SP Electricity North West

QUEST

Trials and Analysis Report

Issue 1

Version Control

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1. Abbreviations

Abbreviation	Description
ANM	Active Network Management
AVC	Automatic Voltage Controller
BaU	Business as Usual
BSP	Bulk Supply Point
BSP TSF	Tap Stagger Functionality on a BSP level
CE	Control Engineer
CLASS	Customer Load Active System Services
CLASS-DR-MM	CLASS Demand Reduction Mitigation Mode
CLASS-DB-MM	CLASS Demand Boost Mitigation Mode
CLASS-DRF-SM	CLASS Demand Reduction Full Safe Mode
CLASS-DRTQ-SM	CLASS Demand Reduction Three Quarters Safe Mode
CLASS-DRH-SM	CLASS Demand Reduction Half Safe Mode
CLASS-DROQ-SM	CLASS Demand Reduction One Quarter Safe Mode
CLASS-DBF-SM	CLASS Demand Boost Full Safe Mode
CLASS-DBH-SM	CLASS Demand Boost Half Safe Mode
CLASS-MM	CLASS mitigation mode
CLASS-SM	CLASS safe mode
CMP	Contention Management Process
CVR	Conservation Voltage Reduction
DB	Demand Boost (CLASS Function)
DBF	Demand Boost Full (CLASS Function)
DBH	Demand Boost Half (CLASS Function)
DER	Distribution Energy Resource
DNO	Distribution Network Operator
DR	Demand Reduction (CLASS Function)
DRF	Demand Reduction Full (CLASS Function)
DRTQ	Demand Reduction Three Quarters (CLASS Function)

DRH	Demand Reduction Half (CLASS Function)
DROQ	Demand Reduction One Quarter (CLASS Function)
SP ENWL	SP Electricity North West
NESO	National Energy System Operator
ESQCR	Electricity Safety, Quality and Continuity Regulations
EHV	Extra High Voltage
GSP	Grid Supply Point
HV	High Voltage
ICCP	Inter-Control Centre Communications Protocol
LCT	Low Carbon Technologies
LFDD	Low Frequency Demand Disconnection
LFDD-MM	Low Frequency Demand Disconnection Mitigation Mode
LV	Low Voltage
MW	Megawatt
NE	Network Efficiency
NEM	QUEST's Network Efficiency Mode
NMS	Network Management System
NSS	Network State Simulator
OC6	Grid operating code 6
OC6-MM	OC6 Mitigation Mode
OC6-VR-MM	OC6 Voltage Reduction Mitigation Mode
OC6-DD-MM	OC6 Demand Disconnection Mitigation Mode
SE	Schneider Electric
SGS	Smarter Grid Solutions
SMST	Smart Street
SYSCON	System Condition
TPL	Technique Priority List
TPS	Technique Priority Selector
TSF	Tap Stagger Functionality
UI	User Interface

2. Executive Summary

This report presents the findings from the series of operational trials conducted using the live QUEST system deployed across the Whitegate GSP area. The trials were designed to validate QUEST's ability to coordinate multiple voltage control techniques in real time, including CLASS Demand Reduction (DR) and Boost (DB), Smart Street (SMST), Network Efficiency Mode (NEM), BSP Tap Stagger functionality (BSP TSF), together with Active Network Management (ANM) techniques and emergency response protocols such as OC6 and LFDD.

The trial programme covered over 100 scenarios, ranging from isolated function activations to complex multi-technique coordination under both normal and emergency system conditions. Each trial was configured with specific function levels, priorities, and performance targets, and was executed using either proactive or responsive coordination logic.

Key outcomes from the trials include:

- Consistent achievement of CLASS DR and DB targets across a range of function levels.
- Effective coordination between Smart Street and CLASS, with safe mode logic applied to prevent voltage conflicts.
- Effective coordination between ANM systems and CLASS in case of CLASS activation.
- Measurable 33kV loss reduction through NEM, with dynamic adjustment based on system conditions. Effective coordination between NEM and CLASS, with safe mode logic applied to prevent voltage conflicts and to provide enough "tap room" for CLASS to perform DB functionality.
- Successful mitigation of QUEST functions during emergency transitions, ensuring compliance with NESO instructions.
- Validation of Tap Stagger's ability to absorb reactive power and support voltage stability.

The trials confirmed that QUEST operates in accordance with its functional specification and use cases. While most trials met their success criteria, a small number revealed operational constraints or deviations, which were explainable and have informed recommendations for future refinement.

Overall, the results demonstrate that QUEST has proven that the system is capable of delivering coordinated voltage management, network efficiency, and enhanced service reliability across SP ENW's distribution network. Business as Usual (BaU) deployment will require some additional development and integration work and will be subject to SP ENW business case and financial approval.

3. Introduction

The QUEST project is a flagship innovation initiative led by SP Electricity North West (SP ENW), developed in collaboration with project partners Schneider Electric (SE), Smarter Grid Solutions (SGS), Fundamantals, NESO and Impact. QUEST is designed to deliver coordinated, real-time voltage management across multiple control systems, including CLASS, Smart Street, NEM, ANM, and Tap Stagger functionality. Its overarching goal is to optimise network performance, reduce losses, support NESO services, and enhance customer outcomes, all while maintaining statutory voltage limits.

This report presents the results and analysis of the operational trials conducted on the live distribution network under the Whitegate GSP area. These trials were executed using the live QUEST system, as deployed within SP ENW's production environment, and are distinct from the SGS digital twin simulations which model QUEST behaviour using IPSA and Python-based emulation.

The operational trials were designed to validate QUEST's functionality under a range of real-world scenarios, including:

- Individual technique activations (e.g., CLASS DR at 25%, 50%, 75%, and 100%)
- Multi-technique coordination (e.g., CLASS + Smart Street + NEM)
- Emergency system transitions (e.g., OC6 Voltage Reduction, OC6 Demand Disconnection, LFDD)
- Reactive power support via Tap Stagger

Each trial was configured to test specific aspects of QUEST's coordination logic, system response, and ability to meet defined performance targets.

This report outlines the methodology used to conduct these trials, presents the results observed from the live system, and provides analysis and insights into QUEST's operational behaviour and readiness for business-as-usual deployment.

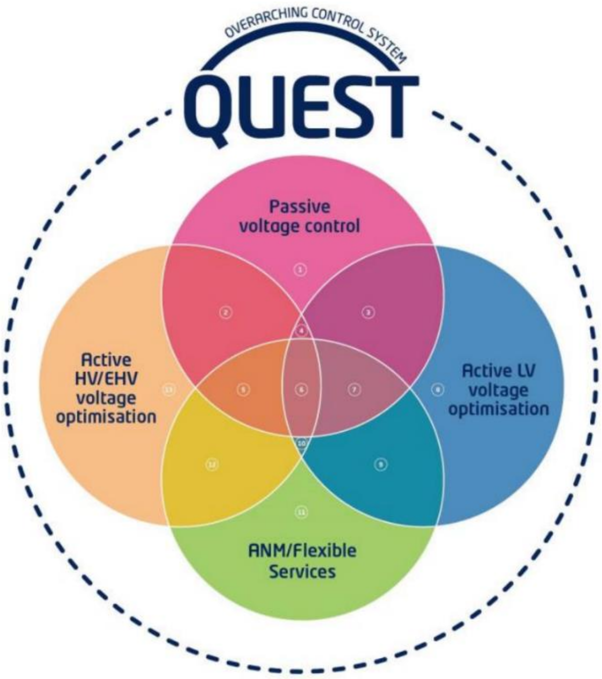


Figure 1 QUEST Coordination Logic Venn Diagram

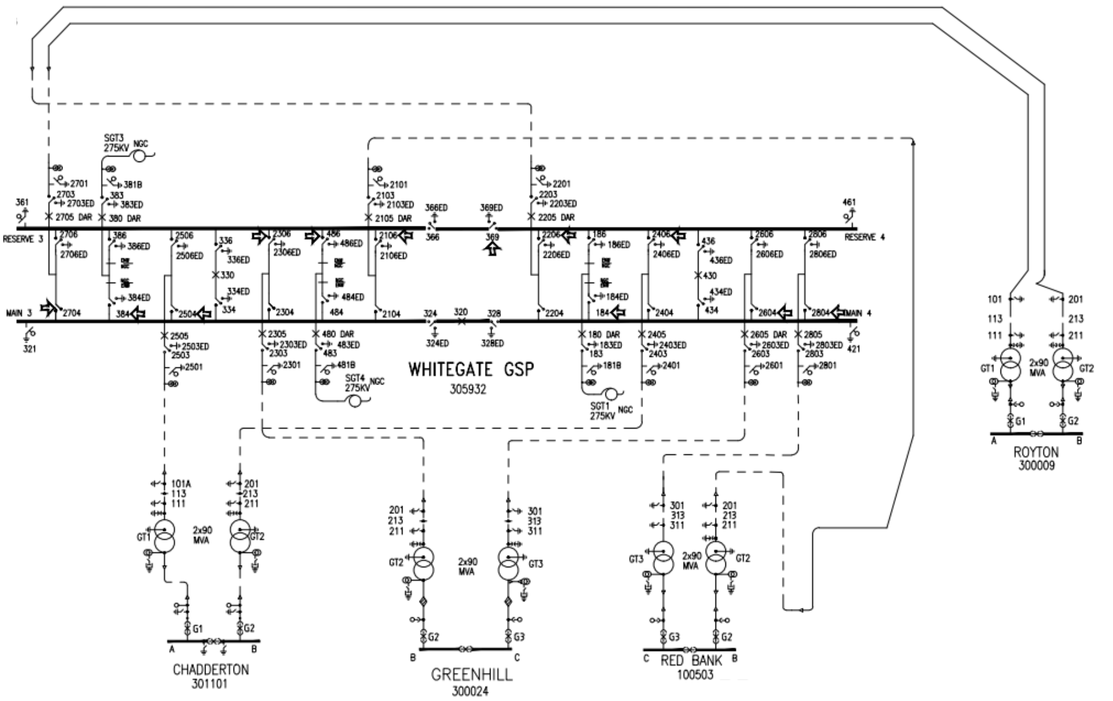


Figure 2 Whitegate GSP 132kV Schematic – QUEST Trial Area.

4. QUEST Functions Overview

The QUEST system integrates a combination of new and existing voltage control and network optimisation functions across SP ENW's distribution network. Each function plays a role in improving system efficiency, managing demand, and supporting compliance with NESO service requirements. During operational trials, these techniques were tested both individually and in combination to validate their behaviour under real-world conditions.

Further details on each technique are available in the QUEST Functional Specification document. This specification, published as an earlier project deliverable and accessible via the SP ENW website, provides comprehensive information on the voltage control methods incorporated within QUEST.

4.1. CLASS Demand Reduction (DR)

CLASS DR reduces network demand by lowering voltage at primary substations through tap changes. The function operates at predefined levels (25%, 50%, 75%, 100%), each linked to a specific voltage target and an expected percentage of demand reduction.

- Demand Reduction Full (DRF) targets approximately 5%, and
- Demand Reduction Half (DRH) targets around 3%—both are established techniques used in BaU.

For QUEST, two additional levels have been introduced within the CLASS relays:

- Demand Reduction Three Quarters (DRTQ) targeting 4%, and
- Demand Reduction One Quarter (DROQ) targeting 2%.

These new levels give QUEST finer control to achieve its overall target and share benefits with other techniques. During trials, CLASS DR was tested both independently and in combination with other techniques. QUEST coordinated the activation of CLASS DR, ensuring demand reduction targets were met by applying the appropriate DR level while avoiding conflicts with Smart Street and NEM.

The objective was to confirm that QUEST can apply different DR levels across multiple CLASS primaries to satisfy defined targets. For example, if CLASS has priority and is set to DRTQ, but the target is not met at that level, QUEST is expected to escalate to DRF on selected primaries until the target is achieved.

4.2. CLASS Demand Boost (DB)

CLASS DB is an existing technique which increases network demand by raising voltage at primary substations. It was tested at 50% and 100% function levels, with the goal of validating QUEST's ability to deliver demand increases without causing voltage violations. CLASS DB was coordinated with Smart Street and NEM, and trials confirmed that QUEST could prioritise DB while holding other techniques in safe modes.

4.3. Smart Street (SMST)

Smart Street applies Conservation Voltage Reduction (CVR) at secondary substations by adjusting transformer taps to lower LV voltages. This technique reduces energy consumption and customer demand without impacting service quality. Under normal operation, Smart Street sets optimal tap positions for service transformers to keep LV voltages as close as possible to statutory limits defined by ESQCR.

When coordinated by QUEST, Smart Street can be placed in a safe mode or adjusted dynamically based on Technique Priority Lists (TPLs) and function levels. Safe modes are applied when higher-priority techniques, such as CLASS, require headroom, ensuring that simultaneous deep voltage reductions do not risk LV excursions. Smart Street does not conflict with NEM; its interaction is primarily with CLASS, where QUEST either limits Smart Street's function level or applies safe mode to respect CLASS priority.

During trials, Smart Street was tested both in isolation and alongside other techniques. QUEST successfully managed Smart Street settings in real time, maintaining compliance with ESQCR limits while demonstrating coordinated control within the overarching optimisation framework.

4.4. Network Efficiency Mode (NEM)

NEM is a new QUEST technique designed to improve network efficiency by reducing system losses on the 33kV network. It achieves this by raising voltage targets at BSP transformers, which lowers current flow and associated losses. NEM operates at multiple function levels, allowing incremental adjustments to balance efficiency gains against potential voltage rise risks.

Under QUEST coordination, NEM interacts primarily with CLASS and, in some cases, BSP Tap Stagger if there is insufficient tap room to perform both functions simultaneously. NEM complements CLASS DB but can conflict with CLASS DR when voltage headroom is limited. It does not conflict with Smart Street, as this operates independently of NEM adjustments.

During trials, QUEST dynamically managed NEM based on Technique Priority Lists and system conditions, applying safe modes when CLASS DR or DB was active to maintain statutory voltage limits. This ensured that efficiency improvements did not compromise demand reduction or NESO service delivery. Scenario analysis confirmed that NEM can deliver measurable loss reduction under normal conditions and integrate effectively within QUEST's optimisation framework, provided priority logic, and tap constraints are respected.

4.5. BSP Tap Stagger Functionality

Tap Stagger is a new QUEST feature that creates a controlled reactive power sink by introducing a tap imbalance between paired BSP transformers. Three stages of TSF are provided for BSP transformers, which are effectively 2 taps apart (TS1), 4 taps apart (TS2) and 6 taps apart (TS3) from one another. This technique provides an alternative to installing dedicated reactive compensation equipment, such as STATCOMs, by leveraging existing assets.

Tap Stagger was tested in simulation and live trials to validate its ability to absorb MVAr and support voltage stability. QUEST managed Tap Stagger activation based on system conditions and technique priorities, ensuring that reactive power absorption did not conflict with other objectives. Trials confirmed that Tap Stagger can deliver NESO reactive services when required, but its operation must be balanced against increased transformer losses and potential secondary voltage rise.

4.6. Active Network Management (ANM)

Active Network Management (ANM) systems manage real-time control of Distributed Energy Resources (DER) and flexible connections to maintain network stability and thermal limits. Within QUEST, ANM coordination ensures that voltage optimisation actions do not conflict with DER dispatch or flexibility services.

Two ANM systems were integrated into QUEST:

- Decentralised ANM– Simulates real-time DER control for thermal constraint management.
- Cloud ANM – Simulates flexibility service dispatch for day-ahead and intraday scenarios.

Note: Although Central ANM was not configured in the NMS production system, a logic for coordinating Central ANM was introduced in QUEST. During the trials, only Decentralised and Cloud ANM were coordinated by QUEST.

These ANM systems interface with QUEST via ICCP links. The coordination philosophy is based on mitigation modes: when QUEST initiates actions such as demand reduction or demand boost, ANM systems temporarily hold back normal operations (e.g., prevent release of constrained generation or demand) until QUEST signals that voltage optimisation is complete. This prevents ANM from counteracting QUEST benefits by inadvertently increasing export or import during voltage control events.

4.7. Emergency Functions

QUEST supports three emergency functions:

- OC6 Voltage Reduction (VR): Intended to reduce voltage at primary substations by 3% or 6% to lower demand.
- OC6 Demand Disconnection (DD): Involves opening HV circuit breakers to shed load when voltage reduction is insufficient.
- Low Frequency Demand Disconnection (LFDD): Disconnects 33kV circuits during low frequency events.

While QUEST does not directly execute these actions (e.g., reducing voltages or opening breakers), it plays a critical role in supporting the wider system response by transitioning relevant voltage control techniques in operation at the time, into their respective mitigation modes — such as OC6-VR-MM or LFDD-MM.

The QUEST system includes an additional button within the user interface for Black Start but no additional logic is provided within this research and trials phase of the project.

During trials, QUEST correctly inhibited or adjusted the behaviour of techniques like NEM, Smart Street, and ANM, locked tap positions where required, and ensured that coordination logic aligned with emergency protocols, thereby enabling the network to respond appropriately to system stress conditions.

5. Methodology

The QUEST operational trials were conducted using both pre-production (TEST) and production environments (PROD), each designed to test different aspects of system behaviour and coordination logic.

5.1. Trial Environments

Pre-Production (TEST) Environment: QUEST was deployed on a dedicated server interfaced with a Network State Simulator (NSS). This environment allowed for safe testing of coordination logic, emergency transitions, and function interactions without impacting live operations. Simulated load profiles and voltage conditions were used to emulate realistic network behaviour.

Production (PROD) Environment: QUEST was integrated with the live system via ICCP, enabling real-time coordination with field devices, substations, and voltage control assets. During these trials, QUEST assumed control of QUEST assets in the Whitegate GSP area, while other systems such as the BaU CLASS and ANM dispatch were disabled or redirected to avoid conflict.

In both environments, QUEST was integrated with SGS's external ANM systems (both Cloud-based and Decentralised) through ICCP.

5.2. Control Interfaces and Tools

The QUEST Control & Monitoring Dashboard: Provides an intuitive user interface to QUEST, allowing for profiles to be selected, simulated and operated in real-time. The dashboard also provides an overarching view of each technique's status following a trial activation.

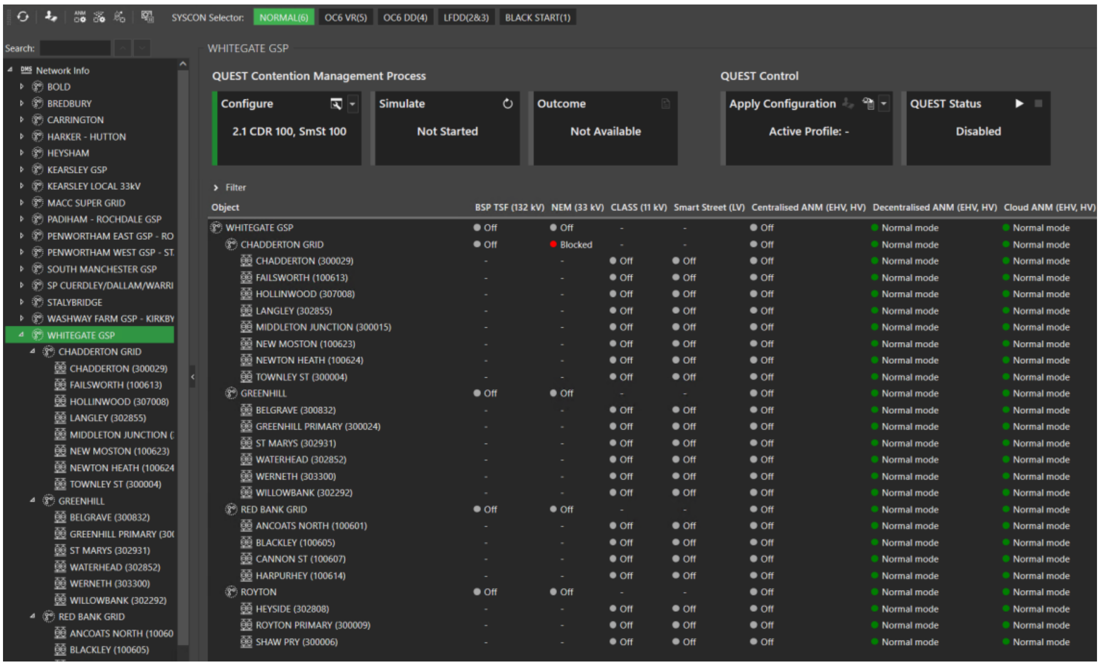


Figure 3 QUEST Control & Monitoring Pre-Activation

Figure 4 below illustrates an example of QUEST's Control & Monitoring Dashboard during an activated trial. The status and mode of each technique can be seen allowing for real-time monitoring of the system.

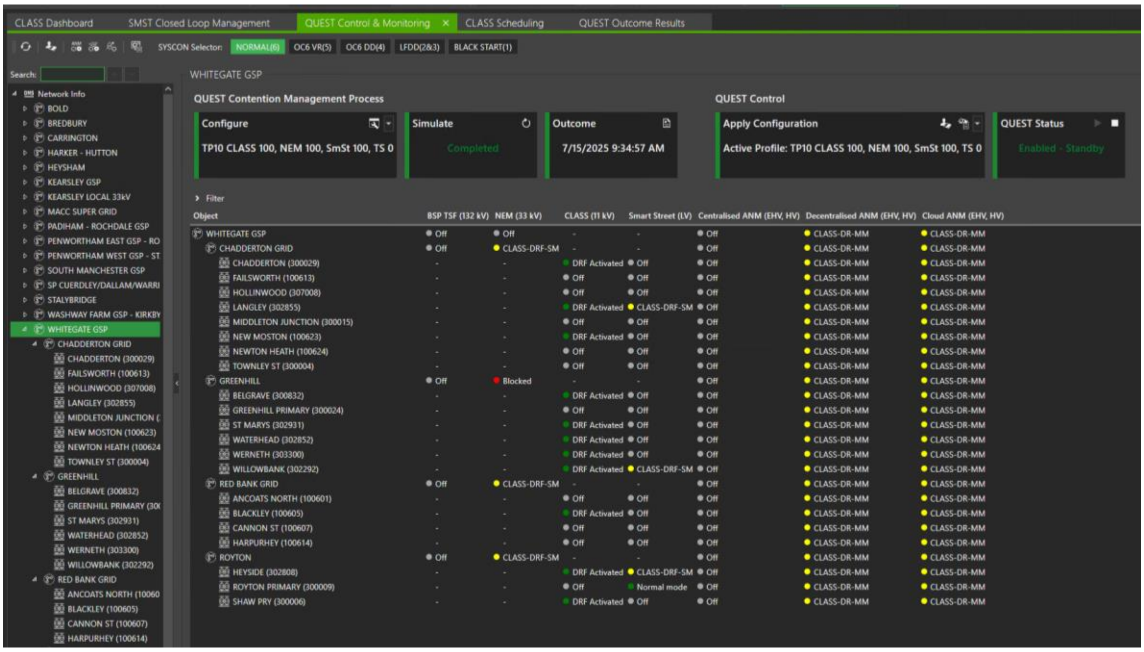


Figure 4 QUEST Control & Monitoring Dashboard Activated

The QUEST Output Dashboard - The dashboard provides real-time visibility into the status of active techniques, voltage levels, function priorities, and coordination actions. QUEST incorporates two distinct output dashboards: one for simulation and one for live operation.

The simulation output dashboard, shown below in figure 5, enables users to safely review QUEST's expected response in a controlled environment before issuing real-time commands to the network. This allows for adjustments and fine-tuning of inputs within the simulation, ensuring optimal performance prior to live deployment.

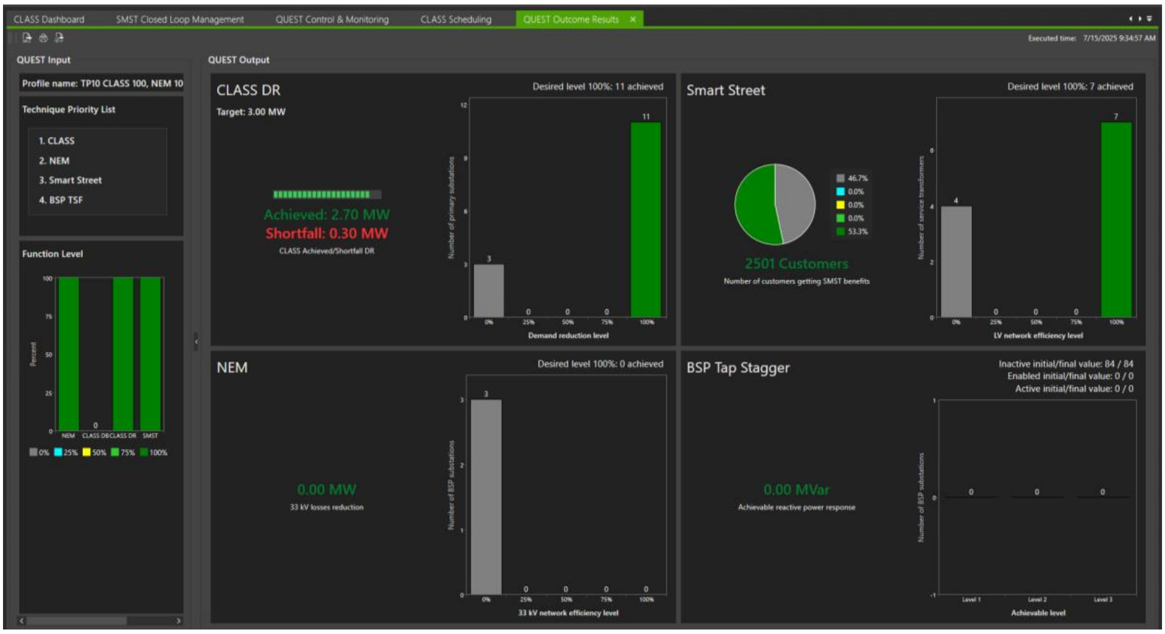


Figure 5 QUEST Simulation Output Dashboard Results

The real-time output dashboard, shown in figure 6 below, is used to validate QUEST's operational response and quantify its benefits. A key enhancement is the inclusion of the Yield Summary, which captures real-time performance metrics. This summary highlights the tangible benefits delivered by QUEST when activated, including reductions in CO_2 emissions, customer energy costs, overall energy consumption, and network demand.

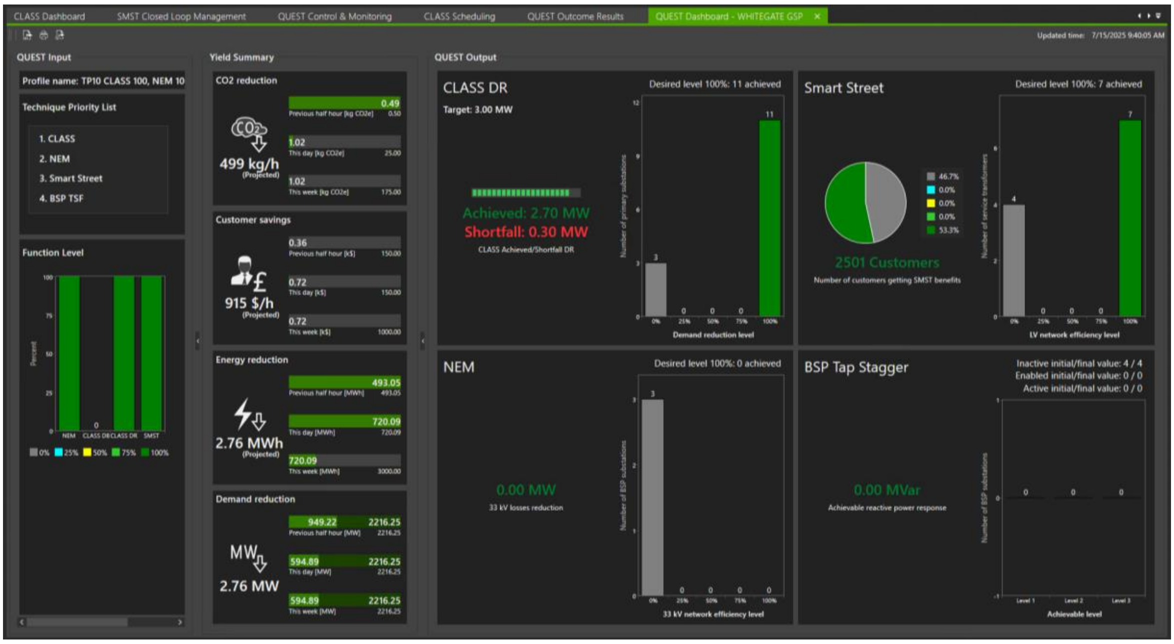
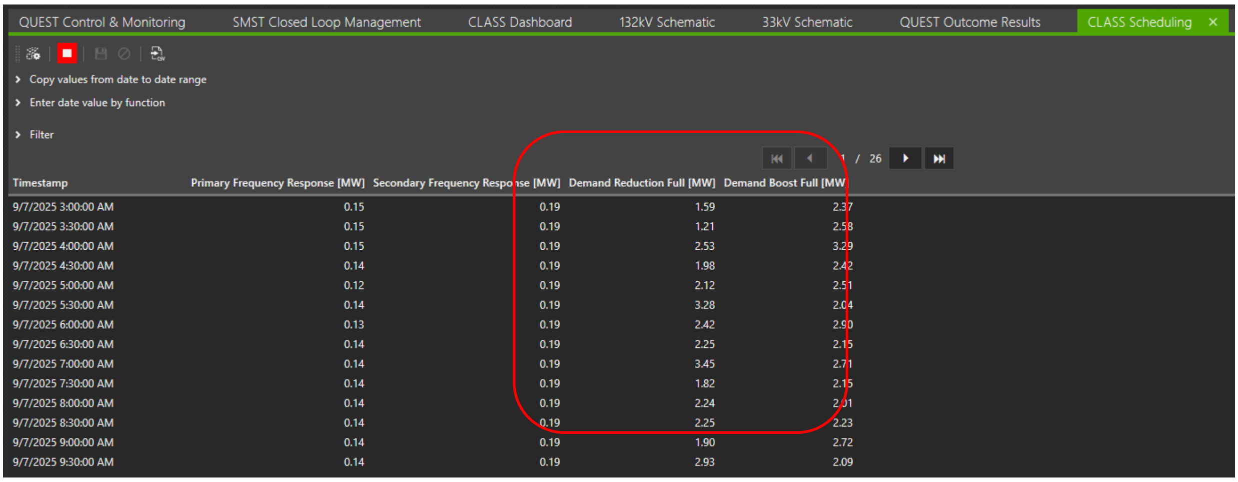


Figure 6 QUEST Real-Time Output Dashboard Results

SYSCON Selector: Enabled manual transitions between system states (Normal, OC6 VR/DD, LFDD), allowing engineers to simulate emergency conditions and observe QUEST's mitigation behaviour.

