day.

For Wave 2 Market Trials, a set of high and low voltage scenarios were introduced as outlined in Table 2 below. These scenarios were chosen as they represent credible scenarios that could happen on the transmission system and were notified to DER so they could consider changing their bidding strategy during the trials. It is important to note that DER were not used to secure the transmission system during Wave 2, and NGESO was not considering DER against alternative reactive power services available to resolve the actual system requirements.

Table 3 Scenarios considered during Wave 2 Market Trials

#	Scenario	System factors	Pre-fault capability (%)	Post fault capability (%)	Scenario description
1	High voltage	- Low south east demand; high DER generation - High import/export from interconnectors	100	100	Likely to use leading capability and keep lagging capability available for network security
2	High voltage	- Low south east demand; high DER generation - Low import/export from interconnectors	100	0	Likely to use leading capability and need little lagging capability available for network security
3	Medium voltage	- High import/export from interconnectors	50	100	Use some leading capability and keep lagging capability for network security
4	Medium voltage	- Low import/export from interconnectors	50	0	Use some leading capability and need little lagging capability for network security
5	Low voltage	- High south east demand; low DER generation - High import/export from interconnectors	0	100	Use very little leading capability and keep lagging capability available for network security
6	Low voltage	- High south east demand; low DER generation - Low import/export from interconnectors	0	0	Use very little leading capability and need little lagging capability available for network security

2.4.1. Availability and reliability of DER

DER Availability in Wave 1

In the Wave 1 trials, over the 1345 hours of available trial time, Table 4 indicates actual available hours from DER. All DER that offered at least 987 hours in voltage control mode and available for instruction received the full participation payment of £45k.

Table 4 Availability of DER in Wave 1 trials

	Total hours available		Reason
DER 1	722	54%	As expected, customer planned to be available for service only certain times of day
DER 2	1345	100%	
DER 3	1176.5	87%	Offered full availability, but some periods when plant unavailable within agreed contractual range (not within agreed P range for trial, could be reviewed post-trial
DER 4	504	37%	Late entrant to trials
Total	**3747.5**		

The NGESO control room were able to dispatch available volumes of DER via PAS as in Wave 1 Optional Trials described above. All bids were automatically accepted during Wave 1, but in Wave 2 this was based on the commercial assessment described in section 3. If no reactive power bids were accepted at a GSP, then it was not possible for the control engineer to dispatch at that GSP.

DER Performance / Reliability in Wave 1

Table 5 Initial results in Wave 1

DER	Comments
1	Initially this DER showed oscillatory behaviour that was due to the different methods of voltage set point calculation between DERMS and DER controllers DERMS calculation based on $\{Q_{target} - Q_{actual}\}$ DER calculation based on $\{Q_{target}\}$ The two controllers were sending competing voltage set points that produced the oscillations
2	Showed inconsistent performance shown by spikes in results as the DER was dropping out of voltage control. This erratic compensation would require additional operational actions to counteract it if left unresolved, that could lead to voltage flicker and instability of other DER
3	Provided Mvar output without any request for reactive compensation and have shown zero output. This may be as a result of transformer AVC action and tap position. There were instances when the DERMS set point was requesting leading Mvar but the DER provides lagging Mvar i.e. the DER was responding in the correct direction but starting off at the wrong Mvar output, hence the overall response was not as expected. If left uncorrected, additional reactive compensation would be required to counteract this behaviour Detailed discussions with DER 3, concluded that this was • heavily influenced by transformer AVC action and tap position, and • that the voltage set point controls part of the site, but there is also a Mvar contribution associated with the active power flows within the site cable network.

4	Joined the trial at a late stage hence there was limited opportunity to assess performance before the system was slowed down. Further technical analysis of this DER was carried out during Wave 2

This initial collective end-to-end trial showed positively some delivery of DER dynamic voltage control with the VPP providing some delivery of Mvars required by the transmission system. However, some improvements needed to be made to DERMS to enhance the technical performance. An upgrade to DERMS was implemented before the start of the Wave 2 commercial trials (see section 2.1 of this report), enabled additional technical analysis to take place during the Wave 2 Commercial trials; these results are outlined below.

Improvements delivered after Wave 1 trials ready for Wave 2

Data traffic between Power On and DERMS

One of the more significant findings during Wave 1, was the increase in data traffic through the UK Power Networks network management systems. This posed a risk to system security as significant volumes of data traffic from DERMS through PowerOn ICCP/FEP placed pressure on the data processing and storage capacity in UK Power Networks' network management system.

As an initial precaution and on the advice of the developer (ZIV), the project team took action to reduce the recalculation frequency of the DERMS controller to stem the flow of data to acceptable levels. This unfortunately reduced the DERMS speed of recalculating its response (to changes at the GSP or the DER), from five seconds to 10 minutes. This led to updates in instructions going from 10 seconds to 20 minutes which considerably impaired both DERMS control and the ability of DER to respond appropriately for the rest of Wave 1 (weeks 3-8).

This issue was later resolved with an upgrade to DERMS, prior to Wave 2. The upgrade introduced configurable dead bands around the voltage set points issued to DER, which gave the UK Power Networks team the ability to set a voltage set point dead band within DERMS. This restricted the volume of set point instructions issued by DERMS, which in turn reduced data traffic through the NMS (network management system).

A further improvement affecting both the volume of data traffic and the consistency of service delivery was the implementation of static RTU limits, where active and reactive power limits, sent from DERMS, were fixed at DER contractual rated values and were not recalculated by DERMS. This again further helped to reduce network data traffic and allowed system controller response times to return to full speed for Wave 2.

Prior to the upgrade, some DER were observed dropping in/out of voltage service, for no obvious reason. The issue was traced to DERMS sending new limits each time the active power changes, in line with the PQ capability. However, with some DER providing fast frequency response (FFR), this meant that the active power was changing every few seconds and hence DERMS was recalculating and reissuing Q limits. Therefore, DERMS was unable to keep up with the constantly changing readbacks from the DER, i.e. several retry attempts were exhausted and the DER dropped out of service mode. This was another issue that was later resolved by the DERMS upgrade prior to Wave 2, where limits were fixed at rated values and hence remained unchanged.

Another observation in Wave 1, was where DER were consistently breaching contractual limits and therefore dropping out of service on a regular basis. An example of this was where a DER was only able to provide active power above 15MW and therefore its active power lower limit was set at 15MW, as per contract. This meant that when the DER output fell below 15MW, it dropped out of voltage service (correctly so) due to an active power lower limit breach. However, the DER would still have been able to provide voltage support down to 0MW, even if not able to provide active power service. Therefore, in this example, a new active power lower limit of 0.0MW was agreed with the customer and implemented in DERMS, which resolved the issue of the DER dropping out of service.

Another example involved a DER with a contractual active power limit of 0.0MW, because the DER had declared it could not deliver both active and reactive power services simultaneously. However, it was observed that the DER was importing up to 8kW during certain periods, which caused the DER to drop out of voltage service. In this case, a new active power lower limit of -0.1MW was agreed with the customer, which again resolved the issue of the DER dropping out of service.

Several instances of oscillations in the reactive response delivered by DER were observed during Wave 1 and Wave 2. Further investigation showed the source of these oscillations to fall into 3 categories:

1. On/off oscillations due to the DER coming in and out of voltage control – this was resolved due to a change in the DERMS integration design noted in section 2.4.1 above.
2. DERMS Setpoint calculation – different methods of voltage set point calculation between DERMS and DER controllers:
    a. DERMS calculation based on $\{Q_{target} – Q_{actual}\}$
    b. DER calculation based on $\{Q_{target}\}$

This resulted in oscillations at some sites where the two controllers were competing for different voltage set points.

This was again resolved with the DERMS upgrade prior to Wave 2, which provided user-configurable set point calculation methods, i.e. the ability to switch between the two-voltage set point calculation methods in DERMS, which ensured full alignment with the DER control systems.

An example of the impact and benefit of this configurability was where a customer reported their DER oscillating wildly. The set point calculation was found to be incorrect and was changed to reflect calculation method #1, which stabilised the DER instantly. The effect of this is illustrated in the graph below:

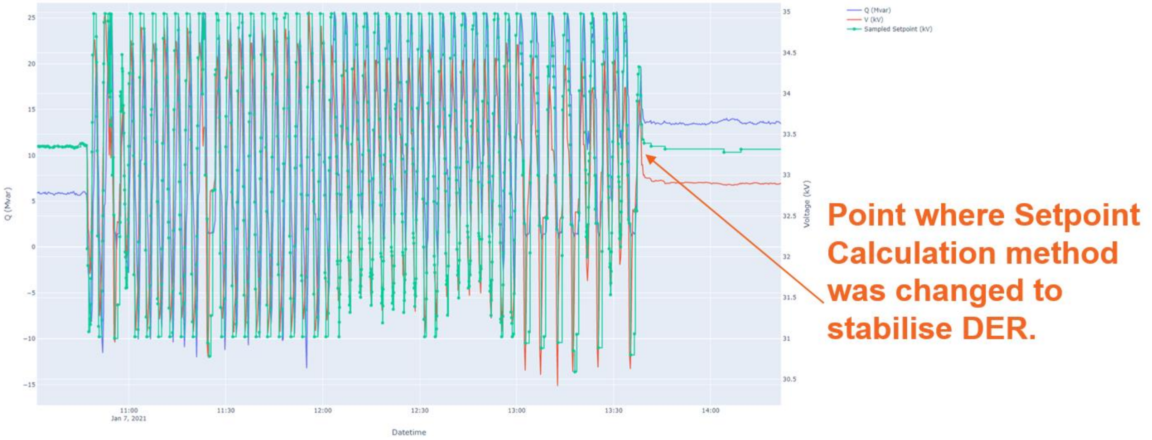


Figure 22 Example of DER instability due to voltage setpoint calculation method

3. DERMS controller gain settings – the controller gain determines how aggressively the controller drives the response to a change in target. Too much gain and the response will overshoot the target and oscillate around the set point; too little gain and the response will be slow and may struggle to reach the target. In this case DERMS GSP controller gain was gradually reduced from 0.7 to 0.6 and finally to 0.5, which gave notable improvements in DER performance, as shown below.

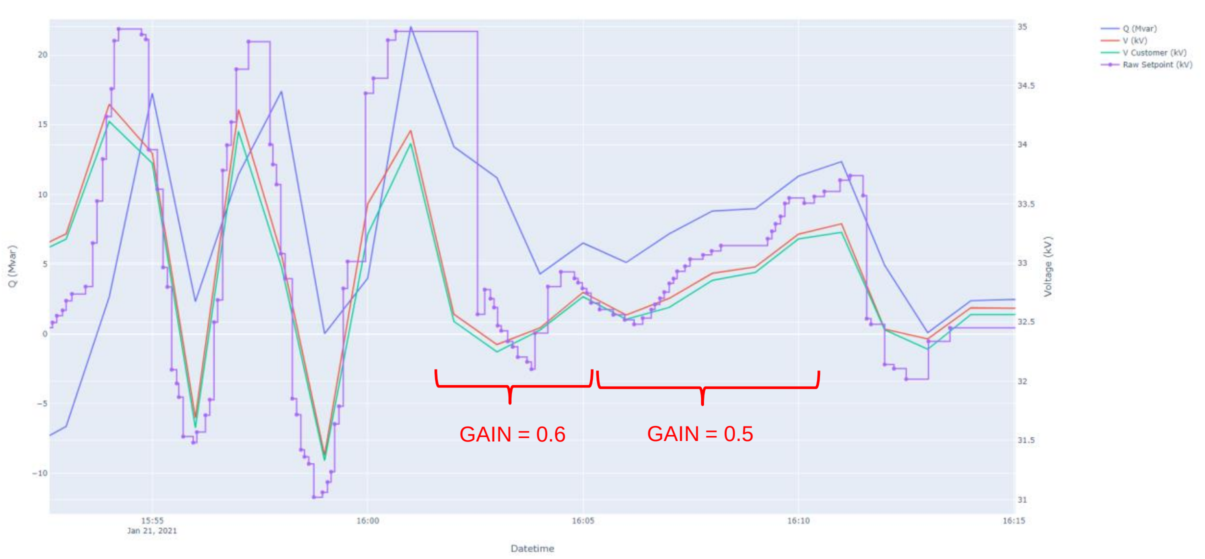


Figure 23 DER performance following adjustments to DERMS control settings

One Customer identified a conflict between FFR and DERMS commands sent to their plant, which caused the assets to disconnect from the DERMS controller. The issue was resolved by the customer and normal operation resumed for the rest of trials but will require deeper investigation by the customer.

One Customer experienced difficulties in re-enabling the service. This was due to their reactive power response being outside their permitted contractual range in its connection agreement (reference section 2.2.1. – Interaction with Connection Agreement). The UK Power Networks team manually re-enabled service delivery once the customer returned to its allowed operating range. The monitoring involved in the Power Potential RTU logic highlighted deviations from contractual range which would not have been noticed in normal operation.

DER Performance Examples in Wave 2

The following graphs (figures 24-27) illustrate examples of the performance of each of the DER in Wave 2, by charting reactive power response against voltage set point and actual voltage at the PoC. For context, the DER responds to the difference between the voltage set point and actual voltage and should be delivering 0.0Mvar when the voltage readings are the same and moving to export or import as the set point goes above or below the actual voltage respectively.

In the examples, each DER demonstrates a response to requests from DERMS, which remains steady over time. As well as demonstrating the initial response, it shows that the DER via DERMS, can deliver a steady state response in the requested direction. This response is sometimes to the maximum lead or lag capability of the plant, but when required, to a smaller value below the full DER capability (if the request was smaller at the Grid Supply Point, or network conditions restricted the output).

Thus, while noting that the Power Potential technical and commercial design was for a dynamic response, the trial has demonstrated technically that a steady state service could also be delivered by DER via DERMS.

These examples are steady response but driven by voltage set point instructions. The DERMS design was to issue voltage set point instructions in order to deliver a reactive power (Q) request to the DER. A 'static' service would normally be delivered by a direct Q request. Further detailed review of technical and commercial implementation would be required to deliver this, but this would be a further development of the Power Potential approach (see section 6.2).

The integration design DERMS-PowerOn-RTU-DER already facilitates direct requests for Q. It would be a change to the DERMS system to instruct a Q set point, rather than instruct V to deliver Q. DER would need to be ready to receive a Q set point signal rather than operate in voltage droop control however, so the commissioning approach would need to be adjusted for this.

In Figure 24 below, the voltage set point adjusts as the local POC voltage alters, to maintain a steady maximum import of reactive power.

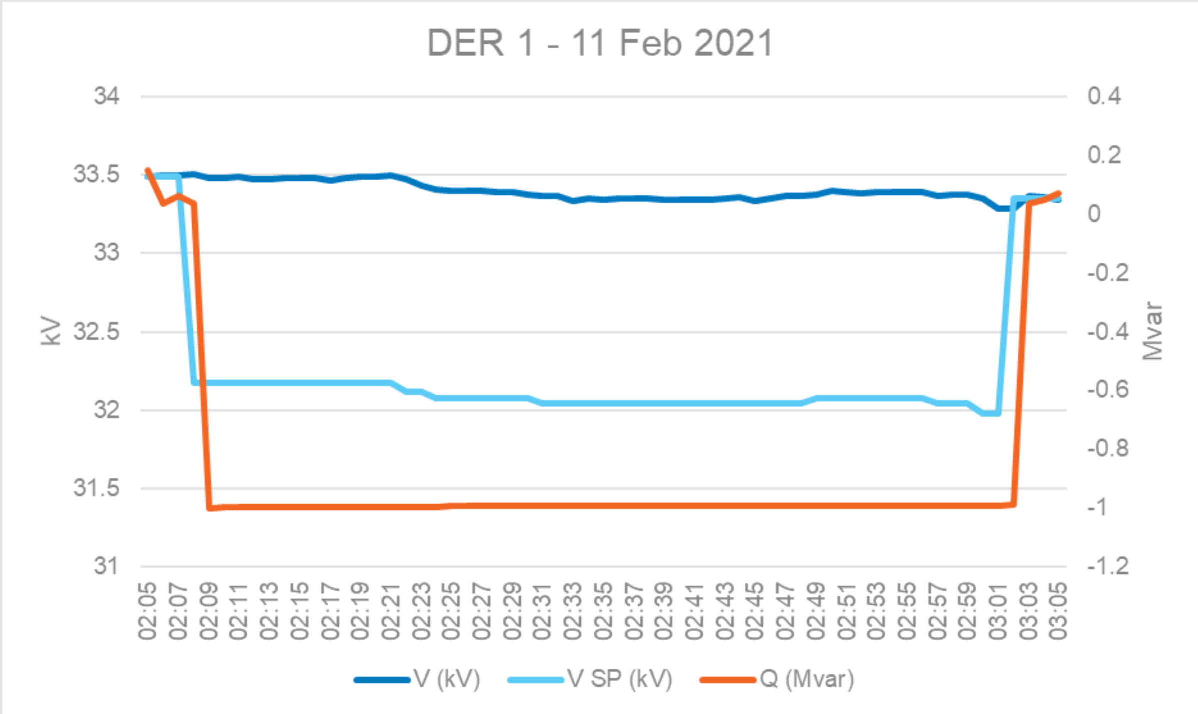


Figure 24 Steady response from DER 1 responding to an import requirement

Figure 25 demonstrates steady reactive export (lag) then import (lead) based on the change in voltage set point and shows how the local POC voltage is lower than the set point during the initial export, then higher than set point during reactive power import.

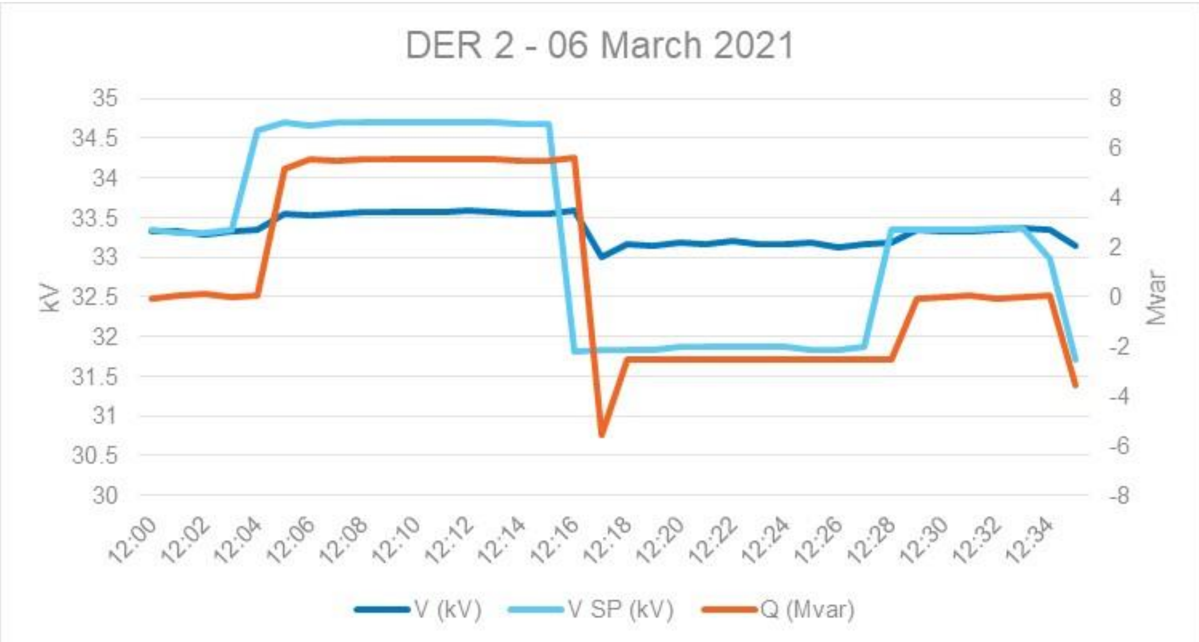


Figure 25 DER 2 responding appropriately to voltage set points in either direction

Figure 26 provides an example where the voltage set point is below actual voltage and importing Mvar. The voltage set point instructions from DERMS then gradually increases until they exceed the actual voltage and the DER transitions through 0 Mvar at the point of crossover, to settle out at a stable export of ~13.5 Mvar.

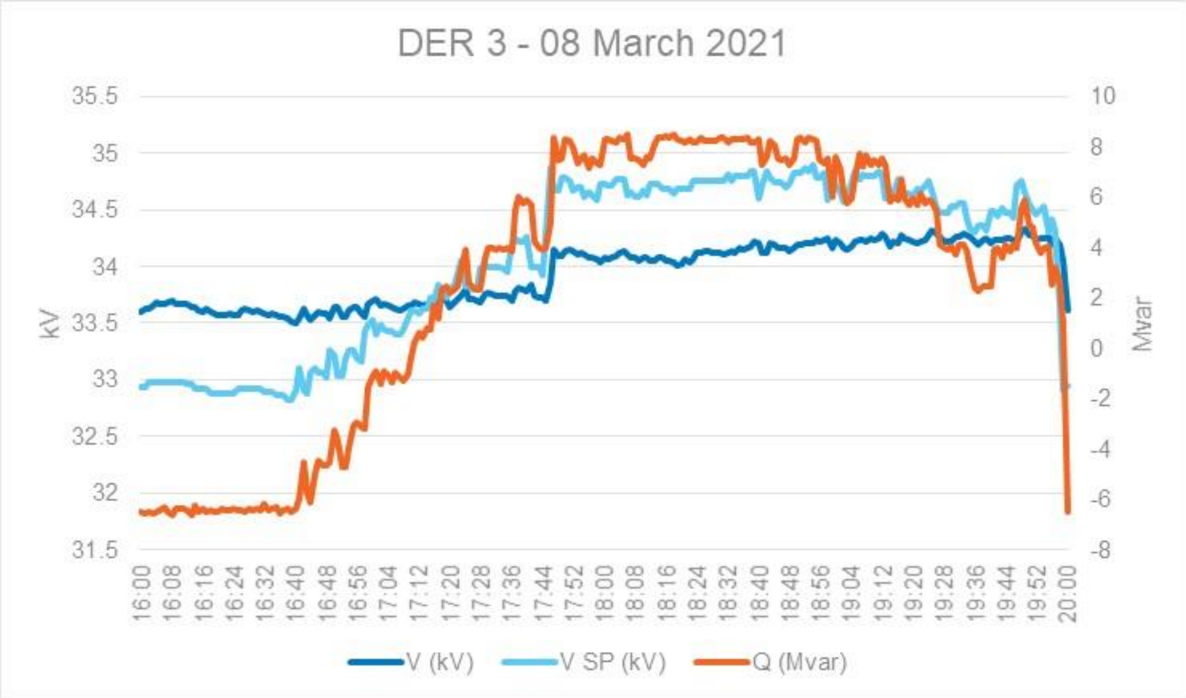


Figure 26 DER 3 responding firstly to an import requirement, then to export requirement

In the next example, DER 4 starts at 0 Mvar when the voltage set point is equal to the actual voltage but then responded quickly to an import requirement, where it remains for much of the day. Note also that although the voltage set point varies, the delta between the set point and the actual voltage remains constant and so the reactive power import remains steady.

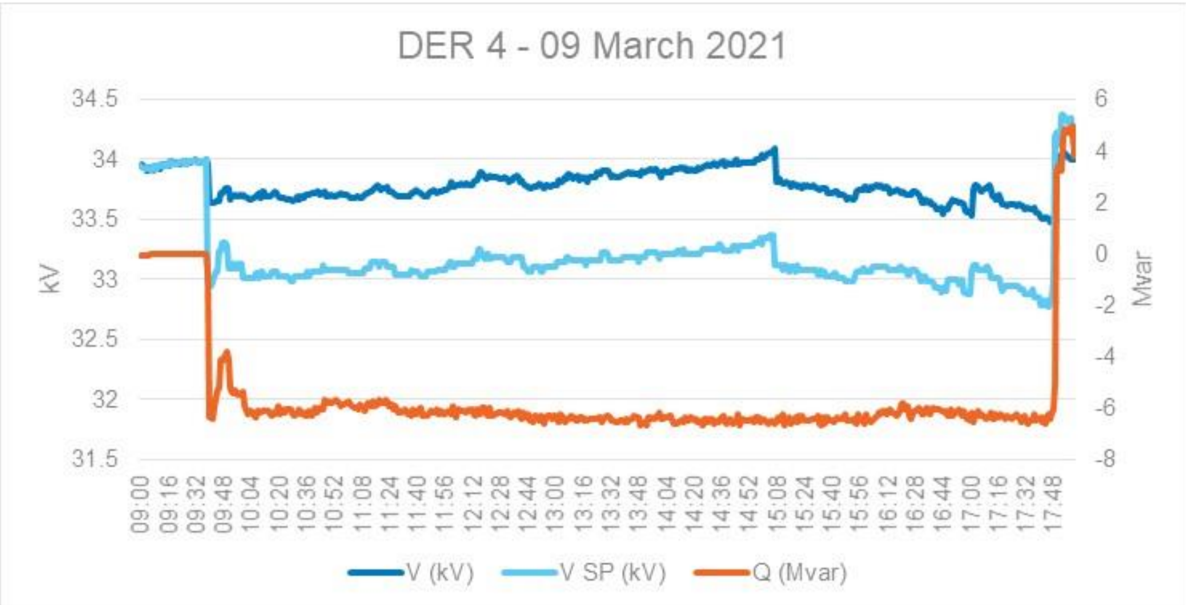


Figure 27 DER 4 responds quickly to an import requirement

DER Availability in Wave 2

In the Wave 2 trials, over the 1,772 hours of available trial time, Table 5 indicates actual available hours from DER.

Table 6 Availability of DER in Wave 2 trials

	Hours accepted and available	% of 1772 hours accepted	Days accepted and available	Mvarh utilisation	Utilisation factor when accepted
DER 1	751.5	42.4%	31.3	261	34.7%
DER 2	996	56.2%	41.5	1,503	15.1%
DER 3	1,508	85.1%	62.8	5,192	17.4%
DER 4	1,565.5	88.3%	65.2	4,838	19.7%
	4,821	68.0%	200.9	11,794	18.1%

DER availability issues were relatively rare in the trial with Table 6 summarising the issues encountered. It must be noted however that particularly in the first half of Wave 2, interruptions in availability of the service from DER may have been masked by interruptions in the availability of the system (see section 2.4.3).

Table 7 Scale of site-specific availability issues in Wave 2 trials

DER 1	None identified
DER 2	Two days five hours at end of Wave 2 – variety of communication issues at the customer's site
DER 3	16 hours due to a site equipment issue, seven and a half hours due to mismatch of limits between site and those issued by DERMS
DER 4	Services disabled on occasions when site produced Mvar outside of its contractual range, resumed once back in range. Noted one day 10 hours due to communication issues between DERMS and DER (not site or DERMS issue, no/slow readback, DERMS was retrying the site)

2.4.2. Availability and reliability of VPP

Dynamic voltage control challenges

From week 3-8 of the Wave 1 trials, there were common themes to the initial results shown for dynamic voltage control by the VPP namely voltage set point sent every 20 minutes which was too slow for requirements

Figures 28 to 30 below, show instances when the service requirements at GSP and Mvar provided by the VPP, were not matching.