Figure 7 SYSCON Selector

CLASS Scheduler: is a core component of QUEST's control logic. It provides the half-hourly CLASS target values that QUEST aims to achieve, forming the basis for how QUEST prioritises actions. Until the defined CLASS target is met, QUEST will not progress to applying benefits from other techniques. This ensures that NESO service commitments linked to CLASS are delivered first, while maintaining system stability. Once the target is satisfied, QUEST dynamically reallocates control to other techniques such as Smart Street or Network Efficiency Mode, optimising overall network performance.



Timestamp	Primary Frequency Response [MW]	Secondary Frequency Response [MW]	Demand Reduction Full [MW]	Demand Boost Full [MW]
9/7/2025 3:00:00 AM	0.15	0.19	1.59	2.37
9/7/2025 3:30:00 AM	0.15	0.19	1.21	2.58
9/7/2025 4:00:00 AM	0.15	0.19	2.53	3.29
9/7/2025 4:30:00 AM	0.14	0.19	1.98	2.42
9/7/2025 5:00:00 AM	0.12	0.19	2.12	2.51
9/7/2025 5:30:00 AM	0.14	0.19	3.28	2.04
9/7/2025 6:00:00 AM	0.13	0.19	2.42	2.90
9/7/2025 6:30:00 AM	0.14	0.19	2.25	2.15
9/7/2025 7:00:00 AM	0.14	0.19	3.45	2.71
9/7/2025 7:30:00 AM	0.14	0.19	1.82	2.15
9/7/2025 8:00:00 AM	0.14	0.19	2.24	2.01
9/7/2025 8:30:00 AM	0.14	0.19	2.25	2.23
9/7/2025 9:00:00 AM	0.14	0.19	1.90	2.72
9/7/2025 9:30:00 AM	0.14	0.19	2.93	2.09

Figure 8 CLASS Scheduler: Providing Target Value

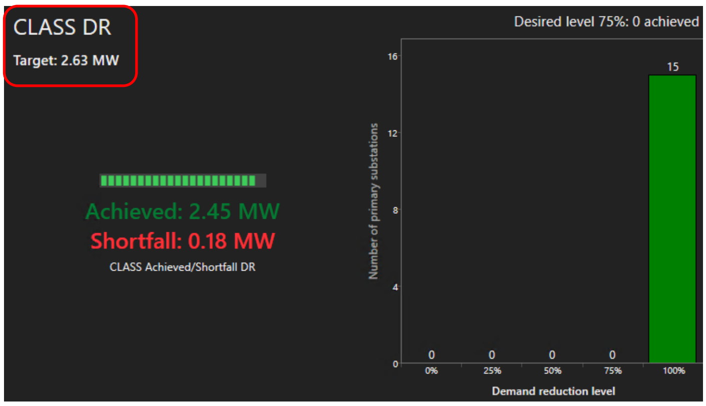


Figure 9 QUEST Dashboard Illustrating Target Value

5.3. Trial Configuration and Execution

Each trial was defined by a QUEST Profile, which included:

- Coordination Type: Either Proactive (based on predefined priorities and function levels) or Responsive (where the LV devices responded in real time to CLASS activations – this functionality was not implemented into this QUEST version due to non-existing fast tap functionality on SMST transformers, but is left in the UI for future reference and to show the concept that was discussed during the design).

- Technique Priority List (TPL): Ordered list of voltage control techniques, determining the sequence of activation and coordination.
- Function Levels (BLENDs): Percentage-based settings for each technique, corresponding to specific voltage targets and expected outcomes.

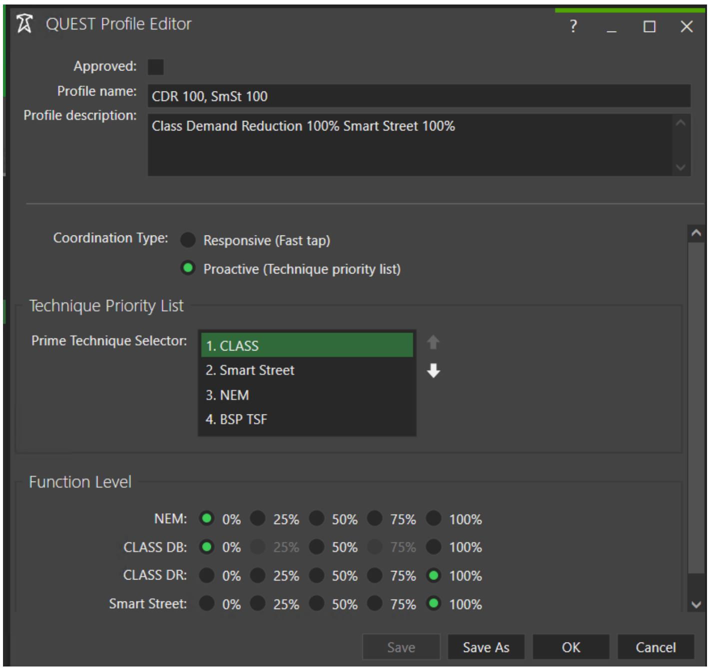


Figure 10 QUEST Profile Editor / Creator

Target Metrics: Demand reduction targets for CLASS DR and DB. SMST and NEM are designed to achieve the maximum benefit available through the decreasing of voltage for SMST and increasing of voltage for NEM as much as possible without violating limits.

Profiles were created and approved by control engineers and applied according to operational procedures. Trials were scheduled to align with system availability, load conditions, and coordination objectives.

5.4. Data Collection and Validation

Measurement Sources: Real-time data was collected from BSPs, primary substations, and secondary transformers. Voltage, demand, and loss metrics were recorded before, during, and after each trial.

Validation Criteria: Each trial was assessed against its defined success criteria, including:

- Achievement of CLASS DR/DB targets
- Voltage compliance across LV and HV networks
- Loss reduction via NEM
- Correct mitigation behaviour during emergency transitions

- Reactive power absorption via Tap Stagger

Trial outcomes were validated using system logs, dashboard data, and post-trial analysis. Where applicable, results were compared with expected behaviour as defined in the QUEST Functional Specification and Use Case documentation.

6. Trial Summary

The QUEST operational trial programme was designed to rigorously test the system's ability to coordinate multiple voltage control techniques under both normal and emergency system conditions. Trials were conducted across the Whitegate GSP area using the live QUEST system, with each scenario configured to test specific coordination logic, function interactions, and system responses.

6.1. Trial Scope and Coverage

Over 100 trials were executed, covering a wide range of configurations and use cases. These included:

Single-technique trials:

- CLASS DR and DB at 25%, 50%, 75%, 100% and CLASS as highest priority technique
- Smart Street CVR at various function levels and SMST as highest priority technique
- NEM voltage optimisation at BSPs and NEM as highest priority technique

Multi-technique coordination trials:

- CLASS + Smart Street
- CLASS + NEM
- Smart Street + NEM
- Full stack coordination (CLASS + Smart Street + NEM)

Emergency system transitions:

- OC6 Voltage Reduction (VR)
- OC6 Demand Disconnection (DD)
- Low Frequency Demand Disconnection (LFDD)

Reactive power support:

- Tap Stagger functionality at BSPs and Primary Substations

ANM

- Centralised + Decentralised ANM systems coordination in case of CLASS activation or in case of emergency system state

Each trial was executed using proactive coordination logic, with predefined Technique Priority Lists (TPLs) and Function Levels (BLENDs). Trials were scheduled to align with system availability, load conditions, and operational readiness.

6.2. Trial Configuration

Each trial was defined by a QUEST Profile, which included:

- Coordination type
- Technique priorities
- Function levels and voltage targets
- Demand reduction or boost targets (where applicable)
- SYSCON state (Normal, OC6, LFDD)

Profiles were created and approved by control engineers and applied via the QUEST Dashboard. Trials were monitored in real time, and all control actions were logged via the Event Summary.

6.3. Trial Logging and Validation

For each trial, the following data was captured:

- Timestamped voltage and demand measurements
- Tap positions and transformer states
- Technique activation status
- System condition and coordination mode
- Achievement of success criteria

Validation was performed against the following metrics:

- Achievement of CLASS DR/DB targets
- Voltage compliance across LV and HV networks
- Loss reduction via NEM
- Correct mitigation behaviour during emergency transitions
- Reactive power absorption via Tap Stagger

7. Trial Results and Analysis

This section presents a summary of the QUEST operational trials, detailing how the system performed across a range of voltage control scenarios. The trials were designed to validate QUEST's ability to coordinate multiple techniques—such as CLASS DR, CLASS DB, Smart Street, Network Efficiency Mode (NEM), and BSP Tap Stagger—under both isolated and combined conditions. Each trial was configured with specific function levels, priority orders, and system states to test QUEST's optimisation logic, responsiveness, and ability to meet defined objectives such as demand reduction, loss minimisation, and voltage compliance.

The results are grouped by technique or coordination scenario, with each subsection including a description of the trial purpose, input settings, activated QUEST sites, and key observations.

7.1. Trial Philosophy

When testing single or multiple techniques, two approaches can be taken:

- Isolated Mode – Techniques can be completely isolated by disabling or blocking all other techniques. This replicates existing BaU operation but via QUEST and provides limited insight into coordination or optimisation.
- Integrated Mode – Techniques can remain enabled but set to 0% function level. This approach prioritises the active technique while allowing QUEST to demonstrate its overarching optimisation logic and maximise system benefits.

Although initial tests used the isolated approach to confirm QUEST was functioning as expected, the trials presented in this report focus on the integrated approach. All techniques were enabled, with control applied through configurable priorities and function levels, providing a realistic representation of how QUEST operates in a live network environment.

This does mean that even in single- and two-technique trials, techniques not specifically targeted could still contribute benefits—demonstrating QUEST's ability to maximise whole-system performance once primary targets are achieved.

7.2. Single Technique Trials

The single technique trials were designed to isolate and evaluate the performance of individual QUEST functionalities—namely CLASS DR, CLASS DB, Smart Street & NEM. By setting all other voltage control techniques to 0% during each test, these trials aimed to confirm that QUEST could independently activate and manage each function in accordance with its configuration, priority, and system objectives. It also confirmed a baseline that QUEST provided a consistent response to the existing standalone CLASS and Smart Street BaU systems.

This approach allowed for a focused assessment of each technique's ability to deliver its intended benefits—such as demand reduction, demand boost & loss minimisation while maintaining voltage compliance and avoiding conflicts. These trials also served to validate QUEST's control logic, command execution, and real-time responsiveness under normal system operating conditions.

7.2.1. QUEST Sites Selected for Single Technique Trials

The following table summarises the sites used during the Single Technique Trials.

Table 1 QUEST Sites Selected for Single Technique Trials

CLASS	Smart Street	NEM
Under Chadderton Grid • Chadderton • Failsworth • Hollinwood • Langley • New Moston • Townley St Under Greenhill • Belgrave • St Marys • Waterhead • Werneth • Willowbank Under Red Bank Grid • Blackley Under Royton • Heyside • Royton Primary • Shaw Pry	Under Heyside Primary: • Goldsmith Ave Under Royton Primary: • Beechwood • Consort Ave • Oozewood Rd Under Blackley Primary: • Victoria Ave Under Willowbank Primary: • Ashdene CL Under Belgrave Primary: • Fold View • Rosary CL Under Langley Primary • Searness Rd • Kirkstone Dr	Under Whitegate GSP • Greenhill • Red Bank Grid • Royton

7.2.2. Known Constraints during Single Technique Trials

As the QUEST trials were conducted on a live operational network, certain practical limitations were unavoidable. Throughout the testing period, some sites were temporarily unavailable due to scheduled maintenance, asset outages, or manual inhibits applied for operational safety.

In several cases, specific transformers or substations were blocked from participating in trials to avoid interference with ongoing network activities. These restrictions are a natural part of working within a real-world distribution environment and were carefully managed to ensure trials remained representative and safe. As QUEST is aware of the LIVE network configuration, it would actively take account of any unavailability and optimise the remaining available network. Whilst this methodology is ideal for a BaU system, it did add complexity for project trials, as one change in the network starting condition result should generate a different network optimisation result.

Where applicable, these constraints have been noted in the table below:

Table 2 List of Known Constraints During Trials

Constraints observed during Single Technique trails
• Chadderton Grid unavailable for NEM trials • Royton Primary unavailable for CLASS trials • Harpurhey Primary unavailable for CLASS trials

7.2.3. CLASS Demand Reduction Single Technique Trials

The CLASS DR single technique trials were designed to validate QUEST's ability to independently activate and manage voltage reduction at primary substations to achieve defined demand reduction targets. These tests were conducted with all other voltage control techniques—Smart Street & NEM — set to 0%, allowing QUEST to focus solely on CLASS DR before optimising with other techniques.

7.2.3.1. CLASS Demand Reduction 100% (CDR 100)

	CLASS DR	CLASS DB	Smart Street	NEM
Priority	1	N/A	2	3
Function Level	100	N/A	0	0

Table 3 CDR 100 Priority & Function Levels

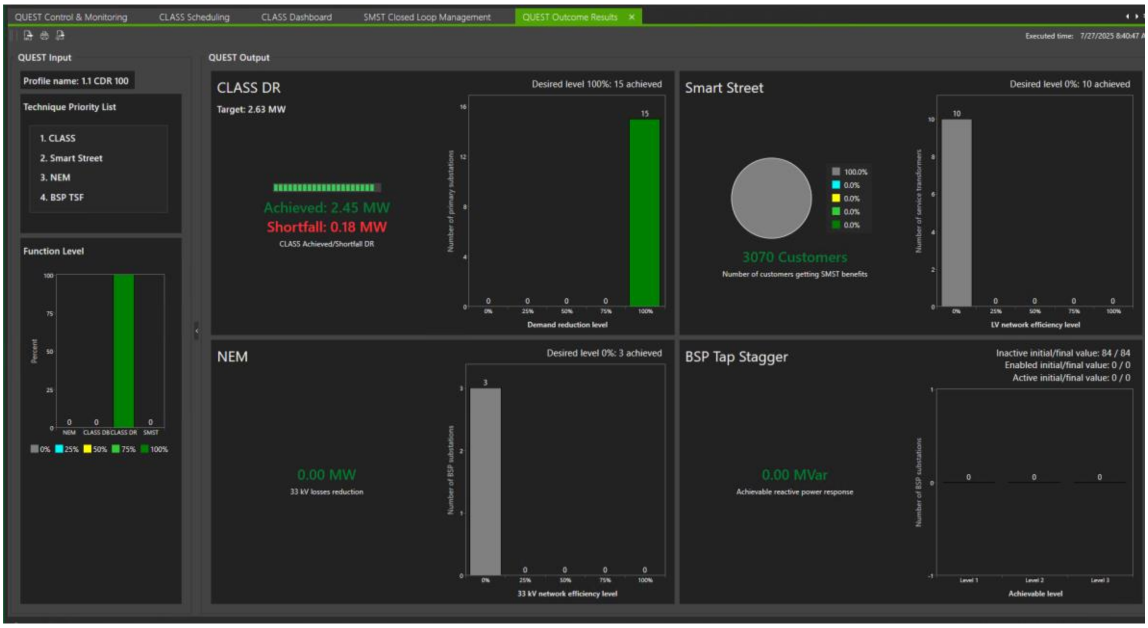


Figure 11 CLASS DR 100 Outcome Results

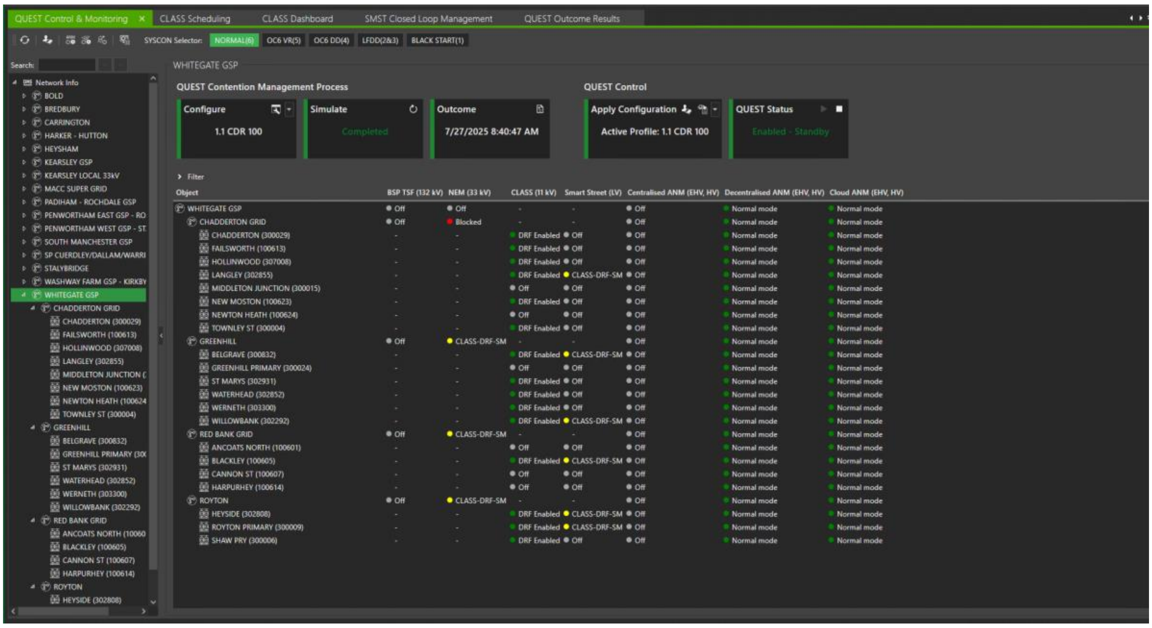


Figure 12 CLASS DR 100 QUEST Dashboard Summary

The results show that CLASS achieved 2.45 MW of the 2.63 MW target across 15 available sites. Since the target was not fully met, QUEST allocated all available system benefit to CLASS DR, as expected based on its priority and function level. Smart Street and NEM sites were placed into their respective safe modes, as shown in the QUEST Dashboard Summary, ensuring statutory voltage limits were maintained throughout the trial.

7.2.3.2. CLASS Demand Reduction 75% (CDR 75)

	CLASS DR	CLASS DB	Smart Street	NEM
Priority	1	N/A	2	3
Function Level	75	N/A	0	0

Table 4 CLASS DR 75 Priority & Function Levels

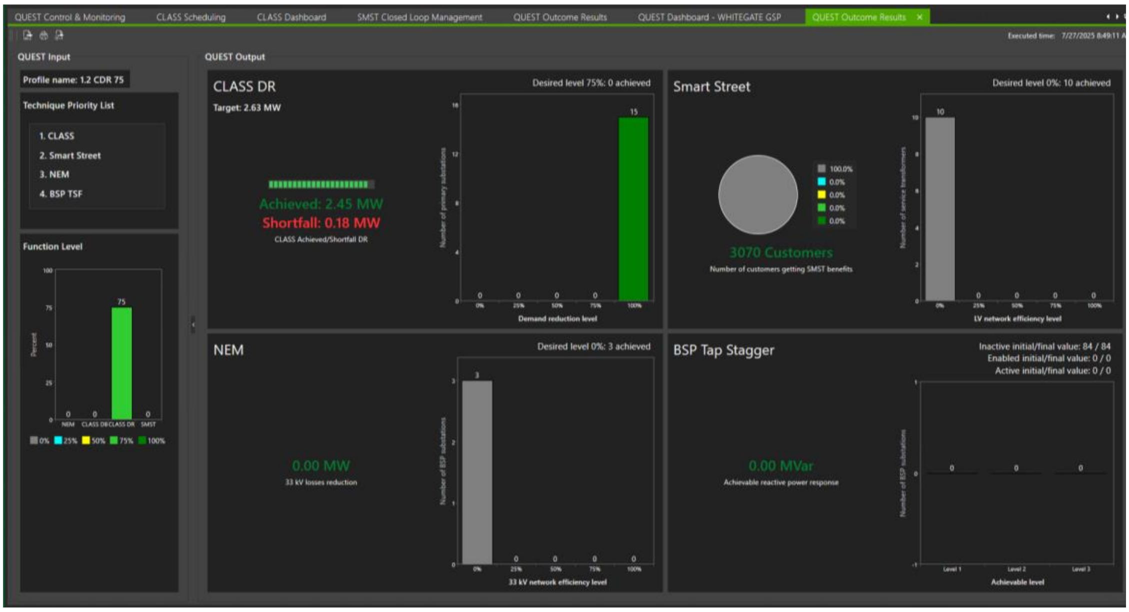


Figure 13 CLASS DR 75 Outcome Results

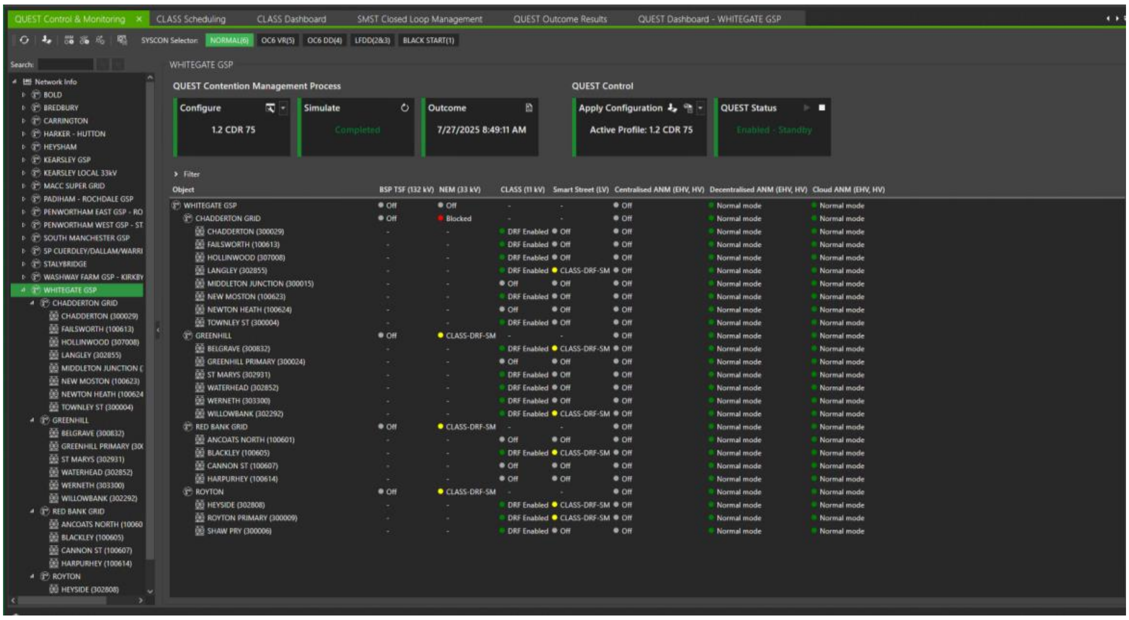


Figure 14 CDR 75 QUEST Dashboard Summary

With the function level set to 75%, the results mirrored the first test with QUEST allocating CLASS DR all available system benefits, as expected based on its priority and function level.

7.2.3.3. CLASS Demand Reduction 50% (CDR 50%)

	CLASS DR	CLASS DB	Smart Street	NEM
Priority	1	N/A	2	3
Function Level	50	N/A	0	0

Table 5 CDR 50 Priority & Function Levels

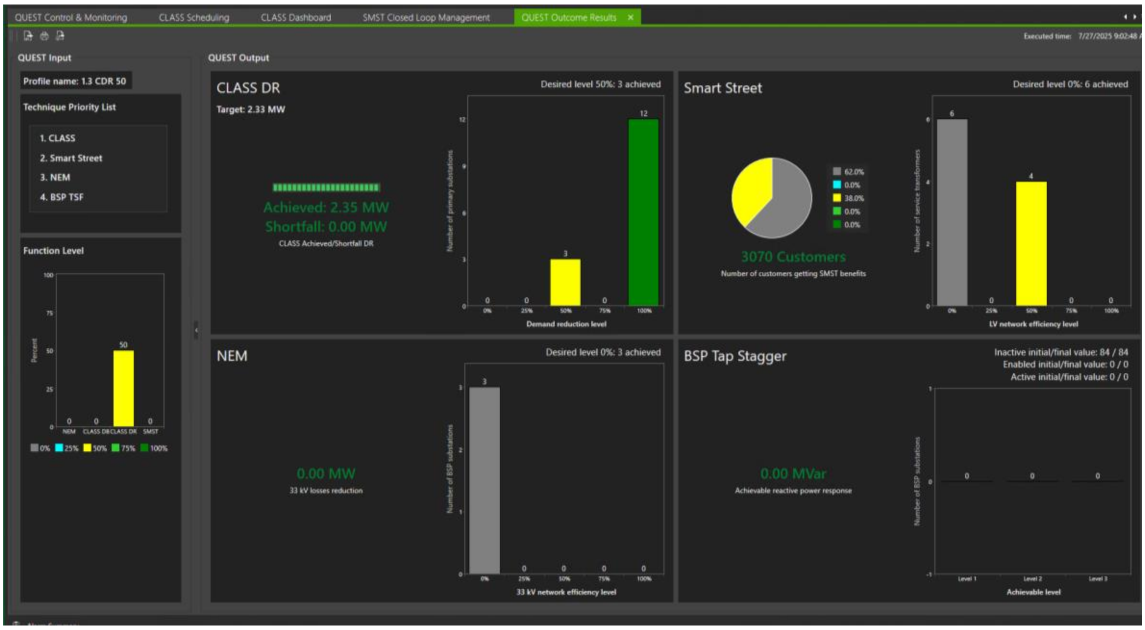


Figure 15 CDR 50 Outcome Results

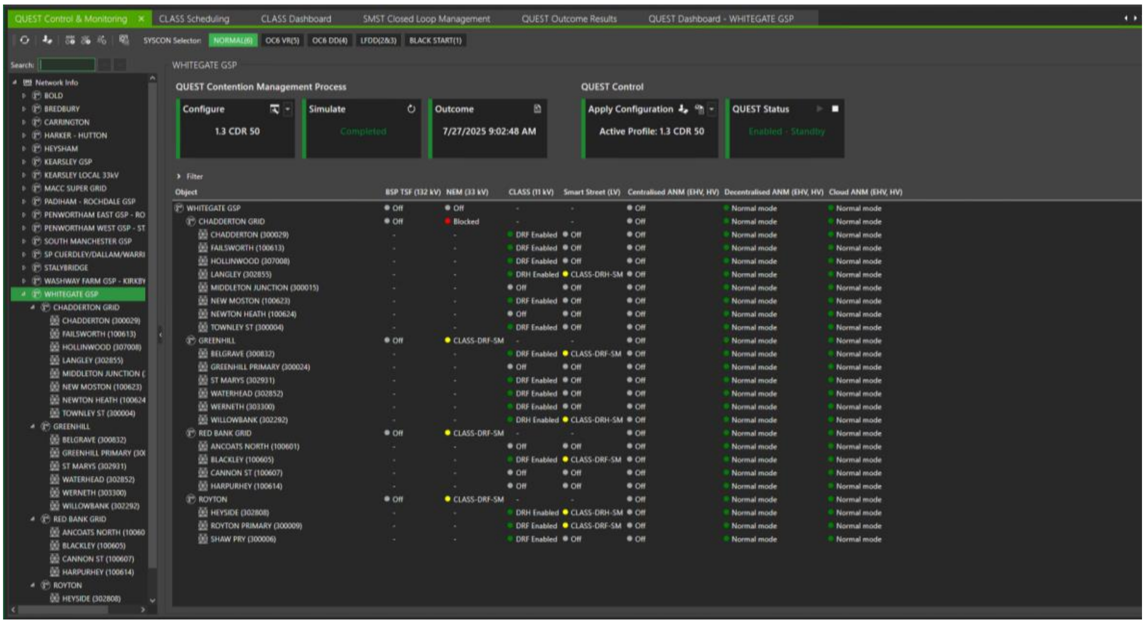


Figure 16 CDR 50 QUEST Dashboard Summary

With the function level set to 50% and the CLASS DR target of 2.33 MW successfully achieved, QUEST was able to optimise further by allocating remaining system benefit to Smart Street, which was configured as priority 2. This resulted in observable benefit across four Smart Street sites providing CVR benefits to customers, demonstrating QUEST's logic of fulfilling the highest-priority objective first, then distributing additional benefit according to the defined priority order. Remaining Smart Street and NEM sites were placed into their respective safe modes, as shown in the Dashboard Summary, ensuring voltage compliance was maintained throughout the trial.

7.2.3.4. CLASS Demand Reduction 25% (CDR 25)

	CLASS DR	CLASS DB	Smart Street	NEM
Priority	1	N/A	2	3
Function Level	25	N/A	0	0

Table 6 CDR 25 Priority & Function Levels

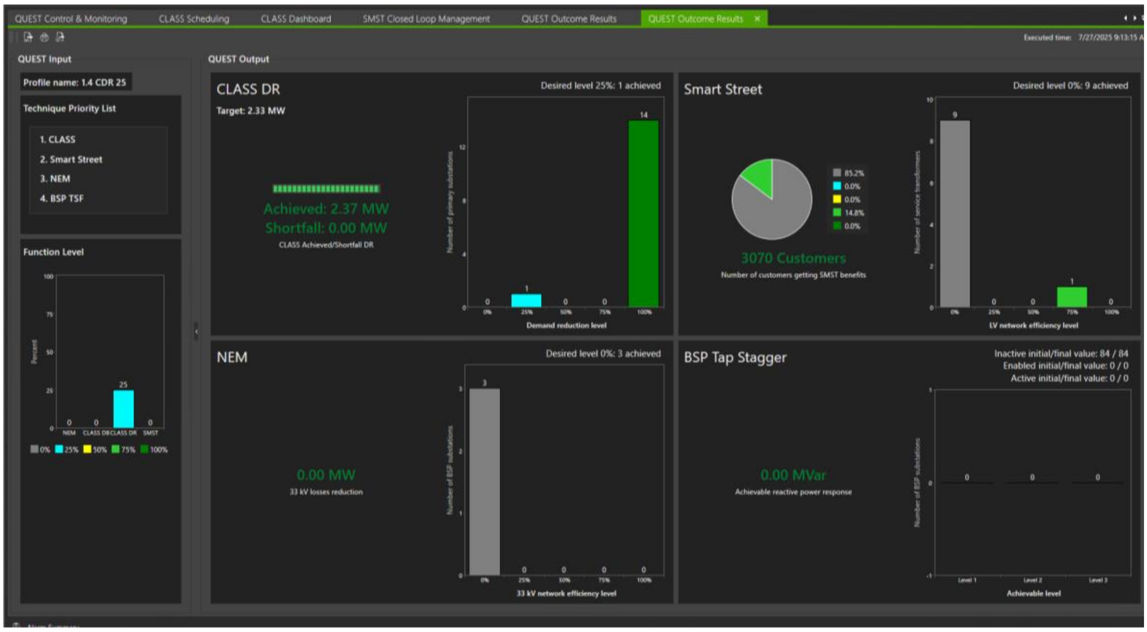


Figure 17 CDR 25 Outcome Results

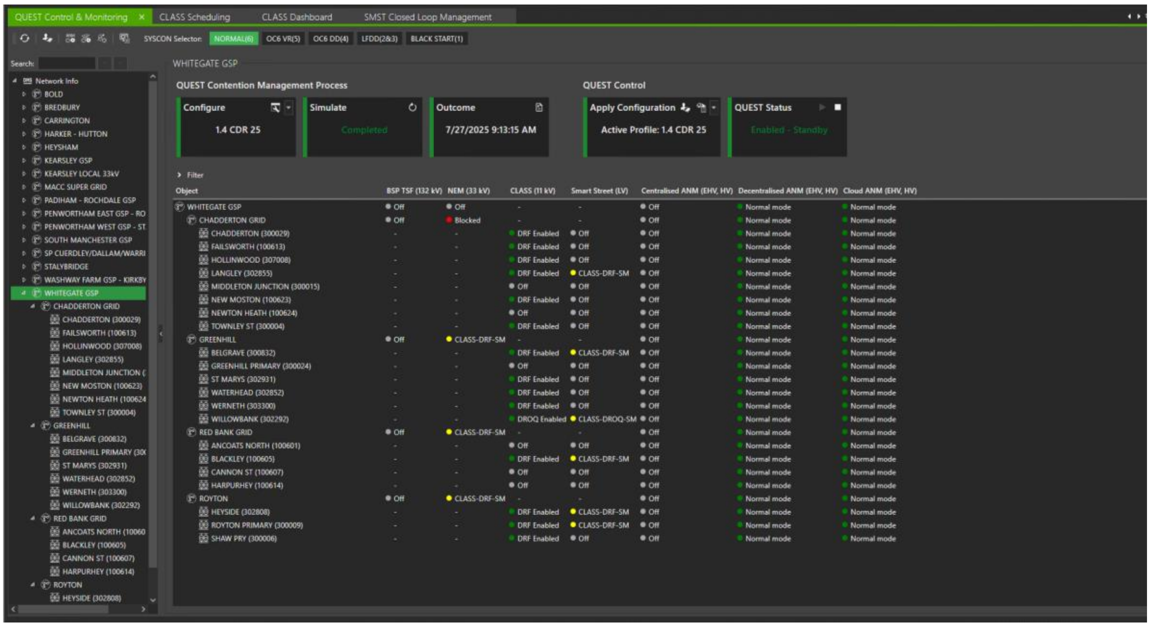


Figure 18 CDR 25 QUEST Dashboard Summary

With the function level set to 25% and CLASS DR successfully achieving its 2.33 MW target, QUEST was able to optimise further by allocating remaining system benefit to lower-priority techniques. This is reflected in the Outcome Results, where one Smart Street site—configured as priority 2—was enabled, demonstrating QUEST's logic of satisfying the highest-priority objective before distributing additional headroom. Remaining Smart Street and NEM sites were placed into their respective safe modes, as shown in the Dashboard Summary, ensuring voltage compliance was maintained throughout the trial.

7.2.3.5. Summary of CLASS DR Single Technique Trials

Although these trials were designed to focus on CLASS, QUEST's optimisation logic remained active throughout. Once CLASS reached its demand reduction target, QUEST could still allocate capacity to the next technique in the priority order—even if that technique was initially set to 0%—to maximise overall system benefit.

The results confirmed that QUEST successfully activated CLASS DR across all tested levels — 25%, 50%, 75%, and 100%—consistently meeting or closely approaching forecasted targets. In cases where the target was not met, QUEST correctly allocated all available system benefit to CLASS DR, in line with its configured priority. In some instances, once CLASS fulfilled its objective, additional techniques such as Smart Street were enabled, demonstrating QUEST's ability to optimise beyond the primary configuration and maximise overall system benefit.

7.2.4. CLASS Demand Boost Single Technique Trials

The CLASS Demand Boost (DB) single technique trials were designed to validate QUEST's ability to independently increase voltage at primary substations to raise network demand in line with target values and operational objectives. These tests were conducted with all other voltage control techniques—Smart Street & NEM — set to 0%, allowing QUEST to focus solely on CLASS DB before optimising with other techniques.

	CLASS DR	CLASS DB	Smart Street	NEM
Priority	N/A	1	2	3
Function Level	N/A	50	0	0

Table 7 CDB 50 Priority & Function Levels

Figure 19 CDB 50 Outcome Results

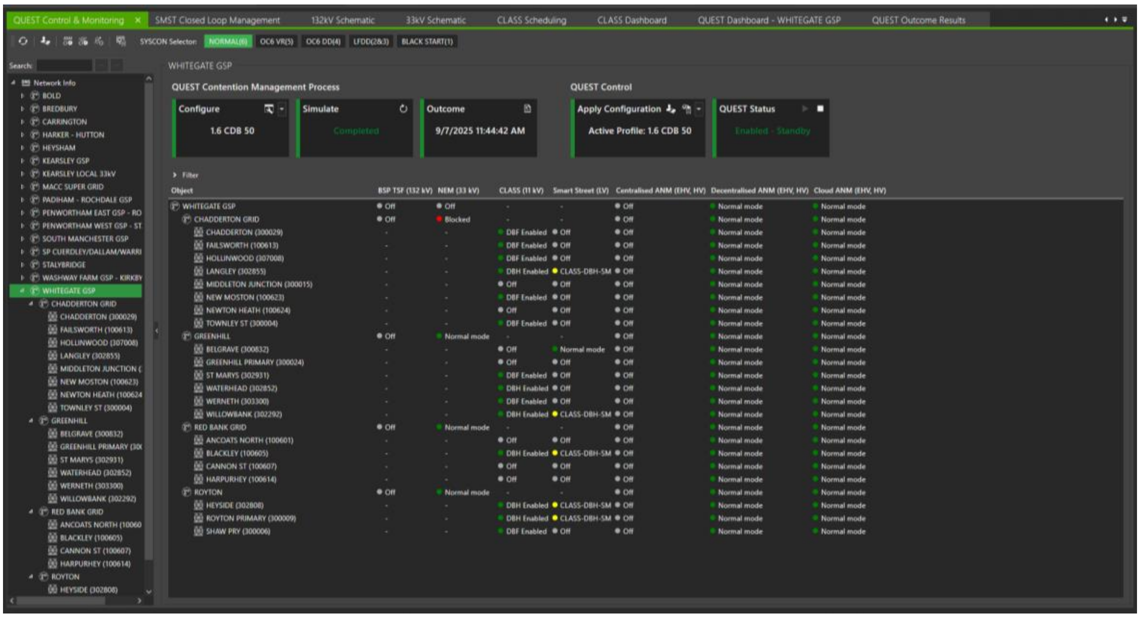


Figure 20 CDB 50 QUEST Dashboard Summary

With CLASS DB set to 50%, QUEST successfully met the full demand boost target as priority 1, while also enabling 10 Smart Street sites (priority 2) and delivering 100% benefit from NEM (priority 3), resulting in a 2.92MW loss reduction. This represents a notable improvement in overall system benefit compared to CLASS DR trials.

The outcome aligns with expectations—NEM's voltage increase at 33kV created headroom via tap adjustments at primary substations, allowing CLASS DB to operate effectively alongside loss reduction. Remaining Smart Street sites were placed in safe mode to maintain voltage compliance, as shown in the Dashboard Summary.

7.2.5. Smart Street Single Technique Trials

The Smart Street single technique trials were designed to validate QUEST's ability to independently control LV voltage optimisation using Conservation Voltage Reduction (CVR) at secondary substations. These tests were conducted with all other voltage control techniques—CLASS & NEM — set to 0%, allowing QUEST to focus solely on Smart Street before optimising with other techniques.

7.2.5.1. Smart Street 100% (SMST 100)

	CLASS DR	CLASS DB	Smart Street	NEM
Priority	2	N/A	1	3
Function Level	0	N/A	100	0

Table 8 SMST 100 Priority & Function Levels

Figure 21 SMST 100 Outcome Results

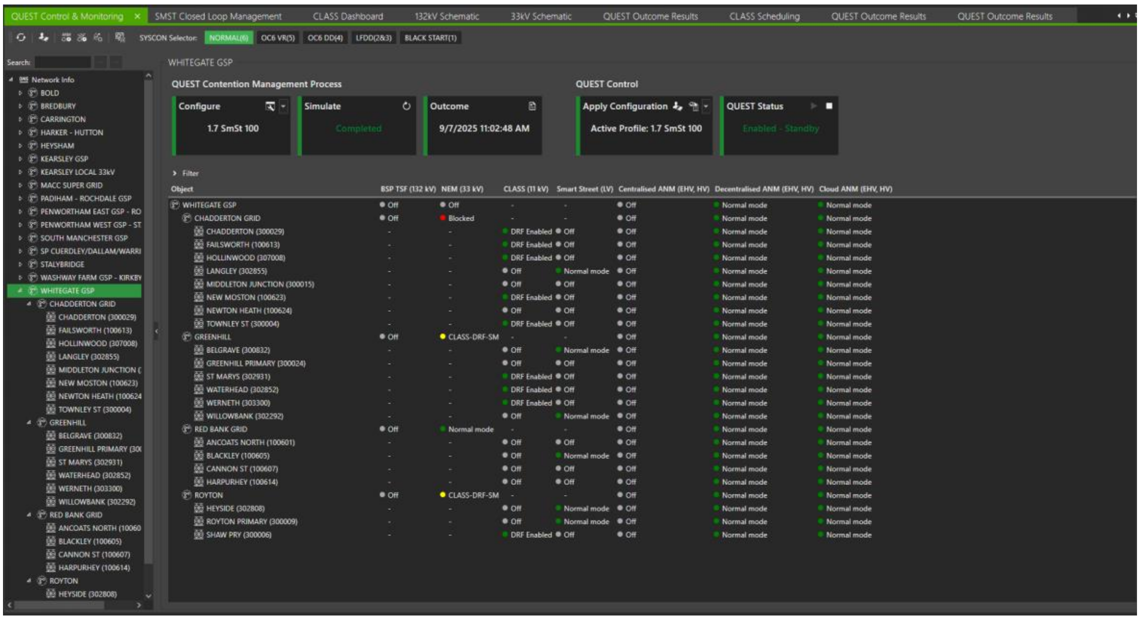


Figure 22 SMST 100 QUEST Dashboard Summary

All 10 available Smart Street sites were activated to deliver benefit to 3070 customers during the trial. In areas without Smart Street coverage, QUEST optimised other techniques—achieving a 2.19MW demand reduction via CLASS DR and a 1.16MW loss reduction through NEM.

7.2.5.2. Smart Street 50% (SMST 50)

	CLASS DR	CLASS DB	Smart Street	NEM
Priority	2	N/A	1	3
Function Level	0	N/A	50	0

Table 9 SMST 50 Priority & Function Levels

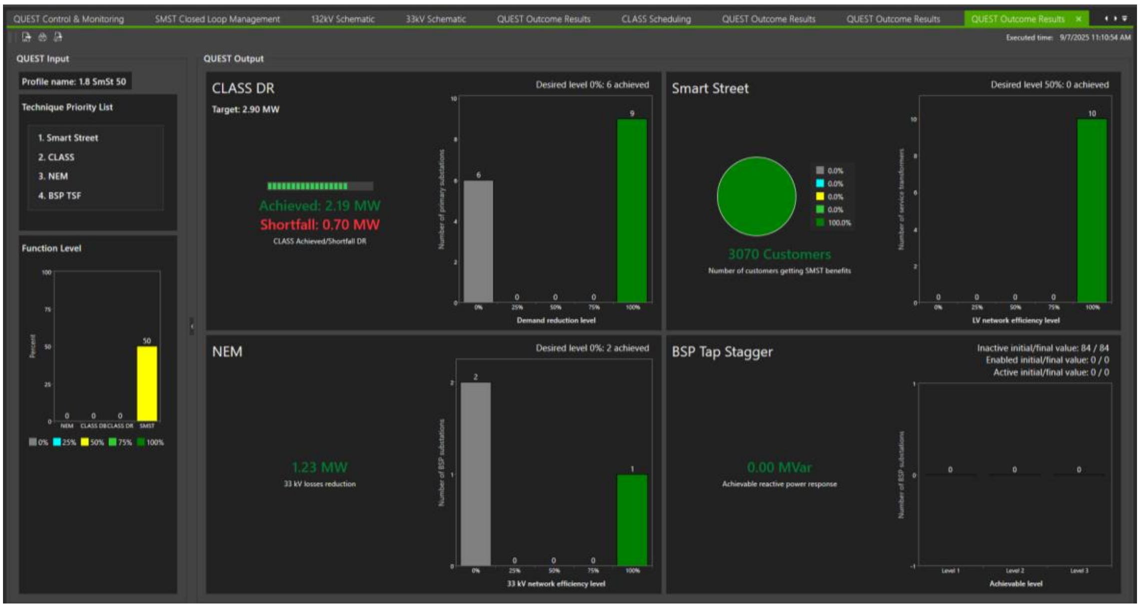


Figure 23 SMST 50 Outcome Results

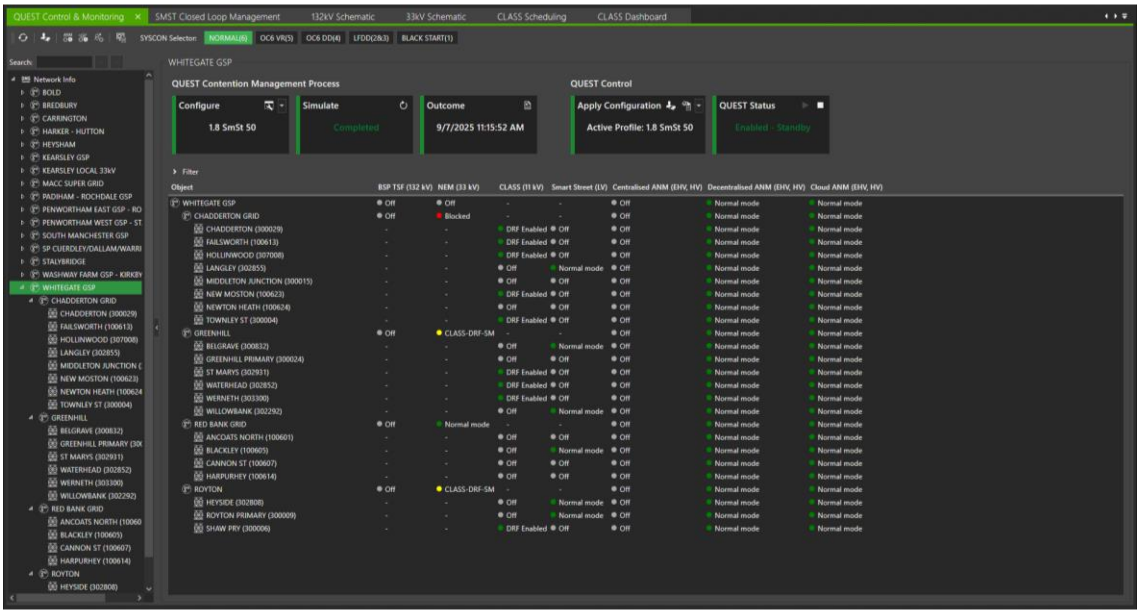


Figure 24 SMST 50 QUEST Dashboard Summary

Similar to previously seen, even at 50% all 10 available Smart Street sites were activated to deliver benefit to 3070 customers during the trial. In areas without Smart Street coverage, QUEST optimised other techniques—achieving a 2.19MW demand reduction via CLASS DR and a 1.23MW loss reduction through NEM slightly above the previous test likely as a result to minor change in network conditions.

7.2.5.3. Summary of Smart Street Single Technique Trials

Although these trials focused on Smart Street in isolation, QUEST's optimisation logic remained active. Once Smart Street achieved its configured objective—or where no Smart Street sites were available—QUEST dynamically enabled lower-priority techniques, even those initially set to 0%, to maximise system benefit.

The trials confirmed QUEST's ability to manage LV voltage optimisation via CVR at secondary substations, with successful tests at 100% and 50% function levels. Voltage targets were met, statutory limits maintained, and demand reduction delivered as expected, validating Smart Street's standalone performance.

7.2.6. Network Efficiency Mode Single Technique Trials

The NEM single technique trials were designed to validate QUEST's ability to independently optimise network efficiency by raising 33kV voltage levels at Bulk Supply Points (BSPs) to reduce system losses. These tests were conducted with all other voltage control techniques—CLASS & Smart Street — set to 0%, allowing QUEST to focus solely on NEM benefit before optimising with other techniques.

7.2.6.1. Network Efficiency Mode 100% (NEM 100)

	CLASS DR	CLASS DB	Smart Street	NEM
Priority	2	N/A	3	1
Function Level	0	N/A	0	100

Table 10 NEM 100 Priority & Function Levels

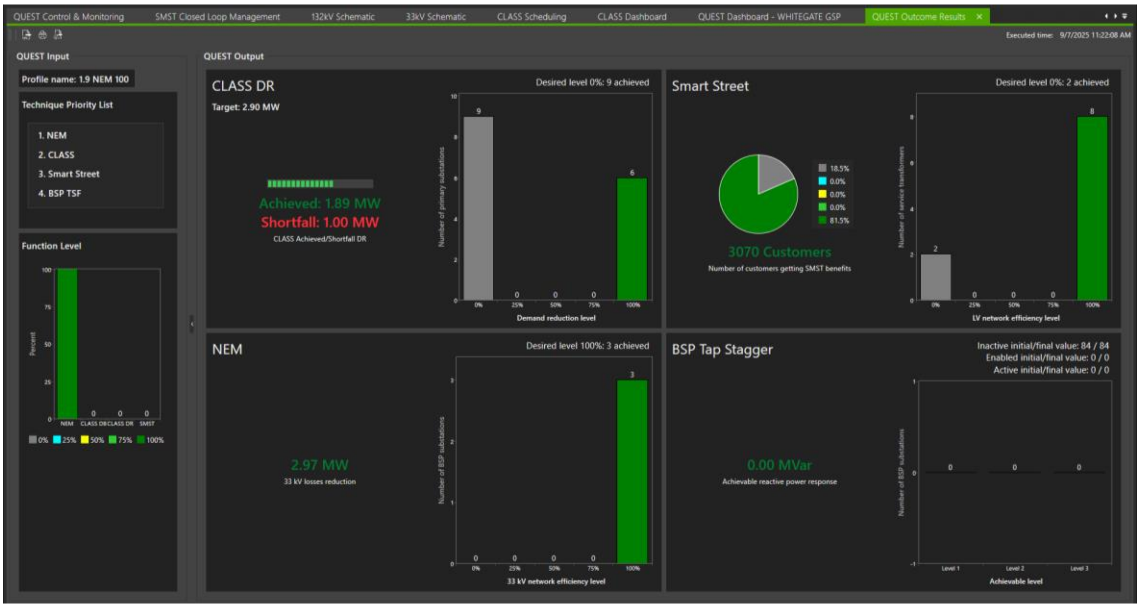


Figure 25 NEM 100 Outcome Results

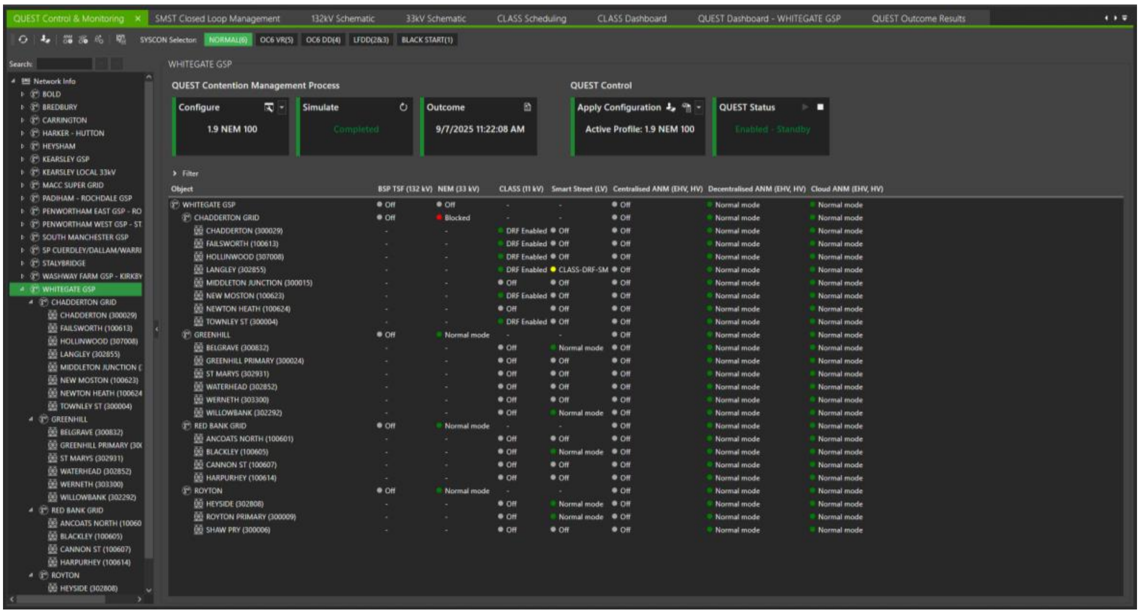


Figure 26 NEM 50 QUEST Dashboard Summary

NEM delivered 2.97MW of network benefit during the trial. Due to operational constraints at Chadderton Grid, one of the four NEM sites was unavailable; however, its connected primary substations contributed a CLASS demand reduction of 1.89MW. Additionally, Smart Street sites—such as Blackley under Red Bank Grid—where NEM was active and CLASS was deactivated, provided CVR benefits to customers.

7.2.6.2. Network Efficiency Mode 50% (NEM 50)

	CLASS DR	CLASS DB	Smart Street	NEM
Priority	2	N/A	3	1
Function Level	0	N/A	0	50

Table 11 NEM 50 Priority & Function Levels

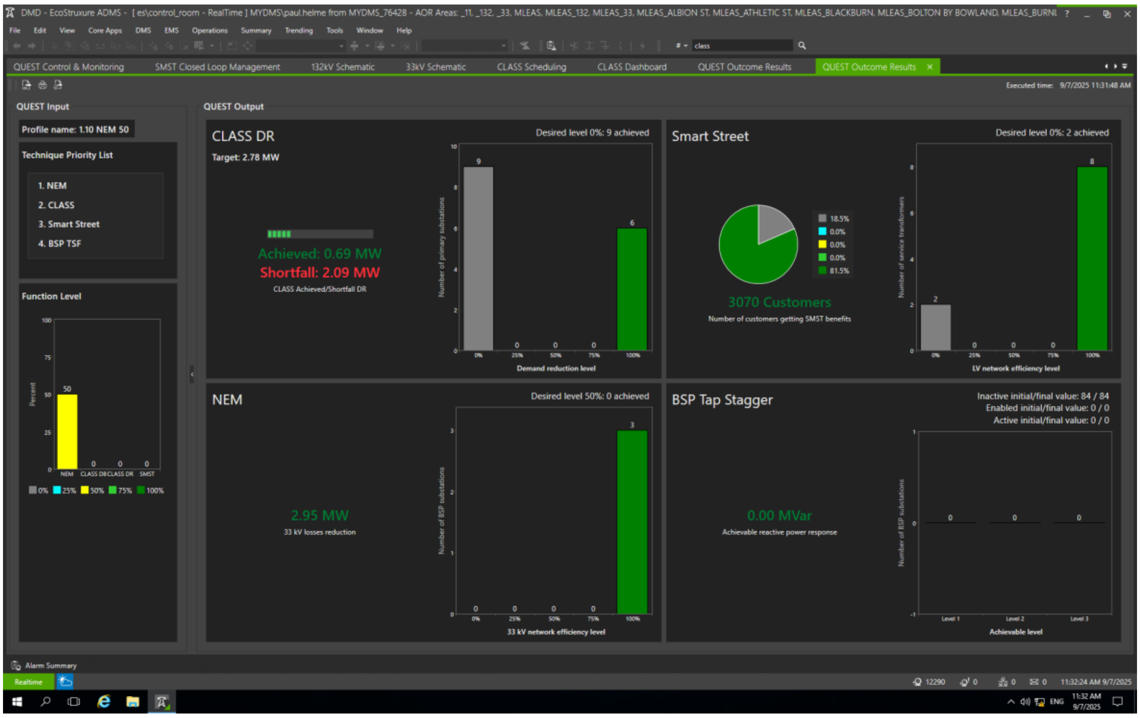


Figure 27 NEM 50 Outcome Results

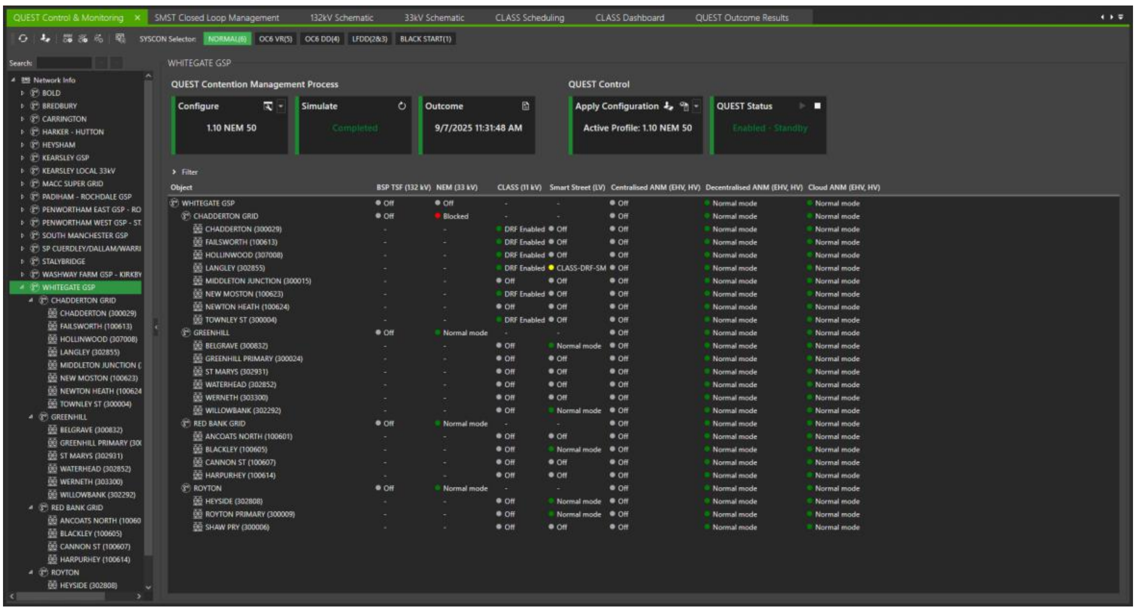


Figure 28 NEM 50 QUEST Dashboard Summary

Coordination at 50% delivered similar NEM benefits to the 100% trial, but CLASS demand reduction dropped significantly from 1.89MW to 0.69MW. This difference is attributed to changes in network connections during the trial, despite using the same sites.