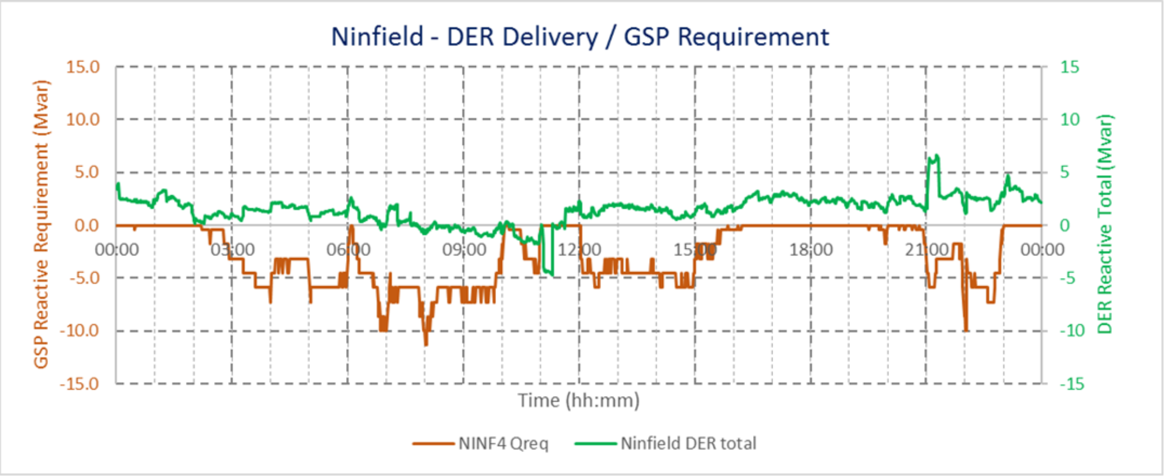


Figure 28 Ninfield – DER Delivery during initial weeks of Wave 1

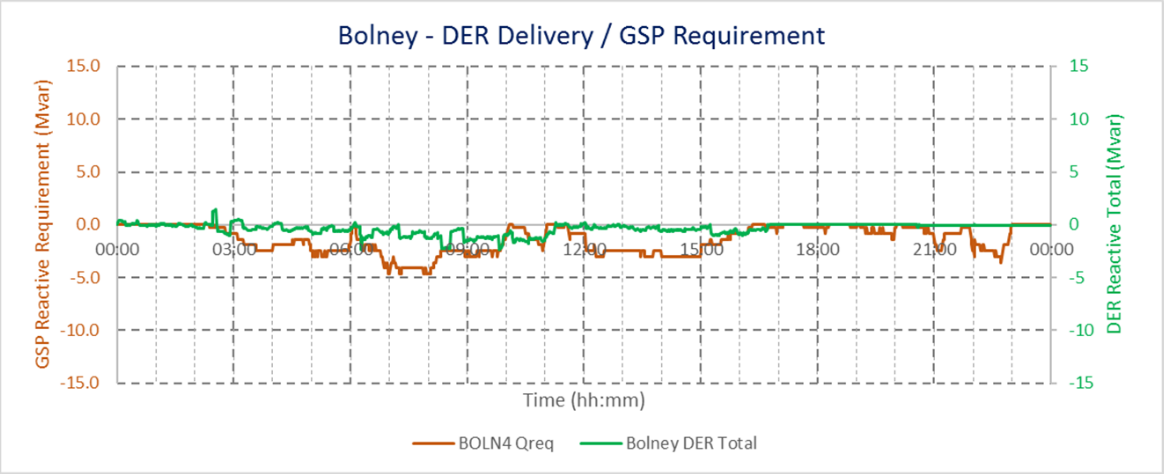


Figure 29 Bolney – DER Delivery during initial weeks of Wave 1

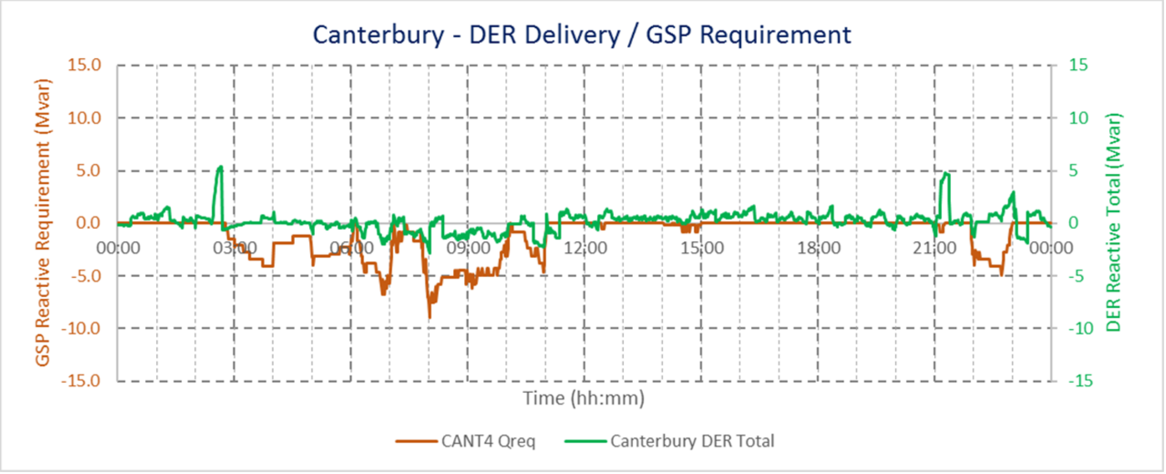


Figure 30 Canterbury – DER Delivery during initial weeks of Wave 1

At one VPP due to issues with its most significant generator, when a lagging reactive requirement is requested, the VPP delivers lead, or zero Mvar is requested and the VPP delivers Mvars.

Calculation of expected Reactive Power Delivery by VPP

The section below outlines the performance of reactive power delivery that was designed and implemented in DERMS, with how it differs to dynamic voltage provided by non-Power Potential generators at transmission level.

Basic equation for voltage response

The basic formula linking voltage, reactive power and voltage slope is:

Equation 2

Voltage slope = (Voltage Target – System Voltage) / (Reactive Power Output/ Reactive Power Base)

Therefore:

Equation 3

Reactive Power Output = (Voltage Target – System Voltage) / (Reactive Power Base x Voltage slope)

Expected reactive power delivery at the GSP

At the GSP, DERMS is applying a voltage dead band to the voltage target so there is no reactive response expected while system voltage is within the dead band.

The reactive response is expected to be delivered progressively as the system voltage moves outside the voltage dead band. When calculating the reactive power response, the target voltage in the formula should be adjusted by the dead band.

Therefore, when considering response to a high system voltage

Equation 4

Reactive Power = (Voltage Target[+DB] – System Voltage) / (**Reactive Power Base** x Voltage slope)

Or for a low voltage

Equation 5

Reactive Power = (Voltage Target[-DB] – System Voltage) / (Reactive Power Base x Voltage slope)

Expected reactive power delivery from the DER

The basic formula is applied at the DER point of connection without a dead band to derive an expected reactive power output (Qcalc) in the results presented in the next section.

VPP results from the trials

Outlined below are the results and performance expectations from the trials

- The expected response is that the VPP has the Reactive Power Base equal to the **DER capability at the GSP**, so that a 4% change in GSP voltage would lead to full dispatch of the DER.
- The results show the DER is being instructed to deliver its maximum reactive capability irrespective of a 4% change in GSP voltage.
- The DER/VPP has reached maximum delivery for a very small 0.3% fall in GSP voltage rather than a 4% fall in GSP voltage. There is no capability left to secure a post-fault fall in system voltage and there is no proportional service response
- In fact, these expectations were not part of the DERMS design which assumed

- a nominal **100Mvar base** at the GSP so the DER is unable to deliver for larger voltage changes.
- a slower integral controller for instructed service delivery (while proportional response according to the droop control would be expected for DER self-dispatch).

- That may also result in the observed oscillations in the VPP/DER output system when the GSP voltage set point is close to the dead band

The following results are demonstrating:

Dynamic voltage control performance of VPP (GSP3) on 19 January

The following compares expected delivery assuming a GSP requirement based on 100Mvar or ~11Mvar (DER effective Capability). This aligns with DERMS assuming a 100Mvar capability and illustrates that the DER/VPP had reached maximum for a very small approx. 0.4% fall in GSP voltage rather than a 4% fall in GSP voltage. There was no capability left to secure a post fault fall in system voltage.

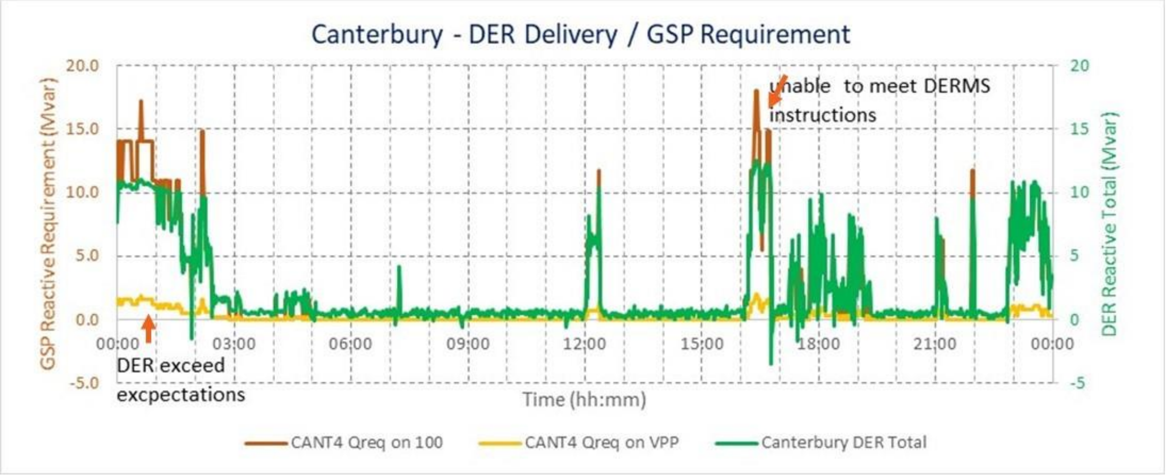


Figure 31Canterbury – DER delivery (GSP requirement at 100Mvar base)

The DER Mvar output in the graph above had been scaled by its effectiveness, so that it can be compared at the GSP level. At a 100Mvar GSP reactive power base, the DER in the VPP was unable to meet the GSP requirement (up to 18 Mvar in the example) for several reasons. Principally this was because the amount of contracted Mvar was much less than 100 Mvar, after effectiveness the maximum effect of the contracted DER at GSP level was only 11 Mvar. However, while there are examples of DER under-delivering based on the instructions issue by DERMS, there are several other factors which limit the instruction to the DER or its ability deliver up to 11 Mvar at the GSP:

- DERMS complies with statutory voltage limits on the distribution network, so when the local voltage is high, DERMS cannot send a voltage set point to request the full DER lag range – this occurred particularly in the early morning in this example.
- DER and DERMS compliance with the PQ envelope defined contractually for the site – the maximum Q range may not be available at all active power levels
- A defect in DERMS which caps the Mvar request from DERMS to the DER at the GSP requirement (without adjusting for effectiveness, which would increase the request to the DER)
- A systematic error in the voltage measurement used by the customer versus the voltage measurement used for DERMS control, leading to an uninstructed Mvar spill from the site of 0.5-1 Mvar.

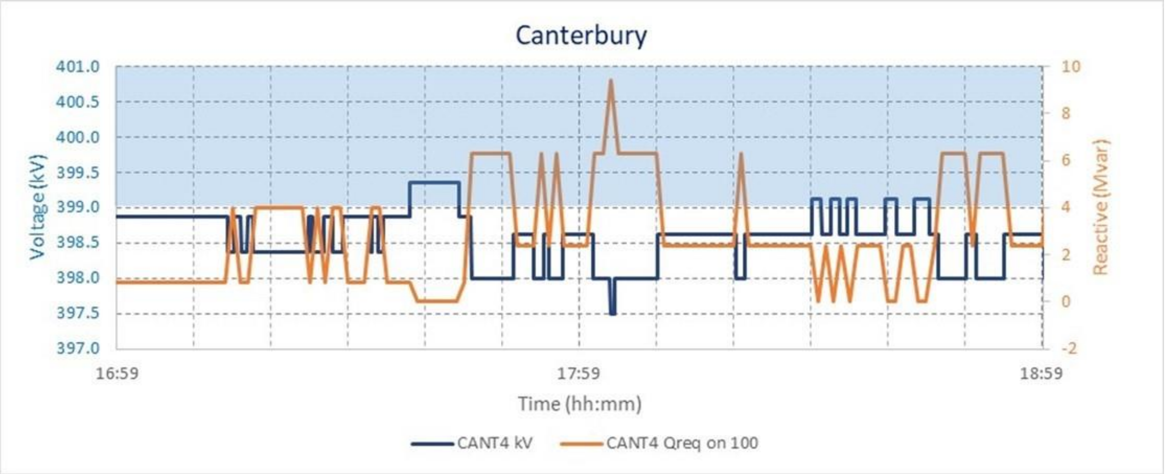


Figure 32 Dynamic voltage control performance of VPP (GSP requirement at 100Mvar base)

Figure 33 below shows a representative period during the trial when the NGESO control room specified a target voltage and dead band. From approximately 09:00, the system voltage goes outside of the dead band, hence triggering a reactive power response from DER; the required reactive response is shown in green.

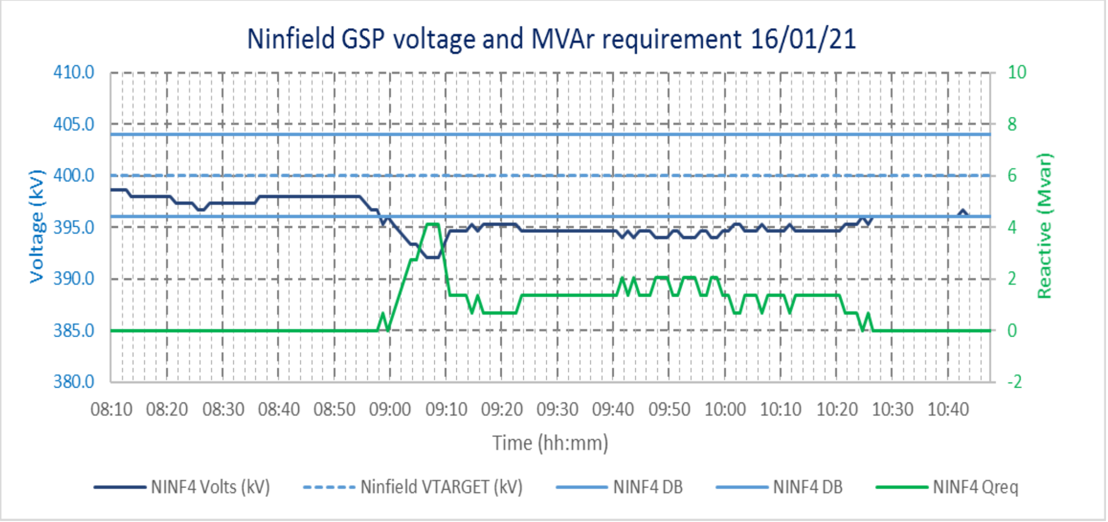


Figure 33 Ninfield – DER Delivery (GSP requirement at 100Mvar base)

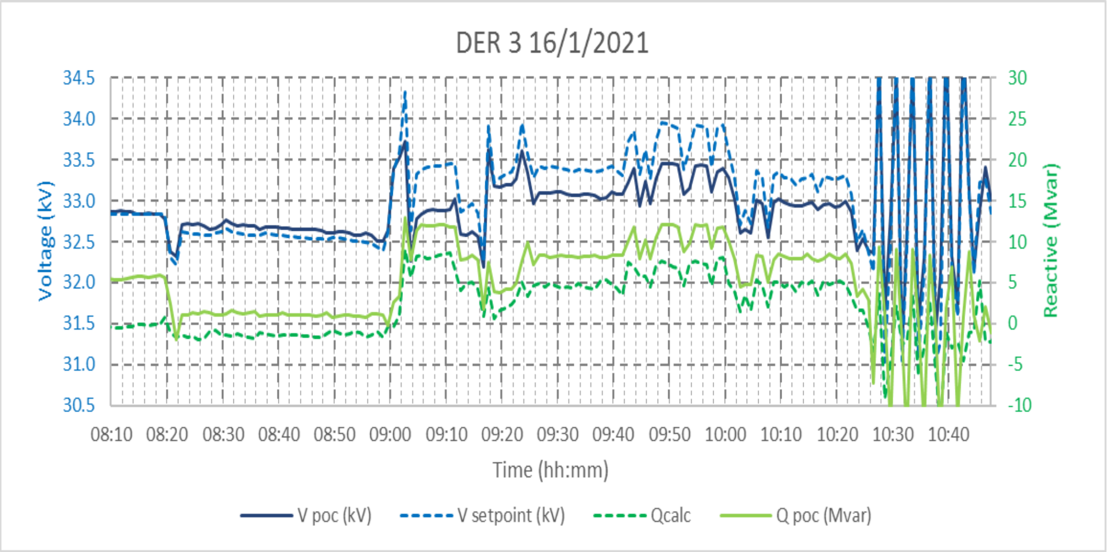


Figure 34 DER Delivery at Ninfield

Figure 34 shows the corresponding DER response at Ninfield during the same time period and generally shows the DER contributing to the overall response requirement correctly between 09:00 to approximately 10:20.

Prior to this, from around 08:20 to 09:00, the GSP voltage is within the dead band, though the DER is delivering Mvar which should not be the case. If this behaviour was seen across multiple DER and GSPs, this would be a concern to the NGESO as it represents unexpected Mvar compared to that instructed, that could require additional compensation to be acquired from other sources which would increase overall reactive power service costs.

From around 10:30 the GSP voltage is close to the dead band, and the same oscillatory performance can be observed as described above.

Potential solutions to achieve a proportional response from DER

Several solutions to achieve a proportional response from DER were considered during the trials which are further outlined in section 6.2.3 of this report ("GSP Q base enhancement"). One of these solutions was to mimic the correct Q base by changing the GSP droop slope equal to the effective capacity of the DER at the GSP. This would instruct a full DER response in a post-fault scenario to cause at least a 4% voltage change at the GSP.

At the point that this solution was proposed, it was not possible to implement it in the either PAS or the live DERMS before the end of the trials. This was due to other regulatory requirements for PAS to continue delivering BAU balancing services, and further development and testing, in the case of DERMS.

However, it was possible to test the effect of changing the GSP droop slope equal to the effective capacity in the pre-production DERMS for one DER and a reduced mandatory test was carried out to ascertain whether a proportional response could be obtained.

The test was carried out using a GSP droop slope of 81kV/100Mvar. The results are shown in the table below and demonstrates that the DER can deliver less than its maximum capability when instructed for a smaller response

Table 8 Results from changing GSP droop slope to mimic Qbase

GSP Voltage Setpoint (kV)	GSP Simulated Voltage (kV)	Voltage dead band (+-kV)	Delta Q requested (Mvar)	Q real-time @ GSP (Mvar)	DER Q actual (Mvar)
396	400	1	-3.704	3.4	-3.66
384	400	1	-18.518	-14.016	-18.51
404	400	1	3.704	11.374	3.69
416	400	1	18.518	22.983	18.51

It is to be noted that if the service were also to be used in a pre-fault scenario e.g. to address sustained high voltage periods during low net demand on the transmission system by requesting a consistent lead response from DER (Mvar absorption), that would increase the utilisation. A higher reactive power base at the GSP could be used if that was the only use-case.

2.4.3. Availability and Reliability of Control Systems (DERMS and PAS)

Wave 1 Optional Trials

There were two issues affecting availability of the DERMS system in Wave 1 — an initialisation issue and a server update scheduled at the wrong time. These led to a loss of system availability of four hours in a total trial length of 1,345 hours, representing 99.99% system availability. Neither of these were problems in DERMS, but in the supporting systems which affected DERMS.

1. The ICCP link between DERMS and PowerOn was enabled at the start of trials on 14 October and DER were put into DERMS control, but DER were not going into V service. The issue was traced to incorrect signage of the read back signals for all DER i.e. DER acknowledgement to DERMS of a signal such as voltage limit being received. The DERMS developer, ZIV, inverted the polarity of the readback signals at the ICCP's Front End Processor to align with the RTU at site and DERMS commands, and service delivery resumed (2:46 hours lost). This caused the DER 'Current Day' graphs to invert on the DERMS Web interface, but this was a cosmetic rather than functional issue. The issue occurred due to a mismatch in the sign convention between test and live systems.
2. On the penultimate day of trials (9 December), the DERMS servers restarted unexpectedly, following a security update which was scheduled too early. This caused parts of the DERMS configuration to become distorted. The services were disabled in liaison with UK Power Networks' control engineers, while settings were reinstated and checked, before DERMS and DER could return to service (1:25 hours lost). The remaining server security updates were scheduled after the Wave 1 trial period, and a DERMS database update was later delivered to address the distortion.

Experience in Wave 1 with the server update highlighted the importance of outage co-ordination for any system component for the rest of the trials and into BAU. In the Wave 1 configuration (in which DER were automatically accepted for all offered availability, and did not make price bids), the DERMS system was not dependent on PAS in order to accept availability and deliver the services. Thus, trials were able to continue despite short PAS outages on 14, 21 and 28 October, although no new instructions from NGESO Control Engineers could be implemented.

There were six issues affecting the reliable function of the PAS and DERMS systems in the trial – no trial time was lost as a result of any of these.

1. The volume of data traffic PowerOn-DERMS, leading to the slowdown of the system in weeks 3-8 of the trial, as described in section 2.
2. Daylight saving ended in the UK at 02:00 on Sunday 25 October 2020, when clocks went back by one hour. The DERMS software had been developed to handle the clock change, but the DERMS supplier ZIV Automation identified that DERMS would fail to send availability to PAS at 14:00 on Saturday 24 October. To continue the trials and DER experience of making themselves available

in voltage control, it was agreed to continue without instruction from PAS on the Sunday. The DERMS supplier subsequently updated the software and confirmed that DERMS can send PAS availabilities during future clock changes, but the Wave 2 trial stops just prior to the spring clock change

3. The live implementation of DERMS was not sending day-ahead availability updates to PAS automatically each day. ZIV identified a defect in how the software had been built, which required a patch to resolve. To avoid delaying the trials for this, a manual workaround was identified in which the UK Power Networks team updated the date manually each day for each GSP at 23:00. However, for practicality, this was carried out at either 08:00 or 17:00. No trial time was lost, and the defect was resolved ahead of Wave 2, so the manual workaround was no longer required and error messages from PAS ceased.
4. PAS was not able to see DERMS metered data submissions (utilisation). The PAS Team identified that metered data was being sent from DERMS with a millisecond time format in accordance with the web services specification, and PAS was updated to receive the data.
5. Red screens on the DERMS web interface on 20 October – due to a brief power outage which led the secondary installation of DERMS to briefly become the primary. No interruption to service delivery, and web interface restored without causing problems for DER availability submissions.
6. Future Availability submissions being rejected by PAS on 7 December. Following further investigation with ZIV, the issue was found to be an error in the number of service windows for the file (48 for wave 1 and six for wave 2/3), the windows would not be processed and NGESO's PAS system rejected the availability submission from PAS. It was subsequently found that NGESO had changed PAS to Wave 2 configuration early, hence causing the error. This was changed back to Wave 1 (48 periods) to resolve the issue.

None of these issues recurred in the 12-week Wave 2 trial and gave the project great learning.

After the Wave 1 trials had completed and DERMS had been upgraded, an issue was identified when re-enabling the link between PAS and DERMS, that the DERMS internal database will need restarting to re-establish the communications. Failure to do this prevented DERMS from sending the Real Time Metering (RTM) updates to PAS. This issue was identified in preparation for DER 5's Mandatory Trial, and no trial time was lost. An additional step was added to the installation instructions.

Wave 2 Market Trials

Wave 2 service commenced on 6 January 2021, with two DER. A further two DER joined the trial on 8 January after resolving issues with how to declare their bids appropriately, the bidding process being slightly more complex than in Wave 1.

There were three issues affecting availability of the DERMS system in Wave 2.

Firstly, on 15 January, additional logging to investigate system performance caused a system crash. The system was unavailable for 40 minutes, with an additional 90 minutes for system checks before services were restarted. This logging method was avoided for the rest of trials.

Secondly on 15 February, there was a minor installation error after the upgrade (a piece of case sensitive configuration) which prevented DERMS from sending availabilities to PAS. This prevented service delivery for 24 hours.

On 16 March, it was observed that services had stopped for the two DER associated with the Ninfield GSP in DERMS. The root cause was identified as two processes in DERMS (PAS, and a module processing data from PowerOn) writing to the DERMS database simultaneously. Normally these instances are handled by locking the database objects so that they can only be written to by one process at a time, then rolling back and reattempting the second change. However, a bug in the code meant that for this rare specific change, the rollback did not work correctly, leading to corruption of the in-memory version of the database. As it appeared the underlying database was not corrupted, and a controlled restart of the database was implemented on 17 March which caused the system to be unavailable for one hour and 45 minutes while the restart and checks were performed.

The system crashes due to logging and the reset to resolve the memory corruption led to a loss of system availability of 27:55 hours in a total trial length of 1772 hours, representing 98.5% system availability.

However, the reset had not fully resolved the memory corruption, and trial services on Ninfield GSP stopped after 1 and a half hours. This meant that two DER lost 11 days eight hours of opportunity for service delivery and ten days of opportunity to bid for the services. On this basis, for those customers only, system availability for service dropped to 84.8% during the Wave 2 trials.

The DERMS developer identified how to resolve and prevent the memory corruption on the live system, but due to the time required to deliver, test and upgrade the live UK Power Networks system, this resolution could not be applied before the end of the trials. However, an important failure mode has now been identified for any post-trial solution.

Thus, while system availability was high in Wave 2, this trial wave revealed an important issue with reliable function of the system with repeated and previously unknown temporary loss of PAS-DERMS connectivity. Thus, while both the PAS and DERMS systems remained live and available, this triggered DERMS to repeatedly disable delivery of the voltage service from DER.

In the DERMS system for Wave 2, if communications failed between PAS and DERMS in either direction for more than two minutes, either for planned or unplanned outages, the voltage services would be disabled at the GSP level in DERMS. This ‘Q Mode Abort’ signal (visible in DERMS only) would disable the DER service automatically. It could only be manually reset by the UK Power Networks team. A two-minute period was chosen for DERMS consistency with the alert period for ‘no communications’ for all other PAS services. There was no automatic re-enabling of the services.

This monitoring of system communications and consequential action had been intended for Wave 1 trials but was delivered as part of the DERMS upgrade for Wave 2. It was introduced to ensure that PAS and DERMS remained in communication during service delivery e.g. that services would not continue if DERMS could not receive updated GSP set points from NGESO’s control engineers or was not sending real-time metering data on service delivery to them. However rather than responding to long-duration outages, it revealed new modes of short-term communication failure.

Firstly, it showed that the PAS system was periodically disconnecting for a few minutes, separated by up to an hour, on a 29 -hour cycle, including overnight and weekends. This was due to a scheduled ‘recycling’ activity in the PAS services, although this could occur sooner if the system cache was full, or after a planned PAS system outage. During each disconnection, NGESO would be unable to send updated information to and from PAS. The day-ahead processes were unaffected, but this affected the issue of updated GSP set point instructions. Thus, neither the original disconnection nor the subsequent service disable was visible to the NGESO Control Engineers. It was not obvious until later that instructions had been rejected.

The NGESO team investigated whether the PAS reset times could be arranged to occur during business hours each day. This was not possible, and the cycle was changed to a consistent 24- hour cycle, at 03:10am and 04:10am. This triggered a 4-5 hour interruption each day until the DERMS services could be re-enabled by UK Power Networks, but this regular time for the set daily window was chosen for easier monitoring and so that NGESO Control Engineers could easily avoid making new instructions to the service at this time.

The second issue affecting PAS-DERMS communications was related to inconsistent issue and receipt of ‘real time metering’ (RTM) data from DER to DERMS to PAS. This should have been sent from DERMS to PAS every 15 seconds, but on occasion this would also be interrupted for more than two minutes. This could cause the same disabling of services. This occurred much less frequently than the PAS disconnection and did not have a predictable cycle, so the system was not reset until the next scheduled check. The full communications path was investigated, and no issues found, and logging provided to the DERMS developer for review. The exact reason for the occasional interruption in RTM metering was not identified. This would need to be investigated further for a BAU solution, including a review of the impact on services due to a pause in metering data provided for visibility to PAS (not a control input).

Once visibility of the PAS reset cycle was provided to the UK Power Networks team, a rota of daily checks and resets was implemented to re-enable the services after every disable. The overall impact of lost service delivery time from 9 January to 12 February was 19% of service hours (145.7/763) triggered by loss of connectivity between PAS and DERMS for more than two minutes. 48.7% was due to the scheduled reset cycle in PAS and 51.3% due to the interruption in metering data from DERMS. The PAS reset cycle caused 23 interruptions to service whereas DERMS caused 15 interruptions –

however the predictable nature of the PAS interruptions meant that (with planning) services could re-enabled relatively quickly. This was particularly as the UK Power Networks team supported re-enabling the system at evenings and weekends; otherwise it is estimated that ~50% rather than 19% of service delivery time would have been lost in this initial phase of Wave 2.