7.2.6.3. Summary of NEM Single Technique Trials

The NEM trials confirmed QUEST's ability to independently optimise network efficiency by raising 33kV voltages at BSPs to reduce system losses. One BSP was unavailable due to operational constraints, but its connected primary substations contributed CLASS demand reduction benefits.

Activated BSPs delivered maximum NEM benefit, and their associated primary substations showed no CLASS demand reduction—allowing Smart Street sites, such as Blackley under Red Bank Grid, to provide CVR benefits. Loss reduction was in line with expectations, with no over-voltage issues observed during low-load periods.

7.2.7. Single Technique Trials Summary

The single technique trials confirmed that QUEST can successfully coordinate and control each voltage management technique—CLASS DR, CLASS DB, Smart Street & NEM —when operating in isolation. In every case, QUEST tried to maximise the benefits of the chosen voltage control technique which means:

- Allowing it to run in Normal mode of operation in case of Smart Street,
- Applying the required level of demand increase/decrease to satisfy the targets, in case of CLASS DB/DR
- Allowing it to run on the maximum level of voltage increase in case of NEM.

The single technique trials also confirmed the logic and response levels within the BaU CLASS and Smart Street functionality had been ported correctly to within the QUEST software being tested.

Importantly, QUEST's optimisation logic remained active throughout these tests, ensuring that once the highest-priority technique met its target, additional techniques could be enabled to capture further benefits where conditions allowed. This behaviour demonstrates QUEST's dynamic, benefit-driven approach to maximising overall system performance, even in scenarios designed to focus on a single function.

7.3. Multi-Technique Trials

The multi-technique trials were designed to assess QUEST's ability to coordinate and optimise multiple voltage control techniques operating simultaneously under realistic network conditions. These included combinations of CLASS DR, Smart Street, NEM, and occasionally CLASS DB, with varying function levels and priority orders. The trials evaluated how QUEST resolves conflicts, applies safe mode logic, and delivers system benefits without breaching voltage compliance.

Although BSP Tap Stagger (TSF) functionality was designed into QUEST and BSP TS successfully tested in isolation, early results showed it had no material impact on the optimisation of other techniques. TSF trials confirmed that the system consistently had sufficient headroom (Tap positions) to meet voltage targets for CLASS, Smart Street, and NEM, regardless of whether tap stagger was active. To maintain clarity and focus, TSF was excluded from the multi-technique coordination trials.

The optimisation analysis therefore concentrates on CLASS, Smart Street, and NEM, where meaningful interdependencies were observed. A selection of representative trials is presented in this report to illustrate QUEST's coordination capabilities; however, these examples are not exhaustive and do not reflect the full scope of testing undertaken.

7.3.1. QUEST Sites Selected for Multi-Technique Trials (2 Techniques)

The following table summarises the sites used during the Multi-Technique Trials.

Table 12 QUEST Sites Selected for Multi-Technique Trials

CLASS	Smart Street	NEM
Under Chadderton Grid • Chadderton • Failsworth • Hollinwood • Langley • New Moston • Townley St Under Greenhill • Belgrave • St Marys • Waterhead • Werneth • Willowbank Under Red Bank Grid • Blackley Under Royton • Heyside • Royton Primary • Shaw Pry	Under Heyside Primary: • Goldsmith Ave Under Royton Primary: • Beechwood • Consort Ave • Oozewood Rd Under Blackley Primary: • Victoria Ave Under Willowbank Primary: • Ashdene CL Under Belgrave Primary: • Fold View • Rosary CL Under Langley Primary • Searness Rd • Kirkstone Dr	Under Whitegate GSP • Greenhill • Red Bank Grid • Royton

7.3.2. Known Constraints during Multi-Technique Trials

As the QUEST trials were conducted on a live operational network, certain practical limitations were unavoidable. Throughout the testing period, some sites were temporarily unavailable due to scheduled maintenance, asset outages, or manual inhibits applied for operational safety.

In several cases, specific transformers or substations were blocked from participating in trials to avoid interference with ongoing network activities. These restrictions are a natural part of working within a real-world distribution environment and were carefully managed to ensure trials remained representative and safe. Where applicable, these constraints have been noted in the table below:

Table 13 List of Known Constraints During Trials

Constraints observed during Single Technique trails
• Chadderton Grid unavailable for NEM trials • Harpurhey Primary unavailable for CLASS trials

7.3.3. CLASS Demand Reduction / Smart Street Trials

These trials were designed to validate QUEST's ability to coordinate two core voltage management techniques—CLASS DR at primary substations and Smart Street CVR at secondary substations—when operating simultaneously. The aim was to ensure QUEST could apply the correct prioritisation logic, enabling the higher-priority technique to meet its target first while maintaining statutory voltage limits across the network.

Once the primary objective was achieved, QUEST was expected to optimise further by enabling the secondary technique to deliver additional benefit without causing low-voltage violations. These trials demonstrate QUEST's capability to dynamically balance multiple control strategies and maximise overall system performance under realistic operating conditions.

7.3.3.1. CLASS DR and Smart Street 100 (CDR 100 SMST 100)

	CLASS DR	CLASS DB	Smart Street	NEM
Priority	1	N/A	2	3
Function Level	100	N/A	100	0

Table 14 CDR 100 SMST 100 Priority & Function Levels

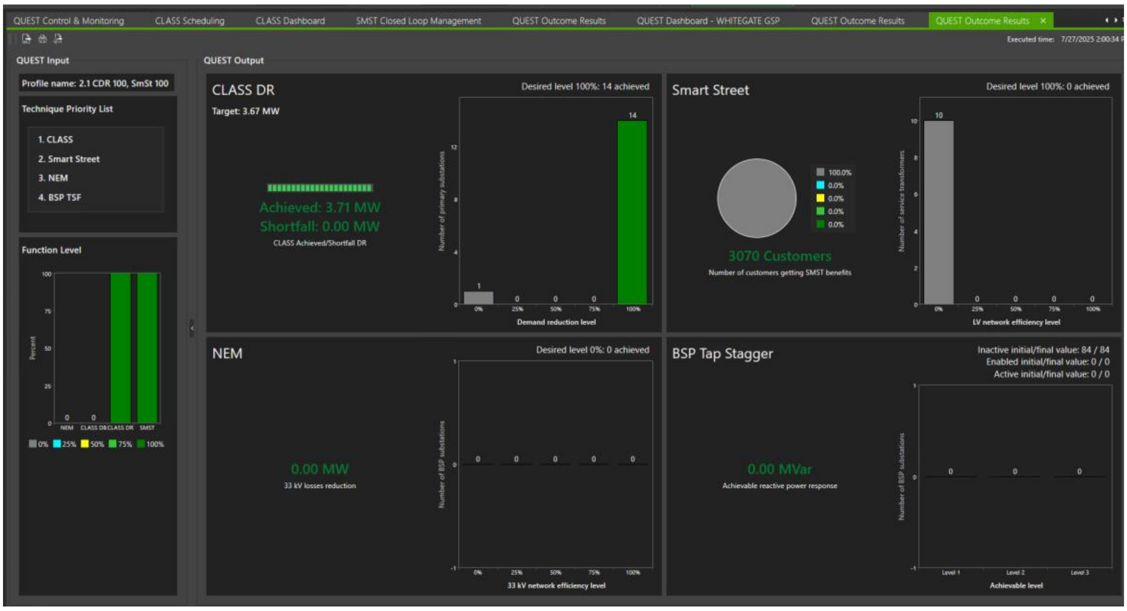


Figure 29 CDR 100 SMST 100 Outcome Results

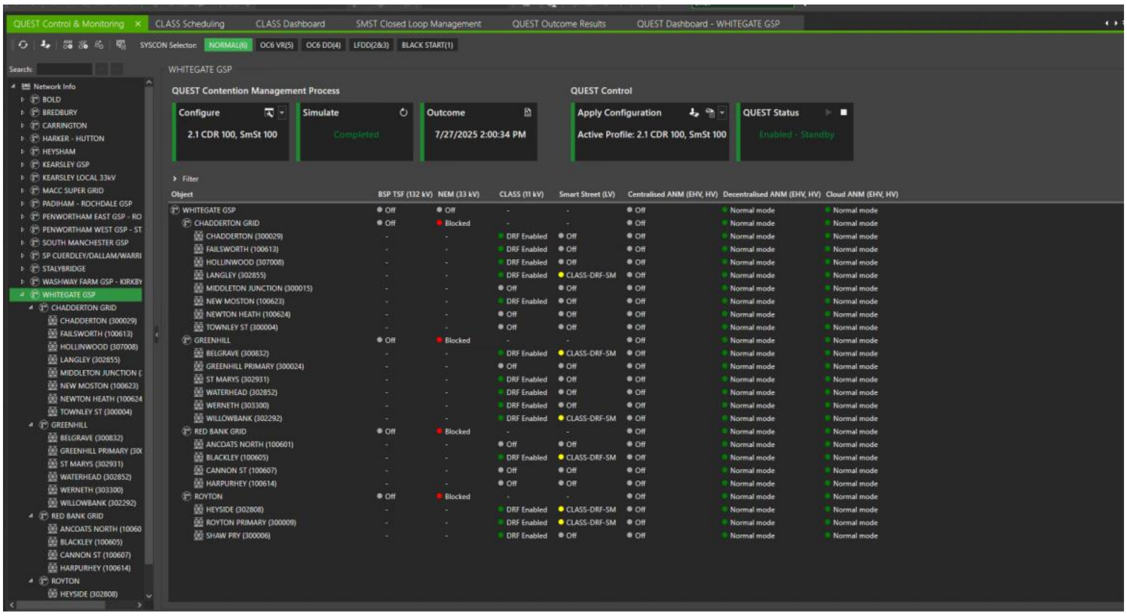


Figure 30 CDR 100 SMST 100 QUEST Dashboard Summary

With CLASS as priority 1 and 100% function level, QUEST has enabled all available CLASS sites achieving 3.71MW reduction on a target of 3.67MW. All available Smart Street sites are connected to primary substations which have been used to CLASS and are therefore not available to provide Smart Street benefit.

7.3.3.2. Smart Street & Class DR 100 (SMST 100 CDR 100)

	CLASS DR	CLASS DB	Smart Street	NEM
Priority	2	N/A	1	3
Function Level	100	N/A	100	0

Table 15 SMST 100 CDR 100 Priority & Function Levels

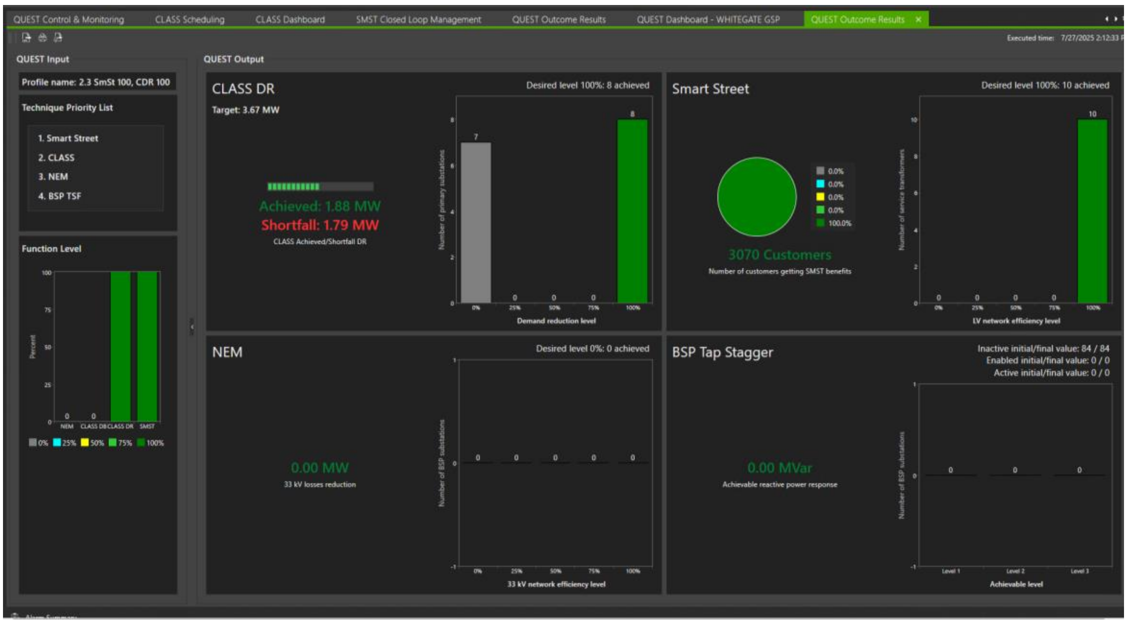


Figure 31 SMST 100 CDR 100 Outcome Results

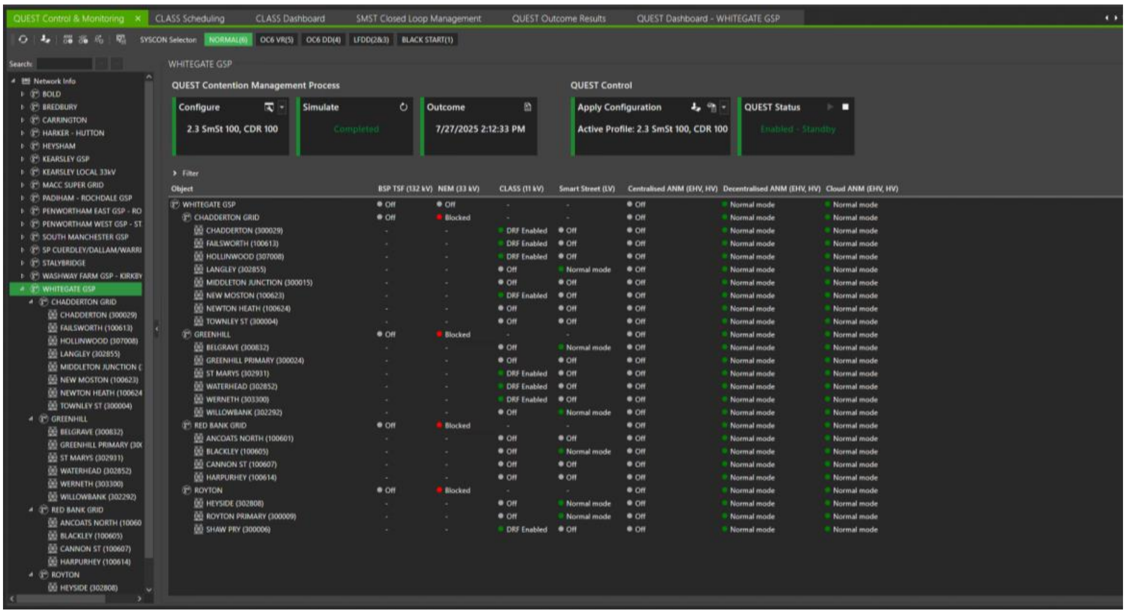


Figure 32 SMST 100 CDR 100 QUEST Dashboard Summary

With priority 1 changed from CLASS to Smart Street, we can now observe all 10 available Smart Street sites have been activated providing benefit to 3070 customers. The primary substations which do not have Smart Street sites connected, are providing CLASS DR benefit of 1.88MW.

7.3.3.3. Class DR & Smart Street 50 (CDR 50 SMST 50)

	CLASS DR	CLASS DB	Smart Street	NEM
Priority	1	N/A	2	3
Function Level	50	N/A	50	0

Table 16 CDR 50 SMST 50 Priority & Function Levels

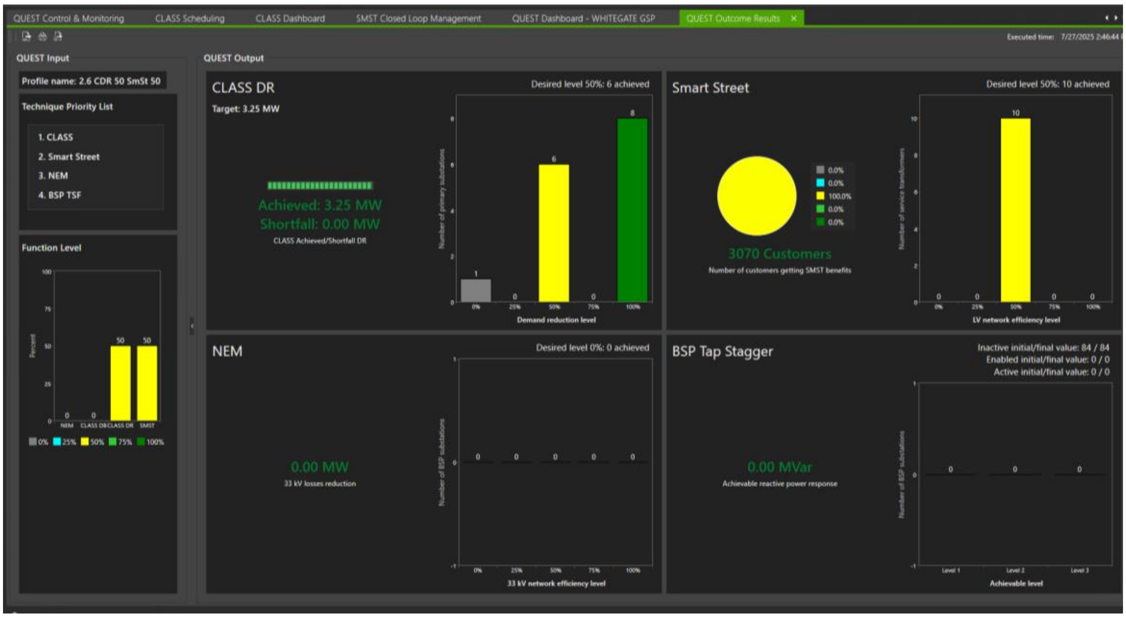


Figure 33 CDR 50 SMST 50 Outcome Results

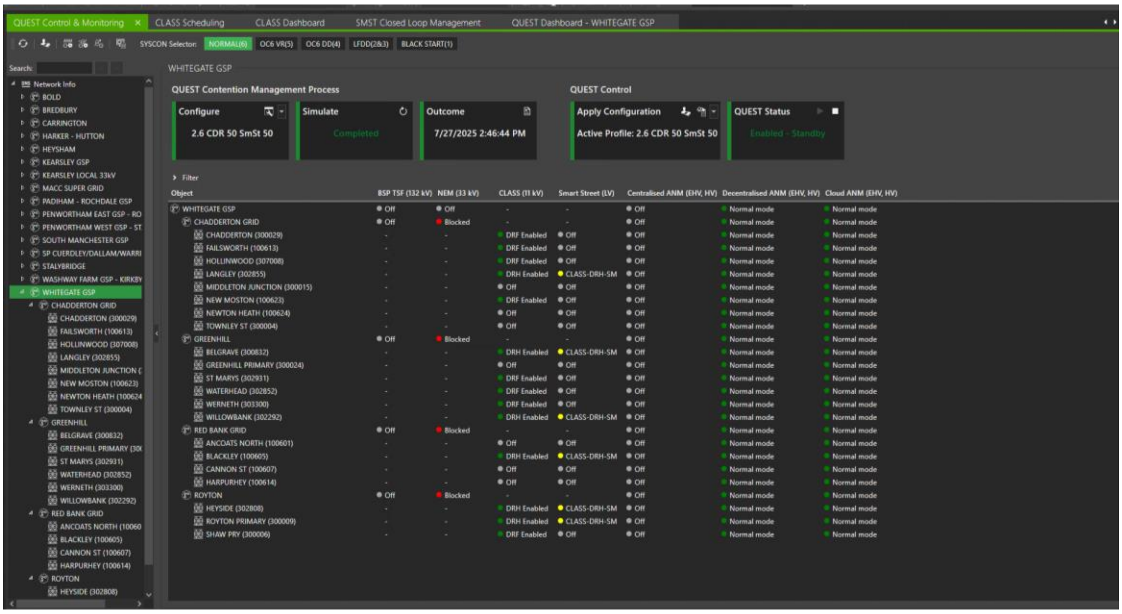


Figure 34 CDR 50 SMST 50 QUEST Dashboard Summary

The same trials have then been re-run but with the function levels set to 50%. With CLASS as priority 1, the system has managed to achieve its CLASS target of 3.25MW. In contrast to the 100% function level, QUEST has now been able to operate Smart Street at the remaining CLASS sites using their 50% voltage set points providing CVR benefit to customer connected. Please note that QUEST has raised the DR level from DRH to DRF for several CLASS primaries to meet CLASS targets. The selected primaries were carefully chosen to avoid impacting Smart Street benefits, ensuring that none of them supply areas with Smart Street enabled.

7.3.3.4. Smart Street & CLASS DR 50 (SMST 50 CDR 50)

	CLASS DR	CLASS DB	Smart Street	NEM
Priority	2	N/A	1	3
Function Level	50	N/A	50	0

Table 17 SMST 50 CDR 50 Priority & Function Levels

Figure 35 SMST 50 CDR 50 Outcome Results

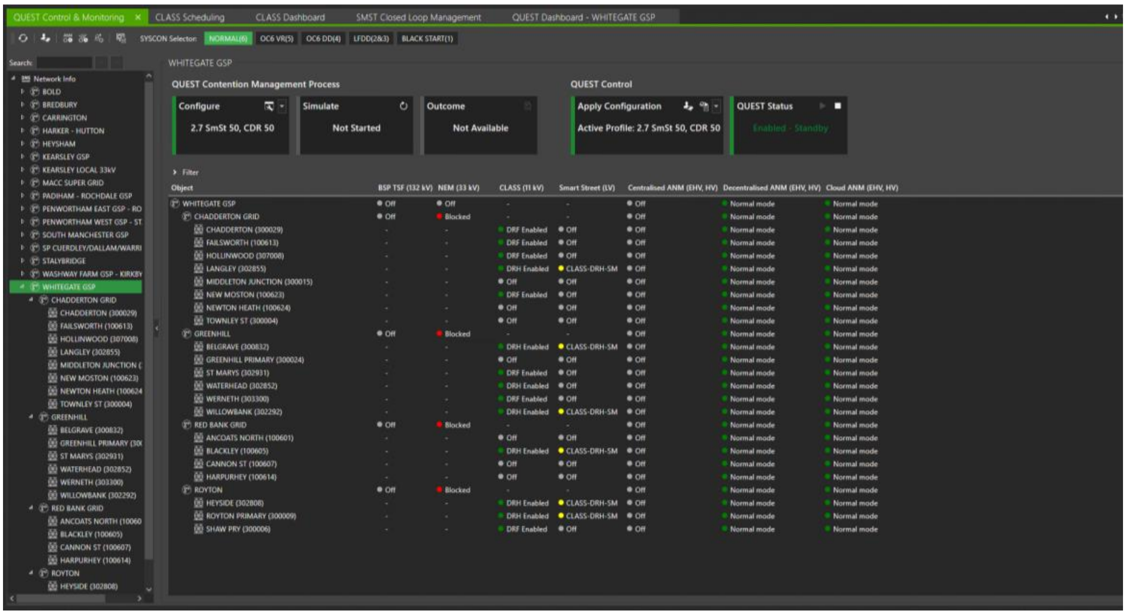


Figure 36 SMST 50 CDR 50 QUEST Dashboard Summary

With the function level still set to 50% but the priority order changed from CLASS in priority 1 to Smart Street we can observe a similar response with all 10 Smart Street sites providing benefit. The only notable difference was the CLASS target was reduced; CLASS was therefore able to achieve its new target with more sites set to demand reduction half instead of full.

7.3.3.5. Summary of CLASS DR & Smart Street Trials

These trials confirmed QUEST's ability to coordinate CLASS DR and Smart Street under different priorities and function levels. QUEST consistently ensured the highest-priority technique achieved its target first, then enabled the next technique to maximise benefit—all while maintaining voltage compliance. This demonstrates QUEST's dynamic optimisation and effective conflict management between HV and LV controls.

7.3.4. CLASS Demand Boost / Smart Street Trials

These trials were designed to validate QUEST's ability to coordinate high-voltage demand boost actions with low-voltage optimisation using Smart Street. The objective was to ensure that when both techniques are active, QUEST applies the correct priority order, prevents conflicts, and maintains statutory voltage limits. By testing different function levels and priorities, these trials assessed how QUEST balances the need to increase demand at the HV level while optimising LV voltages for efficiency, demonstrating its capability to deliver combined benefits without compromising network stability.

7.3.4.1. CLASS DB & Smart Street 100 (CDB 100 SMST 100)

	CLASS DR	CLASS DB	Smart Street	NEM
Priority	N/A	1	2	3
Function Level	N/A	100	100	0

Table 18 CDB 100 SMST 100 Priority & Function Levels

Figure 37 CDB 100 SMST 100 Outcome Results

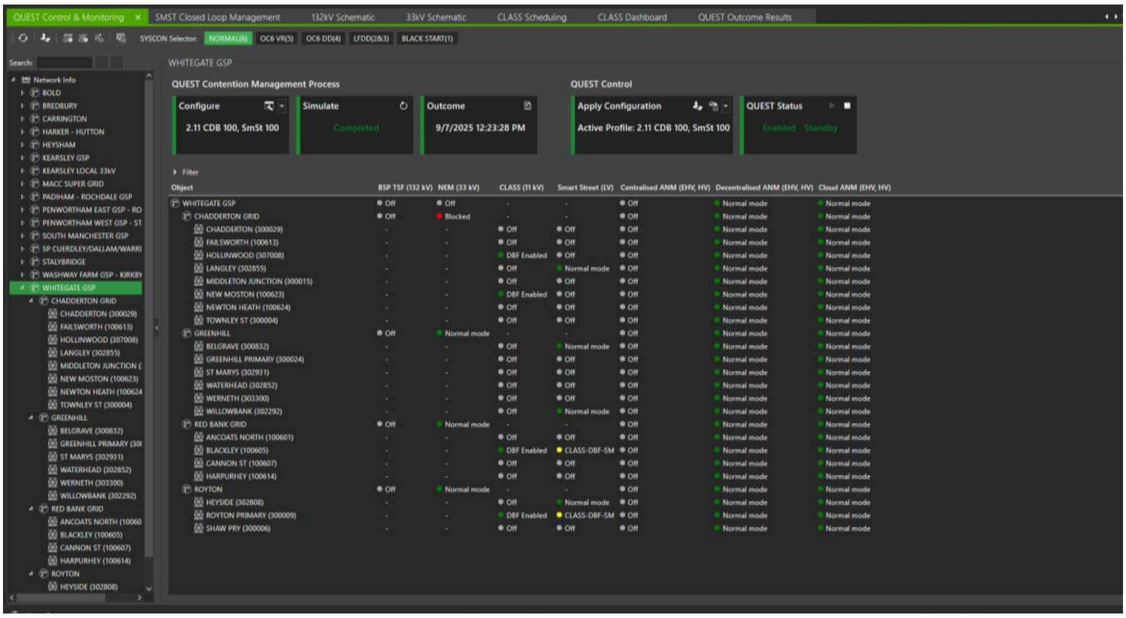


Figure 38 SMST 50 CDR 50 QUEST Dashboard Summary

The first trial prioritised CLASS DB over Smart Street both at 100% function level, to meet the CLASS target of 1.33MW – QUEST selected 4 CLASS sites, 2 of which has Smart Street sites connected. The sites with Smart Street connected were put into their Safe Mode to avoid voltage violations whilst the remaining 6 sites were able to achieve CVR benefit to connected customers. NEM was also unblocked in these trials and was able to achieve 3.07MW loss reduction. As was observed in the single technique trials, NEM can be operated at 100% without impacting CLASS DB functionality.