While the interruptions had no impact on the day-ahead processes in Wave 2, they were affecting the ability to utilise the service and assess technical performance, while also increasing the support needs for UK Power Networks. Thus, it was agreed with the PAS team that the PAS-DERMS link timer would be increased to 15 minutes as opposed to two minutes before disabling of services. This made the DERMS system less sensitive to the communications loss to facilitate the continuation of the trials, rather than resolving the underlying issues in PAS or DERMS (to be reviewed for BAU). This change was included in the DERMS upgrade applied to the live system on 12 February, and there were no occasions in which the service was disabled due to PAS-DERMS communications interruption for the rest of the Wave 2 trials.

The February upgrade of DERMS also resolved a defect in which DERMS should have assumed that DER bids would be rejected in the absence of any nomination from PAS for a particular GSP. All nominations were automatically processed. The default acceptance behaviour was suitable for testing and the Wave 1 trials, but not the commercial service. To resolve this the NGESO team shared the nominations daily by email, so the UK Power Networks team could manually confirm in DERMS when there was no nomination in PAS. This manual workaround did not prevent delivery of the trials, and this data was shared throughout trials for end-end service validation.

The DERMS upgrade in February was completed in less than three hours on a Friday, with system checks completed that day. However due to the day-ahead processes needed for trials, and because trials were not being run for every weekend, the upgrade was linked to a four-day interruption in trial delivery.

2.5. Forecasting of available reactive power response at the Grid Supply Point

Forecasting within Power Potential project was expected to be utilised to forecast both demand and DER output, using a combination of historical demand/output data and forecast weather data. This was originally planned to be carried out by using the DERMS forecaster., This functionality was developed and tested, however it was not used during the trials, due to the data issues. An alternative approach was used as described below.

The day-ahead forecast of available reactive power response for the VPPVPP per service window (four hours in Wave 2) was based on a combination of:

- Whether each DER in the VPP offered to be available for service
- The average across the service window of estimated available reactive response of the DER in each half hour, based on:
    - DER's own day-ahead estimate per half-hour of their active power output P (this was their expected operating level or EOL),
    - The defined operating envelope PQ envelope
- The effectiveness of the DER at the Grid Supply Point
- Summed across all DER.

The methodology for creating this forecast was fully-tested and applied in trials with complete accuracy. For example it was noted that on a windy day (high EOL), one windfarm had a small reactive range and another had a large reactive range due to the shape of its PQ curve. This was reflected by the DERMS in the available service volume in Mvar which was sent from DERMS to PAS at 14.00 daily.

A change in active power output relative to the day-ahead prediction would change the available volume on the day, and DERMS would be able to dispatch reactive service (if instructed to do so by PAS) based on the real-time active power level and the defined PQ envelope.

For the live trials, DERMS used DER's own submitted day-ahead predictions of their active power output per half-hour (expected operating level or EOL), rather than a separate prediction of active power output by

DERMS. A forecast of active power output using historic load and generation data was demonstrated as a proof-of-concept part of the DERMS Factory Acceptance Test (see section 6.1 on DERMS Forecaster).

2.6. Active Power Trials

Active power trials were conducted during the Wave 2 trials at the Bolney and Ninfield GSPs on Saturday 6 March 2021 and Friday 19 March 2021 respectively.

The objective of these trials was to demonstrate the technical capability of DER and DERMS to provide an active power response via DERMS instruction and also to test both active and reactive power instructions simultaneously. With reference to the Power Potential Market Procedure, after receiving an instruction, the DER unit would need to be capable of responding by automatically ramping the active power generated up and/or down according to the DERMS instruction and within the plant limitations indicated by the Minimum and Maximum Active Power Parameter's submitted. The active power instructions were for a limited time (approximately five minutes each), i.e. the instruction was sent to the DER and once the required MW was achieved (taking into account plant ramp rates), the instruction was held on for five minutes. The MW instruction was issued as a MW set point and calculated relative to the submitted EOL. The contract noted that DER needed to meet the MW set point within two minutes of receiving the instruction.

2.6.1. Active Power Only Test

The first test on 6 March commenced at 11:06, with an active power (P) request at the Bolney GSP of +5.0MW. This resulted in a correct response at the GSP (GSP active power flow & cost responses) but no response seen at DER and no target sent to DER from DERMS).

It appeared that a P-Mode Service Enable instruction was being issued by DERMS but the DER Services readback from DER was not being received.

Approximately 40 minutes later, the project team decided to enable Active Power Service P-Mode manually, which allowed the DER to enter P Mode and the DER Services readback was then received. This approach was applied straight away to the next site on 19 March, which saved considerable time on the second active power trial.

The first DER on 6 March was a Battery Storage unit, which provided the capability to go in either direction (import or export from an EOL and real-time actual power of 0.0MW. By inspection of Figure 35Figure 35 below, we can observe that the DER responded accurately, in both directions, to an instruction at the GSP. Also, we can see from Table 9 that the response time is under 20 seconds (even allowing for the 15 second refresh rate in the PI data), which is well within the two-minute requirement.

Table 9 Active Power instructions at Bolney

Time of Instruction	Expected Operating Level (EOL)	Requested Active Power Response at GSP (MW)	Expected MW at DER	Real Time MW at DER	Active Power Response Time following receipt of instruction (seconds)
11:47	0	+5	+5	+5.02	<20
11:54	0	-5	-5	-5.17	<20
11:58	0	0	0	0	<20

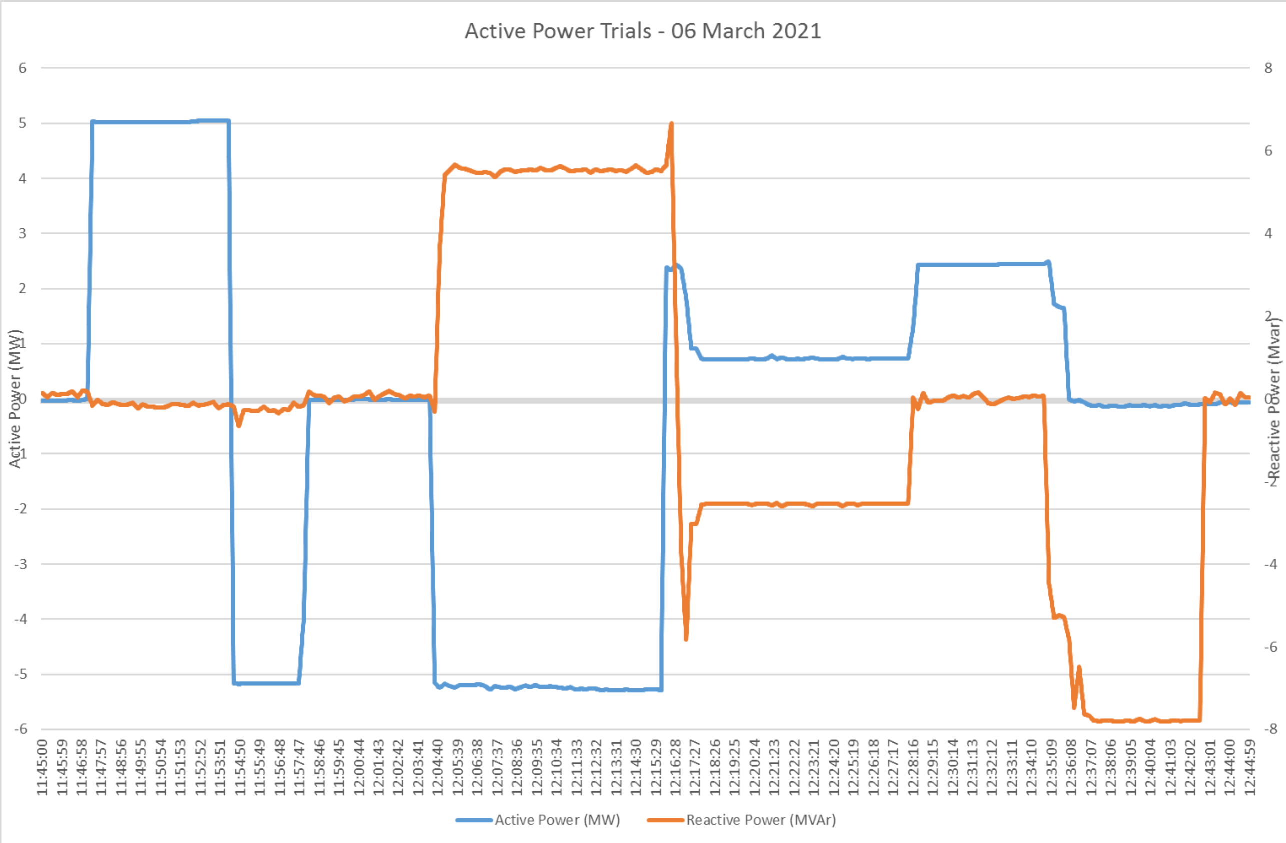


Figure 35 Active Power Trial at Bolney

By contrast, the second test on 19 March involved a wind farm, which was characterised by slower active power ramp rates and heavy dependence on weather conditions. This meant that real-time DER active power output on the day was hovering around ~20MW, significantly less than the forecast EOL of 29.41MW. This presented difficulties on the day as the active power levels were fluctuating just above the minimum active power parameter (minimum permitted controllable level of active power output).

Interestingly, when a reduction of -3MW was requested at the GSP, there was no response at the DER. The initial expectation was that the DER would reduce its output from the real-time 18.33MW to 15.33MW. However, it became apparent that DERMS was controlling the response based on the EOL (29.41MW) not the actual DER output (18.33MW). Thus, the DER was already delivering less than the target and therefore did not need to respond any further.

This was proven with an instruction of -13MW at the GSP, which gave an expected target of 15.03MW (based on the EOL for the next settlement period = 18.03MW) and the DER output reduced accordingly to 15.31MW (slight error due to fluctuating wind conditions). See Figure 36 Active Power Trial at Ninfield below:

Table 10 Active Power Instructions at Ninfield

Time of Instruction	Expected Operating Level (EOL)	Requested Active Power Response at GSP (MW)	Expected MW at DER	Real Time MW at DER	Active Power Response Time following receipt of instruction (seconds)
11:10	29.41	-3.0	-27.41	18.33	No Response
11:15	29.41	0	15.03	14.34	No Response
11:37	28.03	-13	15.03	15.31	~30

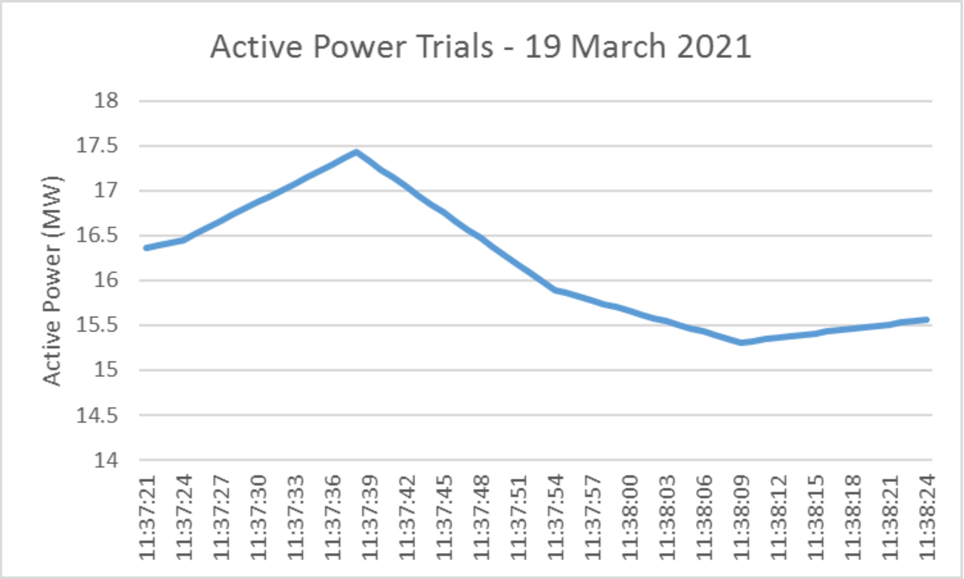


Figure 36 Active Power Trial at Ninfield

Another interesting observation was the target MW at the DER, which appeared to change incrementally, i.e. instead of moving to the final expected target value, the target MW would increase/decrease by a small amount and wait for the actual MW to catch up before changing further.

Speed of response was around 30 seconds, which was slightly longer due to the slower ramp rates in the contract but still within the specified two minutes.

2.6.2. Simultaneous Active & Reactive Power Test

The purpose of this test was to ensure the DER could provide active power response while still delivering voltage support.

On 6 March, the DER was instructed to deliver -5MW, whilst at the same time respond to an increase in the Voltage set point of 20kV at the GSP.

Figure 35, shows that initial response was good with DER delivering Active power of 5.1MW and lagging Q response of +5.65Mvar, in line with RTU limits and a sensitivity factor of 67%.

However, following a further MW request to +2.5MW and a change in voltage set point to 380kV (-40kV), the DER responded well initially but then the active power response eased back from +2.5 to ~0.9MW and the reactive power fell to 2.546Mvar (target 9.7Mvar).

A further test was then carried out with the voltage set point set to 400kV with a dead band of 5kV, i.e. no reactive power request. However, the DER delivered an active power of +2.5MW, as requested.

The opposite test was then carried out, where the MW request was set to 0.0MW and the voltage set point set to 380kV. This resulted in reactive power response of -7.8Mvar.

This quite clearly demonstrates a conflict between simultaneous active and reactive power delivery with the battery storage unit.

A similar test was carried out on 19 March with the wind farm. However, an active power request of -13MW was given at 12:01, whilst the DER was delivering -12.59Mvar in response to a voltage set point change. The DER responded accordingly with no loss of Mvar.

2.6.3. Conclusions

As there were only two DER that took part in the active power trial, so it is difficult to draw wide-ranging conclusions, though the tests showed that DER can successfully deliver active power and the simultaneous delivery of active and reactive power is achievable within the technical framework outlined for the project.

The tests showed that delivering both reactive and active power at the same time is more challenging, and the configuration of the DER controller, DER P-Q limits and any interaction with the DERMS is important. In the case of DER 2, it appeared that the reactive power service was prioritised over-active power which could have implications for combining or stacking a range of ancillary services.

Additional learning was also captured in terms of how DERMS sends active power instructions in terms of a difference in MW compared to the EOL rather than to a specific MW value. This was shown to be challenging if the actual output of the generator is different to the EOL and will need to be considered in any future design. For testing purposes, using this methodology has proven the concept on a technical level, though further review would be required to determine the consequences of how DERMS instructs active power in this way across multiple DER/GSPs (i.e. how MW shortfalls or over estimation would be catered for) and updates EOL declarations due to system faults.

During the trials two DER were participating in both the Firm Frequency response (FFR) and Enhanced Frequency Response (EFR) markets with no significant conflicts. It is envisaged that DER would continue to be technically capable of delivering active balancing services alongside Power Potential based on the results of the simultaneous active and reactive power testing.

3. Commercial Learning (Wave 2)

3.1. Power Potential Wave 2

Power Potential Wave 2 trials commenced in January 2021, with participants submitting their service availability on 5 January for the first service start deliver on 6 January 11:00am.

Wave 2 follows the Optional Technical Trials (Wave 1) of the live trials where trial participants submitted their hours of availability (at settlement period granularity) for reactive power for the whole of that period. During Wave 1 Optional Trials, the project could utilise, DER while they were armed to provide the Power Potential service, through a NGESO instruction, and UK Power Networks' coordination.

Wave 2 saw competitive bidding among participants, the purpose of Wave 2 was to facilitate "price discovery" from DER, within the limitations of the trial budget, from DER allowing them to freely bid both utilisation and availability prices to reflect any risk or cost associated with the provision of the service in the most efficient way.

During the Wave 2 trial period, DER submitted availability and utilisation prices into the DERMS through a web interface at the day-ahead stage. DERMS then provided costs of the aggregated VPP to NGESO, which in turn made a procurement decision based on volume available and accounting for the overall and daily trial budget. Feeding back to the DERMS where DER would see the production schedule responses by 5pm day ahead.

A DER from a VPP which was procured, was then committed to being available to provide reactive power services in its accepted service window (for which it received an availability payment). On the following day, at the start of the relevant service window, the DER received voltage set points from DERMS, which could necessitate the injection or absorption of reactive power throughout the window (for which utilisation payments are made, based on the accepted bid of the DER).

The resource procured during Wave 2 was not considered a system resource and was therefore not used to secure the system. This was considered surplus to the network requirements to test the price discovery principle, given the unproven nature of the service at this time.

Prior to participation in either wave trial participants were required to complete a Mandatory Technical Trial.

3.1.1. Wave 2 Trial Participation and Sensitivity (Effectiveness)

Within the Wave 2 there were a total of four DER representing various technology types, and a total of 46.30 lead Mvar and 51.34 lag Mvar, participating in the Power Potential trial. Each DER was assigned to a specific VPP representative of the GSP against which it was most effective. There were very high levels of DER participation in the auction from each VPP competitively bidding against each other. Across the Wave 2 period DER had the opportunity to bid for and potentially provide a service in a total of 1,772 operational market hours.

Further details of trial participants are provided in the Table 11 below, one additional participant was unable to complete the Mandatory Technical Trials and therefore did not meet the requirement for participation.

Table 11 DER Trial Participation Summary – range of reactive power delivery in Wave 2

GSP	DER	Technology	Indicative effectiveness range (%) for DER which are most effective at this GSP	No. of hrs Accepted
Ninfield	DER 1	Solar	36 – 84 %	1,508
	DER 3	Wind		
Bolney	DER 2	Battery	36 – 71 %	996
Canterbury North	DER 4	Wind	42 - 69%	1,566

Sensitivity or effectiveness with respect to a GSP provides an indication of sensitivity of a DER' reactive power injection/absorption at a particular GSP. The effectiveness allocation of a DER to a GSP is done according to where this value is shown to be the greatest (GSP reactive power variation Q_{GSP} divided by a DER reactive power variation of Q_{DER}).

The range of effectiveness factors for trial participants is between 67% and 84%. For each DER, this is an input to the DERMS and is used at day-ahead to indicate the scale of Mvar contribution to the VPP at the GSP. Further details on the effectiveness factor were provided to DER in Section 3.3.2.2 of the Market Procedure document. Each DER has been informed of their own effectiveness, but due to commercial sensitivity, it was not appropriate to share individual effectiveness factors with other DER participating in Power Potential Market Trials.

The approximate indication of typical effectiveness factors under intact network conditions for each GSP was calculated based on load-flow analysis with a network model, based on the locations of DER who would have been eligible to participate in Power Potential. Some DER can help resolve network issues more effectively than others and this indication could provide each DER with a good insight into how their DER compares to other service providers.

In a future business as usual application, we expect indicative effectiveness to be reviewed on at least an annual basis, or DERMS may be further developed to calculate effectiveness values on a daily basis.

Effectiveness was calculated as a percentage input to DERMS with a two decimal place precision. Previous analysis had showed that for the intact network, the difference in effectiveness from the extreme of loading (minimum to maximum) was of the order of 2% e.g. 63% to 65%. In a live trial, it was not feasible to precisely measure effectiveness by comparing DER and GSP outputs, given changes in demand and generation from thousands of customers associated with a GSP as well as changes in the network topology. Mandatory Trials with the larger DER indicated the calculated values were of the correct order.

3.1.2. DERMS User Interface for DER

In February 2020, UK Power Networks requested DER to provide the names and email addresses of those requiring access to the DERMS Web Interface. Each participating DER nominated several company representatives to be authorised with either read-only or read-write access to review/input availability and price offers. The DER technical parameters used in the DERMS were copied from the DER Framework Agreement. In total there were 30 registered users across the five DER.

The registered DERMS users were provided with the Wave 1 DERMS web interface user guide in May 2020 (see Figure 33); this allowed users to become familiar with the dashboard screens and terminology.

The login details to access the DERMS production environment were shared with users in June 2020 and users were offered help to register and receive an overview. Brief demonstrations were provided at the Regional Market Advisory panel meetings with a fictitious DER. 11 overview sessions were held on a DER-specific basis to maintain confidentiality, as DERMS did not have full functionality with the fictitious DER.

From October 2020, DER were accessing the DERMS web interface to indicate their availability to provide reactive power for the Wave 1 Optional Trials, and could see real-time performance data.

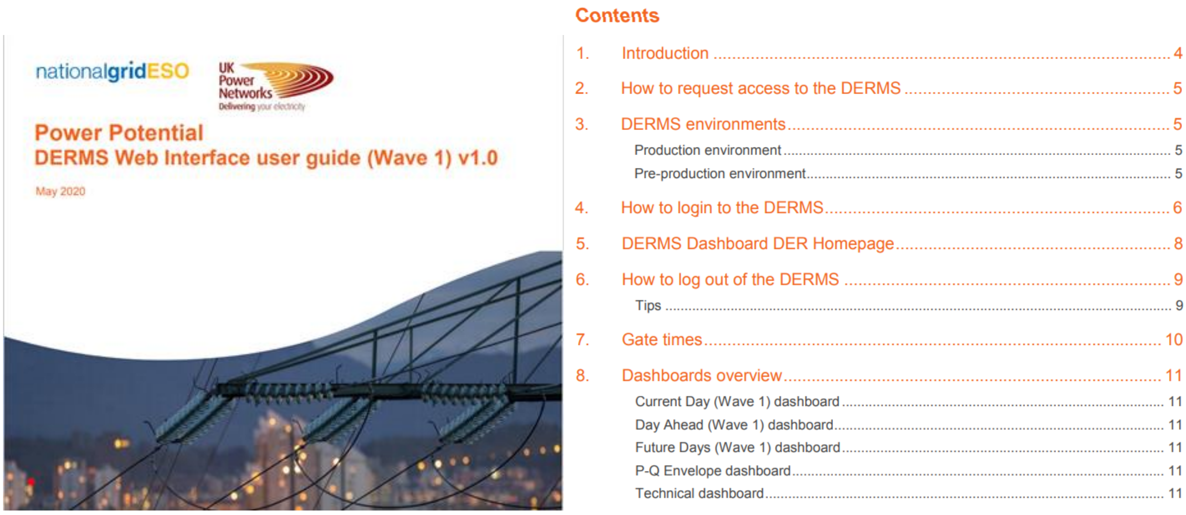
DERMS users were sent the Wave 2 web interface user guide in December 2020 and the Wave 2 trials began in January 2021. DER could enter an availability price (£/Mvar/hr), utilisation price (£/Mvarh), reduce their offered Mvar reactive range if necessary, and see the nomination response to their offers (accepted, or rejected with a reason). Each DER could either submit availability and bids day-ahead by 14.00 or submit a bulk upload spreadsheet two days-ahead for up to a month.

For part of the Wave 2 trial, due to site issues, one DER needed to restrict its Mvar range. This functionality was thus proven to be of real value – otherwise the DER would have had to withdraw from the trial.

A dedicated phone number and email address were provided for DERMS support, only four incidents were reported, two of which being password resets.

Customer feedback was generally positive in terms of the DERMS web interface, with constructive suggestions for a future service:

1. The customer user interface in DERMS could include accepted volume and activated volume, to enable understanding of the value of service and improve bidding to deliver the service when needed.
2. An API connection for data submission would be necessary to transition to BAU. This would minimise manual inputs in DERMS, which consume too much operational time.
3. The ability to see planned DER constraints on the DER Web Interface would also be appreciated.


nationalgridESO

UK Power Networks Delivering your electricity

Power Potential

DERMS Web Interface user guide (Wave 1) v1.0

May 2020

Contents

Figure 37 DERMS Web Interface user guide for DER (first issue for Wave 1)

3.1.3. Assessment and Nomination Process

The Power Potential project was provided with a specific budget allocation for payments to DER for participation within the trial £567k. The closedown report will include details of project spending. In the Wave 1 Optional Technical Trial DER received a participation payment based on the number of hours that the DER was available with a minimum requirement of 373 hours. To facilitate Wave 2 an assessment and nomination process was required, to deliver the auction, this process was verified by Imperial College London.

During Wave 2 nominations for service provision were made with the aim of accepting the most economic VPPs whilst operating within the budgetary constraints. (The VPP concept is explained in section 2).

The nomination and assessment processes were undertaken by constraint analyst at NGESO and was carried out as a day-ahead auction process, broadly as follows:

- At 14:00, the DERMS closes the declaration gate on the DERMS Web Interface, collects bids and provides values, associated with each VPP, taking into consideration network constraints, Mvar availability range (combined lead and lag), expected utilisation adjusted for effectiveness and associated costs. The DERMS sends this to the PAS system for the NGESO assessments team to review.
- At 14:00 NGESO would assess the bids, sent by the DERMS, based on the volumes, prices tendered, estimated utilisation expected and the trial budget. The aim being to procure the largest overall volume across the most economic VPPs.
- The procurement strategy was evaluated against a daily budget spend. This daily spend was derived by considering the total budget, the minimum number of trading hours for the trial and the volume of Mvar available in the market. All VPPs are considered and compared against the daily budget taking into consideration the availability costs and an estimated utilisation level of 85%. If

the total cost across all VPP exceeds the budget, then only the most economic VPPs were accepted.

- Before 17:00 NGESO would decide how much of each cost stack, at each GSP, for each service window (EFA Block), it would procure, and communicates this to DERMS.
- At 17:00 the DERMS updates the production schedule responses tab on the web interface confirming if the DER bids were accepted or rejected.
- At the point of nomination all DER receive feedback on the result of their tender. This feedback includes one of seven rejection reason codes if a tender was rejected.
- At the start of the accepted service window, the DER receive a ‘V Service Enable signal’ from DERMS and voltage set points, which may necessitate the injection or absorption of reactive power throughout the service window until DERMS issues a revised set point.

3.2. Trial Results

This section presents the commercial results and observations from the auction trials during Wave 2 of the Power Potential trial. Wave 2 of the trial was designed to support “price discovery” from DER that were able to bid on both availability and utilisation price in a competitive environment, amongst themselves, within the confines of the trial budget. DER were able to reflect any risk or cost associated with the provision of the service in the most efficient way they chose.

The Wave 2 market operated for a total of 1,772 hours this was slightly less than the original objective of the project, to run the market for a minimum of 1,800 hours. To maximise the opportunity available and project learning the auctions were run across both weekdays and weekends. There were also a number of periods where DERMS was unavailable due to upgrade work being undertaken.

Results from the trial indicate that the average prices accepted for availability and utilisation were in the range of £1.18 to £4.58 £/Mvar/h and £5.19 to £9.35 £/Mvarh respectively at GSP/VPP level (after application of effectiveness to DER bids, and adjustment for expected volume at GSP as outlined in section 2.5). Throughout the trial there were different bidding strategies across the various GSPs. These are displayed in the graphs below showing the availability and utilisation prices accepted at each GSP/VPP across the Wave 2 trial.

Please note as mentioned in section 3.2.2 due to assessment and nomination challenges in the first weeks of the trial, there were errors in the interpretation of the service cost information transferred from the DERMS to PAS. This impacted the assessment and nomination process with the service cost submissions for the first three weeks of the trial being underestimated by NGESO. This resulted in some bids being accepted when they would have otherwise been rejected at the tendered price. This error affected one GSP in particular and where it has occurred, it has been highlighted in the presentation of the trial results.