7.3.4.2. Smart Street & CLASS DB 50 (CDB 50 SMST 50)

	CLASS DR	CLASS DB	Smart Street	NEM
Priority	2	N/A	1	3
Function Level	50	N/A	50	0

Table 19 SMST 50 CDR 50 Priority & Function Levels

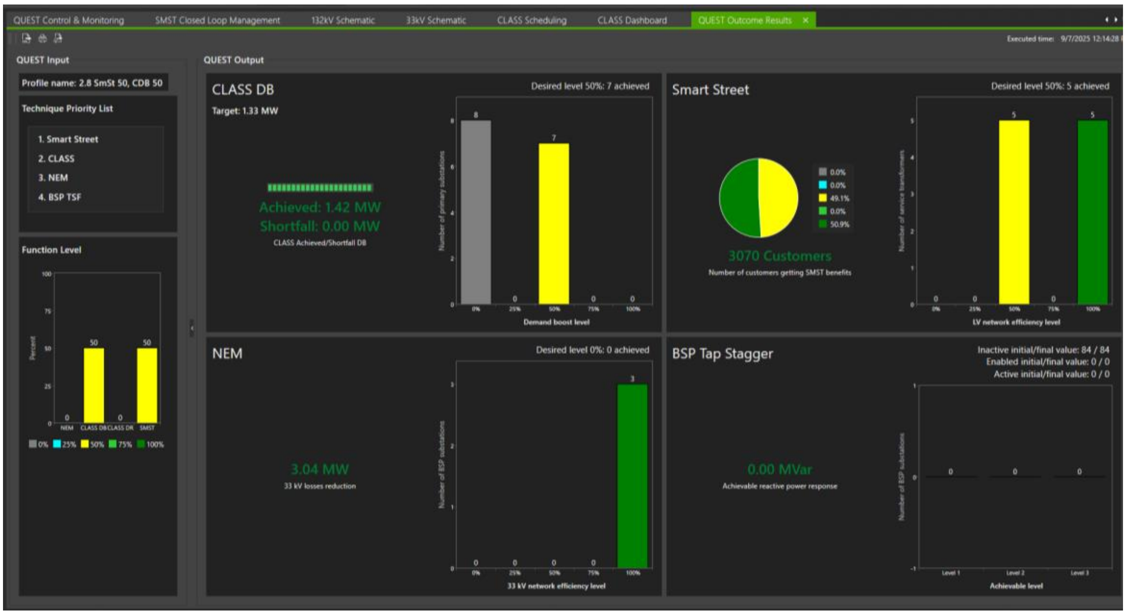


Figure 39 SMST 50 CDB 50 Outcome Results

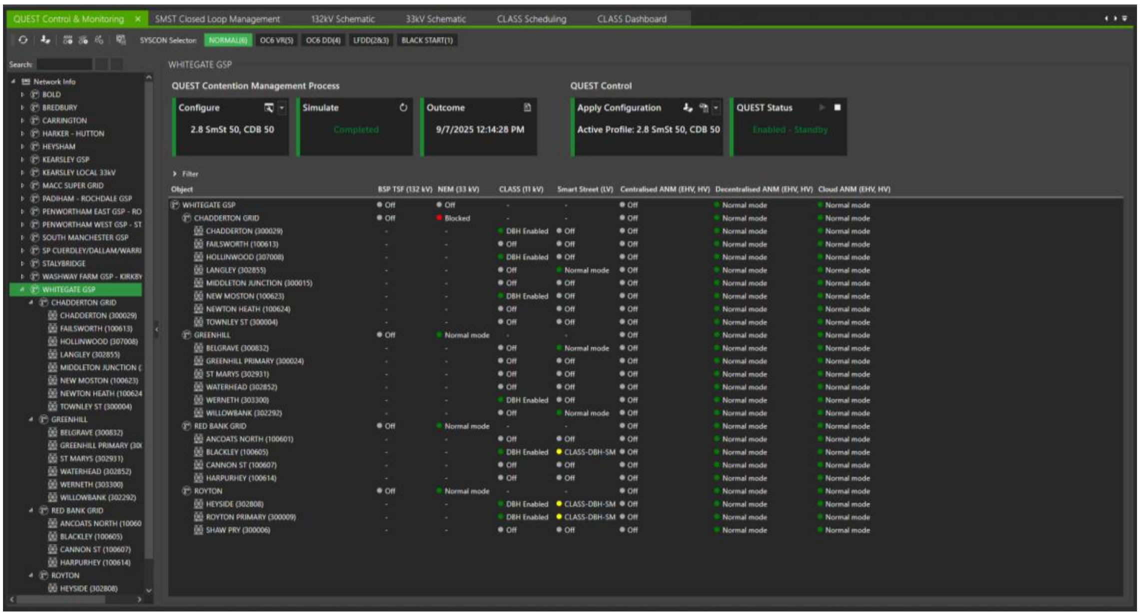


Figure 40 SMST 50 CDB 50 QUEST Dashboard Summary

With priority 1 changed from CLASS DB to Smart Street and the function level changed from 100% to 50%, it can be observed that an additional four Smart Street sites are now activated providing greater CVR benefit and demonstrating QUEST correctly prioritising the Smart Street response over CLASS. Even with the additional Smart Street sites activated, CLASS was still able to provide to achieve its target value of 1.33MW with 7 sites activated. Despite being set to 0%, NEM is also able to provide 100% of its available benefit equating to 3.04MW losses reduction.

7.3.4.3. Summary of CLASS DB & Smart Street Trials

These trials validated QUEST's ability to coordinate CLASS DB and Smart Street under different priority settings. When CLASS DB was prioritised, QUEST successfully raised HV voltages to achieve demand boost targets while ensuring LV voltages remained within statutory limits.

When Smart Street was given higher priority, QUEST adjusted CLASS DB, accordingly, allowing LV optimisation first without compromising system stability. Across all scenarios, QUEST demonstrated dynamic optimisation—maximising benefit from the leading technique before enabling the next in priority order.

7.3.5. QUEST Sites Selected for Multi-Technique Trials (3 Techniques)

The following table summarises the sites used during the Multi-Technique Trials (3 Techniques).

Table 20 QUEST Sites Selected for Multi-Technique Trials

CLASS	Smart Street	NEM
Under Chadderton Grid • Chadderton • Failsworth • Hollinwood • Langley • New Moston • Townley St Under Greenhill • Belgrave • St Marys • Waterhead • Werneth • Willowbank Under Red Bank Grid • Blackley Under Royton • Heyside • Royton Primary • Shaw Pry	Under Heyside Primary: • Goldsmith Ave Under Royton Primary: • Beechwood • Consort Ave • Oozewood Rd Under Blackley Primary: • Victoria Ave Under Willowbank Primary: • Ashdene CL Under Belgrave Primary: • Fold View • Rosary CL Under Langley Primary • Searness Rd • Kirkstone Dr	Under Whitegate GSP • Greenhill • Red Bank Grid • Royton

7.3.6. Known Constraints during Multi-Technique Trials

As the QUEST trials were conducted on a live operational network, certain practical limitations were unavoidable. Throughout the testing period, some sites were temporarily unavailable due to scheduled maintenance, asset outages, or manual inhibits applied for operational safety.

In several cases, specific transformers or substations were blocked from participating in trials to avoid interference with ongoing network activities. These restrictions are a natural part of working within a real-world distribution environment and were carefully managed to ensure trials remained representative and safe. Where applicable, these constraints have been noted in the table below:

Table 21 List of Known Constraints During Trials

Constraints observed during Single Technique trails
• Chadderton Grid unavailable for NEM trials
• Harpurhey Primary unavailable for CLASS trials

7.3.7. CLASS DR, Smart Street, NEM 100 (CDR 100, SMST 100, NEM 100)

	CLASS DR	CLASS DB	Smart Street	NEM
Priority	1	N/A	2	3
Function Level	100	N/A	100	100

Table 22 CDR 100 SMST 100, NEM 100 Priority & Function Levels

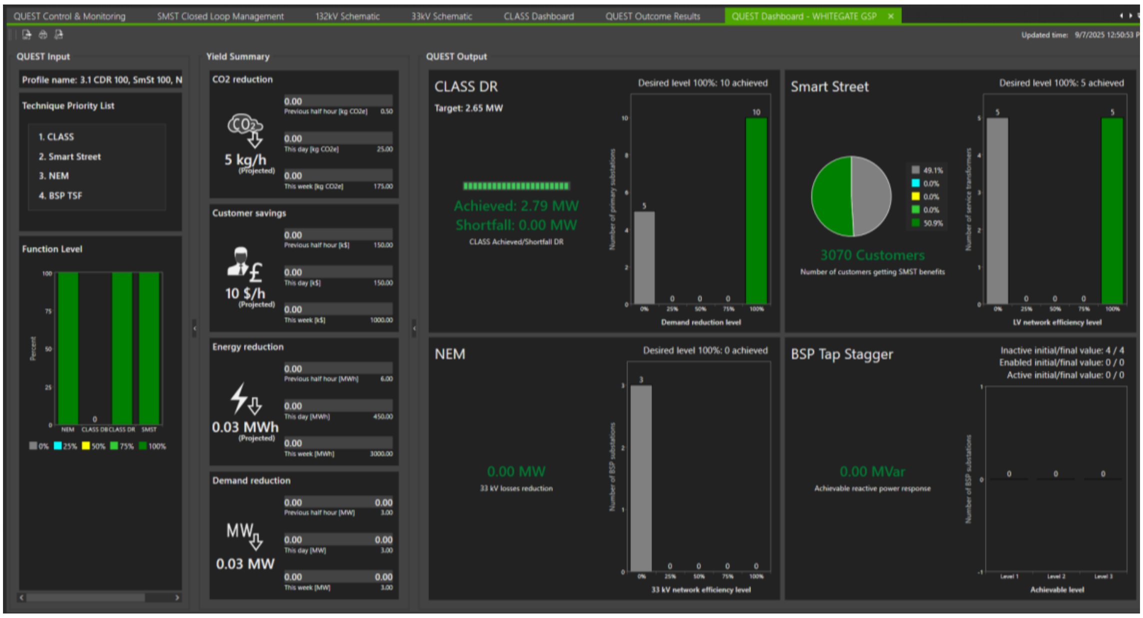


Figure 41 CDR 100 SMST 100 NEM 100 Outcome Results

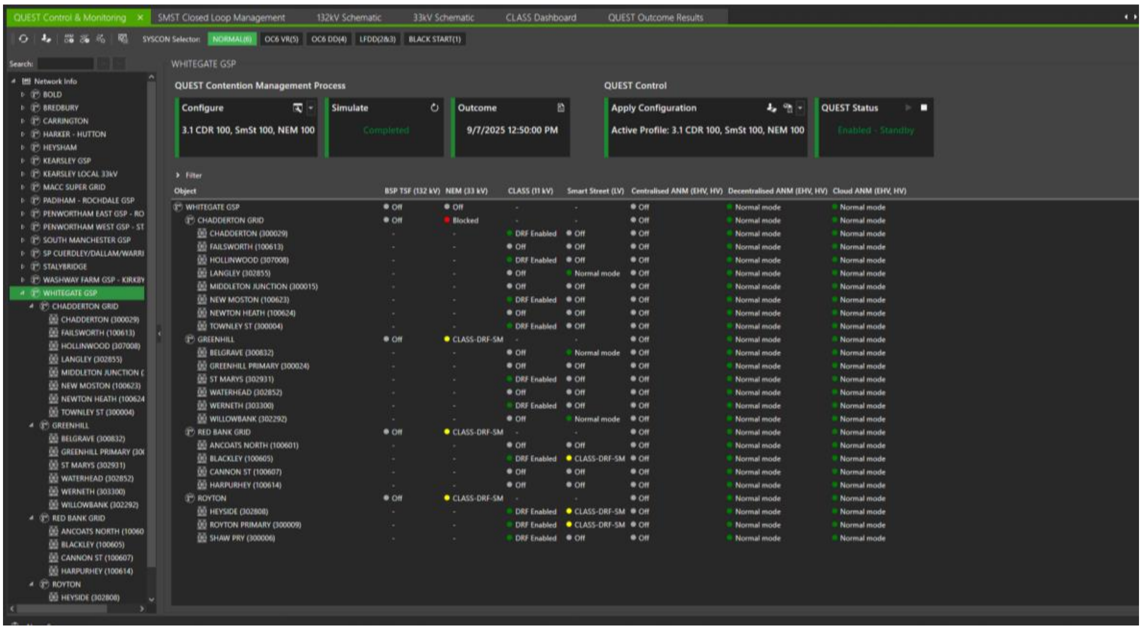


Figure 42 CDR 100 SMST 100 NEM 100 QUEST Dashboard Summary

In this trial, QUEST prioritised CLASS DR, followed by Smart Street and NEM, with all techniques set to 100% function level. CLASS DR successfully met its target of 2.65 MW, delivering a 2.79 MW response across ten sites. Once the target was achieved, QUEST disabled CLASS sites connected to Smart Street, allowing CVR benefits to be realised at five secondary substations. This provided measurable benefit to customers while maintaining voltage compliance. As CLASS was fully active across the serving BSPs, NEM did not contribute any loss reduction benefit during this trial.

7.3.8. Smart Street, NEM, CLASS DR 100 (SMST 100, NEM 100, CDR 100)

	CLASS DR	CLASS DB	Smart Street	NEM
Priority	3	N/A	1	2
Function Level	100	N/A	100	100

Table 23 SMST 100, NEM 100, CDR 100 Priority & Function Levels

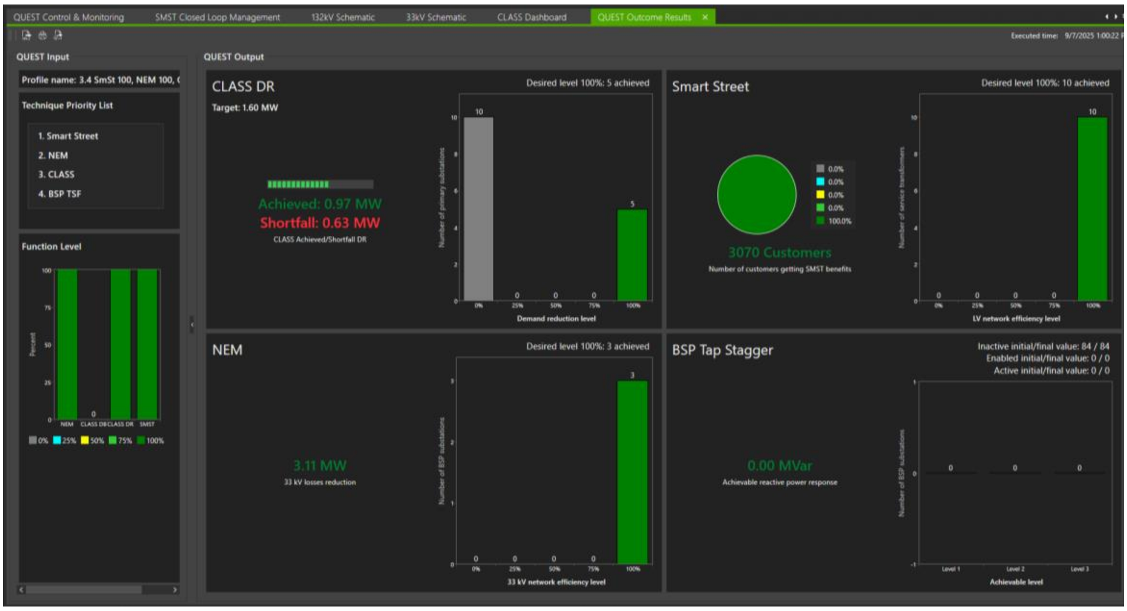


Figure 43 SMST 100, NEM 100, CDR 100 Outcome Results

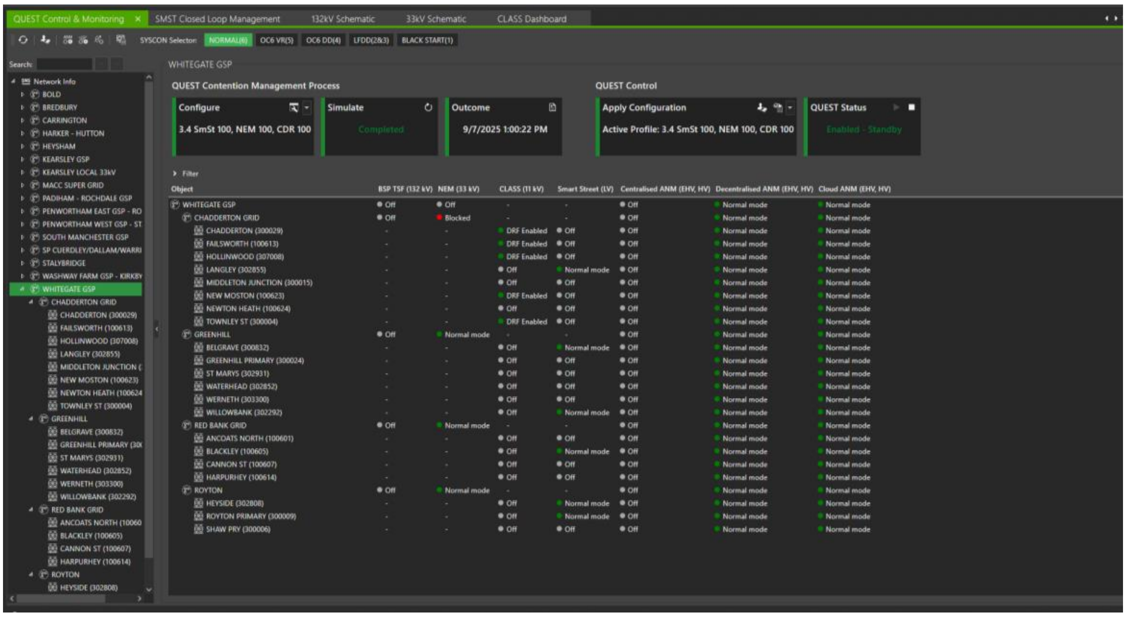


Figure 44 SMST 100, NEM 100, CDR 100 QUEST Dashboard Summary

In this trial, the priority order changed to Smart Street, followed by NEM, and then CLASS SR with all systems operating at 100% function level. Smart Street successfully activated all ten available sites, delivering CVR benefits to 3,070 customers. NEM achieved its full potential, reducing losses by 3.11 MW. CLASS also delivered a demand reduction of 0.97 MW; however, this outcome was likely influenced by an operational constraint at Chadderton Grid. It is anticipated that, if this restriction were removed, NEM's loss reduction would have been greater, and CLASS DR's response would have approached 0 MW.

7.3.9. NEM, Smart Street, CLASS DR, (NEM 100, SMST 100, CDR 100)

	CLASS DR	CLASS DB	Smart Street	NEM
Priority	3	N/A	2	1
Function Level	100	N/A	100	100

Table 24 NEM 100, SMST 100, CDR 100 Priority & Function Levels

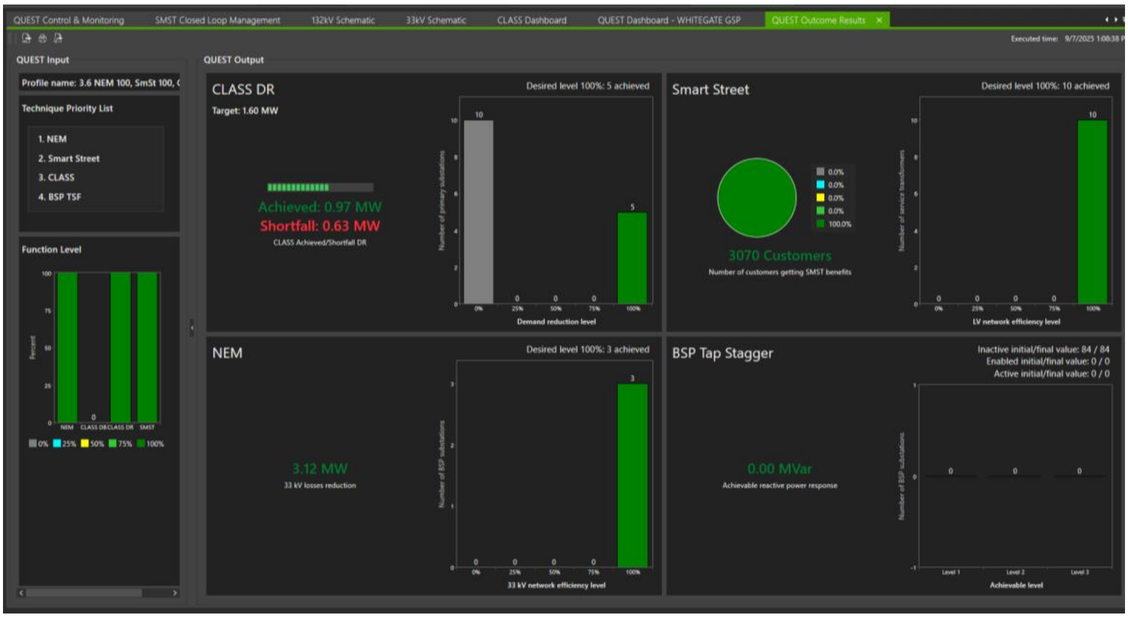


Figure 45 NEM 100, SMST 100, CDR 100 Outcome Results

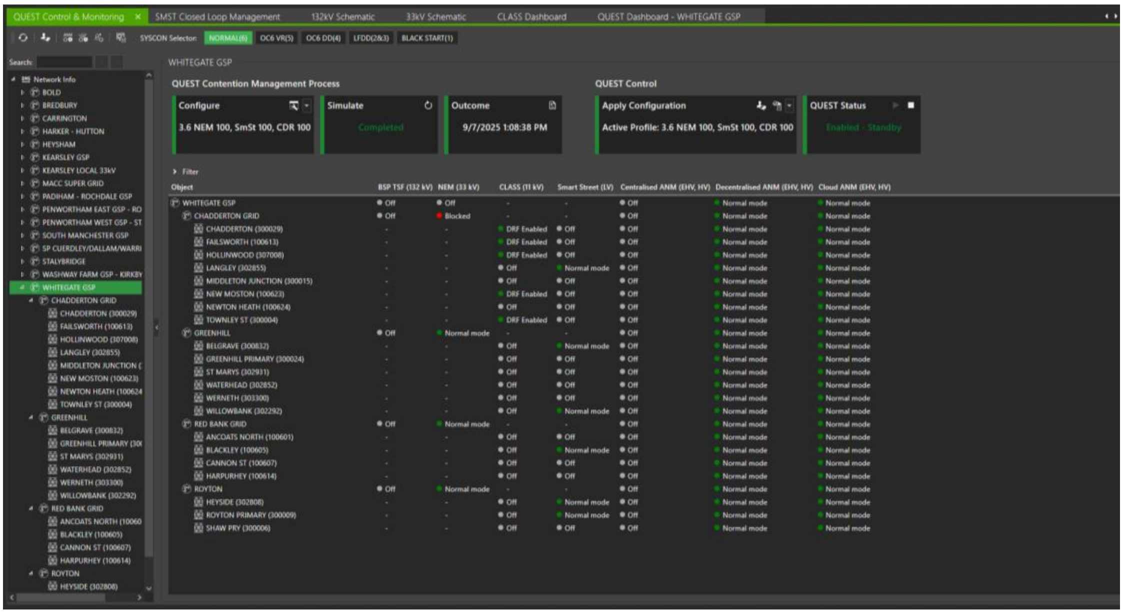


Figure 46 SMST 100, NEM 100, CDR 100 QUEST Dashboard Summary

With the priority order adjusted to NEM, followed by Smart Street and then CLASS DR, the system's overall response remained largely consistent with the previous test. CLASS operates at an intermediate voltage level—between NEM's 33kV and SMST's 0.4kV—so assigning it a lower priority allows both NEM and SMST to diminish CLASS's potential benefit in favour of their own. This trial has demonstrated that SMST and NEM do not directly influence each other unless CLASS is actively engaged.

7.3.10. CLASS DB, NEM, Smart Street 100 (CDB 100, NEM 100, SMST 100,)

	CLASS DR	CLASS DB	Smart Street	NEM
Priority	N/A	1	3	2
Function Level	N/A	100	100	100

Table 25 CDB 100, NEM 100, SMST 100 Priority & Function Levels

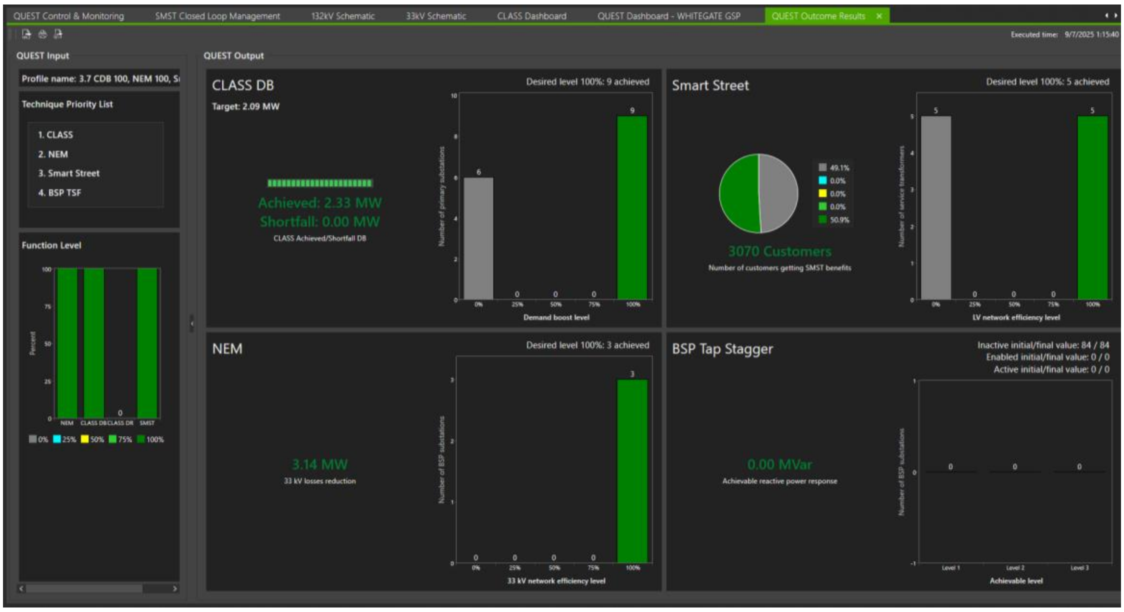


Figure 47 CDB 100, NEM 100, SMST 100 Outcome Results

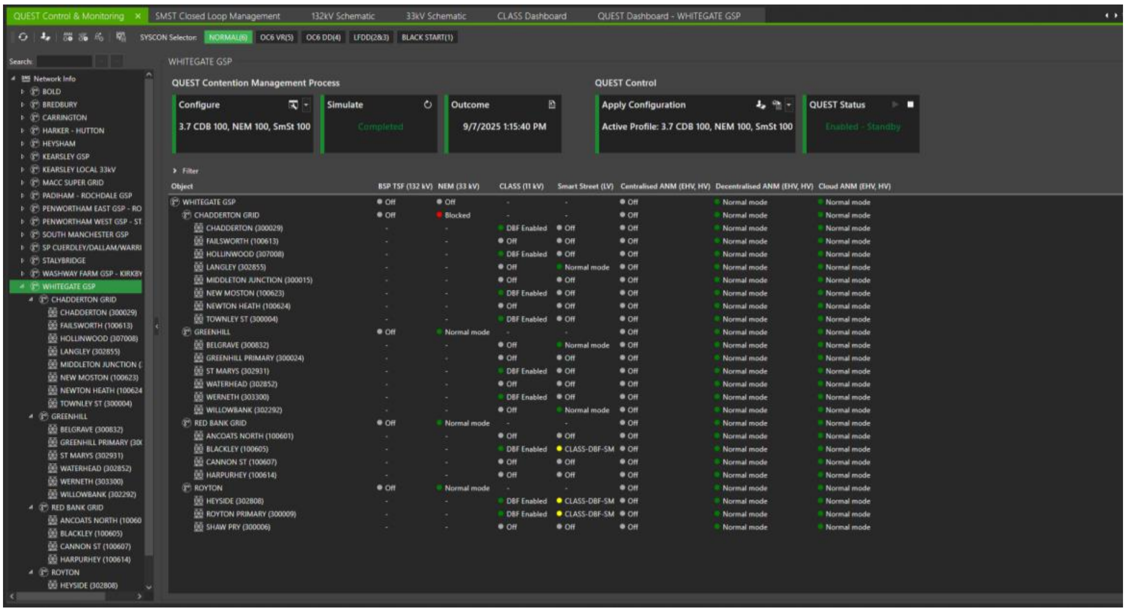


Figure 48 CDB 100, NEM 100, SMST 100 QUEST Dashboard Summary

This trial prioritised CLASS DB over NEM and Smart Street. QUEST successfully enabled CLASS DB to meet its target of 2.09 MW, delivering a 2.33 MW response across nine sites. Once the target was achieved, QUEST disabled CLASS sites connected to Smart Street, allowing CVR benefits to be realised at five secondary substations—benefiting over 1,500 customers. NEM also operated effectively, achieving its maximum loss reduction benefit of 3.14 MW across three BSPs. As observed in previous trials, NEM complements rather than conflicts with CLASS DB, enabling both techniques to meet their respective objectives without compromise – this was anticipated during the QUEST design phase that NEM would only conflict with CLASS DR, this assumption has been confirmed through the trials.

7.3.11. NEM, Smart Street, CLASS DB 100 (CDB 100, NEM 100, SMST 100)

	CLASS DR	CLASS DB	Smart Street	NEM
Priority	N/A	3	2	1
Function Level	N/A	100	100	100

Table 26 NEM 100, SMST 100, CDB 100 Priority & Function Levels

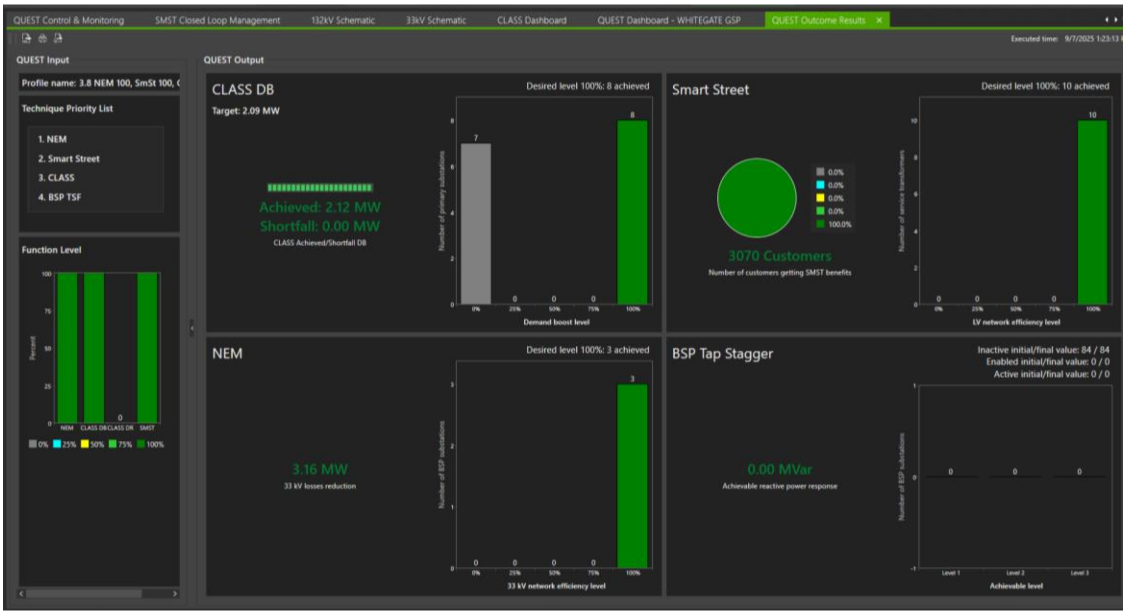


Figure 49 NEM 100, SMST 100, CDB 100 Outcome Results

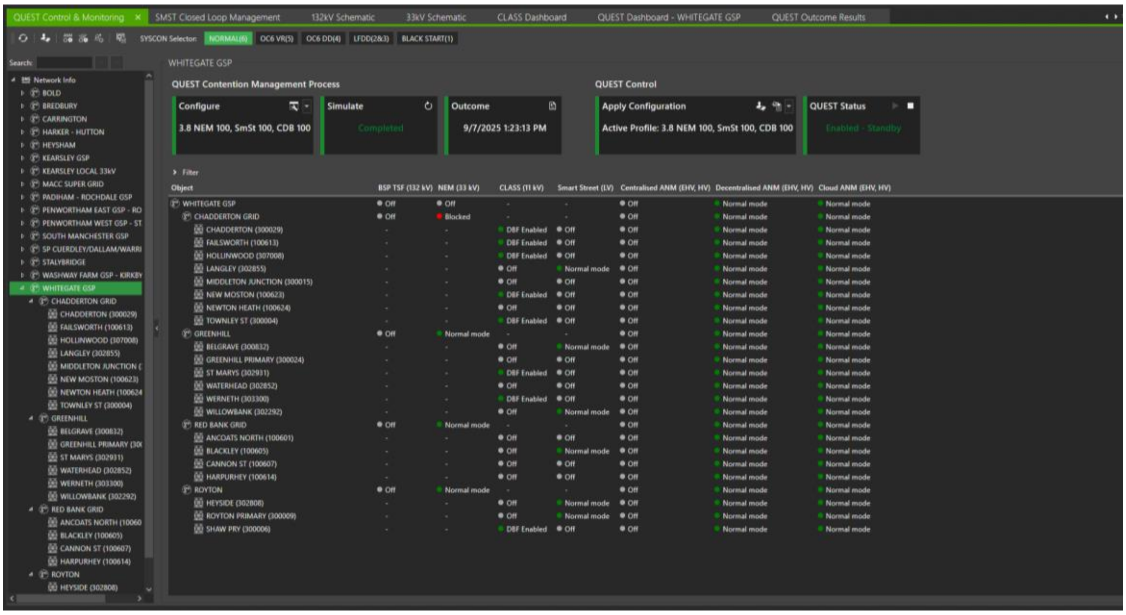


Figure 50 NEM 100, SMST 100, CDB 100 QUEST Dashboard Summary

This trial prioritised NEM, followed by Smart Street, with CLASS DB as the lowest priority. NEM achieved its maximum loss reduction benefit of 3.16 MW across three BSPs, while Smart Street delivered full CVR benefits to approximately 3,070 customers. Despite its lower priority, CLASS DB still met its target of 2.09 MW across eight sites—likely due to an operational restriction at Chadderton Grid that inhibited NEM, allowing CLASS DB to activate. Without this constraint, it is expected that NEM would have delivered greater benefit, and CLASS DB would have remained inactive. This trial highlights how network conditions can influence optimisation outcomes, even when priority logic is correctly applied.

7.3.12. CLASS DR, NEM 50, Smart Street 50 (CDR 50, NEM 50, SMST 50)

	CLASS DR	CLASS DB	Smart Street	NEM
Priority	1	N/A	3	2
Function Level	50	N/A	50	50

Table 27 CDR 50, NEM 50, SMST 50 Priority & Function Levels

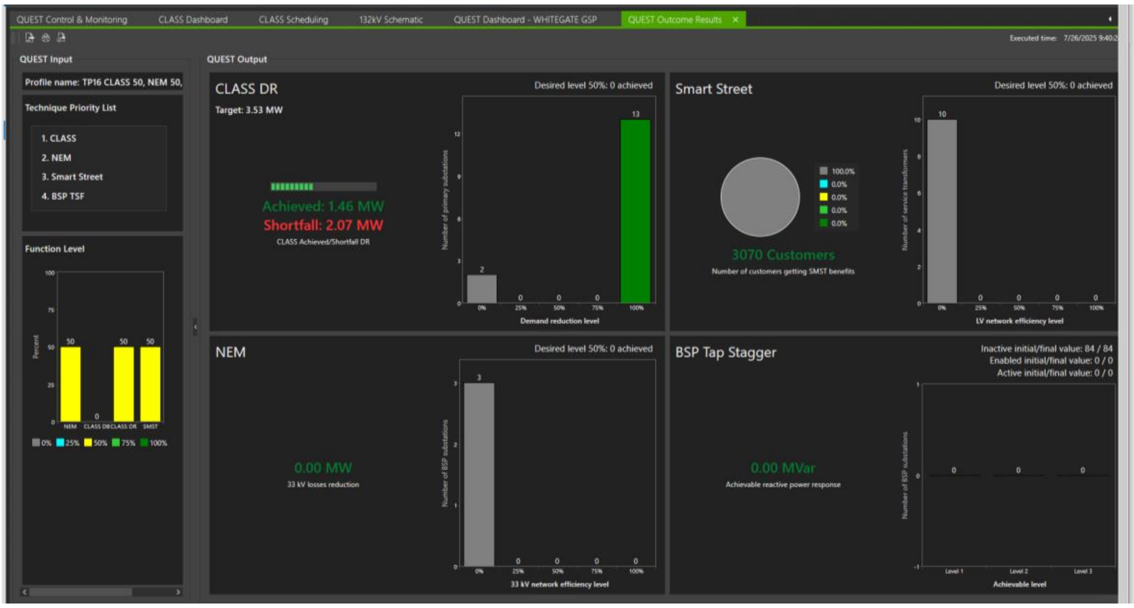


Figure 51 CDR 50, NEM 50, SMST 50 Outcome Results

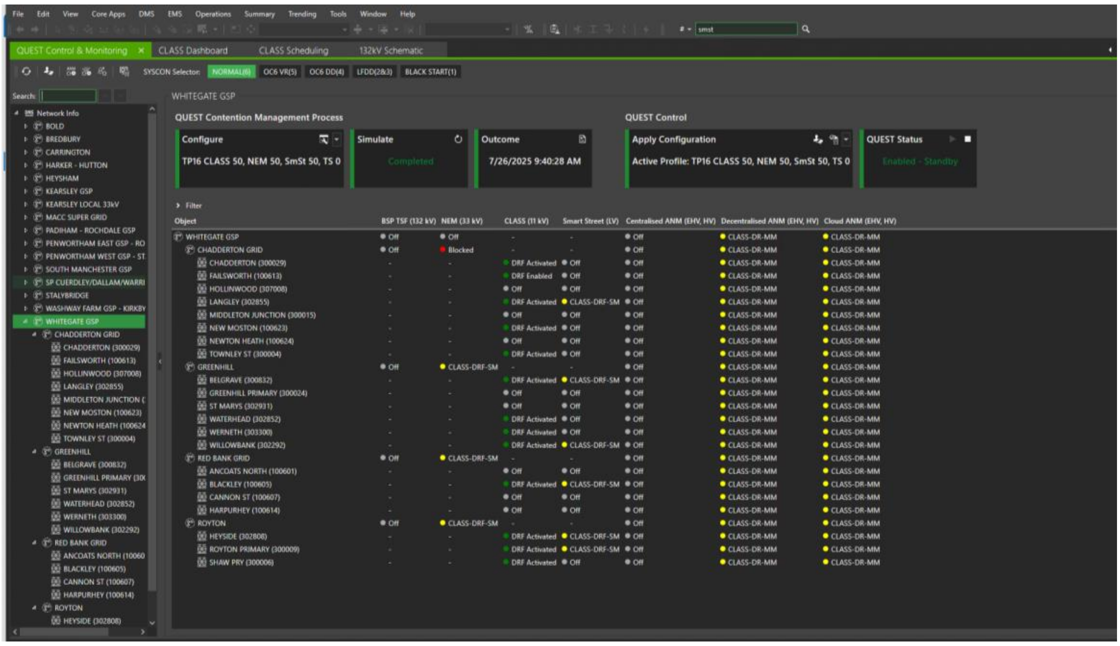


Figure 52 CDR 50, NEM 50, SMST 50 QUEST Dashboard Summary

This trial prioritised CLASS DR, followed by NEM, then Smart Street as the lowest priority – all with 50% function level. CLASS DR achieved 1.46MW demand reduction, a shortfall of 2.07MW from the 3.53MW. As a result, all available system benefit was applied to CLASS DR – correctly honouring position in the priority order.

7.3.13. Smart Street, CLASS DR, NEM 50 (SMST 50, CDR 50, NEM 50)

	CLASS DR	CLASS DB	Smart Street	NEM
Priority	2	N/A	1	3
Function Level	50	N/A	50	50

Table 28 SMST 50, CDR 50, NEM 50 Priority & Function Levels

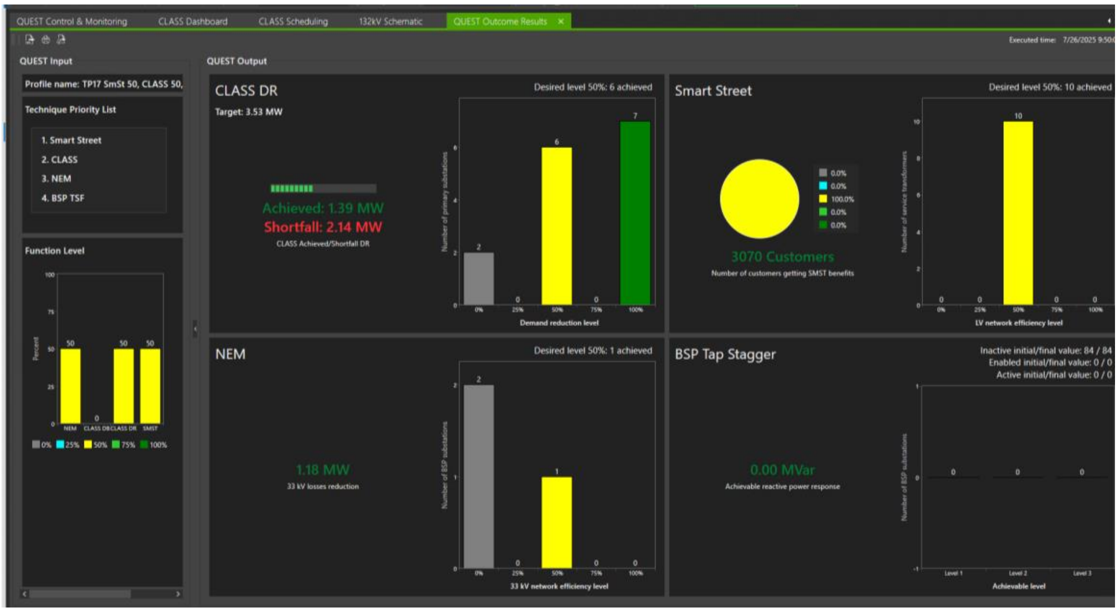


Figure 53 SMST 50, CDR 50, NEM 50 Outcome Results

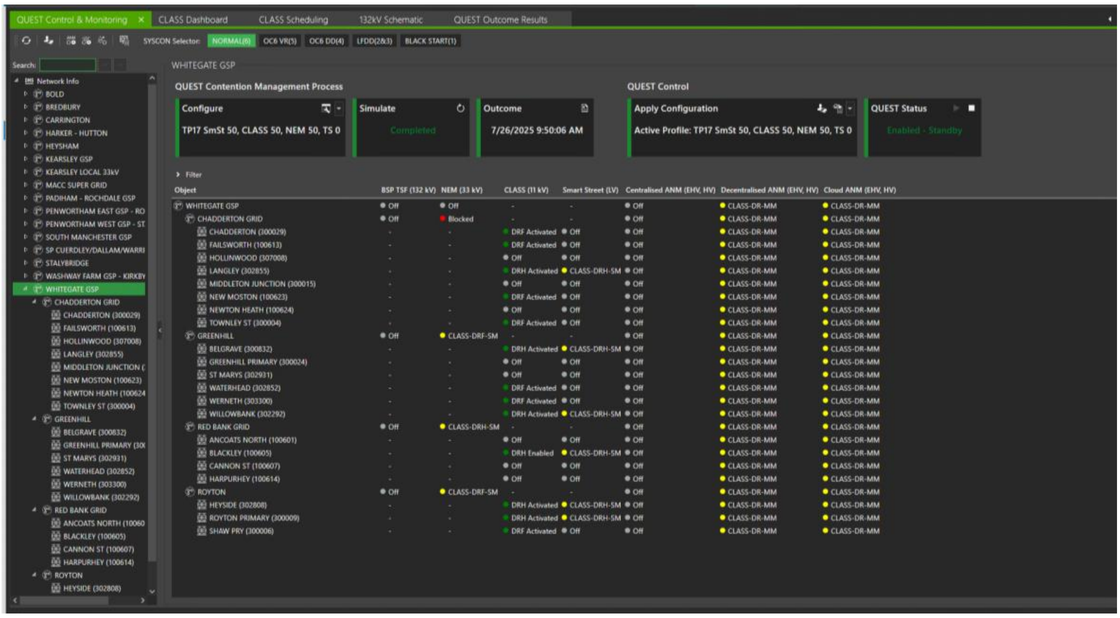


Figure 54 SMST 50, CDR 50, NEM 50 QUEST Dashboard Summary

In this trial, Smart Street was prioritised ahead of CLASS DR, followed by NEM. As a result, all Smart Street sites were enabled at their 50% functionality level, delivering CVR benefits to connected customers. The remaining system benefit was then allocated to CLASS DR, which achieved a demand reduction of 1.39 MW. Additionally, NEM was able to deliver benefits due to the 50% voltage set points applied at Blackley Primary, creating sufficient headroom for a NEM activation and resulting in a 1.18 MW loss reduction. This trial highlights QUEST's capability to blend multiple techniques and maximise overall system benefit.

7.3.14. NEM, CLASS DR, Smart Street 50 (NEM 50, CDR 50, SMST 50)

	CLASS DR	CLASS DB	Smart Street	NEM
Priority	2	N/A	3	1
Function Level	50	N/A	50	50

Table 29 NEM 50, CDR 50, SMST 50 Priority & Function Levels

Figure 55 NEM 50, CDR 50, SMST 50 Outcome Results

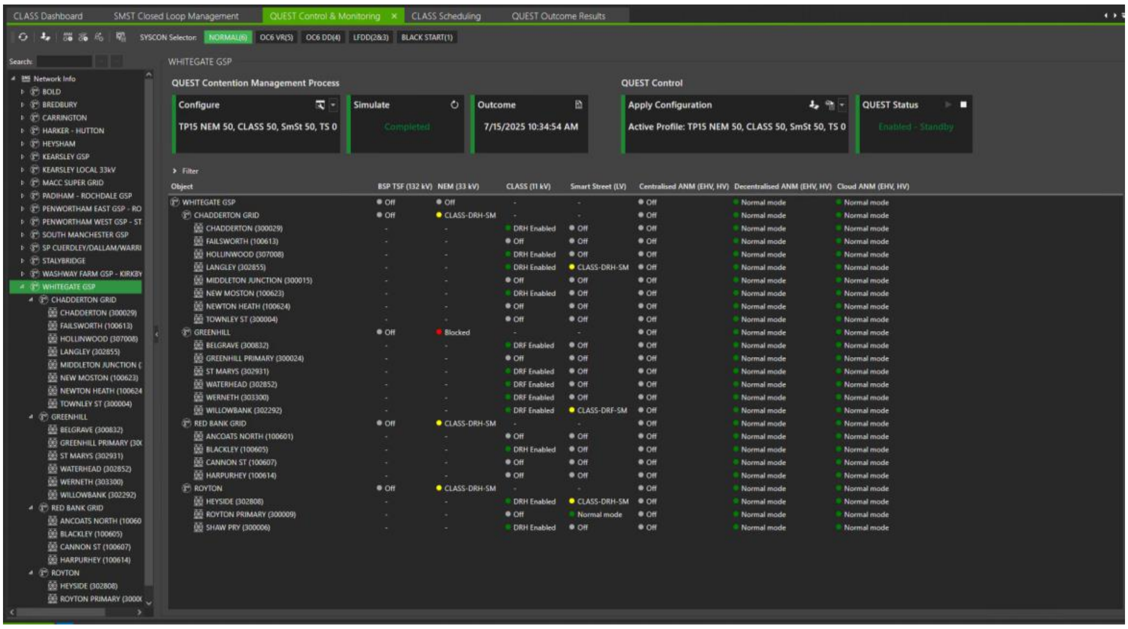


Figure 56 NEM 50, CDR 50, SMST 50 QUEST Dashboard Summary

This trial prioritised NEM, followed by CLASS DR and Smart Street, with all techniques set to 50% function level. NEM achieved a 2.66 MW loss reduction across three sites operating at their 50% VSP. The reduced NEM level provided sufficient headroom for CLASS DR, which delivered 1.39 MW of demand reduction—eight sites operated at 50%, while five connected under a blocked BSP due to an operational constraint were set to 100%. The CLASS DR sites, operating at reduced voltage set points, also allowed Smart Street to deliver CVR benefits to at eight sites serving customers without conflict.

7.3.15. Summary of Multi-Technique Trials

The multi-technique trials demonstrated QUEST's ability to coordinate CLASS DR, CLASS DB, Smart Street, and NEM to optimise overall system benefit under varying priority orders. While CLASS DR did not always meet its full target, QUEST correctly allocated all available CLASS benefit to the technique itself, without diverting capacity to lower-priority functions.

Smart Street consistently delivered CVR benefits when prioritised, and NEM achieved notable loss reductions when voltage headroom allowed. CLASS DB coordination required Smart Street to operate in compatible modes to avoid counteracting demand boosts. Overall, the trials confirmed QUEST's capability to dynamically manage competing objectives and blend outputs across techniques, with priority order playing a key role in determining which benefits were realised or constrained.

7.4. Time-Series Trials

The time-series trials were designed to test QUEST's ability to dynamically adjust coordination and priorities during live operation as system conditions change. Unlike static trials, these scenarios involved sequential activation of techniques—such as CLASS Demand Reduction, Smart Street, and NEM—within the same trial window.

The objective was to validate that QUEST can seamlessly transition between configurations, reapply safe mode logic, and optimise benefits in real time without causing voltage violations. These trials demonstrate QUEST's capability to respond to evolving network requirements and maintain its benefit-driven optimisation approach under changing priorities.

To test the time-series functionality, three test profiles were used and programmed to re-calculate at 10minute intervals with no intervention by the Control user.

- Test 1 – NEM 50, SMST 50, CDR 50 activated 10:05-10:15
- Test 2 – CDR 50, NEM 50, SMST 50 activated 10:15-10:25
- Test 3 – SMST 50, CDR 50, NEM 50 activated 10:25-10:35

Test activated at 10:05 with pre-populated schedule until 10:35.

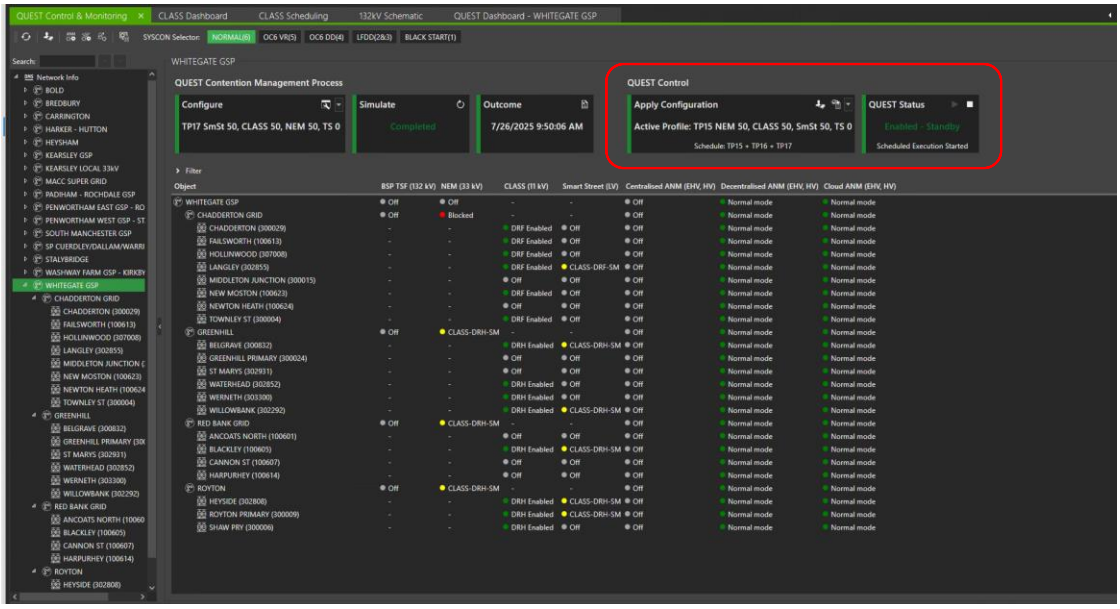


Figure 57 Time-Series Test 1 Dashboard

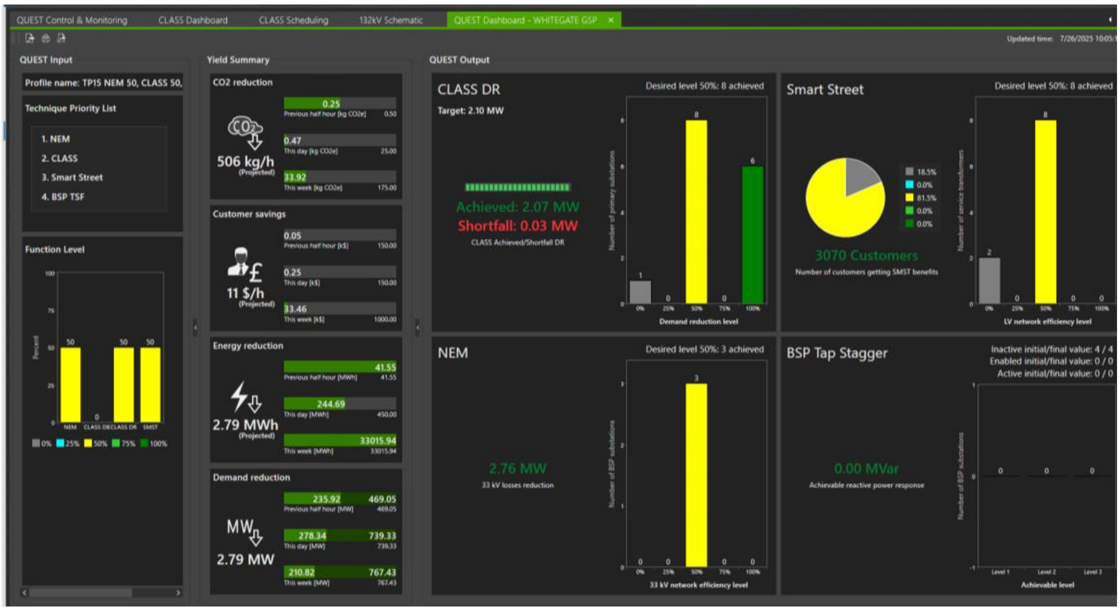


Figure 58 Time-Series Test 1 Output Results

The QUEST system was activated at 10:00, at 10:05 the first test profile automatically activated and generated results as shown in the Output Results.