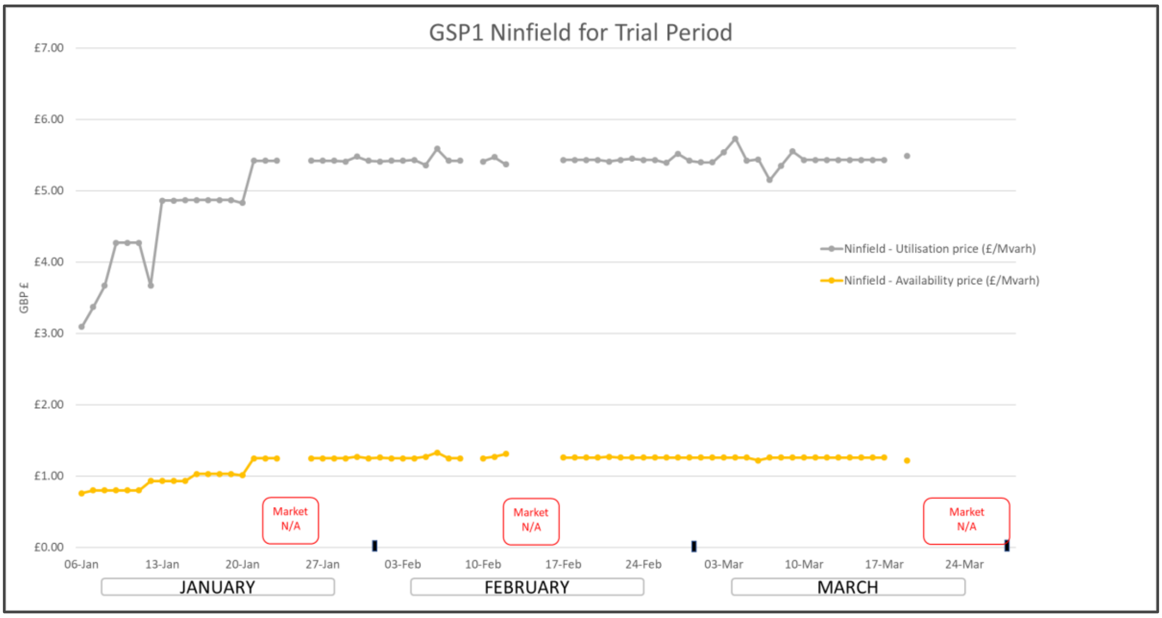


Figure 38 Availability and Utilisation Prices Accepted Ninfield (GSP 1)

GSP 1 – Ninfield (Solar & Wind) — Across the Wave 2 trial period:

- Average availability price accepted at this VPP was **£1.18** /Mvar/h
- Average utilisation price accepted at this VPP was **£4.17 /**Mvarh
- The total volume utilised at this VPP was **5453** Mvar
- Total number of service hours accepted was **1508**
- Total number of days not procured **10**

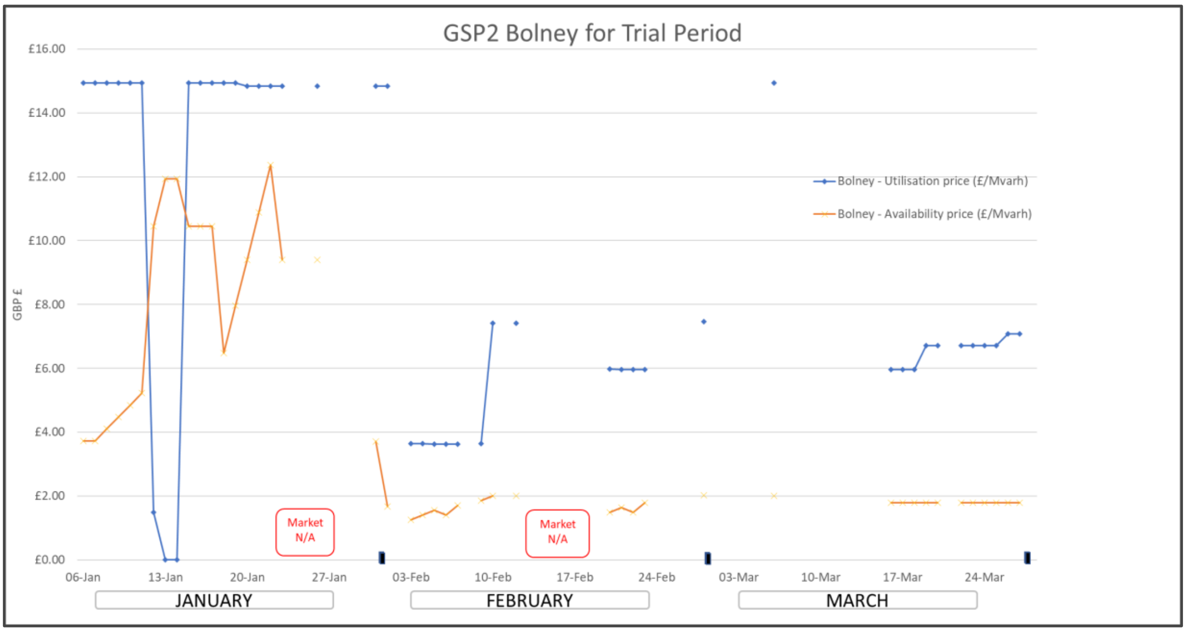


Figure 39 Availability and Utilisation Prices Accepted Bolney (GSP 2)

GSP 2 – Bolney (Battery) –– Across the Wave 2 trial period:

- Average availability price accepted at this VPP was **£4.58** /Mvar/h
- Average utilisation price accepted at this VPP was **£9.35 /**Mvarh
- The total volume utilised at this VPP was **1503** Mvar
- Total number of service hours accepted was **996**
- Total number of days not procured **29**

This GSP was accepted in weeks 1-3 which was subsequently found to be in error due to issues found, and later addressed, in the assessment process

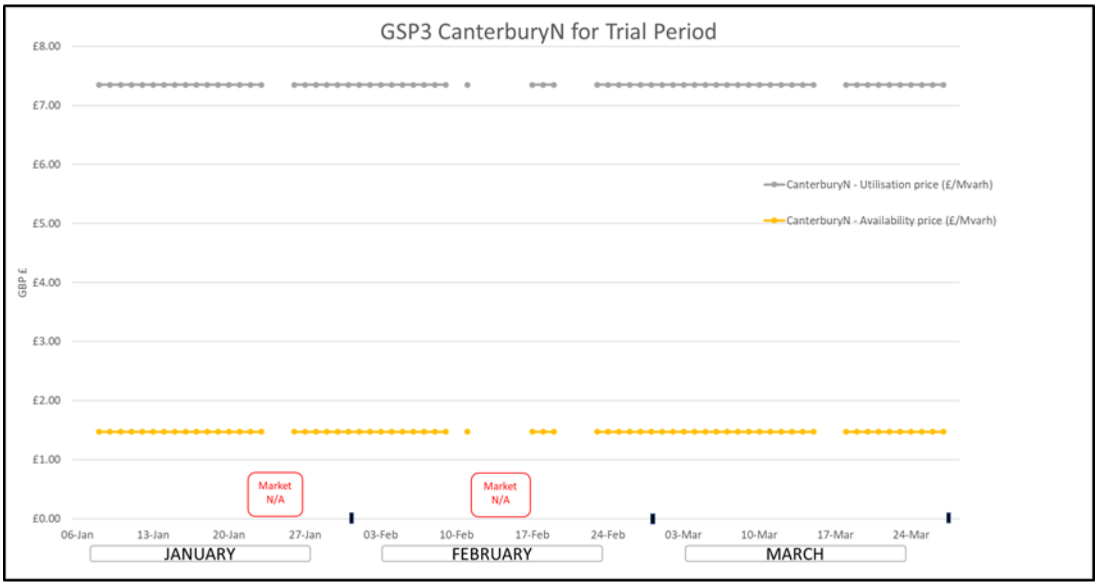


Figure 40 Availability and Utilisation Prices Accepted Canterbury North (GSP 3)

GSP 3 – Canterbury N (Wind) – Across the Wave 2 trial period:

- Average availability price accepted at this VPP was **£1.47** /Mvar/h
- Average utilisation price accepted at this VPP was **£7.35 /**Mvarh
- The total volume utilised at this VPP was **4838** Mvar
- Total number of service hours accepted was **1566**
- Total number of days not procured **6.3**

Key Observations from the trial results:

- VPP/GSP 1 Ninfield there was some variation in prices from this provider with gradual increases in prices during the first three weeks of the trial, potentially testing the threshold of price acceptance level and testing the interplay between utilisation and availability pricing strategies. The VPP then moved to a more consistent pricing strategy for the remainder of the trial period.
- VPP/GSP 2 Bolney varied its pricing strategy considerably during the first three weeks of the trial tendering utilisation as high and as low as £14.93/Mvarh and £0/Mvarh respectively. Similarly, the availability prices tendered varied with the highest and lowest being £11.94 and £1.79/Mvar/h respectively again occurring during the first three weeks of the trial
- VPP/GSP 3 Canterbury North remained at the same price during the entire Wave 2 period favouring to bid lower availability prices and a higher price for the utilisation of the service
- Generally, after the first three weeks DER adjusted prices in response to project communication regarding the corrected assessment process being put in place in week four.
- During later weeks Bolney GSP was rejected due to being uneconomic, their prices were reflective of reduced efficiency within the plant inverter.
- Competition across the GSP was limited with only two GSPs actively adjusting prices. After the first three weeks one of those GSPs moved to more static pricing. Additional market liquidity was required to see more variable pricing creating more competition and presenting greater nomination options for the project.

3.2.1. Commercial Trial Market Reporting

Each week the project captured and shared summary trial data with trial participants through a weekly market report. The aim of the report was to provide an aggregated view of weekly average availability and utilisation prices accepted, total volumes of lead and lag nominated as well as the any reasons for rejections. The document also provided a summary of general comments related to service delivery and/or nominations in the previous week as well as providing a look ahead at the various network scenarios and Target Average Costs (TAC) being used for the following weeks. As indicated within the Market Information Report the TAC was used in the assessment logic to ensure nominations within the budget limit. If on a rolling basis, actual costs incurred were equal to or less than the TAC, then there should be sufficient budget to ensure that the project commitment to 1,800 "market hours" could be met. However, if the rolling average cost is higher than the TAC, then this is an indicator that there may be insufficient budget to deliver 1,800 market hours.

A template of the Wave 2 Market Report can be found in the Appendix 3. The report format was updated throughout the trial based on participant and project level feedback as required. The project team has received some specific points from DER on aspects of information that could further be shared to enhance the information available to the market for any enduring reactive power service. This information is captured in Table 11 below and will also be incorporated in any further considerations in the event of development of an enduring service.

Table 12 Trial participants' feedback

Category	Participants Feedback
General	To improve access and provide historic records, market reporting could be done via a webpage, storing all past reports.
Reliability, Controllability, Performance & Utilisation	To understand the reliability and controllability, performance and utilisation levels of each DER • Information on technology/participant reliability and performance during the trial are now being shared with stakeholders as part of the end of trial reporting process. Detailed information on DER performance can be found in section 2 • During the trial performance issues were raised and addressed on a one-to-one basis with individual DER • Post-trial feedback from DER: suggestion to provide statistics on utilised Mvar per hour of day etc. to understand better the system needs.
Effectiveness	Additional information was requested on effectiveness, this provider also wanting the ability to infer other DER effectiveness. • During the trial each DER was informed of their own indicative effectiveness factor calculated under intact network conditions relative to the GSP where the DER was most effective • Additional information was also shared as part of the market reporting to provide insight into how they may compare to other DER • Specific individual asset effectiveness levels are not shared at the transmission-connected level; however, we will review how sharing this information could impact, market behaviour.

Category	Participants Feedback
Volume Requirements	DER requested that volume requirements be shared in advance of tender should this service move into a competitive market. • This would be consistent with data shared for other balancing services however reactive data lags behind other services. Further consideration is required to understand how this could be accommodated and the impact. • Further work is underway within NGESO on the Future of Reactive Power project. This work will allow NGESO to gain a better understanding of future reactive power requirements and how they are procured. The learning from Power Potential is also being used to support that work.
Production Schedule – Reasons for rejection	Clarity on reasons for rejection during the auction trial • During the trial DER may not receive the accurate reason code for rejection i.e. they may have received a reason code of "Nothing procured" when the reason for rejection was that the generator was uneconomic. • This is down to how the system was developed and the limited competition within some GSPs i.e. where a single DER operates in a GSP the "Nothing procured" reason supersedes all other reason codes.
DER level data	Request for market reporting on any potential BAU service to be done at the DER level. • DER-level reporting for participants could consider what information at DER level to include in market reporting. This was not a specified DERMS requirement for trials (procurement decisions were at the GSP/VPP level, and market reporting accordingly). However consistent with UK Power Networks' commitments to transparency in a flexibility-first approach to all network requirements, UK Power Networks would support more granular market reporting where accepted by participants and NGESO

3.2.2. Key Commercial Trial Challenges

The project captured several areas within the commercial processes and framework that presented challenges during the trial, these are covered below:

Assessment & Nomination Challenges — The assessment and nomination, within the daily auction process of the Power Potential trial was carried out by NGESO. Overall, the automated elements of the process which involved data being sent from DERMS to PAS worked appropriately and as designed. However, during the trial period several challenges arose due in part to the manual nomination and assessment process, interpretation and labelling of data within the PAS system as well as resourcing constraints leading to increased risk of errors in the nomination process. The errors that occurred during the nomination process have been captured below. Where these errors have occurred the DER has been compensated in line with the nominations and service delivered. For those events the assessment process has been rerun to ensure accurate data is provided for reporting.

- During weeks 1-3 of the nomination process the assessment team identified an error in the data being used to carry out the assessment. The total cost data being presented in the NGESO system this was being incorrectly interpreted as £/EFA block rather than a £/hr cost. This was due to the inadequately labelled fields within PAS. In addition, the utilisation costs were being presented as a cost for the full DER reactive +/- range rather than the minimum driving lead/lag requirement. This required manual manipulation before being fed into the assessment process. The errors on the process were correct and applied within the trial from the 27 January 2021.
- On a couple of occasions where the assessment was not being run by the dedicated resource the incorrect nominations were made due to human error and the process competing with other BAU priorities.
- The accepted service prices for each GSP now represented in this report reflects the service price/cost of the DER providing the service at the full range tendered adjusted for effectiveness at the GSP. During the assessment and nomination, the acceptance of reduced volume was not available. Where DER were previously nominated for a partial requirement, this was therefore not affected through DERMS. Where a, not effected, partial nomination was taken this would have been reported at a higher price in the weekly market reports due to the assumption that this was being effected through DERMS those prices have now been corrected in this final reporting to reflect the actual cost based on the full range procured.
- System update required to ensure visibility, by the assessment team, of changes to the tendered VPP data prior to the completion of the nomination process.

Participation levels – The level of participation seen in the trial provided little competition across the three VPPs and four DER.

Fixed Budget – Operating within a fixed budget also created some limitations the budgetary considerations was factored into the assessment process to ensure nominations were being made within the bounds of the trial budget. Taking into consideration the budget limitations, limited liquidity within the trial market and the Wave 2 duration for price discovery the concept of a TAC indicating to participants a price range within which the budget limits would be maintained. Participants were informed that this was only shared as a guide and has not been interpreted as a ceiling by participants in formulating their bids.

4. Activities incurring costs to deliver trials

Further details of the costs to deliver the trials will be provided in the Final Closure report due by 30 July 2021, as not all costs had been incurred at the time of writing the report.

With that proviso, section 4.1 of the report addresses the bid evidence criteria relating to the financials of each party, while sections 4.2 and 4.3 describe the types of activities incurring costs during the trials.

4.1. Financial summary

The financials of each party subject to DER commercial confidentiality

The four key parties were NGESO, UK Power Networks, ZIV Automation (DERMS developer) and the DER trial participants.

In particular, the final payment to DER has not been made at the time of writing this report. The final month's settlement statement (for Wave 2 in March) was issued as scheduled by UK Power Networks on 14 April, with the contractual review period for NGESO and DER lasting until 28 April 2021, with payment due in May. Total payments to DER users across as a result of the whole trial are expected to be £392k, representing 70% of the budget allocated to DER participation and is subject to that final validation.

Costs incurred by the DNO (UK Power Networks) in delivering the trials, were funded by the Power Potential project, with NGESO and UK Power Networks contributing 10% of the project budget, and UK Power Networks bearing 65% of costs incurred in excess of the project budget. The remaining 35% of project excess was covered by NGESO.

Activities from ZIV Automation (related to development of the DERMS solution) were also funded through Power Potential project budget.

As a percentage of the project budget, the percentage split of costs incurred in relation to system development, integration and delivery for trials was:

- 6% NGESO for development of PAS functionality
- 33% for UK Power Networks for DERMS and for DER integration with UK Power Networks systems
- 21% for ZIV Automation for DERMS development

The costs incurred by the DNO, the uplift applied to DER bids, and hence net revenue the DNO receives

UK Power Networks' total costs to deliver the commissioning, ongoing system development and trials from January 2020 to March 2021 were £1,180,885.

As described in SDRC 9.7, the financial approach to trials delivery was a simple pass-through to NGESO of the cost to UK Power Networks of making payments to trial participants for the services delivered in trials. As such, there was no uplift applied to DER bids.

Thus, there was zero net revenue or cost to the DNO associated with payments made by trial participants; UK Power Networks' costs were met by the project budget and by the project partners as noted above.

4.2. Trial delivery activities incurring costs by NGESO

NGESO total costs to deliver system integration activities were £866,000. The following activities were done on the PAS side of NGESO during the trials. These activities were funded from the Power Potential project budget:

- PAS ASDP system development for Power Potential components including availability, nominations and RTM data with new Graphical User Interface (GUI)
- Additional data requests utilising existing manual process of daily data extractions in FTP folder of ASDP dispatch reports for Settlements.
- Full internal code testing, NGESO change approval and release management
- Service Support alignment and planning in conjunction with DERMS team.
- Control room support and training including documentation of a new training manual and creation of user accounts
- Collaborative PAS-DERMS end to end testing including connectivity check and go-live support.

4.3. Trial delivery activities incurring costs by the DNO

The principal cost types for UK Power Networks in delivering systems and trials for the project are set out below. This covers principal activities since detailed design – due to the staged approach to trial delivery with incremental increases in scope, system development and test continued in approval. In addition to this were the commercial and contractual development aspects covered in SDRC 9.3 and 9.4 e.g. signing framework agreements, variations to connection agreements, and documentation related to how DER would be paid as new suppliers on a self-bill arrangement.

System development, test and delivery

- Supply contract with ZIV Automation for DERMS system (including licence extension, and contract variations associated with changes in requirements)
- Management with ZIV of scope of software releases, test planning and installation and configuration of DERMS releases (on test and live systems).
- IS design (logical and physical architecture), then procurement hardware
- Development of detailed integration design (DERMS-PowerOn-RTU-DER controller), including design and delivery of GE RTU logic developments for Power Potential
- Creation of test harness for DERMS-PowerOn-RTU-DER integration and functional test, development of an RTU-DER interface schedule, refined through laboratory testing with DER.
- Development of DERMS web interface guide, DER user registration and training to access the interface so that DER
- DERMS and E2E system testing – co-ordination, test delivery and issue resolution, including system for tracking defects and observations during test and trials (hypercare)
- Preparation to issue monthly settlement statements; set up development of BI system to produce the Wave 2 statements, create data flows from PI data historian and DERMS into BI system.
- Change approvals process for DERMS – initial DERMS install (December 2019), then five upgrades to the live system to increase functionality and address defects or issues identified in trial.
- Control room – training and support

Commissioning and mandatory trial delivery

- Develop test and trials procedures e.g. Mandatory Trial, some with NGESO
- Develop commissioning procedures (UK Power Networks only)
- Prepare sites and commission DER (five customers, ~20 site visits), including resolution of site-specific issues with DER customers.
- Manual site operations – periodic locking of transformer tap changers
- Run Mandatory Trials (five customers, ~15 attempts), addressing customer and systems issues as they arise.
- Co-ordinate all commissioning and Mandatory Trials resource including Outage Planning support

Regular costs in Wave 1 and Wave 2 trials

During this trial period, with the exception of platform support and IS Azure hosting costs for DERMS and PAS-DERMS of around £4k/month, all costs were labour costs on the following activities.

- Daily system checks, daily data capture and daily manual workarounds during Wave 1 and Wave 2. Various manual workarounds were supported by the UK Power Networks team in the first 14 weeks of E2E trials due to software defects –– this burden was reduced in the final six weeks of trial to checks and data capture only.
- Logging of trials issues and any unavailability of DER, DERMS or PAS - responding, investigating and resolving issues as they arose.
- ZIV trial support contract
- Trials support for all DER to raise queries during trials.
- Communication to DER/RMAP stakeholders - review meetings with DER, newsletters, review of NGESO's Wave 2 market reports.
- Production and issue of monthly settlement statements; manual preparation of Wave 1 availability statements, manual production of DERMS input to BI for Wave 2, checking of statements, issue of invoices to NGESO, follow up on late-payment of invoices, and issue self-bill invoices to pay DER.
- Trial analysis for reporting

5. Trial Learning, Performance and Recommendations during trials

5.1. Assessment of Learning Outcomes from the trials

The table below summaries the key learning outcomes that were included in the NIC project bid document and had defined success criteria.

Table 13 Key Learning Outcomes

Learning outcomes	Measurements	Success	Comments
Ability of the solution to accurately estimate the response at GSP level. (Dynamic and steady state)	% error of calculated response and actual response per GSP % error of calculated effectiveness of DER and actual effectiveness	+/- 5%	The solution delivered provided maximum delivery of either leading or lagging reactive power at the GSP for small changes in GSP voltage (either dynamic or steady state) rather than providing maximum reactive power with a 4% change in GSP voltage, due to the GSP reactive power baseline used. Improvements to this response delivery were evaluated on a test version of DERMS that provided a 4% droop response from DER (as described in section 2.4.2)
Time of solution services response in line with NGESO requirements	% difference in planned and dispatched time	+/- 5%	During the trials there were no specific times when NGESO control room engineers sent dispatch instructions as these were entered when time allowed within their BAU activities. Hence the time of the dispatch time is predominantly influenced by the response times of the DER in the next section.
Time response in sending at a revised voltage target to DG	% difference in planned and dispatched time	+/- 5%	(see section 2.2) The Grid Code/European Connection Conditions requires an onshore non-synchronous generating unit to achieve 90% of the reactive power output within one second (see Appendix 7). The range of response time across all participants was from 2 – 21 seconds
Capacity of the DER to provide a combination of reactive and active power services simultaneously	% error between Mvars and MW planned (contracted) and produced	+/- 5%	(see section 2.5) The DER that participated in the reactive and active power trials successfully demonstrated that it is achievable to combine services simultaneously. The average percentage error comparing the expected MW to actual MW achieved was between 2% and 12%. For Mvar, for one of the DER, there were challenges with its in individual plant controller indicating a conflict between the reactive and active power service modes, so percentage error was approximately 75%. For the other DER, there was no alteration in Mvar service delivered when MW service was also delivered.

5.2. General learning outcomes

At high-level, Power Potential has demonstrated that an integrated automated procurement and dispatch approach can be implemented live to deliver end-end reactive power services from DER to transmission. We also ran short trials of simultaneous instruction from DERMS by NGNGESO for both active and reactive power services – highlighting potential future systems development. This approach enables a new source of voltage control for transmission. From a distribution safety perspective, we have demonstrated that this can be delivered with an agreed safe operational PQ envelope, appropriate 'failsafes' in PowerOn and the RTU, complying with statutory voltage limits for the distribution networks, and providing appropriate visibility to UK Power Networks' Control Engineers, as described in the Network Operating Procedure for the project.

As set out in section 2, the trials enabled us to develop approaches to commissioning and capability test, with the DER Technical Requirements, DER Interface Schedule and DER commissioning procedure being the key output documents.

After the individual DER commissioning and their individual mandatory trials, the end-end collective live technical and commercial trials ran for 20 weeks from October 2020 to March 2021. Through Power Potential, we have demonstrated a world-first regional reactive power market – a DERMS enabled day-ahead offer of services by DER, and then NGNGESO procurement of those services against a budget. Based on that day-ahead procurement, we demonstrated automated delivery of reactive power services by DER for transmission voltage control. This was integrated with NGESO platform for Ancillary Services (PAS) and UK Power Networks' PowerOn network management system, providing visibility for both licensees' control engineers.

NGESO, UK Power Networks and ZIV Automation gained insight in how to deliver and operate the systems and processes to enable these services, integrated with other operational systems and processes. This included learning related to system availability, expected and delivered response, commissioning processes, the contractual framework and settlements.

Participating DER gained important learning about operation in voltage droop control, how to interface for distribution network control, and to resolve conflicts between delivery of reactive power services and other services e.g. active power delivery to the balancing market, Fast Frequency Response (FFR), Enhanced Frequency Response (EFR) dynamic containment.

Based on trial experience, as outlined in section 5, we delivered multiple DERMS improvements, for consistency and ease of service delivery, as well as some PAS changes. We also identified multiple system and process improvements for delivery in any BAU transition, as outlined in section 6, e.g. improving visibility of current and past DER availability, both technically and commercially.

Links to key documents are provided in Appendix 4

Recalculation of allowed operational envelopes could unlock further reactive range and improve estimation of available response in the medium-term, but the effects are currently marginal and require significant additional effort in creating and validating the new data flows.

An additional design change could adjust the response instructed by transmission to be smaller and scaled proportional to the contracted DER volume at the GSP – this was demonstrated in test to reduce oscillation in the response requested by NGNGESO and be more consistent with transmission alternatives.

Power Potential was designed as a single dynamic service to meet the dynamic and steady-state use cases in the bid. Through this project, we have identified that a DERMS system could enable both DER to self-dispatching for a dynamic service and a subsequent enhanced instructed dynamic service i.e. each within 2-5s.

However only one out of five DER, demonstrated they were capable of the fast operation in voltage droop control to respond in 2-5s. Thus, while the high-level concept was proved at a systems level a fully dynamic (<5s from request to delivery) service was not demonstrated end-end. Power Potential was trialled as a single dynamic service, but key elements could be applicable to either a dynamic or steady-state case. These include the integration design, the use of a defined PQ envelope for the service range of each DER, and the high-level procurement/market approach.

5.3. Technical evaluation of the end-to-end service value to NGESO

Voltage control, (both a static and dynamic control) has become increasingly important to NGESO as system operator for the transmission system. Constraints on the transmission system can take many forms of (e.g. thermal/angular stability/voltage), and these constraints are more acutely seen due to the evolving power system and the decrease in large Grid Code compliant generators.

The Grid Code is a common industry document that details the technical requirements for connecting to and using the National Electricity Transmission System (NETS). Compliance with the Grid Code is one of the requirements for the Connection and Use of System Code (CUSC). The Grid Code has been harmonised with the European Connection Conditions (ECC) and extracts are described in Appendix 7 of this document.

In recent years the increase of smaller, asynchronous, generators which are often renewable, has created a much less predictable energy landscape. This has led to a more dynamic system, with rapidly changing flows, accompanied with less network reinforcement, means there are greater challenges in managing the transmission system. Hence, there is now a greater requirement for more automatic voltage support for post fault scenarios to prevent voltage collapse and excessive voltage step change.

The south-east coast of the GB transmission network is unique as it is unusual to have over 3GWs of generation and demand on a single double circuit route over 250km between Hampshire and Kent. This is accompanied by the more recent addition of three large windfarms. There is also a large penetration of DER from renewable sources (wind and solar).

NGESO sends voltage instructions to all Balancing Mechanism participants by altering the voltage set point and voltage droop characteristic (which is usually set at 4%). The expectation is that the generator will respond to the system voltage accordingly. During the Power Potential, control engineers issued instructions using voltage set points, voltage dead band and droop characteristics, though on a per GSP basis instead of to individual generators. The concept of a VPP was developed within the project which currently does not exist within the Grid Code. The VPP aggregates both the technical and economic characteristics of DER located within a GSP region whilst considering any distribution network constraints.

As the NGESO control room did not have visibility of individual generators, it is important that there is alignment between the reactive volume shown to be available with what will be delivered. However, this was not the case with some of the DER trialled in the project as there were instances when there were more Mvar either absorbed or injected, than was requested. From an NGESO service perspective, it would mean that additional reactive capability would have to be bought from another provider to compensate DER that spill Mvar which is a further cost to consumers.

A fully dynamic response to the transmission system, where the dynamic response from end to end should be less than 30 seconds (i.e. in line with the time required for transformer tap changer operation). However, NGESO can utilise voltage support across various timescales as shown directly below.

Constraint	Requirement	Response time needed
Dynamic voltage stability	Post-fault	1 – 5 seconds
High voltage	Pre-fault	Seconds, minutes, hours

As the range of response times across the DER in the project was from 2 to 25 seconds, with the inclusion of an average communications latency of one second, it has been shown that dynamic reactive power response can be achieved.

However, due to the maximum 45 Mvar volume across GSPs from DER participating in the project it was not possible to see the full contribution of reactive compensation at the transmission level. This is especially of note given that transmission level reactive compensation equipment is approximately 60 – 100Mvar.