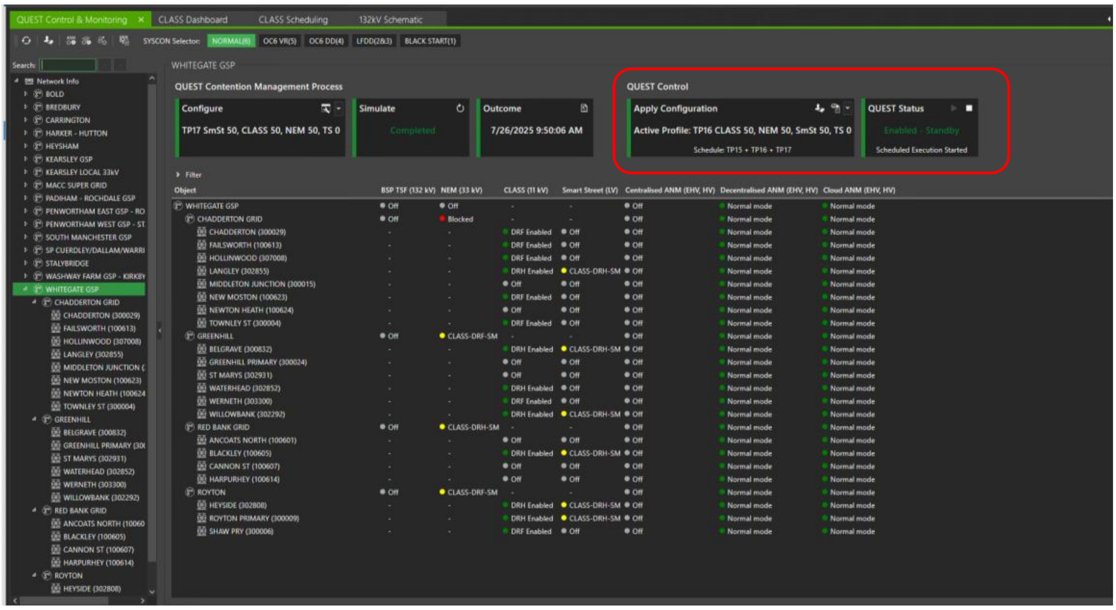


Figure 59 Time-Series Test 2 Dashboard

Figure 60 Time-Series Test 2 Output Results

At 10:15 the QUEST system automatically and successfully re-prioritised from NEM, CLASS, Smart Street to CLASS, NEM, Smart Street then re-calculated and enabled the system. Output Results shown in Figure 60 can be seen with newly generated benefits to customers.

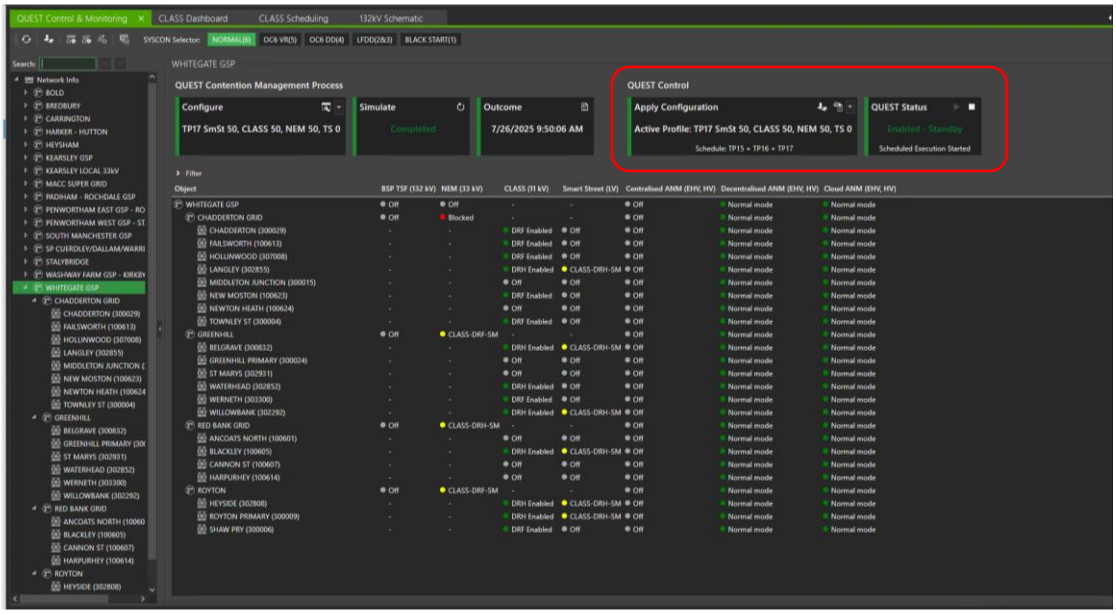


Figure 61 Time-Series Test 3 Dashboard

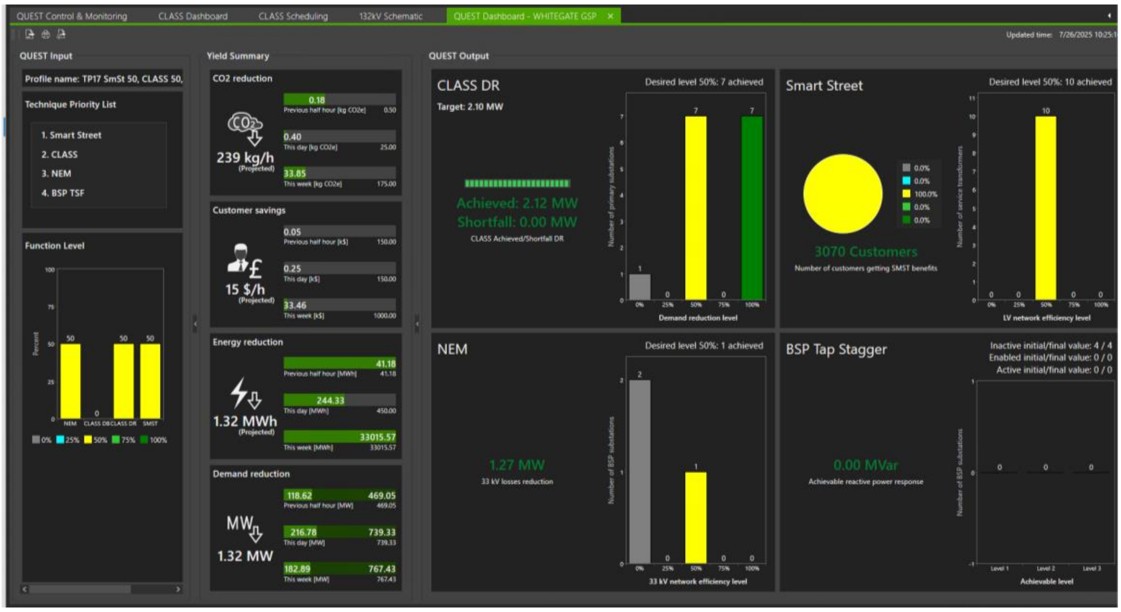


Figure 62 Time-Series Test 3 Output Results

At 10:25 the QUEST system automatically and successfully re-prioritised from CLASS, NEM, Smart Street to Smart Street, CLASS, NEM then re-calculated and enabled the system. Output Results shown in Figure 62 display can be seen with newly generated benefits to customers.

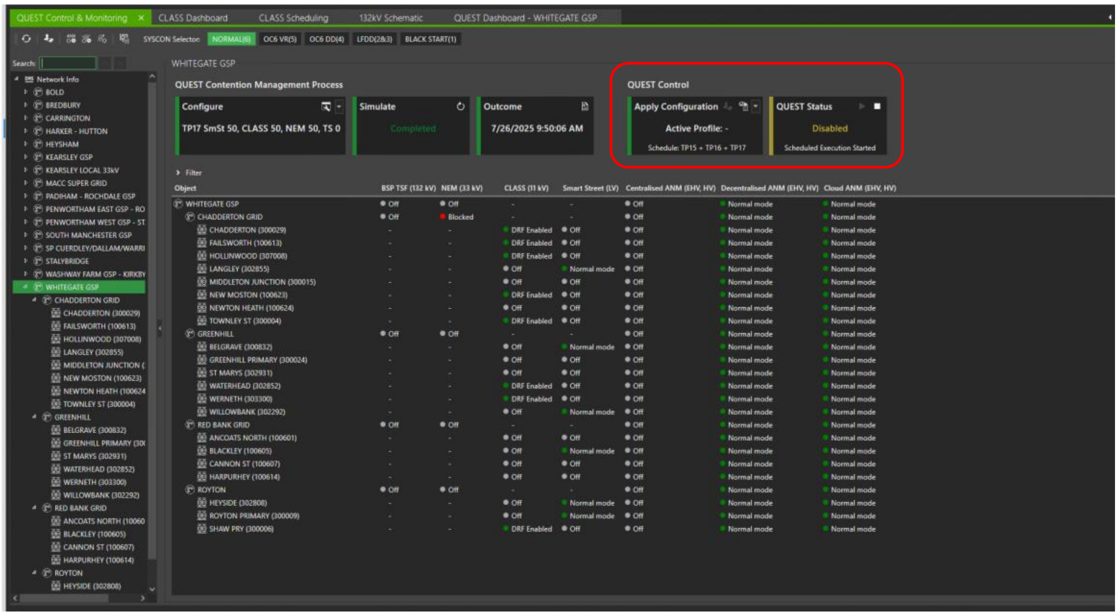


Figure 63 Time-Series Trial Finished Dashboard

At 10:35 QUEST is deactivated according to the defined schedule. Upon deactivating QUEST operation, the most important thing is to leave the system in a safe operating condition. That means that voltage control techniques cannot be returned in a normal operating mode, because that could lead to a potential conflict between voltage control techniques, or even to a situation with voltage values outside of the ESQCR limits. Having that in mind, after QUEST is deactivated, it considers which voltage control technique takes priority and based on the priority list in defined in the last active QUEST profile, QUEST performs the appropriate actions.

For example, if CLASS has priority, upon turning QUEST off, CLASS remains enabled, but SMST is switched off in order to prevent low voltage violations in case of CLASS activation. On the other hand, if SMST has priority over CLASS, then SMST is returned to a CVR mode (normal mode of operation), and all CLASS primaries that supply SMST transformers are put in inhibit mode. It is then up to the CE to determine what are the next steps re regarding the operation of each voltage control technique, whether CLASS scheduling mechanism should be enabled to continue scheduling CLASS primaries or whether SMST should continue operating in CVR mode or it should be switched off, etc.

The only task for QUEST is to leave the system in a safe operating condition. It is important to note that NEM, as a new module introduced through QUEST, is switched off upon deactivating QUEST. Switching NEM off means returning it to a failsafe target voltage defined as a NEM 0% function level. As can be seen from the Figure 63, once QUEST is deactivated, NEM is switched off. Because the last active QUEST profile prioritized Smart Street over CLASS DR, Smart Street returns to its normal operating mode on every primary substation. CLASS DR, however, changes from Enabled to Off on all primary substations where Smart Street is active: Lengaley, Belgrave, Willowbank, Blackley, Heyside, and Royton Primary. On all other primary substations where Smart Street was not enabled, QUEST leaves CLASS DR enabled.

7.4.1. Time-Series Trials Summary

The time-series trials demonstrated QUEST's ability to dynamically adjust priorities and coordination during live operation. In these tests, techniques such as CLASS Demand Reduction, Smart Street, and NEM were activated sequentially within the same trial window, requiring QUEST to reapply safe mode logic and update function levels in real time.

The results confirmed that QUEST transitioned smoothly between configurations, maintained statutory voltage limits, and maximised benefit from each technique before enabling the next in priority order. This behaviour validates QUEST's capability to respond to changing network conditions and deliver continuous optimisation without manual intervention.

7.5. Emergency system transitions

These trials were designed to validate QUEST's ability to respond to changes in system state by transitioning between normal operation and emergency conditions, such as OC6 Voltage Reduction (VR), OC6 Demand Disconnection (DD), and Low Frequency Demand Disconnection (LFDD).

The objective was to ensure QUEST correctly applies mitigation modes to voltage control techniques, sends appropriate commands to external systems, and maintains network stability during these critical transitions. By simulating manual activations, the trials assessed QUEST's responsiveness, coordination logic, and ability to prevent conflicts while supporting NESO requirements.

7.5.1. OC6 VR Trial

The OC6 VR trial was designed to validate QUEST's ability to transition from a normal operating state to an emergency system condition triggered by an OC6 Voltage Reduction event, and then return to normal operation. Conducted under the Emergency System Operating State, the test aimed to confirm that QUEST correctly interprets SYSCON changes and applies appropriate mitigation modes to each voltage control technique.

The trial involved switching QUEST from Normal to OC6 VR and back again using the SYSCON selector while a test profile was active. The objective was to ensure that QUEST sets each function into its correct mode and sends the appropriate commands during each transition. Specifically, NEM, Smart Street, and ANM were expected to enter the OC6-VR-MM mitigation mode, while CLASS remained unchanged.

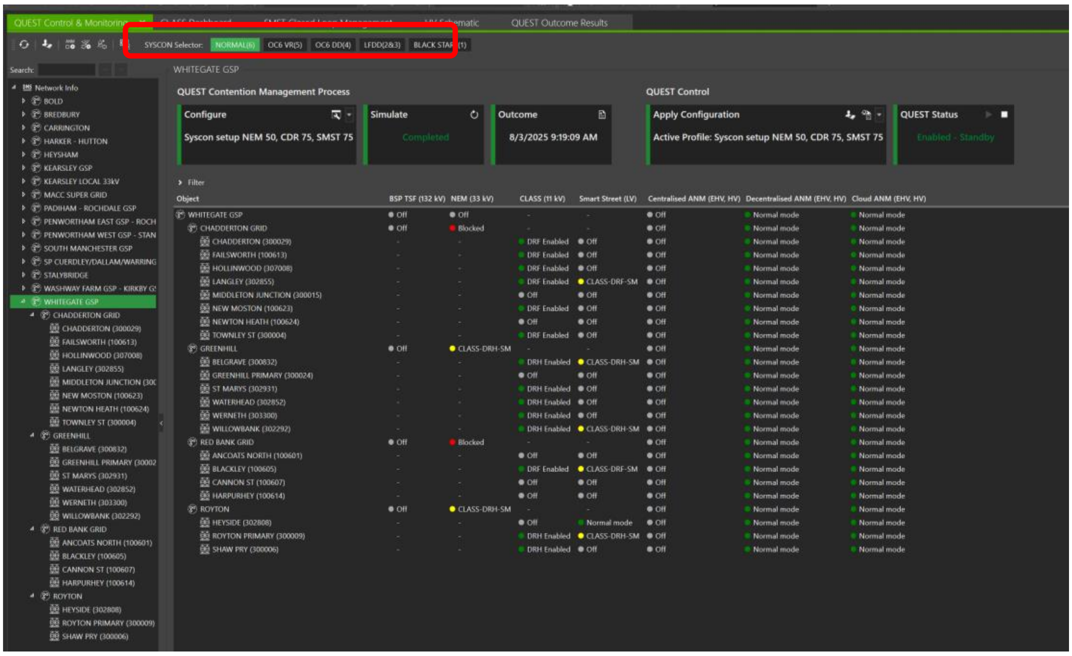


Figure 64 QUEST Activated in SYSCON NORMAL

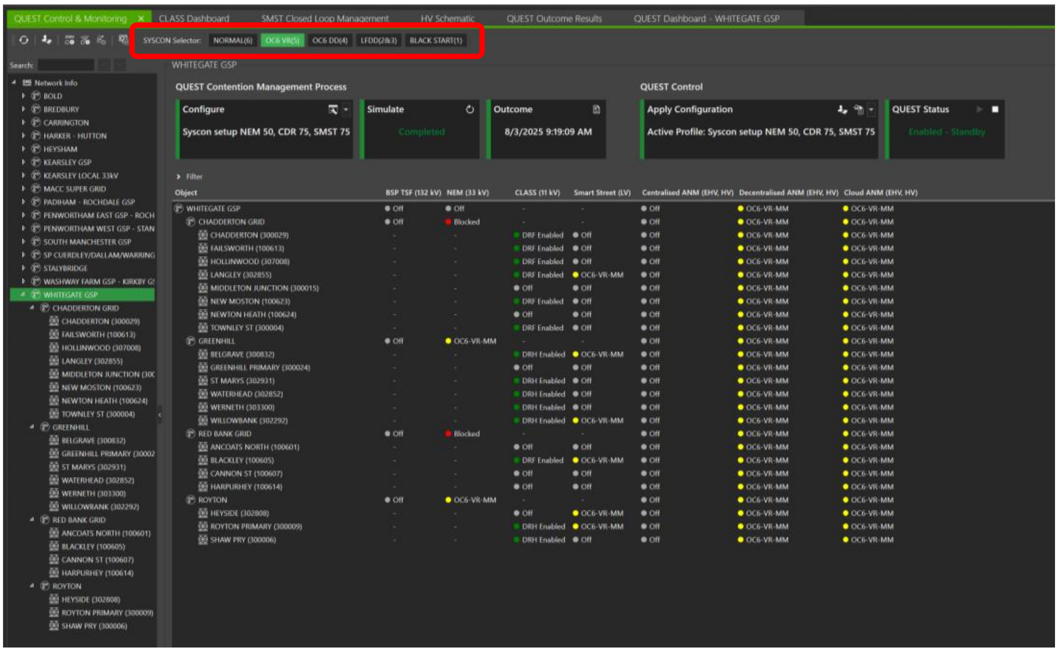


Figure 65 SYSCON OC6 VR Activated

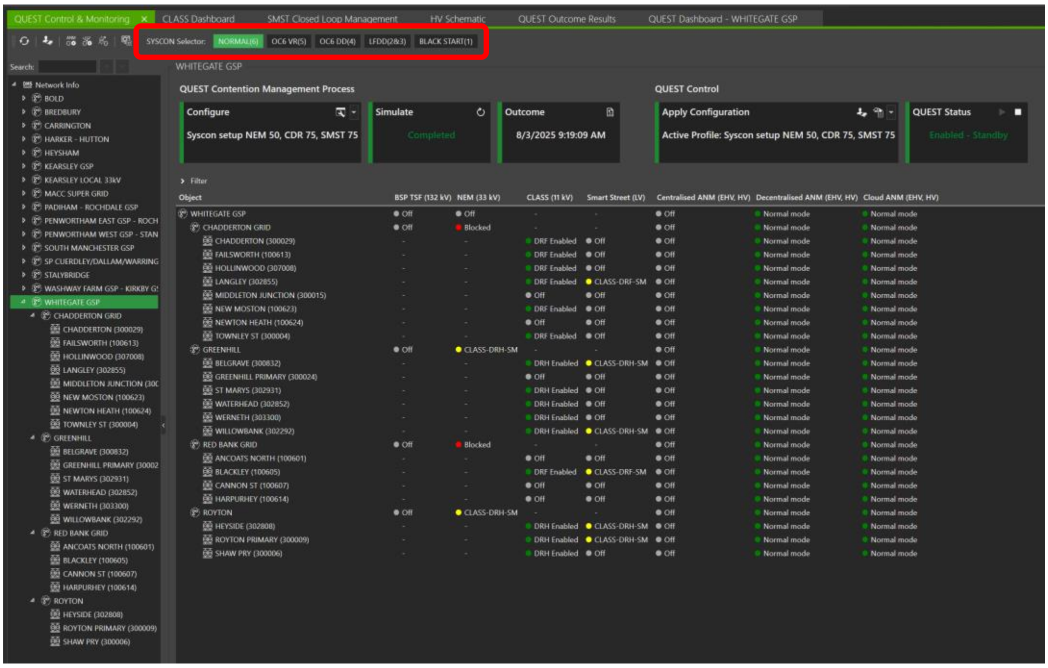


Figure 66 SYSCON state returned to NORMAL.

The system successfully transitioned from NORMAL to OC6 Voltage Reduction (OC6-VR), with NEM, Smart Street, and ANM entering their respective OC6-VR mitigation modes, while CLASS remained unchanged. The following actions were applied by each technique:

- ANM: Held previously curtailed demand to prevent its release.
- NEM: Disabled Network Efficiency Mode at all BSPs by applying the voltage target associated with a 0% NEM function level.
- Smart Street (SMST): Locked all SMST transformers at their current tap positions.

This behaviour illustrates QUEST's ability to respond to emergency voltage reduction instructions from the NESO, ensuring coordinated system actions and maintaining network stability during critical events.

7.5.2. OC6 DD Trial

The OC6 DD trial was conducted to validate QUEST's response to an emergency system condition triggered by an OC6 Demand Disconnection event. Using Reactive Coordination under the Emergency System Operating State, the trial involved transitioning QUEST from Normal to OC6 DD and back again via the SYSCON selector.

The objective was to verify that QUEST correctly applies mitigation modes during this transition, specifically setting NEM, Smart Street, and ANM into OC6-DD-MM mitigation mode, while CLASS remains unchanged. Additionally, all transformers were expected to lock into their voltage settings as they were prior to the SYSCON change. Success was defined by QUEST sending the appropriate commands upon each mode change and ensuring all systems responded as expected.

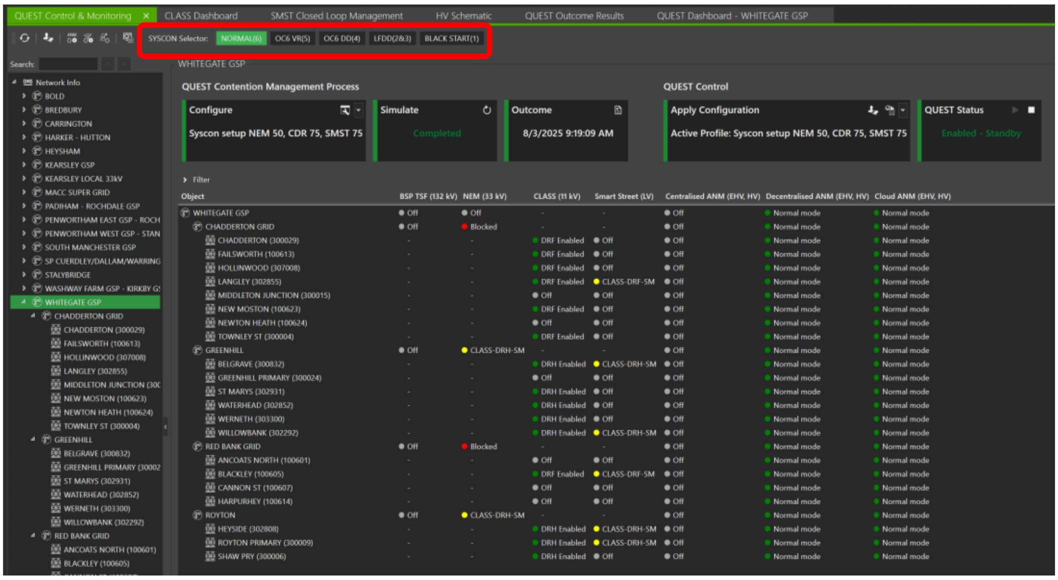


Figure 67 QUEST Activated in SYSCON NORMAL

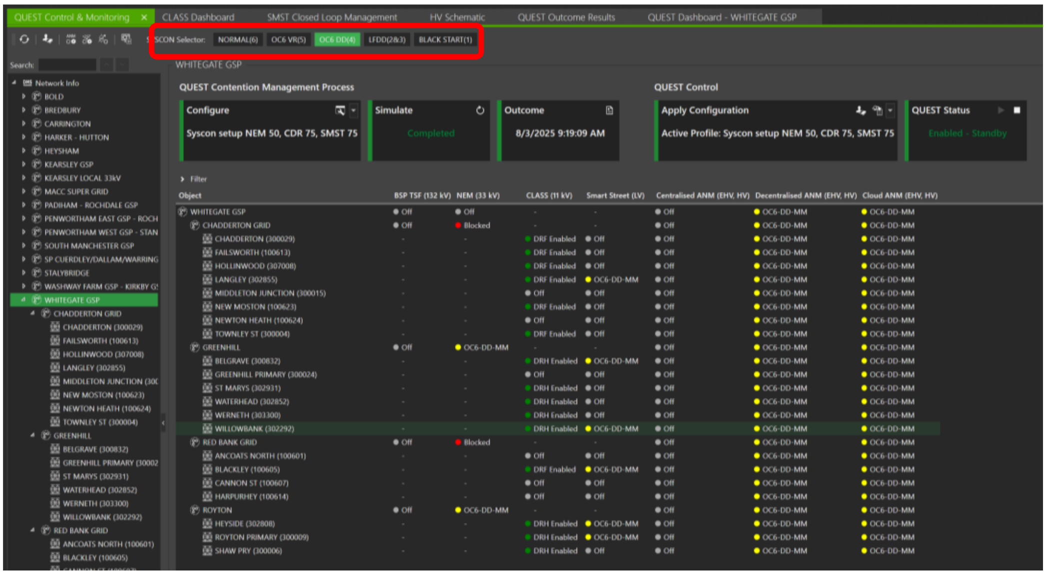


Figure 68 SYSCON OC6 DD Activated

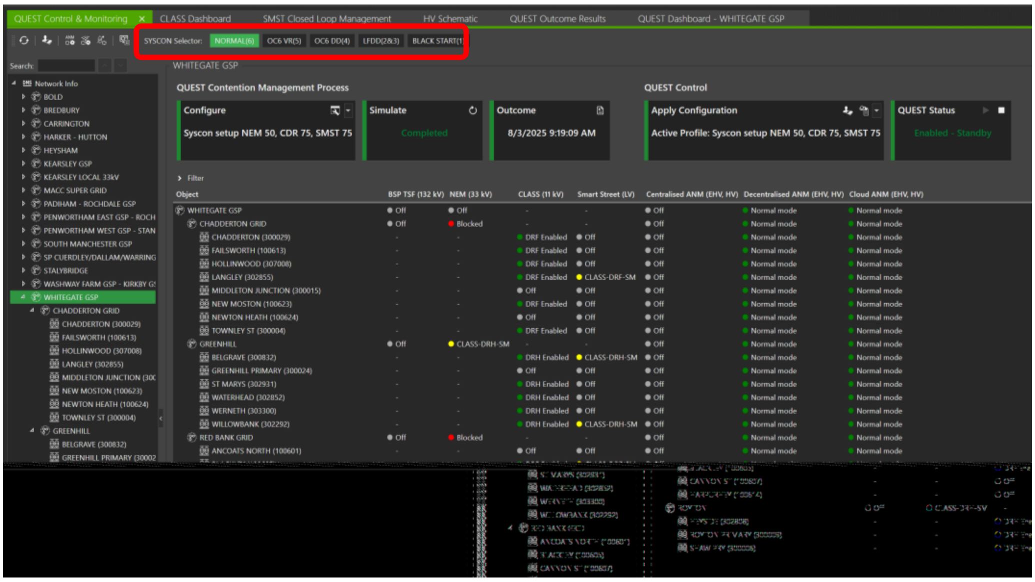


Figure 69 SYSCON state returned to NORMAL.

The system successfully transitioned from NORMAL to OC6 Demand Disconnection (OC6-DD), with NEM, Smart Street, and ANM entering their respective mitigation modes, while CLASS remained unchanged. The following actions were applied:

- ANM: Held previously curtailed demand to prevent its release.
- NEM: Disabled Network Efficiency Mode and locked BSP transformers at the voltage target they were set to before SYSCON-4 activation.
- Smart Street (SMST): Locked all LV transformers at their pre-event tap positions to maintain stability.

This behaviour demonstrates QUEST's ability to respond to NESO emergency demand disconnection instructions, ensuring coordinated system actions and maintaining network integrity during critical events.

7.5.3. LFDD Trial

The LFDD trial was designed to validate QUEST's response to emergency system conditions triggered by Low Frequency Demand Disconnection events. While both manual (MLFDD) and automatic (ALFDD) activation scenarios were planned, only the MLFDD trial was executed, as it was not possible to simulate an actual automatic LFDD event without a real system frequency excursion – the ALFDD was modelled and simulated using the consultancy model digital twin.

The MLFDD trial was conducted under the Emergency System Operating State using Reactive Coordination, involving a manual transition from Normal to LFDD and back via the SYSCON selector. The objective was to confirm that QUEST correctly sets each function into its appropriate mode and sends the expected commands. Specifically, NEM and ANM were required to enter the LFDD-MM mitigation mode, with commands sent to BSP transformers to disable NEM by setting target voltages to the predefined 0% level, except where NEM was blocked. ANM systems were prevented from releasing previously curtailed demand. Smart

Street remained in normal or safe mode depending on conflict resolution, and CLASS remained unchanged.