The trial has shown the potential for dynamic voltage response from DER being enacted via DERMS, though significant improvements (as outlined in section 7 of this report, “Key learning for implementation into Business as Usual”), would be needed to transform what has currently been developed into a more predictable, reliable service.

5.4. Reactive Power Requirements and Cost Comparisons

5.4.1. Reactive Power Requirements

Reactive power services are how NGESO ensures voltage levels on the system remain within a given range, above or below nominal voltage levels. NGESO instructs generators or other asset owners to either absorb or generate reactive power to manage voltage levels. Voltage management is carried out on a regional basis. Reactive Power generation and absorption of Reactive Power within a region of the electricity system needs to be met by generation of Reactive Power from that region.

NGESO requirements for both Reactive Power generation and absorption (static and dynamic service) are currently met through a combination of balancing services and network asset investment. Historically, Reactive Power has been provided through a combination of synchronous generation and network assets such as Reactive Compensation equipment. Network assets for Reactive Power (capacitors, reactors) which have historically provided most of the baseload for Reactive Power, have been very cost effective against market options. These are required to comply with the system security standards, or to meet Reactive Power requirements. NGESO then uses balancing services to fill the gap when network assets are not available and/or when system requirements are higher.

5.4.2. Reactive Power Sources & Procurement

As patterns of generation and demand have changed on the system, the availability of Obligatory Reactive Power Sources (ORPS) at the times when they are needed most has become more challenging. This leads to some regions of the country not having enough ORPS providers available when needed, making those areas more challenging to manage and potentially giving rise to a voltage constraint.

Similarly, at times there is not enough capability on the system to reduce voltage levels so the ESO may dispatch out of merit synchronous generation via trades or the balancing mechanism. There is also work underway to develop further approaches which aim to access reactive capability in a more economic and sustainable way such as through NGESO voltage Pathfinder tenders and the Power Potential project.

NGESO can procure Reactive Power generation and absorption through two routes in the market; however, it can only use these if the provider is running to provide real power when there is a Reactive Power requirement. The routes described below do not enable NGESO to ensure a provider is available:

1. The Obligatory Reactive Power Service (ORPS), which is outlined in the Connection and use of System Code (CUSC) and must be provided by all generators with an ORPS, which is outlined in the Connection Mandatory Services Agreement.
2. The Enhanced Reactive Power Service (ERPS) is a tendered commercial service as outlined in the CUSC. It is for providers who can go beyond the Obligatory Reactive Power requirements. It is also for providers who do not have to offer ORPS but can meet or exceed the ORPS performance standard. NGESO have not had a contract for this service since October 2009 and have received no tenders since January 2011.

5.4.3. Reactive Power Challenges in the South East

The south-east of England has seen significant growth in DER connections to the distribution network due to the region's geographical position and solar and wind resources. This growth trend is being replicated in other areas of the country. The south-east coast transmission network interfaces with UK Power Networks' distribution system at four GSPs: Bolney, Ninfield, Sellindge and Canterbury North, located in Sussex and Kent. Apart from the growth in DER, the south-east coast network is influenced by the presence of three interconnectors with continental Europe. The south-east coast network includes 2 GW of peak demand and 5.5 GW of large generation including wind farms, nuclear power stations and a combined cycle gas-fired power plant.

The growing levels of intermittent renewable generation means NGESO is faced with increasing operational challenges managing the voltage and thermal limitations under certain network conditions, while still being able to transfer electricity to the country's load centres. Capacity to connect more generation on the south-east of England, namely at the GSPs in Canterbury, Sellindge, Ninfield and Bolney, is being restricted due to upstream constraints on National Grid's transmission network. The constraints include:

- Dynamic voltage stability: requiring reactive power delivery at short notice.
- High voltage: managing the voltage on the network during low load periods.
- Thermal capacity: potentially leading to generation curtailment during the summer maintenance season.
- The challenges of managing reactive power vary between locations, however similar challenges are being experienced in different areas. To provide voltage support in the area, increasing reactive compensation is needed. DER connected to the distribution network in the area have the potential to provide reactive and active power services to the transmission system

It is envisaged that the services provided by DER could alleviate transmission constraints, while respecting constraints in the distribution network. This will unlock whole systems benefits such as additional network capacity and operational cost savings to customers.

5.4.4. Price Comparison of Reactive Power Services

The project aimed to compare the prices seen within Power Potential trial against the alternative option to access reactive power service to support system requirements. In this section the Power Potential service is being considered against the below build and non-build alternatives to access reactive power/voltage support:

- ORPS – The ORPS default payment rate currently stands at £3.74/Mvarh for March 2021[1]. This service is a mandatory service provided by transmission connected generators and is paid on volume utilised. There is no availability payment associated with service from transmission connected generators.
- Network Assets (STATCOM/SVC) – The cost of the Power Potential service is viewed against the cost of accessing the service by building a transmission connected STATCOM. The price/cost associated with the STATCOM has been derived by taking the long run marginal cost of a STATCOM across the asset life (20 years). The assumptions for the cost related to STATCOM/SVC were presented in the Cost Benefit Analysis (CBA) section of the project bid document, this can be found here. This is a value of £1.50/Mvarh, but based on a committed investment rather than deployed as delivered in the case of ORPS or trading on additional generation.
- Trading on Additional Generation – NGESO may also be required to buy on additional generation to meet reactive power requirements in a certain region. For this review the project has considered transmission-connected generation plant within the south east region that has been traded on to the system to be available to provide voltage support. The cost to NGESO of bringing on additional generation are synchronisation costs to run the unit from trades and balancing mechanism actions as well as utilisation costs for the increase or decrease in Mvars. Across the Power Potential Wave 2 trial period the cost of bringing on additional generation for voltage support was ~£616k (data up to February 2021). However, the prices at which these individual units are instructed are not available to the market and will vary.

Figure 41 Market Price Comparison, below provides a view of the average availability and utilisation prices accepted across the three GSPs for the second trial month, February 2021, against the default

[1] https://data.nationalgrideso.com/backend/dataset/7e142b03-8650-4f46-8420-7ce1e84e1e5b/resource/e2e6f74c-ebca-48b3-b2ae-e4652d296dca/download/reactive-default-payment-rate-feb-2021.pdf

payment rate paid to transmission connected generators (ORPS) and the equivalent price of the service from a STATCOM/SVC.

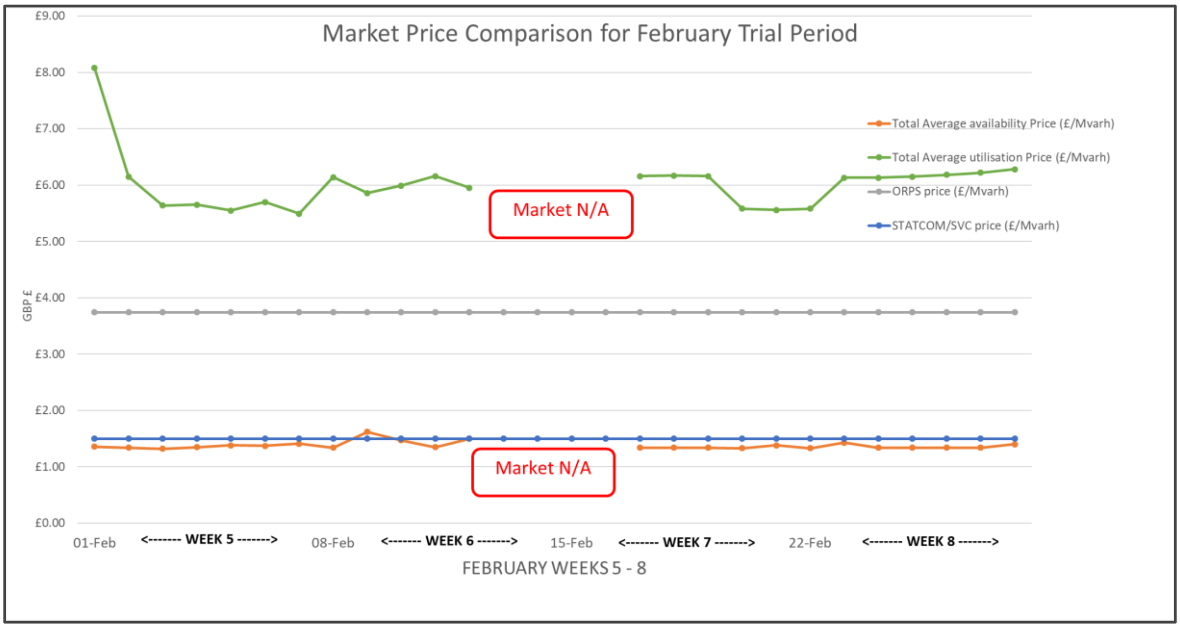


Figure 41 Market Price Comparison

There are several challenges with making a direct price comparison with the various reactive power procurement options. Further aspects of each these options need to be taken into consideration.

Table 14 Reactive Power Procurement options

Reactive Power Procurement Options	**Further consideration**
Power Potential Reactive Power	• Consideration of any additional cost required to deliver the service to NGESO. To include but not limited to ongoing costs associated with account management (DER recruitment, contracting, query management, settlement etc.); DER commissioning costs, NGESO system (PAS) costs and DERMS integration, maintenance, and ongoing development. • Power Potential service payment structure is currently based on an availability and utilisation price, other alternatives such as ORPS is based on a utilisation price only, plus the synchronisation costs (trading on). Leading to a challenge with a direct comparison. • Assessment of the potential volume/liquidity that will need to be seen in the market to ensure adequate competition and liquidity levels deliver a valued service.
Obligatory Reactive Power Service (ORPS)	• There is currently reactive reform work underway within NGESO, working with the industry to review aspects of the reactive power market and potentially this could potentially involve a review of the ORPS service. Further details on the Future of Reactive Power project are explained in the Electricity System Operator Roadmap to 2025.

Reactive Power Procurement Options	Further consideration
Network Asset (STATCOM/SVC)	• Normally the STATCOM is of most value when the number of years' service against a fixed capital cost is greatest. As the number of years' service lessens the price per year of the STATCOM increases. • Consideration is therefore required to determine an accurate projected timeframe for this requirement to calculate a reflective price for the STATCOM.
Trading Additional Generation	• The cost of trading an asset to provide voltage support will vary from region to region depending on the voltage requirement for that region. • In addition to reactive power services there are several other benefits provided by these assets that are traded on to provide voltage support. These include stability, inertia, increased fault levels, frequency response and scale. • Challenge in unbundling these benefits assigning a single comparable reactive power £/Mvarh price.

6. Future Systems Functionality

Looking to the future of Power Potential, the project has identified a number of design features that could be incorporated into a future BAU solution. Some of these features were already planned and developed during the early the stages of Power Potential but for reasons of complexity, budget and time constraints, were de-scoped from the original design.

Additionally, the live trials have identified further system enhancements that could also deliver significant improvements in a BAU environment.

There was no automatic transition of the Power Potential services from trial to BAU from a contractual perspective – as noted in SDRC 9.7 (DSO risk-reward) the contractual agreements and incentive framework were scoped suitable for the trial only to maximise learning opportunities.

6.1. Systems Functionality Developed but not Trialled

In the detailed design, developed during 2017 and 2018 (see SDRC 9.1 and 9.2), the project set out to deliver the original bid method (2016) in an optimal design for a long-term BAU solution — able to be continually updated from live systems, and expanded to deliver maximum reactive response. This detailed design was ambitious but has ensured that the project has always delivered learning relevant to the potential delivery and expansion of the services post-trial i.e. the value case for the project. However due to the complexity of the combined end-end solution, with the budget and time constraints, the project has focused the delivered system for live trial, to bid requirements, with learning related to the longer-term value delivered as part of design, development and test. This action has avoided more significant cost impacts and delay to trials, ensuring that we prove an automated solution in line with bid requirements, while delivering offline learning on those longer-term objectives in the detailed design.

Specific parts of the design that have provided important learning in test and development, but were de-scoped from implementation in our live trials (and were not specifically named in the original bid scope) are:

1. DERMS using a CIM-compliant model with network and SCADA updates from live PowerOn
2. Power Potential Alarms & Indications in PowerOn
3. Fully Automated Settlement Reporting
4. Systems Backup and Failover.

6.1.1. DERMS using a CIM-compliant Network Model Import from PowerOn

The trial ran with fixed operational ‘PQ envelopes’ to ensure network security. Recalculation of allowed operational envelopes using day-ahead and real-time load flows could unlock further reactive range and improve estimation of available response in the medium-term. This would require the use of CIM-compliant network model import from PowerOn. The effects are currently marginal as DER would not have offered larger volumes in trial, and this would require significant additional effort in creating and validating the new data flows. However, this could be considered for a BAU solution.

In the detailed design, for delivering the DERMS work package, the design specified that DERMS would operate with a CIM (Common Information Model) standard compliant internal network model and be able to ingest and use a CIM-compliant network model exported from PowerOn.

The delivered DERMS works internally based on a CIM-compliant database structure. CIM-compliant model ingestion by DERMS has been proven as part of FAT. UK Power Networks has exported a CIM-compliant model (funded outside of the Power Potential project) and ZIV Automation has proven that they can process a CIM-export from PowerOn as a one-off validation exercise. However, the detailed electrical network model used in trial is a CIM-compliant model derived from a UK Power Networks planning model, rather than a network model being continually updated during trial from the live PowerOn network management system. The IT-infrastructure for the model transfer was designed and partially implemented as part of our learning around how such a system would be implemented in future.

However, with the combination of work in Power Potential and via the Flexible Connections and DERMS related project, formerly known as Active Networks Management (ANM – see Figure 45, section 7), UK Power Networks identified that data validation would be a significantly more extensive task than envisaged at bid stage. The wider project identified model convergence to a standard required for operational decisions, necessitated data validation activities for the whole SPN network licence area, rather than targeted to the immediate network around the five trial participants. Delivering this validation work for Power Potential and therefore adding this cost to Power Potential was not justifiable. This validation work will instead be delivered under UK Power Networks' Flexible Connections and DERMS related project by the end of 2021 (not innovation funded).

As a result, we will continue to use a single network model throughout the trials. This has removed the need for extensive validation of an electrical model in PowerOn, and the approach to modelling the network only required real-time data inputs at the GSP and at the DER. Our data quality improvements focused on returning Power Quality Monitoring data at DER sites to the PowerOn system for the first time. This has resulted in an improvement on the frequency, precision and accuracy of the previous data inputs from transducers. No changes were made to NGESO's measurement data at the GSPs (this was previously considered but rejected due to additional cost); a method was instead developed by UK Power Networks to transfer the required data over serial ICCP links to the DERMS system with low latency for control purposes.

This approach to data quality differed to the original bid to upgrade or data correct many of the intermediate measurement points. Detailed analysis of asset upgrades for data quality improvement took place, but the implementation cost and timescale were again not justifiable mindful of the project budget and timeframe. Work on the wider SCADA data correction algorithms by the developer and in a state estimator within PowerOn was therefore progressed (see SDRC 9.4). However, we identified that with relatively sparse data points on the distribution networks, and changes in the network configuration associated with a new Richborough GSP, data correction by state estimation would be more cost-effectively delivered for BAU applications after the data validation activity for UK Power Networks' ANM project has been delivered.

To enable the simplified approach to the electrical model in DERMS, conservative network security limits were implemented on the scale of service from each DER (defined in a 'PQ envelope' in the contracts and entered in DERMS). Practically, this had minimal impact on the scale of DER reactive response delivered in trial; only one customer would potentially have offered any greater range under the approach in the original detailed design. Both UK Power Networks and DER participants wished to proceed cautiously with Mvar range offered in trial, to ensure the security and operability of the network, before considering expansion post-trial. This delivery approach allows the Wave 1 to Wave 2 system transition to become a low risk activity, avoids a change in contracts and a significant system change part-way through the trial.

Future development post-trial to use a CIM-compliant network model would maximise the future scale of service delivery (both in terms of ease of adding DER automatically from the PowerOn CIM model, and maximising the potential scale of service per DER in all network conditions, particularly when those DER are delivering both Power Potential and other flexibility services). However, the implemented solution demonstrates delivery of reactive service, and simultaneous with active service, addressing the bid requirements for live trial and provides a candidate for post-trial BAU service development.

6.1.2. DERMS 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, 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.

Testing of the forecaster functionality began in December 2019 as part of the full solution pre-FAT by ZIV Automation and completed its FAT in July 2020.

6.1.3. Switching Schedule Inputs

Switching schedules are produced when HV switching operations are carried out on the UK Power Networks network. These are prepared and entered into the PowerOn main database, administratively by Switching Engineers.

Switching schedules are required in DERMS to feed the Future Availability and Service modules for the purpose of calculating future network requirements leading up to real-time. The preferred approach would have been to set up an interface between PowerOn main database and DERMS CIM, to feed switching status information directly to DERMS. However, the project faced two key challenges.

- UK Power Networks Control Systems Automation (CSA) team and GE resources, required to provide this interface, are heavily committed on other priorities and therefore unable to deliver in the required timescales.
- The process for producing 132kV switching schedules is not currently set up in PowerOn. This is historic in SPN where the running arrangement for an outage could depend on prevailing network conditions on the day, so running arrangements have always been applied using on-demand switching. As such this would have required significant policy change within the control team, exposing the project to further time and cost on the project.

6.1.4. Inputs to DERMS to reflect planned DER outages

The original full DERMS design was 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 load-flow 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 key benefit to the Power Potential is that the Service Module will calculate the optimum DER production dispatch that satisfies the service request at the lowest cost. The algorithm issues set points 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.

Again, due to the aforementioned budget and resource constraints and issues with providing switching schedule inputs to DERMS, this element of the design was de-scoped and instead a manual approach for restricting DER output was adopted for the live trials. Where a DER active and/or reactive power needs to be restricted due to a network outage, the constraints are entered manually in DERMS by the Outage Planning Manager. However, while this approach can be tolerated for a small number of DER during a limited period of trials, this would be unsustainable for increasing numbers of participants, across multiple regions in BAU.

A new Outage Planning tool (Network Vision) was commissioned in 2020, which already accesses data from PowerOn CIM. An alternative approach is therefore to harness the information within the new planning tool and create an interface with DERMS.

6.1.5. DERMS Systems Back-up and Failover

To provide contingency against system component failure, a backup and automatic failover of DERMS, PowerOn and the associated ICCP links was intended for the design. This would have allowed DERMS to failover automatically between the primary control room, the backup site, or even for DERMS and PowerOn to continue operating on different sites.

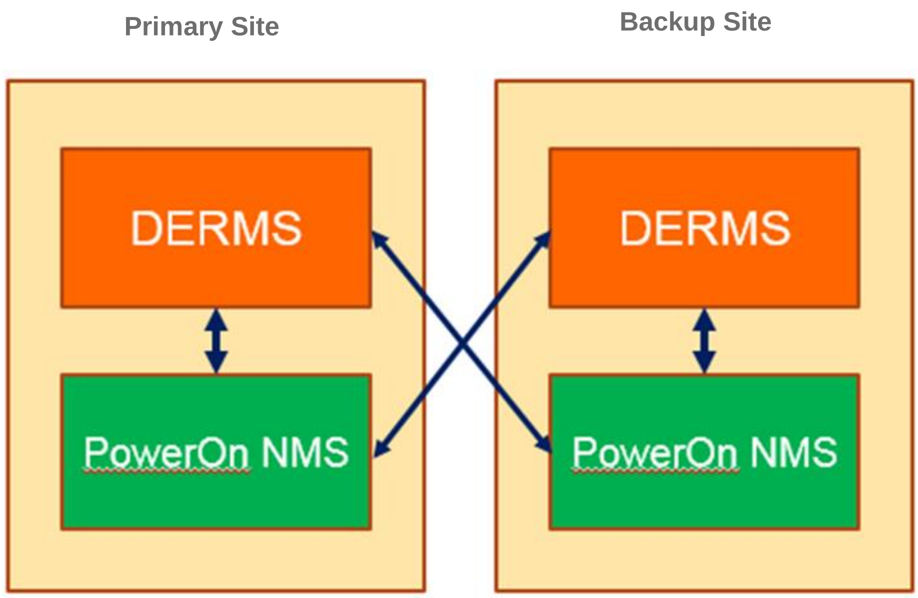


Figure 42DERMS failover arrangement

Manual failover was demonstrated at the end of September 2019. However, in order to fully automate the process, IS developments required a third ‘Arbiter’ node to be added to the infrastructure, in order to manage the automatic failover and backups. The increased complexity and cost of this approach outweighed the benefit for the lives trials, i.e. constant monitoring of DER and Systems was already in place by the project team. Hence the backup was delivered but a fully automated failover would need to be tested and implemented for any future BAU service.

6.1.6. Power Potential alarms and Indications in PowerOn

For each DER site, a dedicated screen showing the DER status was developed in PowerOn and visible to UK Power Networks’ Control Engineers. This indicated measurements services delivered (P, Q, V and power factor), setpoints issued and readbacks from site, RTU operating mode, and operation of all failsafes tested in DER commissioning) Further developments were identified to provide increased visibility in a BAU service.

PAS-DERMS Link failure indications (both ends)

During the trials, the web services link between DERMS (UK Power Networks) and PAS (NGESO) often disconnected momentarily, either due to scheduled PAS resets or PAS outages. If the link was disconnected for more than a specified number of minutes (initially 2 minutes, then fifteen minutes), this would disable the service, signalling the ‘Q Abort’ flag in DERMS. Unfortunately, there was no alarm that indicates this to either control team, or to re-enable the services, so the issue could potentially go unnoticed for several hours until addressed by the project team (as noted in section 2.4.3). This was manageable during live trials due to the constant vigilance of the project team but would need to be implemented for a future BAU service.

Emergency Service Disable Alarm

During times of system stress, the NGESO Control Team require a means of quickly disabling the Power Potential services and placing DER into a safe mode of operation (Contractual). Such a feature was incorporated into the system design, which allowed the NGESO Control Engineer to send an ‘Emergency Service Disable’ instruction from PAS to DERMS. The intention was then for DERMS to disable all services and place DER into Contractual mode automatically and raise an alarm in PowerOn. Whilst the functionality to disable the Power Potential services was tested and delivered, the automatic placing of DER into Contractual mode required the development of a telecontrol feature within PowerOn. This in turn required extensive development and testing to operate with signals from an external control centre. Accordingly, the alarm and fully automated approach were de-scoped from the live trials and an Inter-Control Room Network Operating Procedure developed to manage such incidents via telephone instructions. The UK Power Networks part of the procedure is available as a project output.

Loss of NGESO SCADA data input

Measured parameters at NGESO 400kV sites are not generally available to the UK Power Networks control system. However these are essential for the operation of DERMS. Therefore an ICCP link was developed to provide these values from the NGESO SCADA directly into PowerOn, where DERMS could pick up the values for use in its algorithms. Whilst the loss of this connection was considered to be a very low risk to the network, an alarm to alert the control team would be a necessary for a longer-term solution.

Loss of DERMS to PowerOn Connectivity

DERMS communicates with the UK Power Networks network management system (PowerOn) and thus the rest of the network and DER via another ICCP link. Experience during the trials showed this connection to be robust. However, the loss of this connection would certainly cause a failure of the Power Potential service. The design intention was to incorporate an alarm ‘Orphan’ within PowerOn to indicate such a circumstance, but development timescales and cost vs benefit meant that this alarm was not implemented during live trials. Given the continuous system monitoring by the project team this presented low risk to the network during live trials. However, this functionality would need to be developed and implemented for any future BAU service.

Loss of PQM Data to PowerOn

During the Mandatory Trials, issues were encountered with enabling voltage service on one of the DER. The issue was traced to the PQM meter having dropped out of service, evidenced by the lack PoC measurements in PowerOn and DERMS. The issue was later resolved by rebooting the PQM device on site. Furthermore, because PQM is not yet part of the standard network metering, there are no alarms to indicate an issue. Therefore, if PQM is to be used in any future BAU service, the associated alarm functionality will need to be developed and implemented

6.1.7. Fully Automated Settlements process

A fully automated settlement process had been designed and developed, based on UK Power Networks’ Business Intelligence (BI) system, with data in-feeds from DERMS and PI data historian.

Whilst the data in-feed from PI had been established, issues were encountered with the DERMS to BI data transition.

ZIV had resolved an integration issue with sending settlement data from DERMS to UK Power Networks' BI system ahead of the Wave 2 trials, but the project team queried the validity of values in the report. ZIV advised in January 2021 that they were not able to fully fix the DERMS component which extracts settlement data (DER prices, DER availabilities, PAS nominations and PAS instructions) to BI in time for preparation of the first settlement statement. Therefore, the fully automated settlement process was unable to function properly as expected. PAS instructions e.g. GSP voltage set points could be extracted, but the project team developed workarounds to extract the remaining DERMS data manually daily. This was assembled in the expected format and sent to the BI system for processing, with the metering data from UK Power Networks' PI data historian. The delay in creating the equivalent DERMS input meant that an issue with combining the minute-by-minute settlement metering data from PI, with the data by settlement period was not identified until the first Wave 2 settlement statement was created in February. This was resolved before the next month's statement, and DER were paid in full, but with a delay on their initial utilisation payment.

The automated process design would need to be finalised, tested and implemented for BAU, reflecting the revised commercial and contractual framework for the BAU service.

6.2. Future DSO system enhancements identified during trials

Building on the aforementioned design and developments, the live trials have identified further system enhancements that could deliver a number of significant future benefits. These are categorised into:

- System Enhancements (including DERMS) to improve system efficiency
- Enhancements required to facilitate more effective on-boarding of new DER
- Improvements to facilitate E2E coordination and testing

6.2.1. System Enhancements including DERMS

Automatic Voltage Controls (AVC)

In the early stages of Power Potential, the project team explored the value in optimising the tap changer operation to bring about enhanced reactive power services. Availability of transformer taps is a positive control variable, which if coordinated with DER' reactive power control systems, can enhance the response at the GSP. The project conducted offline studies to determine the best transformer tap settings, which maximises DER' reactive power response

Coordination can be made to enhance the DER reactive power response by adjusting the tap settings. Tap positions were optimised offline to ensure nullification does not happen when the DER is providing Q services. The studies showed which fixed tap positions provide the best enhanced DER reactive power service.

Furthermore, future inclusion of tap optimisation in DERMS will bring even greater benefits.

Influence of AVC on reactive power on the transmission system

In 2017 Moeller & Poeller Engineering (MPE) was commissioned by NGESO to investigate the Power Potential project technical feasibility and to draft the main functional principles of the control and subsequently to further develop the Power Potential concept to test the control philosophy through a series of dynamic studies. This included assessing the benefit of controlling the SGT and GSP transformer taps over the performance of Power Potential for reactive power export.

Background modelling assumptions and system scenarios

A full GB system model in DIgSILENT PowerFactory was provided to carry out the studies. For the purpose of modelling the behaviour of the Power Potential control system in steady state, a voltage droop characteristic for each GSP was considered. Table 15Table 14 shows the voltage droop characteristics used.

Table 15 Voltage droop characteristic parameters considered per GSP

GSP	Dead band (%)	Slope (%)	ΔQmax/min [Mvar]
Bolney	±1	4	±46.62
Ninfield	±1	4	±46.79
Sellindge	±1	4	±34.63
Canterbury	±1	4	±82.19
Richborough	±1	4	±119.86

For the assessment of Power Potential performance, two system scenarios have been considered as follows:

Critical contingency scenario:

- Consisting on the occurrence of the N-D critical contingency associated with the transmission lines: Kemsley-Canterbury & Kemsley-Cleave Hill, under a high-power export form the SC2 system boundary.

High volts scenario:

- Consisting of a low system demand and high voltage scenario across the SC2 400kV power system corridor. In order to assess the maximum hypothetical reactive power that can be absorbed by the embedded plant, artificial voltage sources have been connected at each GSP to fix the voltage at 1.05p.u.

In addition to these scenarios, the operating mode of Thanet wind farm; both in voltage control (Thanet_V_control) and power factor control (Thanet_PF_control), was considered to show the impact of the reactive power restriction on Thanet, even though it is not part of the Power Potential control scheme.

To investigate the net benefit of transformer tap optimisation in terms of Power Potential reactive power capability, the following scenarios were studied:

Current system performance:

- Post tapping and not including the effect of Power Potential, therefore DER are considered to operate in unity power factor. As this case represents the “natural” system response, it is considered as the control case for comparative analysis

PP_ON:

- Post tapping and including the effect of Power Potential. Transformer tap changers operate based on local measurements and set points, without any connection with Power Potential controller. DER are assumed to operate in voltage control mode, with their voltage targets being optimised by the Power Potential controller to follow a voltage droop characteristic at each GSP in line with Table 14. The Power Potential controller supervises the state of the grid, in order to avoid voltage limit violations within the distribution network.

PP_ON_Taps optimised

- Post tapping and including the effect of Power Potential. Transformer tap changer set points are optimised by the Power Potential controller to maximise the reactive power support at each GSP by following a droop characteristic.

Results and Conclusion

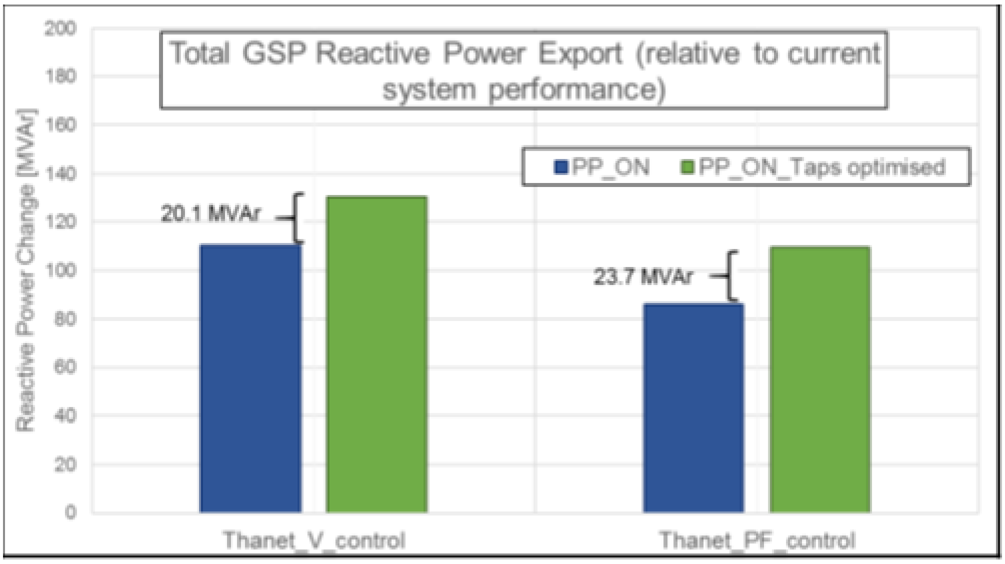


Figure 43 Critical contingency scenario

From Figure 43 above, it can be concluded that, regardless of the voltage control mode considered for Thanet, the added benefit of Power Potential being able to optimise the transformer tap changer position is approximately 20 Mvar, as compared to Power Potential controlling only the voltage set point for the DER controllers. In the case where Thanet windfarm is operating in voltage control mode, the added benefit represents an increment of 18%, whilst in case Thanet windfarm operates in power factor control mode the transformer tap optimisation provides 28% more response in terms of total reactive power.

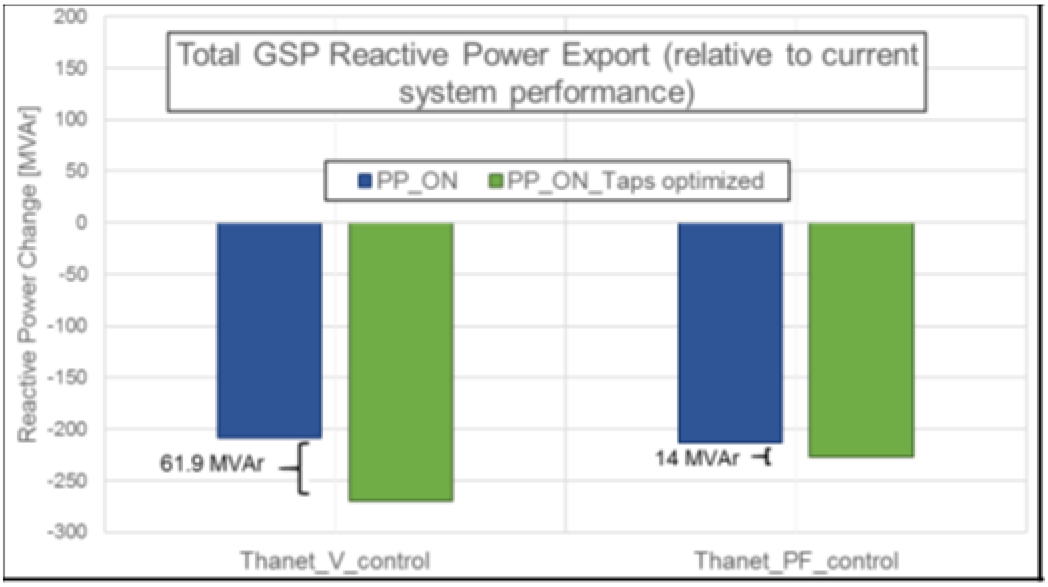


Figure 44 High volts scenario

From Figure 44, it can be concluded that when Thanet windfarm operates in voltage control mode, the benefit obtained from tap optimisation is approximately 62Mvar, that represents 15% more capability to absorb reactive power. If Thanet operates in power factor control, the added benefit from Power Potential being able to optimise tap changer set points is 14 Mvar, equivalent to a 7% increment in the Power Potential reactive power capability.

The results contained in this report show that the Power Potential 'self-dispatch' and 'PP-dispatch' function provide the major part of the reactive power response at the GSP, whilst the super grid transformer tap so optimisation represents only a portion of the total reactive power support that enhances the response in up to 28% in the critical contingency scenario, and up to 15% more in the high volts scenario.

The conclusion was therefore that while the optimisation of transformer taps does provide significant benefit, it was not essential, and a reasonable response could still be achieved without it. Therefore, it was recommended that transformer tap optimisation is not considered as part of the minimum viable product (MVP), given the expense, time and complexity of controlling these transformers at the NGET GSPs and in the UK Power Networks network. However, future inclusion of tap changer optimisation in DERMS will enhance reactive power services provision from DER and will ultimately reduce the cost to consumers by using DSO asset capabilities as part of whole system operation.

Access to historic data in DERMS for UK Power Networks and for customers

The current DERMS design does not allow for effective capture and retrieval of information. An example of this is the where large log files need to be activated at times when known issues are expected and downloaded for review. If not managed appropriately, this can accumulate into large data files, which in turn can impede processor functionality. Therefore, a future BAU service would need to incorporate the following functionality:

- Show previous day's bid submissions, and production schedule responses
- Include dates/times that DER were in/out of service
- Provide performance metrics – required to inform UK Power Networks and customers of the technical and commercial performance of a DER. Examples of the type of metrics that could be deployed are:
    - Average (daily or weekly) time to respond to instruction
    - Average time to reach full reactive output
    - Percentage of full reactive power achieved against instruction
    - Reactive Power range achieved, perhaps split between Lead and Lag
- Improve real-time visibility of whether DER are available in V service – to DER, UK Power Networks
- Improve real-time visibility of actual availability at VPP to NGESO
- Add signals to interface schedule indicating whether DER is due to be available commercially and whether also in V mode. Feedback from one of the PP participants, previously suggested that "DER Available" signals could be sent in real-time via the DNP3 link to the UK Power Networks RTU. This could not be achieved during the trials because there was no link from the DER RTU to the DER central control room. This meant that the only way to tell if the STATCOM was offline, was by attendance at site or interrogation of the DER PLC. Therefore, providing DER Availability via DNP3 is worth investigating in the future.
- Capture actual DER availability Voltage service over time in UK Power Networks' data historian
- Building on enhanced DER-level reporting for participants and UK Power Networks, we could then consider what information at DER level to include in market reports. Although granular data was available for performance monitoring and settlements purposes, this was not a specified DERMS requirement for market reporting during trials, e.g. procurement decisions were at the GSP/VPP level. However consistent with UK Power Networks' commitments to transparency in a flexibility-first approach to all network requirements, UK Power Networks would support more granular market reporting in a BAU environment.

Calculate historic performance metrics for VPP and DER relative to Q requirement

Building on the previous approach to historic data capture, DERMS would also benefit from the ability to calculate and make available relevant performance metrics as follows:

- Store time-series data sent from NGESO to DERMS, derive GSP and Q requirement, and use this for performance calculation.
- Extract the time-series of Q requirement calculated by DERMS at GSP and DER.
- Quantify any under-delivery against contracted range, and highlight the amount related to compliance with for example statutory voltage limits, outage planning restrictions, PQ envelope, and quantify any residual or unexplained under-delivery.

Additionally, DER time-series metering data was shared daily in the end-end trials, but there was a lag in sharing the GSP-level data which delayed identifying the mismatches in expectations of the Mvar GSP requirement, reactive power base and source of DER under performance.

Improve system performance monitoring

A BAU system would benefit from more automatic logging and alerting of issues such as DERMS system availability (including key error messages, database checks), unexpected changes in the volume of data traffic DERMS-PowerOn-RTU-DER, when DERMS logs and ICCP logs exceeded a certain size.

Calculate historic DER and VPP utilisation factors

A future DERMS or associated data historian should automatically produce or be easily queried to produce reports on the past utilisation factor (lead, lag or combined) at each VPP, for the time periods associated with relevant network scenarios (including time of day and/or season as appropriate). DERMS could learn utilisation factors based on how the system is instructed by NGNGESO control engineers.

The trial DERMS allowed the utilisation factor to be adjusted in each service window and VPP, as an input to the commercial data sent from DERMS to PAS at 14.00 each day, but a constant 85% utilisation factor was used throughout.

Review restriction of voltage set point to statutory voltage limit

From a network security perspective, DERMS performs a crucial function to maintain DER within their contractually defined PQ envelope and maintain operation within statutory voltage limits (+6% at 33kV, +10% at 132kV). As a precaution during Mandatory Trials, we introduced a requirement for both issued voltage set points and the measured voltage at the point of connection to stay within those statutory voltage limits. Since it is the difference between the voltage set point and the voltage at the point of connection which drives the scale of the DER reactive power output, this limit can restrict the range of service.

A risk-assessment could be performed to consider whether the restriction on voltage set points issued to DER could be relaxed, as long as the measured voltage at the point of connection was maintained within statutory voltage limits. This could enable DER to deliver a wider range, increasing both their utilisation and their usefulness for service delivery.

Review PowerOn-DERMS data volumes

As covered in section 2.4, the trials identified issues with excessive data volumes through the Network Management System, which posed a risk to network data handling mechanisms. Several measures were put in place to resolve this during the trials, including an upgrade to the DERMS to introduce configurable bandwidths around setpoint instructions and fixed RTU limits. Additionally, FEP logic was revised to allow for increased data logging from the Power Potential servers to SPN. Whilst these measures successfully resolved the data volume issues during trials, a full review of the PowerOn-DERMS data volumes and suitability of the FEPs/IS infrastructure would need to be undertaken for a future service

6.2.2. Approach to add DER to Service

Creating a new DER in DERMS

In order to introduce a new DER to DERMS in the current DERMS approach, this requires a new code release from the developer for the additional DER to be identified in the network model for the appropriate GSP, and for the appropriate DERMS dashboards to be created.

The new code release would then require a system upgrade, involving testing, change approval and implementation. This is clearly inefficient and therefore a future DERMS requires the functionality for authorised users to create new DER customers on the system via a simple user interface. The original design envisaged that new DER could be loaded from the PowerOn network model.

Develop the Power Potential RTU logic for 11kV DER connections.

This could not be delivered within the timeframe of the project but would have potentially increased participation beyond just 33kV and 132kV participants. Needing to develop a bespoke RTU solution was one of the barriers to participation for a potential trial participant in 2019 but was not the deciding factor as that customer faced unusually high costs for upgrade of its inverters to be able to deliver voltage control services.

However, in parallel to the trials, RTU development for UK Power Networks' flexible connections products has progressed for the types of RTU types at typical 11kV connections. Thus, it would only be a small test and development step in future to include 11kV-connected DER in Power Potential services.

DER commissioning functionality within DERMS.

During commissioning, when limits and set points are manually sent to the DER from DERMS, the service module tries to overwrite these as it refreshes every 10 seconds. This has been overcome during commissioning, by changing the refresh rate to 7,000 seconds, which in most cases provides enough time to complete commissioning. However, this is a cumbersome workaround that could be improved by the implementation of a dedicated 'Commissioning' setting for a future BAU service.

Operational Verification of the PQ envelope

The Active Power (P) and Reactive Power (Q) ranges of a DER are tested during the Capability Tests. However, the Q range is tested at the current active power P, at the time of the test, and is not repeated for different values of P. This is largely associated with the DER technology, which may restrict the available MW e.g. a windfarm may be restricted by low wind conditions, or a battery storage unit may be in its charging cycle. This capability would need to be fully tested for any future service, which could be done in one of two ways:

1. Expand the Commissioning procedure to incorporate the additional testing – In some cases, this may extend the process over days, possibly weeks
2. Initial test at single value of P during Commissioning, then carry out ongoing review of DER during operation – preferred approach as it facilitates full test yet allows DER into service sooner.

Active Power Configuration in DERMS

Not all customers wish to participate in the active power service. However, DERMS provides the functionality in the 'DER Day Ahead Wave 2' dashboard, for all DER to view and submit active power parameters in the 'Active Power' tab. This can be distracting or confusing to users, yet there is no easy way to remove this functionality and information for those customers who do not need it. Therefore, DERMS should be equipped with the ability for UK Power Networks to configure this tab according to which services the DER is commissioned for.

Calibration and Accuracy of Network Monitoring

UK Power Networks is able to monitor the response (MW, Mvar, and kV) of each DER using two separate sets of metering:

1. PoC measurements taken at the point of connection between customer and UK Power Networks (meters owned by UK Power Networks)
2. At Customer Measurements (meters owned by customer)

The two sets of metering should be the same but metering accuracy, positioning and calibration can introduce errors. Furthermore, during mandatory trials, the project team have observed differences in the region of 50-100V, for some customers, though typically much smaller. This is an issue because DERMS issues instructions and controls responses based on 'PoC' values, whereas some DER control their responses based on 'At Customer' values, which can lead to differences in DER response versus DERMS instruction. In accordance with UK Power Networks' standards, control and measurement were based on the UK Power Networks' measurements – provision of customer metering was optional in the DER interface. On several occasions when a DER had site issues, customer measurements might not be available for period, whereas there was consistent high availability of the PoC measurements.

For example, one DER was observed 'spilling' reactive power in the order of 1.2Mvar, which corresponded with a 0.1kV difference in PoC to Customer voltage measurement. Theoretically this discrepancy would be expected to lead to an average 1.27Mvar spill (based on 4% droop and contractual Mvar lag range). Combined with the site's relatively large Mvar lag range, this explained the scale of the spill via the droop relationship for the site (see Appendix 1).

This theory was tested by configuring DERMS to control based on the 'At Customer' values. Whilst this reduced the 'spill', particularly in the 'At Customer' reactive measurements, it didn't remove it completely. This suggests some metering inaccuracy in terms of actual values. Both sets of reactive power measurements are more variable than voltage measurements, and further investigations of the accuracy and potential improvements in reactive power metering may be a worthwhile research area going forward as reactive power control becomes a commercial service.

To resolve this issue for a potential BAU service, both the DERMS and DER controllers would need to base their algorithms on the same metering point/measurement, which for compliance with UK Power Networks' network standards, is the PoC measurement. Where this is impractical, e.g. due to proximity of DER to PoC, then the two meters would need to be calibrated to read the same. In both instances, the meters would need to be calibrated to accurately reflect actual parameter values.

Another short-term solution, if there was a consistent offset between the voltage measurements, would be to implement a configurable offset per customer in DERMS from the PoC measurement to convert to a voltage setpoint issued to the DER. However, analysis of the trial data showed that the offset, although consistent within 10V on a day, could vary by 50V between days and on some days the two voltages were near identical.

UK Power Networks' DER Aggregator Interface

Implementation of the aggregator interface was not in the scope of the Power Potential trial. All participating DER communicate in real time via a direct physical connection with an upgraded UK Power Networks RTU on site. However, there is clear stakeholder interest in developing an aggregator interface, and furthermore, scoping interaction with aggregators is a learning objective from the original project bid. Therefore, the project has conducted a feasibility study that provides an assessment of available methods and potential design considerations to develop a DER aggregator interface in the context of the project's requirements. The outcome of the feasibility study has been summarised in the "DER Aggregator Interface to DERMS – Feasibility Study". The document presented at Power Potential Regional Market Advisory Panel (RMAP) and shared with the attendees, trial participants, or those that have expressed interest in developing or connecting an aggregator interface.

The DER aggregator feasibility study is a research and learning report from the project which acts as reference to inform potential future implementation and design of an aggregator interface after the project. Through this interface one or more DER aggregators would be capable of interfacing with DERMS and dispatch services to alleviate transmission network constraints. The document focuses on technical implementation of the interface from DERMS to aggregators and does not cover market design.

The summary outcomes of this documents are:

- All aggregators shall connect to the DERMS through a Web Application Programming Interface (API).
- The DERMS interfaces with the aggregator for DER services rather than carrying out any aggregation and aggregators perform all dispatching operations with their aggregated DER directly.
- Aggregators are managed in the same way other non-aggregated market participants are in terms of market rules.
- A level of complexity is involved in designing and implementing an interface with aggregated DER.

The study covered the following areas:

- Investigating suitability of relevant industry standards and assessing their pros/cons.
- Identifying three relevant industry standards and making comparisons — Open ADR 2.0, USEF and IEEE 2030.5.
- Identifying IEEE 2030.5, as the most suitable for Power Potential, and potentially for future UK Power Networks use cases.

The key design considerations were as follows:

- Consultation with the DERMS provider (ZIV Automation) and potential DER aggregators.
- ZIV Automation's agreement on the suitability and deliverability of the interface using the IEEE 2030.5 standard (as an additional benefit, DERMS already uses REST).
- ZIV Automation provided initial aggregator interface design and implementation approach.

This identified the following key considerations for implementation:

- Investigating the scope, effort, timescale and costs associated with implementation of an aggregator gateway interface in UK Power Networks.
- Assessing the risks involved in terms of uncertainty in overall cost and timescale.
- Assessing the risks involved in terms of the impact on the core design implementation timescale (dependency on the same project resources).
- Ease of implementation and support, efforts, timescale and costs for DER aggregators.

6.2.3. End to End coordination and Testing

This section describes improvements required to facilitate end to end coordination and testing. Whilst all the technical aspects of the end to end systems including PAS were tested thoroughly, some of the procedural or administrative elements were not included in the testing. These are further explained below:

Utilisation Factors

Functionality could be created in DERMS or associated systems to calculate actual utilisation factors in service delivery, and how these vary by DER, GSP, time (learning from service delivery). This would inform the utilisation factors which are an input to the day-ahead commercial assessment. This was done manually in arrears by UK Power Networks from settlements data in project, but this could be monitored continually. It would then be a design decision whether UK Power Networks enables DERMS to update the utilisation factor input based on the learnt behaviour, or this data is shared with NGESO to be an NGESO-advised variable to the commercial assessment.

DERMS GSP Q base enhancement

Section 2.4.2 explains that the DER/VPP reaches a maximum delivery for a very small 0.3% fall in GSP voltage, rather than a 4% fall in GSP voltage. Hence there is no capability left to secure a post-fault fall in system voltage and there is no proportional service response.

The issue is that the current DERMS design assumes a nominal 100Mvar 'Q' base at the GSP, so the DER is unable to deliver for larger voltage changes.

In a potential BAU service, the project proposes that DERMS should provide the following enhanced functionality:

- Auto/manual function to allow for either manual configuration of the Q Base by the user or automatic calculation of the Q Base by DERMS
- Capability for DERMS to automatically calculate Q Base, based on either:
    - ∑Commissioned Capacity (scaled back by Effectiveness at GSP)
    - ∑Accepted Capacity (scaled back by Effectiveness at GSP)

  Note that these parameters should also be configurable in DERMS.

Additional solutions that were considered were:

- Change in PAS; change the droop value from the current 8% maximum to a larger value. This would require a change in code in both PAS and DERMS. The time to develop and test this is estimated to be approximately 50 hours
- Change in DERMS; change the 100Mvar base parameter to be configurable to another number e.g. 15Mvar. This would require another DERMS software release (with prior) development and testing before an upgrade

It is essential that for BAU the Qbase design is changed so the VPP service at the GSP is as expected by the NGESO compliance team. The transmission-connected plants receive a voltage set point from ENCC control engineer and they proportionally react to changes of the system voltage. Furthermore, all transmission-connected plants are providing a proportional dynamic voltage service so currently the performance of DER in Power Potential cannot be compared to transmission plant.

As noted in Appendix 1, the DERMS design was for initial DER self-dispatch with fast proportional (P) droop response to a voltage disturbance, then the issue of voltage set points DERMS then instructs for an enhanced integral (I) response to adjust to meet GSP voltage request. However, working with ZIV Automation, a change was implemented in the DERMS controller to deliver initial percentage of proportional control for any large requests, followed by integral adjustment. This was implemented live in just the last two weeks of trials.

Full end-end process testing and system outage planning

The systems were extensively tested for integration and functionality PAS-DERMS-PowerOn-RTU-DER as part of the project delivery, including DER customer submissions to the DERMS web interface. However key NGESO processes for day-ahead commercial decision-making (manual input to PAS) and market reporting (manual outputs from PAS, and in future DERMS) were not included in that end to-end test to inform how the whole process worked together. This would have identified and resolved problems faced in the Wave 2 trial and would need to be included in introducing any post-trial implementation.

The project has developed detailed records of all testing and defects encountered (both in the test phases and live trials) and how the issues were resolved. Any post trial implementation should use these records to address in design and to test for potential failure modes encountered in trial. The project team was able to flexibly respond to any failure (DER, communications to site, DERMS, PAS) based on careful planning of how each failure type would be handled in each trial phase – including all system outages – this was invaluable and would need to be carried forward post-trial.

Changes to DERMS production schedule responses based on PAS input

After 5pm each day, DERMS provides Production Schedule responses to each DER to indicate whether they have been accepted, rejected due to a distribution network constraint, “Rejected – uneconomic generator” (compared to other DER on the GSP virtual power plant) or “rejected — nothing procured by NGESO” at the GSP. The latter message does not indicate to the DER the reason why nothing was procured e.g. price or volume, as PAS only indicates to DERMS that there is no nomination.

As noted in section 3.2.1, the “Rejected – uneconomic generator” message would only be generated by DERMS if part of the volume was procured on a GSP (but this could technically be due to volume or price reasons, though it would always be the uneconomic generator rejected). Also this message would never be produced if there was only a single generator in the trial or one generator offered less than the 10% volume band.

In the trial, further information was provided in the weekly market reporting to explain rejections, with a clarification that there was no volume requirement in the trial. So the reason for rejection was always economic (DER offered volume and price exceeding daily budget cap).

However post-trial both DERMS and PAS could both be changed to address this and provide better information to the DER. Additional information could be provided from PAS to DERMS on a daily basis to explain any rejection of full or partial volume at a GSP. This could indicate whether rejection was based on either volume requirement or price. The DERMS production schedule codes to DER could then be revised to provide this information at 5pm each day, and reasons for rejection added to the market reporting and settlement reporting

6.3. NGESO PAS functionality improvements

The PAS architecture has been developed to facilitate the Wave 1 and Wave 2 trials in the project. Consideration would be needed to be given to the design of any future reactive power service to fully define the technical requirements in PAS. Set put below is a summary of potential changes that could be incorporated into PAS and interaction with business process that would depend on PAS data.

Contract registration and service design

The contract and registration management processes are important in the design development of a service to ensure DER are recorded correctly against the relevant service, contact and account details are recorded for settlement purposes. The format that has been used in the trial is different to existing settlement processes and there would be other challenges around scalability as the current design only supports four GSPs.

In addition, any future contract arrangements and definition of the technical requirements of the service will have an impact on the dispatch solution.

Availability and nominations

As mentioned in section 3.2.2 of this report (“Key commercial trial challenges”), the assessment and nominations during the trial were carried out using a manual process which was reliant on interpretation of data. To reduce the potential for errors, system functionality could be improved to increase automation as much as possible.

Dispatch functionality

For the reactive power trial, the control room needed to check available Mvar and send dispatch instructions for each of the GSPs included in the project. This is a significant departure from how NGESO currently defines which is based on a geographical region, so sending individual GSP instructions was manageable within existing control room activities for the purposes of the trial due to the small number GSPs involved. Improvements would need to be made to allow for greater flexibility of how dispatch is carried out that better aligns to control room reactive power strategies e.g. perhaps allowing dispatch across transmission system boundaries.

In terms of active power dispatch from PAS, this functionality was not developed during the project. This was due to PAS being an existing operational tool used by NGESO, and business-as-usual activities associated with balancing services were prioritised. Regional Development Programmes (RDPs) that are being jointly developed by NGESO and DNOs to facilitate whole electricity coordination, are investigating approaches to dispatch active power from DER using NGESO and DNO IT systems. Therefore, any further work associated with active power would need to be cognisant of RDPs in relation to the technical solution.

Settlements and Regulatory reporting

The settlements process used during the project is reliant on manually extracting data from the PAS data server. For BAU, this manual process would need to be extended, however there would be challenges with scaling this up to include more GSPs given the amount of data involved. It is recommended that a more automated approach is put in place rather than maintaining this existing resource intensive process.

Part of the NGESO licence condition necessitates that for market transparency, all commercial services that are procured are to be published. Currently it is possible to extract relevant data from PAS servers, though a very manual process is required to translate the information. For BAU, enhancements would be needed to better automate the process for reporting purposes

7. Key learning for implementation into Business as Usual (BAU)

Power Potential has demonstrated the concepts of end to end dynamic voltage control and inherent steady state cases from DER within a VPP. This is a new means of procuring reactive power services using DER capability within a competitive market environment. By introducing additional Mvar capability onto the system, DER could provide a positive impact when used to displace or delay the installation of network assets for the provision of reactive power services. This translates into lower Transmission Network Use of System (TNUoS) charges, paid by demand and generators. However, the project has also identified a number of areas for improvement that need to be addressed prior to accessing the benefits of DER reactive power capability through a Power Potential roll out. These areas are further discussed in this chapter.

To leverage the technical and commercial learnings and solutions identified within the trial, we are keen to explore which elements of functionality and transferable processes from Power Potential can be further developed to fulfil the needs, and expand the future scope of, the UK Power Networks and NGESO Regional Development Programme (RDP).

RDPs are initiatives that look at the complex interactions between distribution and transmission networks in areas with large amounts of transmission connections and distributed energy resources, which are leading to a capacity shortfall. The RDPs that are being developed by NGESO and DNOs to facilitate whole system electricity coordination, are implementing similar data exchange between transmission and distribution in parallel with associated ENA Open Networks workstreams. More information is available at

https://www.nationalgrideso.com/research-publications/regional-development-programmes

The RDPs are designed to look at the whole electricity system and assess a variety of options to resolve specific network needs. They can be triggered by customer connections or wider changes to the electricity system. The south-coast RDP between NGESO and UK Power Networks is developing new markets for transmission thermal constraint management services in a similar geographic location to Power Potential. This will involve the development of a co-ordinated IT solution that will deliver:

- Visibility and data exchange in both directions to facilitate efficient service coordination.
- Management of DER to allow constraints on transmission and distribution networks to be managed efficiently
- A coordinated procurement and dispatch methodology allowing DER to participate in new markets and ensure that we have identified the cheapest solution for the GB consumer
- Co-ordination and service conflict resolution methodologies

The RDP has been running for five years, and NGESO's further experience working with UK Power Networks on Power Potential will be extremely relevant in delivering the future RDP developments ensuring that both parties understand ways of working and IT infrastructure needs. While the RDP's primary focus is on thermal (MW) constraint management, there may also be opportunity as the RDP develops to build in voltage management. The triggers for doing so will be a specific service requirement emerging from customer connections (both distributed and transmission connected), general requirements which are identified through the network planning process or developments in wider reactive power and voltage control markets, currently being progressed under NGESO's "Future of Reactive" work.

7.1. Customer perspective on the project

Customers were approached by the project team, post-trials, to gain their views on their learning and experience from the project, from trials preparation through to trials delivery. The customers were generally very positive from a number of perspectives, e.g. co-ordination of the lab testing and commissioning, and detailed feedback and suggestions have been included throughout this report.

Responses were highly encouraging including:

"A worthwhile exercise… great strategic opportunity …has ability to open markets which have previously been closed to assets like ours".

At a high-level, the Power Potential trials showed them practically how reactive power delivery to transmission, previously closed to generators embedded in the distribution networks, could be opened up and made available to DER via a market approach. They see this as presenting strategic opportunities to provide a service alongside traditional reactive power providers.

The trials also demonstrated how co-ordination of transmission and distribution can happen. More specifically, Power Potential was seen by the participants, as the first major step towards the integration between DER, DNO and ESO, where customers found it useful to be involved in the development stage of embedded reactive power services with the DNO/ESO, not just delivering service requirements.

Participation in Power Potential has been challenging at times – for example delivering the required technical interface with DER power plant controllers, addressing technical conflicts with delivery of other services. In addition, during the Wave 2 price discovery, DER noted a challenge with interpreting rejections for services and developing bidding strategies.

Nonetheless, customers have found the experience valuable in terms of understanding the challenges and identifying any barriers to entry for the future provision of reactive power services from embedded generation.

Furthermore, the trials have encouraged certain customers to increase their focus on ancillary services and review the design and operation of their plant, including maintenance regimes and control room shift training requirements going forward.

Ultimately, following their experience in the trials, all four trial participants were very interested in plans for developing the service into BAU, how and when this will be rolled out and also how the markets will change when not operating within the confines of trial with budget limitations.

7.2. Technical service development

There were a number of technical aspects of the dynamic voltage control service that from NGESO as end service user, are required as improvements and to be taken into further consideration before service transition to BAU.

PAS system implementation into BAU

- Set up secure remote access for authorised users via Virtual Desktop Infrastructure (VDI) and assign static IP address to comply with newly introduced security enhancements.
- Scaling up the PAS system in order to facilitate a larger number of GSPs.

End-end service implementation into BAU

- For transition to BAU, DER will need to pass a set of compliance tests in order to demonstrate compliance with dynamic voltage service requirements (speed of response and operation in voltage droop control – see section 2.2). The practice for service compliance has been established in the Pathfinder projects, which could be utilised for dynamic voltage service.

- The instability or oscillation in the service request from PAS to DERMS needs to be addressed as the response needs to remain stable when issuing GSP voltage set points close to the dead band or passing through zero voltage reference (section 2.4).
- Introducing the service for BAU with the upgraded DERMS implementation, would still require a period of observation to allow DERMS controller tuning per Grid Supply point as performed in the Wave 2 trial (see section 2.5)
- In addition to the PAS-DERMS-PowerOn-RTU-DER testing in the Power Potential project, there should be full end-end validation and testing of the procurement and nomination process.
- Reliability of the service: Feedback to the ENCC on when the service at the GSP is not available (PAS-DERMS communication issue, DERMS error, DER problem or other system issues) ahead or at time of service dispatch. That will allow ENCC not to progress with instructions due to the system errors and will also allow the ESO to procure required service in time from an alternative provider to secure the system. The implementation and timing of the feedback loop needs to be discussed and implemented in the BAU process.

Dispatch strategy

Market strategy vs ENCC dispatch strategy: during the trials we were using the simulated network scenarios with no volume requirement, however for the transition to BAU the real network scenarios need to be used to support the dispatch strategy from ENCC i.e. currently NGESO develops a reactive power strategy on a regional basis and not per GSP. The synergy between both need to be established.

Due to the small number of DER and Mvar volumes, the impact on the transmission system was really small. Sometimes this can cause a problem with the ENCC team dispatching the service. It is important to have higher volumes from VPPs that will have an impact on the transmission system. If volumes remain low, there is a risk that the service will not be prioritised as a solution in ENCC.

From the trials it was evident that the dynamic voltage control service was not providing the proportional voltage service. Improvements in having proportional dynamic voltage control for transition to BAU are required. The changes would need to be done in the DERMS design and implementation.

Modelling of VPP and associated VPP banding, needs to be introduced into planning and operational business processes for the ENCC to use VPP. That requires offline/online modelling for various systems and requirements. As a first step for transition to BAU there is a requirement to define modelling needed for existing processes.

Trials were based on dynamic voltage control per GSP. For BAU, dynamic voltage control needs to be analysed to determine if it is the best approach to have dynamic voltage control per GSP or if it needs to be considered by the wide system area. Implementation needs consideration from ENCC as end user.

In the current trial arrangement, we assume substations are running solid and DERMS does not have solution for split substations arrangements. The substation running arrangement/processes into DERMS when substations are not running solid needs to be implemented.

For BAU, full co-ordination processes would be required to manage planned and unplanned outages on PAS, DERMS and all associated systems including PowerOn and the web-services integration bus between PAS and DERMS. The impacts of such outages would need to be tested to understand their impacts and whether they warranted full or partial withdrawal of services.

Transition to BAU needs to consider a solution for synchronous plants and aggregators. The trial only included non-synchronous plants.

For the Power Potential project, NGESO provided the DERMS system voltage, active and reactive power flows at the GSPs (including the selected voltage reference) via a dedicated ICCP link from National Grid's system to UK Power Networks' PowerOn system. A data-sharing and maintenance agreement would be required for BAU and aligned with ongoing NGESO and DSO activities such as RDP. Whilst this is being enacted under RDP, currently there is limited transmission and distribution data exchange of network flows. For BAU, real-time data exchange over ICCP links would need to be reinforced within appropriate industry codes.

The active power trials provided a good outcome and confirmed that active power service can be delivered simultaneously with reactive power services. However, from NGESO's point of view the active power service from DER is not new, as the active power service is already an established service. In addition, DER that wish to provide both active and reactive power simultaneously will need to demonstrate full compliance against their PQ capability.

Review of UK Power Networks Power Potential Procedures for BAU

Two key procedures were developed for use during the Power Potential trials (see Appendix 4).

- Network Operating Procedure (NOP 50 036) – Covering the operational control by UK Power Networks' Control Engineers of DER operating under Power Potential Trials
- Commissioning Procedure (ECP 11-0702 PP DER) specifically for the additional commissioning of DER to DERMS in accordance with Power potential requirements.

These documents were developed and agreed for use with the Power Potential trials only. In particular, the commissioning procedures still have draft/non-approved status, recognising they are not formally approved for BAU, but would inform development of future commissioning documentation to DERMS. Hence this documentation would require formal review and approval prior to any future BAU service.

7.3. Key Commercial considerations towards implementation into BAU

As part of the Power Potential trial, the project captured some key aspects of the current commercial arrangements, framework and processes within the trial that may require further consideration to be able to support any transition to an enduring service.

- **Contractual Framework –** The contractual design to access reactive power services from DER within the trial was structured as an Inter Operator agreement between NGESO and UK Power Networks alongside a Framework Agreement between UK Power Networks and the DER. Learnings from this arrangement are currently being used to develop RDP arrangements. Further consideration may be required on the evolution of the contractual framework for reactive power services procured from/through the DNO, i.e. for whole system services. Variations may be determined by the scope of changes to the range of commercial and technical issues identified within the trial and evolving reactive power needs. Further consideration of the contractual framework is provided in the SDRC 9.7 report "DSO risk-reward framework".

- **Service Procurement/Funding** – A transition of the service to BAU will require that the procurement of the service is subject to the framework laid down in Condition C16 of the Transmission licences. Ofgem approval is also required for it to be classed as a balancing and funded through Balancing Services use of Systems (BSUoS).

- **DER Contractual Agreement** – Review of the DER contractual framework is required to ensure it would be more closely aligned to standard balancing services terms. Particularly in areas such as performance monitoring, penalties for non-delivery and service payment structure to ensure greater value is being placed in the right areas to drive the right pricing and procurement strategies

- **Conflict of services** — The conflict of services (with other DNO services) needs to be considered to understand implications and interactions with other project such as RDP and project TERRE.

- **Obligations to DNO** — Roles and responsibilities need to be defined in consistency with other DNO approaches as it is expected that DNOs will become increasingly active with greater volumes of DER connected.

- **Level playing field** – Further review is required to determine what steps need to be taken to ensure a level playing field between market options in providing reactive power services (embedded DER and transmission connected generators).

- **Accommodation of additional participants** — Understand the commercial, technical and financial implications of bringing other DER embedded into DNO network into this market improve market liquidity.

- **Procurement Timeframe (Day-ahead auctions)** – The current procurement process and timeframe should be reviewed to understand if this is the best option for the procurement of reactive power service from DER. Areas such as procurement timescales will be considered as part of the future of reactive power market reform which is aimed at designing an effective market based solution for future reactive power procurement based on the technical, commercial and market analysis.

- **Aggregation** – There may need to be further trialling/work to be done on how aggregation may be able to support access to embedded generation for the provision of reactive power services (see section 6.2.2)

- **Nomination and Assessment process** – Several challenges encountered highlighted the need for a fully automated process.

- **Commercial Assessment zone across multiple GSPs** — Procurement for the trial was against a target cost and daily budget cap with an assumed utilisation factor, however this indicated that DER could bid commercially. In the future VPP could be commercially assessed regionally (multi-GSP or zone as defined by NGESO for its voltage assessments) rather than at GSP level, to increase the effective market size and avoid disregarding the effectiveness of DER at a GSP which is not its 'primary GSP'.

- **Evaluation of DER utilisation vs alternative sources of voltage control at transmission level.** The proposed Wave 3 trial extension may have provided insight into how DER could compete technically and commercially against alternative voltage control options available to NGESO. However, Wave 3 was not taken forward due to time and budget constraints, thus we see potential for a further demonstration to inform the market using the new updated DERMS platform, as a stage in the introduction of a BAU service.

UK Power Networks' integrated service development

UK Power Networks sees the DER reactive and active power service development for transmission in Power Potential as part of a suite of future flexibility products managed by its DSO function which the future DERMS platform would facilitate.

In future developments of DERMS, Power Potential services could work alongside flexible connections (previously known as ANM), flexibility services (demand reduction), developments as part of the Regional Development Programme (N-3 operational tripping schemes, and future commercial developments), flexibility services for electric vehicle fleet (Optimise Prime), network reconfiguration (Active Response) and generation constraint management. The Power Potential services could also be expanded for voltage control on the distribution network rather than just as a service to ESO (a future requirement, not currently a business need).

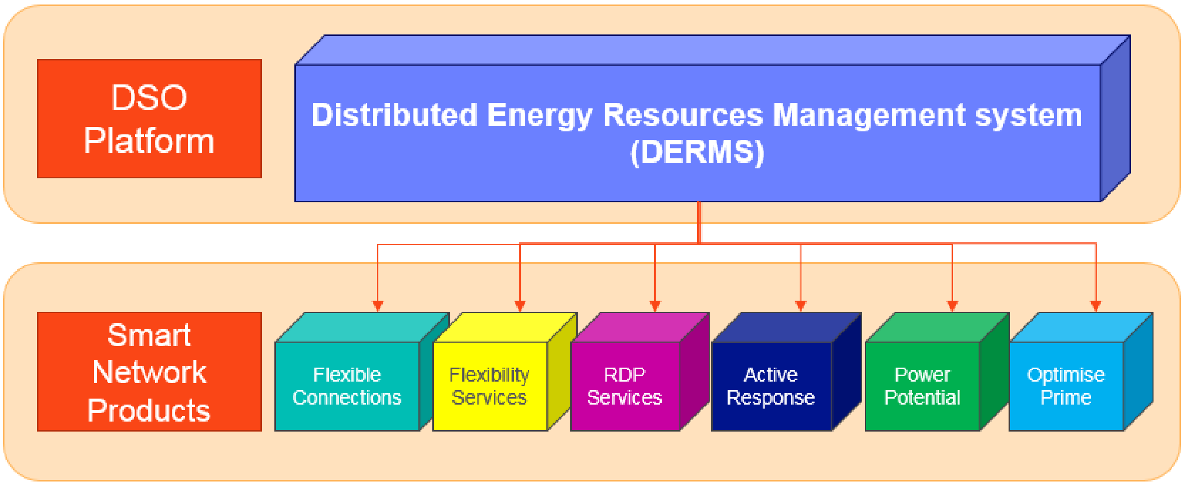


Figure 45 Future view of suite of smart network products enabled by a DERMS DSO platform

UK Power Networks' views on Power Potential reactive power services

Focusing just on reactive power service again, the Power Potential trial has provided the proof-of-concept for dynamic and steady-state voltage services. However UK Power Networks notes the challenges with DER capability for dynamic service in regarding their speed of response (see section 2.2.2). It is also noted that while Power Potential was trialled as a single dynamic service, the integration, the use of a defined PQ envelope for the service range of each DER, and the high-level procurement/market approach could be applicable to either a dynamic or steady-state case, and it could be readily adapted for a static service with a direct request of reactive power, as noted in section 2.4.

The DERMS approach is different to other initiatives in procuring reactive power services from DER. Power Potential accessed a service from a whole DER PQ envelope with no power factor restrictions to create a VPP. It also enabled day-ahead market procurement by service window, rather than longer-term procurement.

Thus UK Power Networks sees the opportunity the Power Potential concept to be split in future into two separately-procured products with different control algorithms to enable wider DER participation – a dynamic and steady-state service (lead and lag range procured, similar to the trialled product) and an additional static service to be developed (lead and/or lag purchased as required). This indicates an opportunity for the Power Potential concept to be used as a basis and foundation for any future reactive power services to NGESO.

NGESO initiatives to procure reactive power services from DER

There are several initiatives currently ongoing with the ESO to address the increase in reactive power requirements by 2025. NGESO's recently launched tender for static services can be found here. There will be a need to manage higher voltage levels on the transmission system, requiring an increase in the provision of Mvar. There are currently three regional voltage pathfinders procuring reactive power to help meet SQSS requirements. These are:

- Short Term Mersey voltage — This focused on existing connections and facilitating providers embedded within the DNO network. Initially contracts were agreed for 2020/21, with a view to tender further for 2021/22. The technical requirements are for static and steady state voltage support.
- Long Term Mersey Voltage — This pathfinder focused on comparing commercial solutions with Transmission Owner network assets. New connections were invited to participate alongside Distribution connections, aggregators, existing providers and the Transmission Owner. To procure static and steady state voltage support in the longer term that is complementary to the previous short-term tender.
- Long Term Pennines Voltage — This service opened to any provider who can meet the requirements allowing them to offer balancing services in conjunction with the reactive power

service. The Pennines pathfinder is ongoing, and adopts the lessons learned from the Mersey pathfinder to develop the service. The technical requirements for the service are for participants to meet static and steady state voltage requirements.

In contrast the Power Potential trial has focused leveraging a DNO energy management system to instruct dynamic voltage support from DER, while also demonstrating steady state. It also provided insights on how to integrate ESO, DNO and DER systems that could be taken forward for a reactive service.

The Future of Reactive work will develop further enhancements to projects such as the NOA Voltage Pathfinders to help meet future operability challenges. The Future of Reactive Power (FoR) project will have explored options for the ESO to access greater volumes of reactive power from previously untapped sources. Therefore, the project team will be coordinating with those undertaking this work to ensure that the pertinent learning associated with Power Potential is shared and utilised where appropriate across these workstreams.

8. Summary and Conclusions

Power Potential is a trial project that successfully demonstrated a world-first regional reactive power market using a DERMS system which enabled day-ahead procurement of reactive power services from DER.

The project has thus demonstrated the concept of end-to-end dynamic and steady-state voltage control from DER with a VPP. The project also provides relevant learning for the development of other future voltage control services from DER. This is a new means of NGESO procuring reactive power services using DER capability within a competitive market environment. By introducing additional Mvar capability onto the system, DER could be used to displace or delay the network reinforcement for the provision of reactive power services.

NGESO, UK Power Networks and the DERMS developer ZIV Automation gained insight in how to deliver and operate the systems and processes to enable these services, integrated with other operational systems and processes. This included learning related to system availability, expected and delivered response, commissioning processes, the contractual framework and settlements.

The key learnings identified from Power Potential trials are valuable input information to support the development of future reactive power markets. While the project has demonstrated end to end dynamic voltage control from DER, there are still number of areas to be addressed prior to achieving the benefits of accessing DER reactive power capability through a Power Potential roll out. These are detailed in Chapter 7, they include: NGESO, UK Power Networks and DERMS system upgrades; NGESO Electricity Network Control Centre (ENCC) integration; DER service compliance, and market and contractual framework design.

To continue to leverage the technical and commercial learnings and solutions identified within the trial, we are now in the process identifying the most valuable elements of functionality from DERMS to incorporate within existing RDPs. RDPs are initiatives that look at the complex interactions between distribution and transmission networks in areas with large amounts of distributed energy resources. They are designed to look at the whole electricity system and assess a variety of options to resolve specific network needs.

This will involve the development of a co-ordinated IT solution that will deliver;

- Real-time visibility of total DER volume within the market which will allow the ESO to assess capability and have assurance of service delivery
- Controllability of DER to allow constraints on the transmission system to be managed efficiently
- Procurement processes allowing DER to participate in the new markets and ensure that we have identified the cheapest solution for the GB consumer
- Co-ordination functionality which will implement primacy rules as being developed in Open Networks

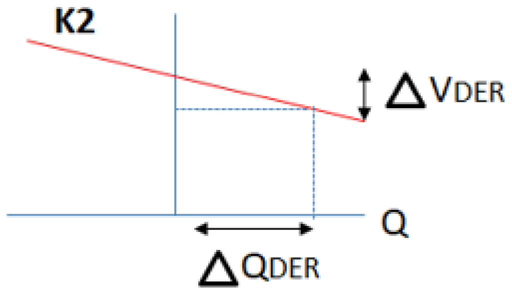
NGESO's and UK Power Networks' experience working together on Power Potential will be extremely relevant in ensuring that both parties understand each other's ways of working and IT infrastructure needs. In addition, the key learnings from Power Potential are being feed into future development work associated voltage Pathfinders and reactive market reform.

nationalgridESO

Appendix 1: Voltage control approach in DERMS design

When a DER is accepted to deliver service in a 'service window', DERMS instructs the DER to operate in voltage (droop) control as in Figure A1.1.

Figure A1.1: DER operating in droop control (figure 4 of detailed design)

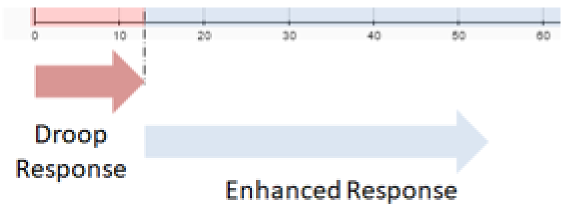


DERMS will send a voltage set point to the DER. Any difference between the set point and local measured voltage will cause a reactive power output at the DER which can affect network voltage to deliver the voltage control service. This means that DERMS issues a voltage set point $\boldsymbol{V_{set-point}}$ to the DER, and for a DER operating in voltage droop control, its reactive power output $\boldsymbol{Q}$ is expected to follow the relationship below between the actual network voltage $\boldsymbol{V_{POC}}$ measured at the PoC of the RTU to UK Power Networks system, and the issued set point. This is scaled by a 4% droop, the contracted maximum reactive power output in Mvar ($\boldsymbol{Q_{rated\ lag}}$) and the nominal voltage (typically 33kV).

$$\boldsymbol{Q} = \frac{(\boldsymbol{V_{set-point}} - \boldsymbol{V_{POC}}) \times \boldsymbol{Q_{rated\ lag}}}{4\%\ \boldsymbol{droop} \times \boldsymbol{Nominal\ Voltage}}$$

It should be noted that the instructions from DERMS are for voltage set points — these in turn deliver a reactive power output and an impact on local voltage via the droop relationship, rather than a direct request for reactive power output. This means that each DER can rapidly adjust their output according the droop relationship if the local voltage changes, rather than waiting for a new instruction from DERMS i.e. this can facilitate a fast self-dispatch response from the DER, followed by an instructed or enhanced response designed to be delivered on a longer timescale (12-60 seconds) as shown in figure A1.2.

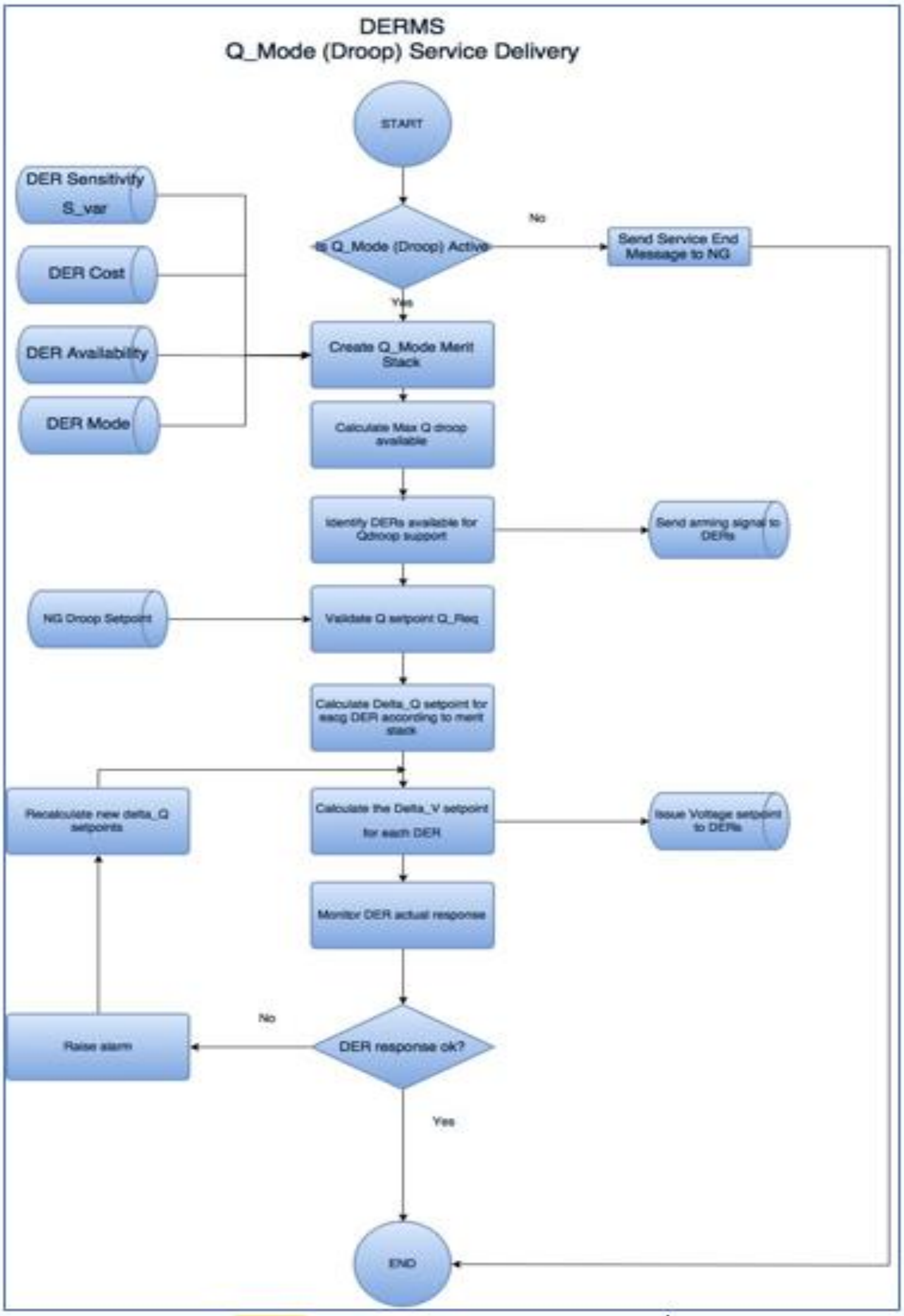
Figure A1.2 Timescale of droop response followed by enhanced response following change in GSP actual voltage (part figure 7 of detailed design)



DERMS issues set points to DER based on the voltage control requirement at the GSPGSP. If there is a difference which exceeds dead band between the GSP Voltage requested from the PAS system and actual reference voltage shared by NGESO, this is converted to a request for reactive power Q at the GSP via the droop relationship at the GSP (see section 2.4)

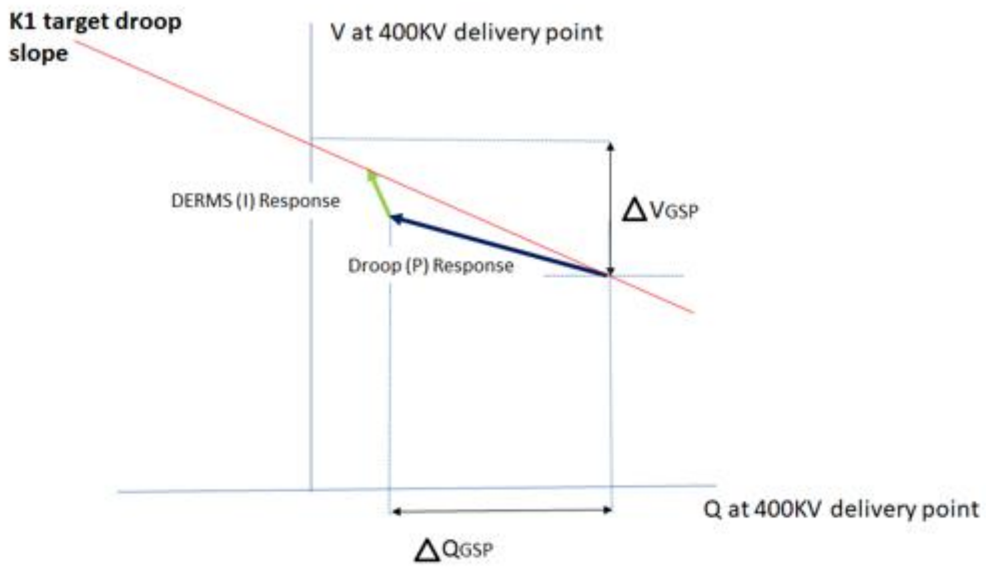
DERMS converts a GSP voltage request to a GSP reactive power request, and then based on the available DER and their effectiveness, converts this into a set of DER reactive power requirements, and issues set points to the DER. This is shown in Figure A1.3.

Figure A1.3: Approach to reactive power service delivery (figure 9 of detailed design)



If there is no reactive power requested at the GSP, DERMS issues voltage set points to all DER equal to their local measured voltage V_{POC} so that the DER is requested to produce zero reactive power output in accordance with the equation above. DERMS monitors and adjusts the issued set point based the transmission requirement and the metering data from the DER site. Thus in combination with any initial DER self-dispatch with fast proportional (P) droop response to a voltage disturbance, with the issue of voltage set points DERMS then instructs for an enhanced integral (I) response to meet GSP voltage request as shown in Figure A1.4.

Figure A1.4. Combination of proportional (P) and integral (I) control (figure 11 of detailed design)



At the end of the trials, the instructed DERMS response was altered for quicker delivery with a combined proportional and integral controller, to deliver an 80% initial response followed by further slower adjustment with the integral controller.

.

Appendix 2: Criteria for approval of each DERMS upgrade

This appendix covers how the process, test and readiness criteria were established to satisfy the functionality, stability and reliability of DERMS for each stage of trials

Functional Criteria: The Product Owner from UK Power Networks, in consultation with NGESO and UK Power Networks' SMEs and the test manager, established the functional Criteria. All 'must have' functional requirements for each Trial phase were given highest priority and all new features and defect resolution were prioritised with the DERMS Supplier, ZIV Automation.

Non-functional Criteria: The non-functional tests carried out to meet the stated criteria for each phase of trial.

Defect categorisation criteria for each phase of trials readiness

- P1 CRITICAL – a "Show Stopper", meaning function is critical for trial and no workaround is possible. The defect must be resolved to complete testing and before trail can start.
- P1 CRITICAL with workaround – Defect is critical for trial but an agreed workaround is available and agreed with UK Power Networks, NGESO and ZIV
- P2 HIGH – functionality affected prevents DERMS from functioning fully but the defect is not a showstopper and either the workaround or lack of it satisfies the agreed trials criteria.
- P3 MEDIUM – functionality affected does not pose a threat to trials
- P4 LOW – All other defects - defect does not directly impact trials objective or functionality
- Known defect acceptance criteria for a DERMS release to go into trials
- Zero P1 'Showstopper'
- One Acceptable P1 defect that even though it affects the functionality of DERMS, a workaround is available without significant risk and overhead
- Up to five P2 defects, and up to 15 P3 and P4
- Release and defect testing completion criteria
- All defects in Hypercare (Live production) and Pre-production are reviewed for prioritisation for each stage of trials and agreed with ZIV Automation
- ZIV Automation builds a new release (when applicable) with new functionalities and defects fixed and a release is made to UK Power Networks
- UK Power Networks' Test Manager/Work stream Lead plans for testing of the release with the agreed criteria for trial readiness
- All new functionality or changes are thoroughly tested
- All P1 Critical defects are fixed and tested before upgrading production environment
- One P1 with workaround is tested and agreed
- All defects are updated in RQM after testing and defect testing report is sent to stakeholders and CAB/CAG
- All evidences of testing, approval from business owner, UK Power Networks' control systems infrastructure and automation leads, and site representative are submitted with an approval from the Test Manager ligula.

Appendix 3: Weekly Market Report template

Wave 2 Market Report (weekly totals)

Trial week no. [ ]

Wave 2 Trial period:	
Wave 2 Trial week 9:	
Market hours	
Date when Target Average Cost (TAC) for Week [ ] issued:	

Market Report weekly summary for Week [ ] issued:	
Market Report weekly summary to be issued by:	12:00 each Tuesday for the week past

Market report Week [ ]:	
Week [ ] Scenario:	
Explanatory scenario detail	The volumes procured are not being used to secure the system during the trials. The assessment is therefore simulating system requirements, via the weekly network scenarios, with the overall aim to procure all volume submitted that is considered economic within the trial budget opportunity.
TAC range for Week [ ] scenario:	

<u>General comments on TAC</u>

The Target Average Cost (TAC) is used within the assessment logic to manage the trial budget, i.e. the actual costs incurred are equal to or less than the TAC and reflects the combination of availability and utilisation submissions. This assumes 85% utilisation for assumed lead or lag reactive power delivery, however, please note that the levels of utilisation will depend on the dynamics of the network in real time and may significantly differ.

We will look to refine the range as we move through the trials and the scenarios. In the meantime, please be aware that Wave 2 is seeking to support general price discovery and it should be understood that the upper end of any range published does not represent a ceiling or target maximum.

<u>Looking back on Trial week no. [ ]</u>

Summary of nominated Mvar volume, availability and utilisation prices at the **GSP level**

	Weekly Summary Trial Week [] scenario: 2 High voltage [from]– [to]				
Grid Supply Point (GSP)	**Total Lead Nominated (Mvar)**	**Total Lag Nominated (Mvar)**	**Average availability Price (£/Mvarh)**	**Average utilisation price (£/Mvarh)**	**Reasons for any rejections**
TOTAL					

Summary of definitions and explanation

Total lead or lag nominated (Mvar)

- is the total procured Mvar across all Electricity Forward Agreement (EFA) blocks for the trial week e.g. if 10Mvar is available for each EFA block for each EFA block (i.e. 4-hour period) for the entire week, then a total of 1680Mvar has been procured across the trial week.

Average availability (£/Mvarh) and utilisation (£/Mvarh) prices

- the average availability and utilisation prices across the nominated volumes for the trial week. The average availability price reflects the £/Mvarh cost to NGESO for the nominated volume and reflects the effectiveness of DER at the GSP. The average covers accepted (nominated) volumes and does not include rejected volumes.

Reason for acceptance/rejection;

- where a DER has been issued on DERMS with a production schedule response “Rejected - nothing procured by NGESO” this is due to rejection of all volume at a GSP/Virtual Power Plant. This may have superseded other rejection codes reflective of the real reason for rejection, as no additional information is being provided from PAS to DERMS on the reason for the rejection. Where this has occurred the Market Report will reflect the actual reasons for rejections at the GSP/Virtual Power Plant (VPP).

General comments on service delivery

Daily trial budget summary

A decision was taken to no longer share the trial budget summary as the number is subject to an accuracy lag as it is based on exposure to actual utilisation which is not fully known until the point of settlement.

Week [ ]

Scenario for week [ ]:	
Trading days:	
Market hours:	
Service windows:	
Expected TAC range for week 10:	

Week [ ]

Scenario for week [ ]:	
Trading days:	
Market hours:	
Service windows:	
Expected TAC range for week 11:	

Report change log

Date	**Comments**

Wave 2 Scenarios

Acronyms:

SE South East

IC Interconnectors

Appendix 4: Links to key project outputs

The following UK Power Networks documents describing key technical outputs from the project are all available on this website

https://innovation.ukpowernetworks.co.uk/projects/power-potential/

DER interface schedule

DER technical requirements

Aggregator feasibility study

UK Power Networks' Engineering Commissioning Procedures (ECPs) applied for Power Potential commissioning for the trial, and informing any BAU approach

- ECP 11-0702 PP DER Commissioning Procedure
- ECP 11-0702a PP DER Commissioning Test Form
- ECP 11-0703 PP DER Commissioning Requirements

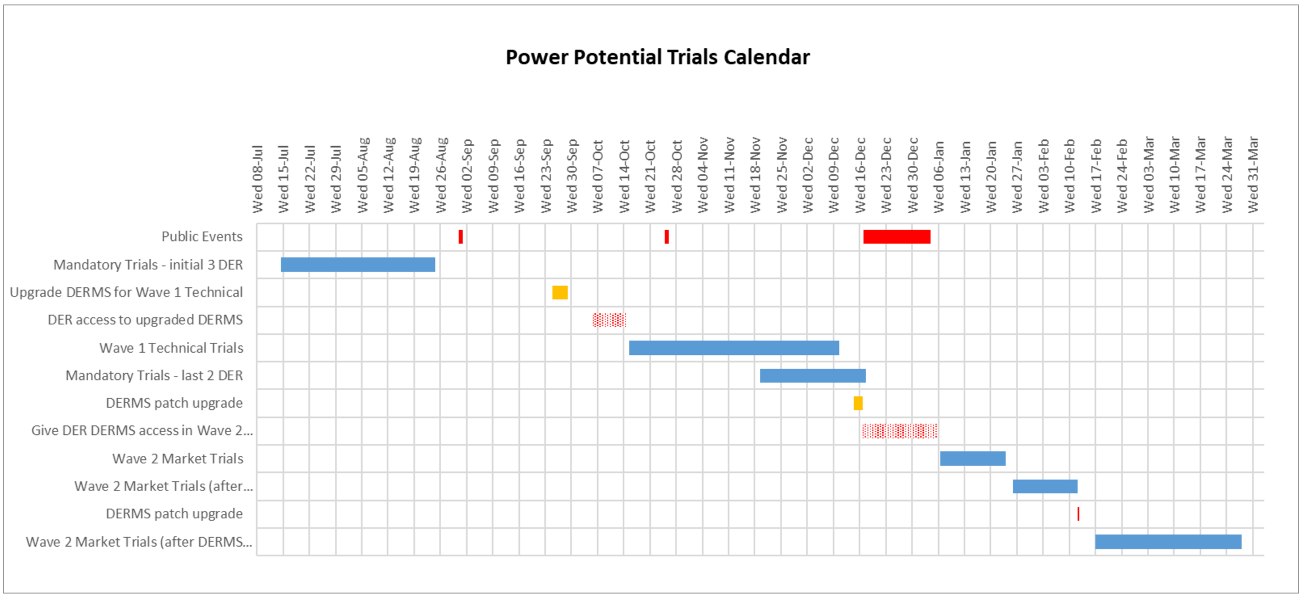
UK Power Networks' Control Room Procedure for trials, and informing any BAU approach

- Network Operating Procedure (NOP 50 036) – Covering the operational control by UK Power Networks' Control Engineers of DER operating under Power Potential Trials

Appendix 5: Trial Calendar

Trial Calendar

Trial Phase (Familiarisation access was in place since June)	DER submit bids by	Service delivery Start Date/Time	Service delivery End Date/Time	Duration Weeks	Duration Days	Duration Hours	Key Events	
Mandatory Trials - initial 3 DER		Tue 14-Jul-2020 11:00	Mon 24-Aug-2020 17:00	5.9	41	990	Easter Monday	Mon 13-Apr-2020
Upgrade DERMS for Wave 1 Technical		Fri 25-Sep-2020 00:00	Tue 29-Sep-2020 00:00	0.6	4	96	Early May BH	Fri 08-May-2020
DER access to upgraded DERMS		Mon 05-Oct-2020 17:00	Wed 14-Oct-2020 14:00	1.3	9	213		
Wave 1 Technical Trials	Wed 14-Oct-2020 14:00	Thu 15-Oct-2020 11:00	Thu 10-Dec-2020 11:00	**8.0**	56	1345	Spring BH	Mon 25-May-2020
Mandatory Trials - last 2 DER		Thu 19-Nov-2020 11:00	Thu 17-Dec-2020 17:00	4.0	28	678	Easter Monday	Mon 13-Apr-2020
DERMS patch upgrade		Mon 14-Dec-2020 13:00	Wed 16-Dec-2020 17:00	0.3	**2**	52	Summer BH	Mon 31-Aug-2020
Give DER DERMS access in Wave 2 configuration		Wed 16-Dec-2020 17:00	Tue 05-Jan-2021 14:00	2.8	**20**			
Wave 2 Market Trials	Tue 05-Jan-2021 14:00	Wed 06-Jan-2021 11:00	Sat 23-Jan-2021 23:00	2.5	17.5	420	Xmas Period	Mon 04-Jan-2021
Wave 2 Market Trials (after nomination pause)	Mon 25-Jan-2021 14:00	Mon 25-Jan-2021 23:00	Fri 12-Feb-2021 07:00	2.5	17.3	416		
DERMS patch upgrade		Fri 12-Feb-2021 07:00	Fri 12-Feb-2021 16:30	0.1	**0**	10		
Wave 2 Market Trials (after DERMS upgrade)	Fri 12-Feb-2021 14:00	Tue 16-Feb-2021 23:00	Sat 27-Mar-2021 23:00	5.6	39.0	936		
Wave 3 removed from trial schedule						**10.5**	weeks	
Active Power Trials on 2 days in March during Wave 2 period						**1772**	hours	



Appendix 6: DER commissioning approach

Pre-Commissioning

Prior to full commissioning DER on site, the following requirements needed to be met.

A UK Power Networks Operational Telecommunication's engineer had to install and commission a UK Power Networks RTU and the smart devices (e.g. link to Power Quality Meter, PQM) in accordance with the project design specification at the DER site. This stage did not need customer's involvement and formed part of the standard (BAU) tele-control tests carried out by the UK Power Networks Operational Telecommunications team. However, due to the innovative nature of the end-to-end solution, including the RTU logic, the configuration and validation of the system's integration required a considerable support from the project team on-site and remotely.

The configuration of UK Power Networks RTU Logic included:

- An upgraded RTU logic software deployed on the UK Power Networks RTU hardware at the DER site
- The UK Power Networks RTU at the DER site is configured with the appropriate PQM measurements (ION or Transducer) and scaling for the RTU Logic and PowerOn
- Tele-control testing with the UK Power Networks RTU and PowerOn is completed
- The UK Power Networks RTU at the DER site is configured with the appropriate configuration, (i.e. indexes) and for the DER local controller

On the day of on-site commissioning, the UK Power Networks Commissioning engineer ran checks according to the Commissioning Quality Plan developed for the project.

- Confirmation with the UK Power Networks Outage Planning team that there is live outage which would cause risk to the network by allowing the DER export variation as part of commissioning (Outage Planning has approved the allowed P/Q envelope specified in the DER Framework Agreement and associated Q range in the signed variation to the customer's connection agreement).
- The customer' expected operating level (MW) on the day is understood and appropriate to start the commissioning tests.
- The manual dispatch values on the day of commissioning, are provided by the UK Power Networks Outage Planning team, consistent with the range specified in the variation to the customer's connection agreement.

Customer Interface Testing conducted during the bench testing had to be repeated on-site to demonstrate full end-to-end connectivity and data transfer to the customer equipment. The objective of end-to-end integration testing was to demonstrate that the DER interface schedule was correctly exchanged between the UK Power Networks DERMS, PowerOn, RTU and the customer's LCS on site. Since the RTU was developed in parallel to the lab-integration testing with all customers, we had to fully test and confirm the DER interface schedule. Customer interface testing did not test the functional behaviour of the UK Power Networks RTU logic and the DERMS solution, rather focused on data exchange and protocol compliance with the customer's LCS. The end-to-end integration testing on site included the following tests:

Data Transfer – to prove that all data required for end-to-end operation was correctly exchanged between the customer's LCS and UK Power Networks' RTU, PowerOn and the DERMS.

DER Measurements – to ensure DER measurements at the PoC received and displayed locally in the UK Power Networks RTU Human Machine Interface (HMI) and in PowerOn and the DERMS user interfaces from the customer's LCS interface. The received measurements had to be within a pre-defined and pre-configured tolerances with the PQM or protection relay.

RTU Master Modes – to confirm the limits, set points and command instructions could be issued to the customer's LCS from various Master sources including local RTU, PowerOn and the DERMS following by receipt of the associated read-backs. The receipt of the issued signals confirmed by customer.

Full Commissioning

Once the prerequisites have been met, UK Power Networks' on-site commissioning involves the following test cases:

DER Operational services – This test was to put DER in different operational modes including arming the DER to provide P or V services as well as reverting them back to Contractual mode (default mode). These tests were confirmed by associated signals being successfully exchanged between the end-to-end systems.

- Instruct (Arm) DER for V Service
- Instruct DER for P Service
- Instruct DER for P Service then V Service
- Instruct DER for Contractual mode while providing V Service
- Instruct DER for Contractual mode while providing P Service
- Instruct DER for Contractual mode while providing both P and V Services
- Loss of Communication detection with DERMS
- Loss of Communication detection with PowerOn
- Loss of Communication with customer's LCS while V Service is instructed
- Loss of Communication with customer's LCS while P Service is instructed

Communication loss – This test was to simulate different link failure scenarios and validate the end-to-end system's response. The test was carried out by simulating link failure and confirming the associated alarms triggered, failsafe actions executed and the customer's LCS responded as expected:

Fail to safe – This test was to simulate the DER non-compliances and validate the end-to-end system's response. The test was carried out by injecting and simulating measurement values at PoC, which did not coincide with the issued limits and confirmed the associated alarms triggered, failsafe actions automatically executed by the RTU and the customer's LCS responded as expected. The tests covered the following scenarios:

- Failsafe due to non-compliance of DER for V Service
- Failsafe due to non-compliance of DER for P Service

Final check – On completion of the commissioning:

- Check customer tele-control connection (Fibre or Cat5e) is secured,
- Ensure both Satellite link and Mobile communication connection links are secure,
- Check all alarms are cleared on PowerOn, RTU and the DERMS.

Appendix 7: National Electricity Transmission System Grid Code/European Connection Conditions Voltage Requirements

Below are the relevant extracts of the National Electricity Transmission System (NETS) Grid Code for transient voltage control which details the technical requirements for connection. The code has been harmonised with the European Connection Conditions (ECC) and is one of the requirements of the Connection and Use of System Code (CUSC).

Extract is taken from

APPENDIX E7 — PERFORMANCE REQUIREMENTS FOR CONTINUOUSLY ACTING AUTOMATIC VOLTAGE CONTROL SYSTEMS FOR AC CONNECTED ONSHORE POWER PARK MODULES AND OTSDUW PLANT AND APPARATUS AT THE INTERFACE POINT HVDC SYSTEMS AND REMOTE END HVDC CONVERTER STATIONS

ECC.A.7.2.2 Steady State Voltage Control

ECC.A.7.2.2.1 The Onshore Power Park Module, Onshore HVDC Converter or OTSDUW Plant and Apparatus shall provide continuous steady state control of the voltage at the Onshore Grid Entry Point (or Onshore User System Entry Point if Embedded) (or the Interface Point in the case of OTSDUW Plant and Apparatus) with a Setpoint Voltage and Slope characteristic as illustrated in Figure ECC.A.7.2.2a.

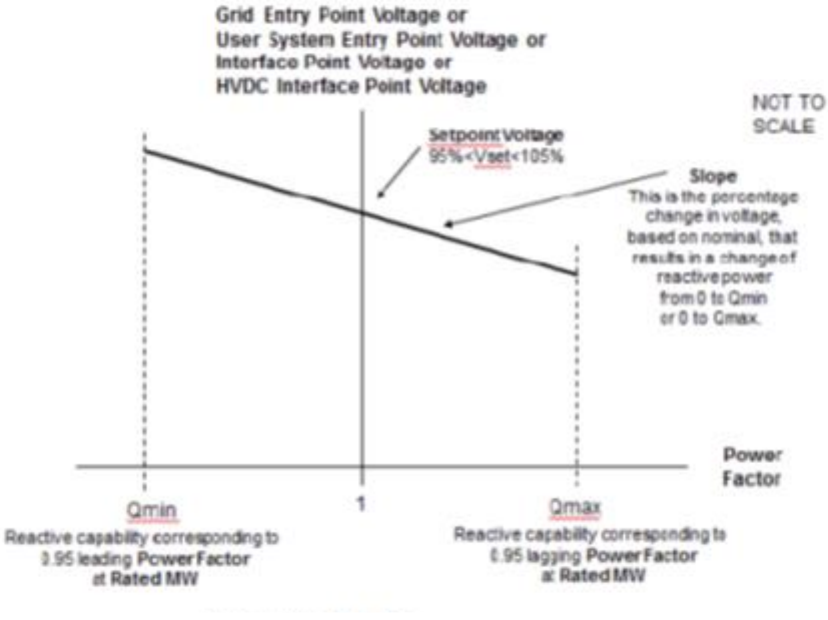


Figure 46 - ECC.A.7.2.2a

ECC.A.7.2.2.2 The continuously acting automatic control system shall be capable of operating to a Setpoint Voltage between 95% and 105% with a resolution of 0.25% of the nominal voltage. For the avoidance of doubt values of 95%, 95.25%, 95.5% … may be specified, but not intermediate values. The initial Setpoint Voltage will be 100%. The tolerance within which this Setpoint Voltage shall be achieved is specified in BC2.A.2.6. For the avoidance of doubt, with a tolerance of 0.25% and a Setpoint Voltage of 100%, the achieved value shall be between 99.75% and 100.25%. NGET may request the EU Generator or HVDC System Owner to implement an alternative Setpoint Voltage within the range of 95% to 105%. For Embedded Generators and Embedded HVDC System Owners the Setpoint Voltage will be discussed between NGET and the relevant Network Operator and will be specified to ensure consistency with ECC.6.3.4.

ECC.A.7.2.2.3 The Slope characteristic of the continuously acting automatic control system shall be adjustable over the range 2% to 7% (with a resolution of 0.5%). For the avoidance of doubt values of 2%, 2.5%, 3% may be specified, but not intermediate values. The initial Slope setting will be 4%. The tolerance within which this Slope shall be achieved is specified in BC2.A.2.6. For the avoidance of doubt, with a tolerance of 0.5% and a Slope setting of 4%, the achieved value shall be between 3.5% and 4.5%. NGET may request the EU Generator or HVDC System Owner to implement an alternative slope setting within the range of 2% to 7%. For Embedded Generators and Onshore Embedded HVDC Converter Station Owners the Slope setting will be discussed between NGET and the relevant Network Operator and will be specified to ensure consistency with ECC.6.3.4.

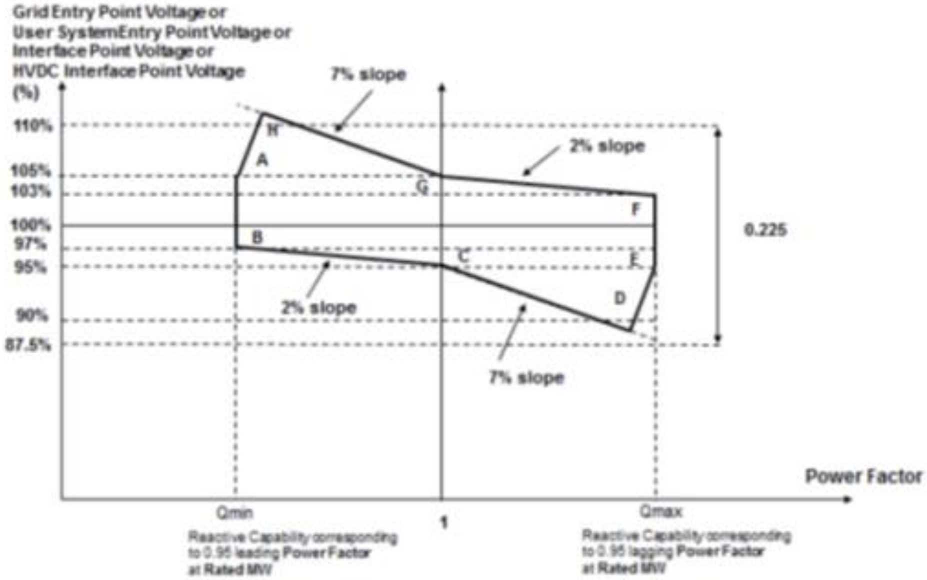


Figure 47 - ECC.A.7.2.2b

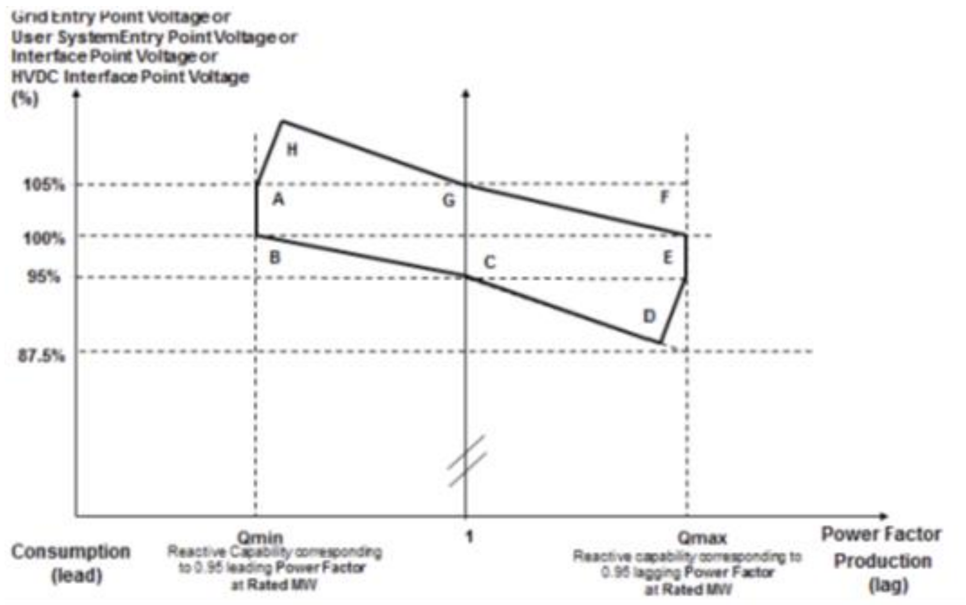


Figure 48 - ECC.A.7.2.2c

ECC.A.7.2.2.4 Figure ECC.A.7.2.2b shows the required envelope of operation for **-**, **OTSDUW Plant** and **Apparatus**, **Onshore Power Park Modules** and **Onshore HVDC Converters** except for those **Embedded** at 33kV and below or directly connected to the **National Electricity Transmission System** at 33kV and below. Figure ECC.A.7.2.2c shows the required envelope of operation for **Onshore Power Park Modules Embedded** at 33kV and below, or directly connected to the **National Electricity Transmission System** at 33kV and below. The enclosed area within points ABCDEFGH is the required capability range within which the **Slope** and **Setpoint Voltage** can be changed.

ECC.A.7.2.2.5 Should the operating point of the, **OTSDUW Plant and Apparatus** or **Onshore Power Park Module**, or **Onshore HVDC Converter** deviate so that it is no longer a point on the operating characteristic (figure ECC.A.7.2.2a) defined by the target **Setpoint Voltage** and **Slope**, the continuously acting automatic voltage control system shall act progressively to return the value to a point on the required characteristic within 5 seconds

ECC.A.7.2.3 Transient Voltage Control

ECC.A.7.2.3.1 For an on-load step change in Onshore Grid Entry Point or Onshore User System Entry Point voltage, or in the case of OTSDUW Plant and Apparatus an on-load step change in Transmission Interface Point voltage, the continuously acting automatic control system shall respond according to the following minimum criteria:

(i) the Reactive Power output response of the, OTSDUW Plant and Apparatus or

Onshore Power Park Module or Onshore HVDC Converter shall commence within 0.2 seconds of the application of the step. It shall progress linearly although variations from a linear characteristic shall be acceptable provided that the Mvar seconds

delivered at any time up to 1 second are at least those that would result from the response shown in figure ECC.A.7.2.3.1a.

(ii) the response shall be such that 90% of the change in the Reactive Power output of the, OTSDUW Plant and Apparatus or Onshore Power Park Module, or Onshore HVDC Converter will be achieved within

- 2 seconds, where the step is sufficiently large to require a change in the steady state Reactive Power output from its maximum leading value to its maximum lagging value or vice versa and
- 1 second where the step is sufficiently large to require a change in the steady

  state Reactive Power output from zero to its maximum leading value or maximum lagging value as required by ECC.6.3.2 (or, if appropriate ECC.A.7.2.2.6 or ECC.A.7.2.2.7);

(iii) the magnitude of the Reactive Power output response produced within 1 second shall vary linearly in proportion to the magnitude of the step change.

(iv) within 5 seconds from achieving 90% of the response as defined in ECC.A.7.2.3.1 (ii), the peak to peak magnitude of any oscillations shall be less than 5% of the change in steady state maximum Reactive Power.

(v) following the transient response, the conditions of ECC.A.7.2.2 apply.

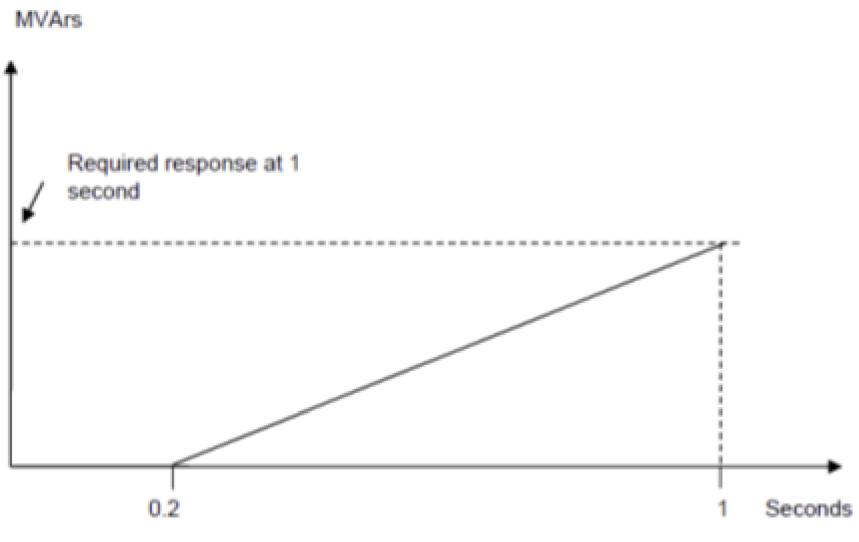


Figure 49 - ECC.A.7.2.3.1a

ECC.A.7.2.3.2 OTSDUW Plant and Apparatus or Onshore Power Park Modules or Onshore HVDC Converters shall be capable of

(a) changing its Reactive Power output from its maximum lagging value to its maximum leading value, or vice versa, then reverting back to the initial level of Reactive Power output once every 15 seconds for at least 5 times within any 5 minute period; and

(b) changing its Reactive Power output from zero to its maximum leading value then reverting back to zero Reactive Power output at least 25 times within any 24 hour period and from zero to its maximum lagging value then reverting back to zero Reactive Power output at least 25 times within any 24 hour period. Any subsequent restriction on reactive capability shall be notified to NGET in accordance with BC2.5.3.2, and BC2.6.1.

In all cases, the response shall be in accordance to ECC.A.7.2.3.1 where the change in Reactive Power output is in response to an on-load step change in Onshore Grid Entry Point or Onshore User System Entry Point voltage, or in the case of OTSDUW Plant and Apparatus an on-load step change in Transmission Interface Point voltage.