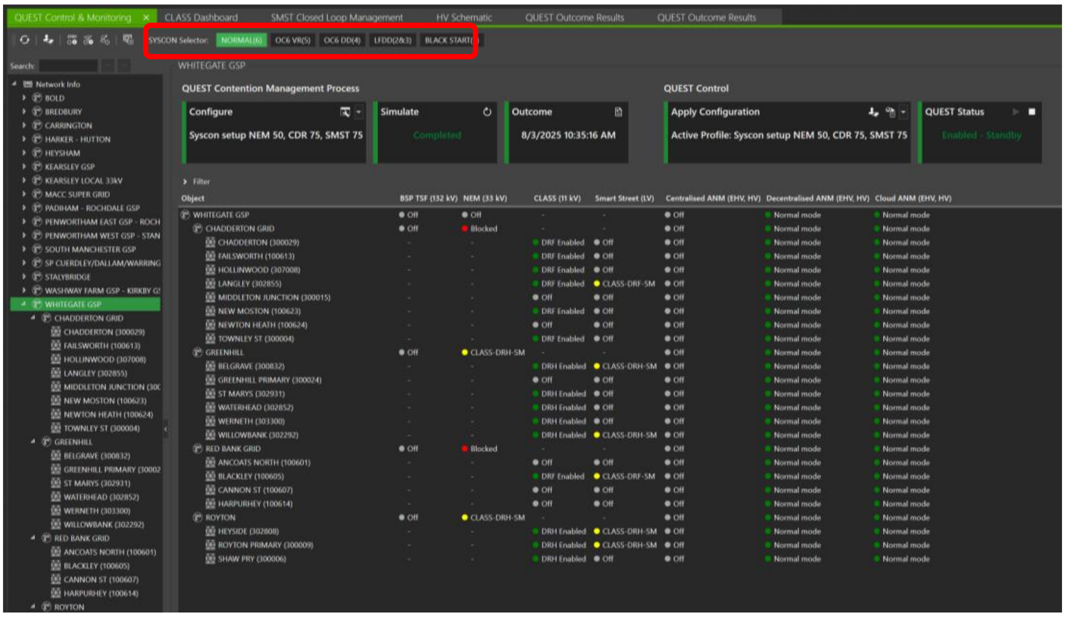


Figure 70 QUEST Activated in SYSCON NORMAL

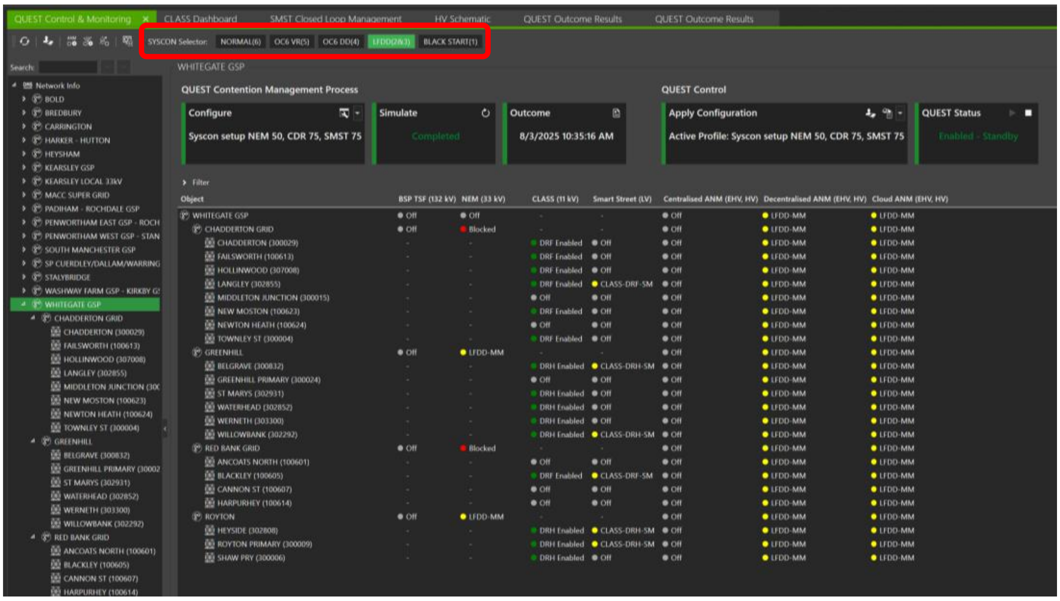


Figure 71 SYSCON LFDD Activated

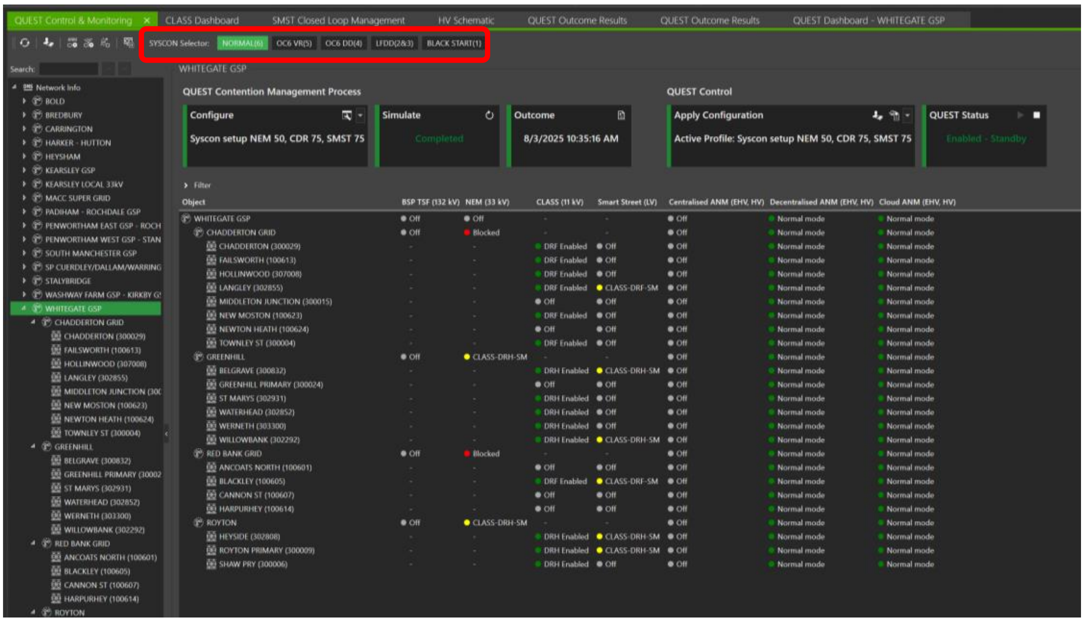


Figure 72 SYSCON state returned to NORMAL.

NEM and ANM were required to enter the LFDD-MM mitigation mode, with commands sent to BSP transformers to disable NEM by setting target voltages to the 0% level, excluding where NEM was already blocked at two sites. ANM systems were prevented from releasing previously curtailed demand. Smart Street remained in its safe mode as coordinated by QUEST, and CLASS remained unchanged.

This trial successfully demonstrated QUEST's ability to manage manual LFDD transitions, ensuring coordinated system behaviour and maintaining network integrity during low-frequency events.

7.5.4. Emergency System Transitions Summary

The emergency transition trials confirmed QUEST's ability to respond quickly and correctly when moving between normal and emergency system states, including OC6 Voltage Reduction (VR), OC6 Demand Disconnection (DD), and Low Frequency Demand Disconnection (LFDD).

In all cases, QUEST applied the appropriate mitigation modes, locked or disabled relevant techniques, and sent correct commands to ANM and NEM systems to prevent conflicts. Transitions were smooth, with no adverse impact on network stability or voltage compliance. These results validate QUEST's readiness to support NESO requirements and maintain safe, coordinated operation during critical events.

7.6. Reactive Power Support

The reactive power support trials were designed to validate QUEST's ability to deliver reactive power absorption at Bulk Supply Points (BSPs) using Tap Stagger Functionality (TSF). This feature creates a controlled imbalance between transformer tap positions to generate circulating current, providing reactive power support to the transmission system during periods of high voltage or NESO requests.

The objectives of these trials were:

- Validate that QUEST can correctly enable Tap Stagger at the configured function level, maintain system stability, and coordinate with other active techniques without causing conflicts or voltage violations.
- Demonstrate the level of reactive power response achievable through tap staggering at BSPs.

These tests also highlight QUEST's ability to incorporate reactive power services within its overarching optimisation strategy. To support validation, the consultancy model digital twin performed independent simulations, providing a benchmark for comparison and verification of the trial results.

7.6.1. Trial Execution

Note: During the build phase, an issue was identified that prevented QUEST from directly controlling BSP tap changers during trials. The root cause was a mismatch in point naming across the control chain—from the QUEST platform through ICCP and SCADA to the transformer AVC. Although a resolution was defined, implementing and testing it would have required significant time and risked delaying the remaining system test schedule.

Project requirements were still met because QUEST's operational logic could be validated, while the physical tap adjustments were carried out via the production NMS system. During testing, QUEST successfully generated the BSP commands, confirming functional integration within the control framework. Manual tap adjustments mirrored the expected QUEST actions, enabling accurate measurement of MVAr absorption at each BSP.

Four BSPs within the Whitegate GSP group (Chadderton, Greenhill, Royton, and Red Bank) were manually staggered up to four tap positions apart—equivalent to BSP Tap Stagger 2 functionality in QUEST. The resulting circulating current was deemed acceptable for safe operation. However, the predicted current for Tap Stagger 3 (six tap positions apart) was assessed as unsafe by ENWL control engineers responsible for network safety.

7.6.2. Observed Performance

When tap stagger was applied at four tap positions apart between paired transformers, the response was consistent across all trials. Typically, one transformer injected between 12 and 14 MVAr of reactive power while its paired transformer absorbed 10 to 12 MVAr, resulting in a net reactive power absorption of approximately 2 to 4 MVAr per BSP.

Across the four BSP sites within the Whitegate GSP group, the cumulative effect was clearly visible at the GSP level. Analysis of reactive power data at Whitegate confirmed an increase of 8 to 10 MVAr during the periods of manual tap staggering, which aligns with the combined net absorption observed at the individual BSPs. This validated the functional concept and demonstrated the achievable response under controlled conditions.

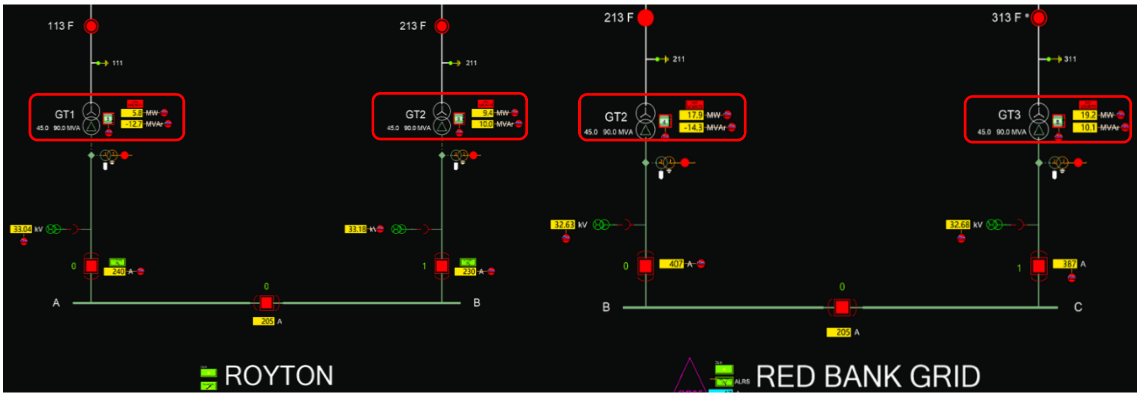


Figure 73 Royton & Red Bank BSP Tap Stagger Active

A technical issue occurred during testing when GT3 was tapped at Red Bank Grid (Figure 73). However, this change was not accurately reflected in the historian data stream, which continued to display a value of zero as shown in Figure 74 (Red Bank OOS). While this caused a minor discrepancy between the actual observed response and the recorded data, the proof of concept remains valid.

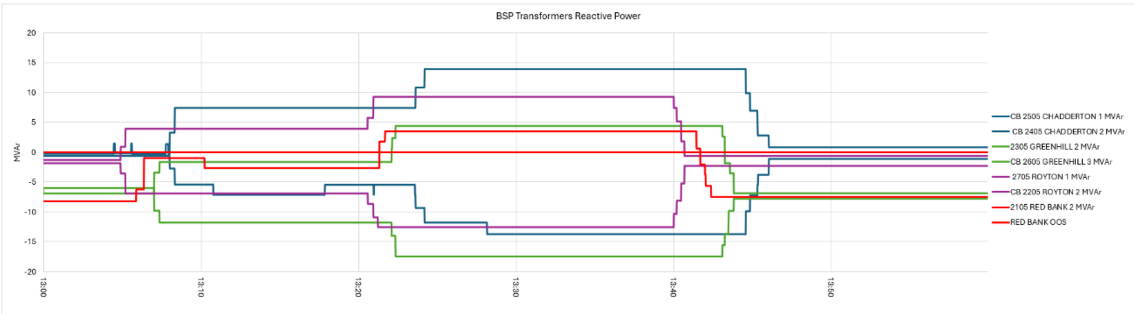


Figure 74 BSP Reactive Power MVAr Per Transformer

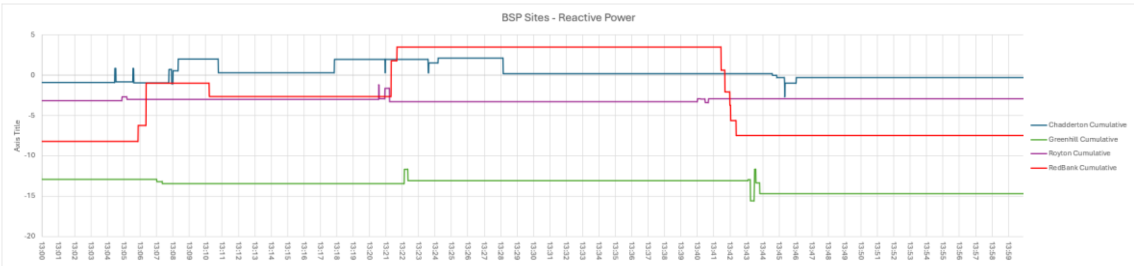


Figure 75 BSP Sites Cumulative Reactive Power MVAr

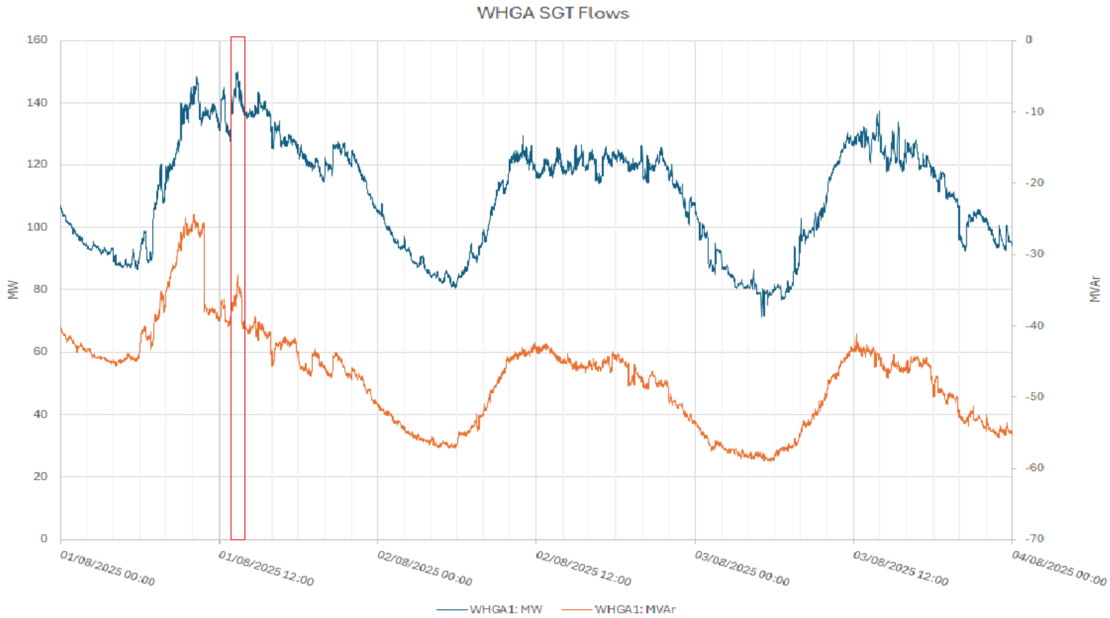


Figure 76 Whitegate GSP Active & Reactive Power Flows

The consultancy model digital twin simulated a comparable response to the live trials, recording approximately 1.5–2 MVAr of reactive power absorption at each of the four BSPs and around 7.5 MVAr aggregated upstream at Whitegate GSP. These results provide an important benchmark, confirming that the observed behaviour in the physical network aligns closely with the predicted performance from the model. This correlation strengthens confidence in the accuracy of the digital twin and its value as a validation tool for assessing TSF's impact under different operating scenarios.

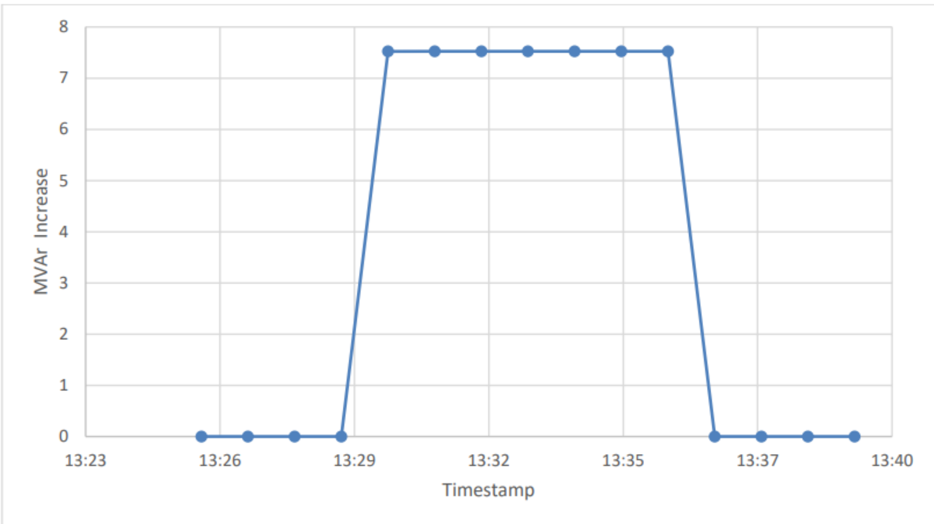


Figure 77 Whitegate GSP Consultancy Model Results

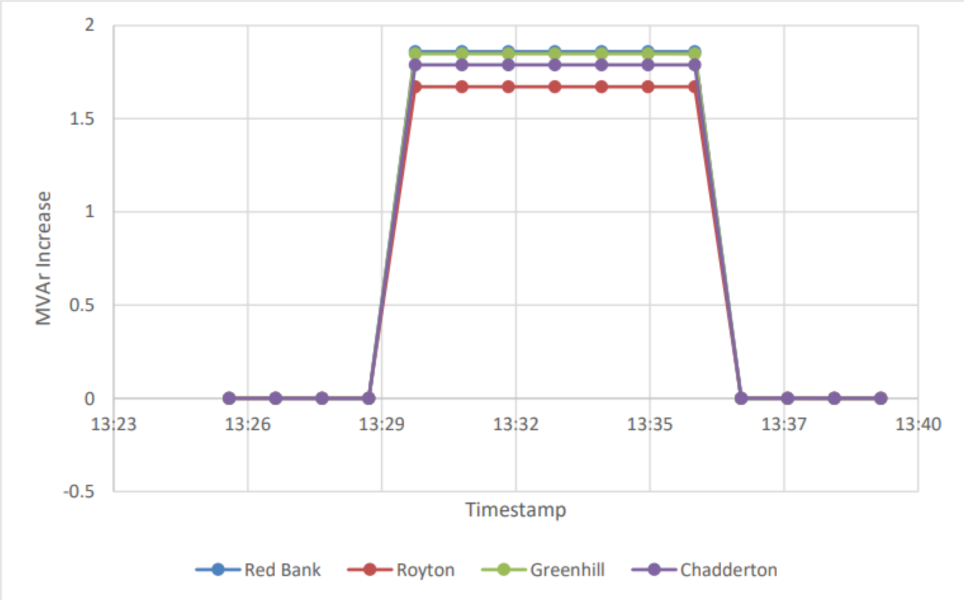


Figure 78 Consultancy Model Individual BSP MVAr Increases

7.6.3. Reactive Power Support Summary

The trials confirmed that Tap Stagger Functionality (TSF) can be activated through QUEST and integrated within its optimisation framework, with additional validation provided by the consultancy model digital twin. Tap positions were adjusted as configured, and reactive power absorption was observed at BSP level. However, the MVAr contribution in isolation was modest, limited by circulating current and associated copper losses.

While TSF operated without conflicts alongside other QUEST techniques during multi-function tests, the observed reactive power was significantly lower than anticipated, suggesting that TSF alone is unlikely to meet NESO reactive power service requirements. Nevertheless, when deployed across the entire SP ENW network, the aggregated effect could be far more substantial, potentially making TSF a viable contributor to NESO services. Future consideration should focus on whether this aggregated benefit justifies wider implementation beyond innovation trials.

7.7. Active Network Management (ANM) Trials

The ANM testing aimed to validate QUEST's ability to coordinate with ANM systems and prevent conflicts between voltage optimisation actions and DER dispatch. Specifically, the trials ensured that when QUEST initiated actions such as demand reduction or demand boost, ANM systems did not counteract these benefits by releasing generation or flexible demand. This was achieved through the implementation of mitigation modes within the ANM control logic, the transmission of these signals via 2 different ICCP set ups, and the receipt of this control by each ANM system.

During the limited time available at the end of the trials and analysis phase, additional testing was completed using the SGS ANM systems to develop our knowledge and understanding beyond the project requirements, on ANM system configurations could best respond to a QUEST signal.

7.7.1. System Setup and Architecture

The ANM testing environment was configured to replicate real-world conditions while allowing controlled validation of QUEST's coordination logic. Two distributed energy resources (DERs) were simulated within the SGS Strata Grid platform to represent generation connected under thermal constraint management. These DERs were selected to create a realistic scenario where ANM could potentially counteract QUEST actions by releasing curtailed generation.

The control hierarchy was structured as follows:

- QUEST acted as the overarching optimisation system, issuing commands to ANM via ICCP.
- ANM managed DER dispatch and applied mitigation modes (Export Hold and Import Hold) when instructed by QUEST.
- DERs responded to ANM commands, either maintaining curtailed output or releasing generation based on network conditions.

This architecture ensured that QUEST could influence ANM behaviour without direct control of DERs, reflecting operational reality. The setup allowed the project team to test both conflict scenarios (where ANM nullified QUEST benefits) and resolution scenarios (where Hold Mode preserved QUEST actions).

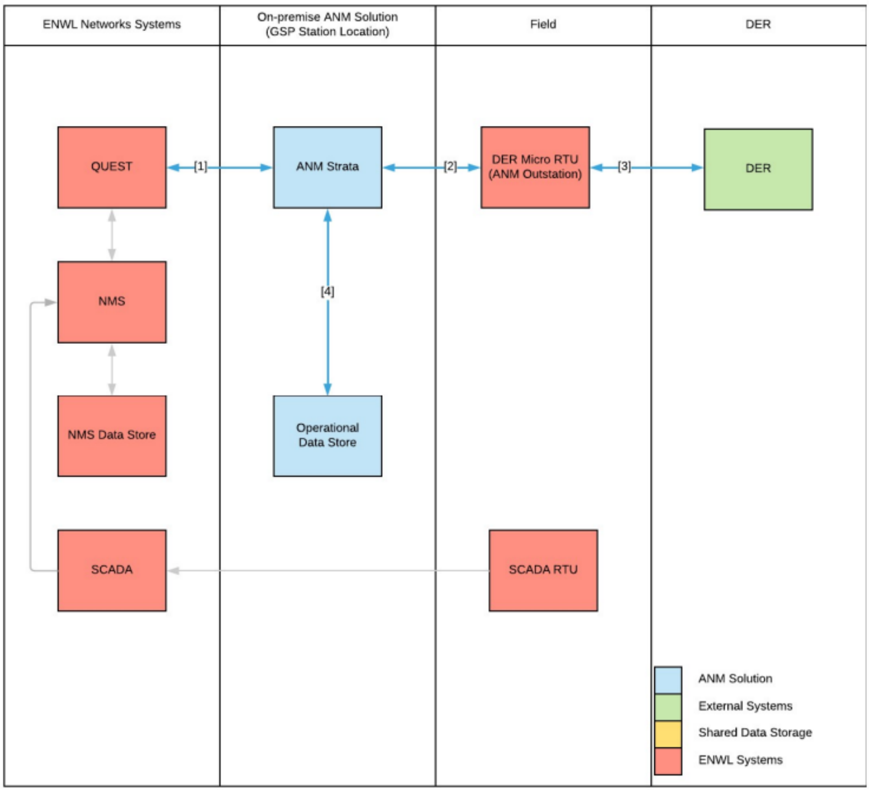


Figure 79 ANM Architecture showing QUEST Integration via ICCP and DER control.

7.7.2. System Overview

Two ANM systems were integrated into QUEST:

- **Decentralised ANM**– Simulates real-time DER control for thermal constraint management.
- **Cloud ANM** – Simulates flexibility service dispatch for day-ahead and intraday scenarios.

Note: Although Central ANM was not configured in the NMS production system, a logic for coordinating Central ANM was introduced in QUEST. During the trials, only Decentralised and Cloud ANM were coordinated by QUEST.

Both systems were configured to accept QUEST commands via ICCP and adjust their operating profiles accordingly:

- **Export Hode Mode** - Prevents DER export increase during CLASS demand boost.
- **Import Hold Mode** – Prevents DER import increase during CLASS demand reduction.

These profiles ensured that ANM held DER outputs at pre-CLASS or pre-QUEST levels during voltage optimisation events.

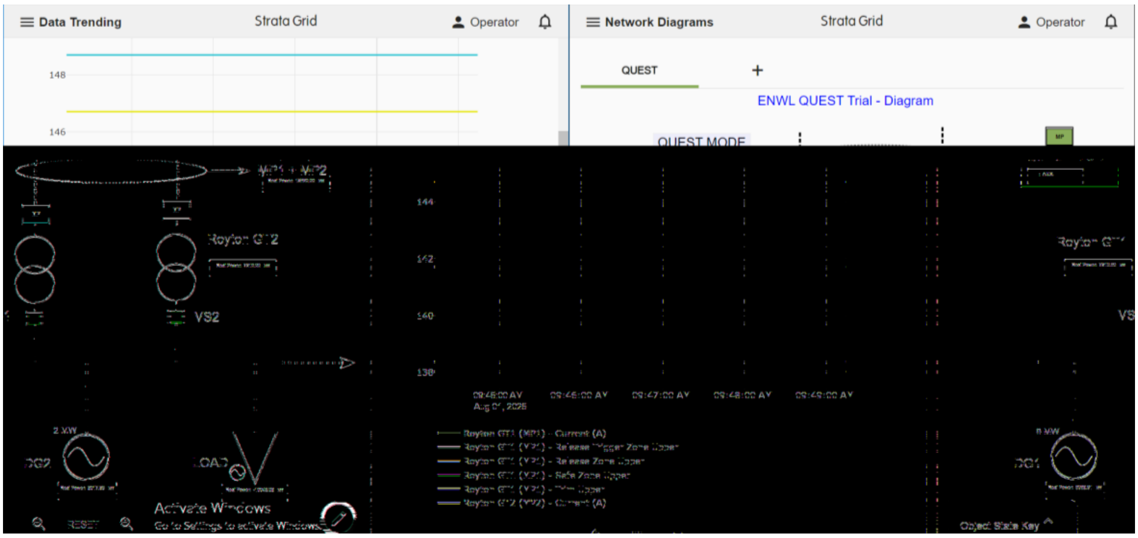


Figure 80 Normal ANM Mode Dashboard and Network Diagram

7.7.3. Operational Logic

ANM operates based on two key thresholds:

- Trim Threshold – When total power flow exceeds this value, ANM curtails DER output to reduce loading.
- Release Threshold – When total power flow falls below this value, ANM normally releases DER output to restore generation.

In standard operation:

- If power flow > trim threshold → DER curtailed.
- If power flow < release threshold → DER released.

During QUEST trials:

- When Hold Mode was active, ANM ignored the release threshold and maintained DER at curtailed levels until QUEST actions were complete.
- Once CLASS actions ended, Hold Mode was removed, and ANM resumed normal behaviour, releasing DER export/import as appropriate.

7.7.4. Trial Execution

The trials simulated thermal constraints and DER responses using SGS Strata Grid and ANM Outstations. Key scenarios included:

- Conflict Scenario (No Hold Mode)
  When CLASS Demand Boost (DBF) was activated, ANM detected additional headroom and released curtailed generation, nullifying the CLASS benefit. This occurred because the release threshold was breached after CLASS reduced power flow, allowing ANM to resume DER export.
- Conflict Resolution (Hold Mode Active)
  QUEST instructed ANM to enter Hold Mode before activating CLASS. ANM maintained DER outputs at pre-CLASS levels, preventing generation release and preserving the QUEST benefit.

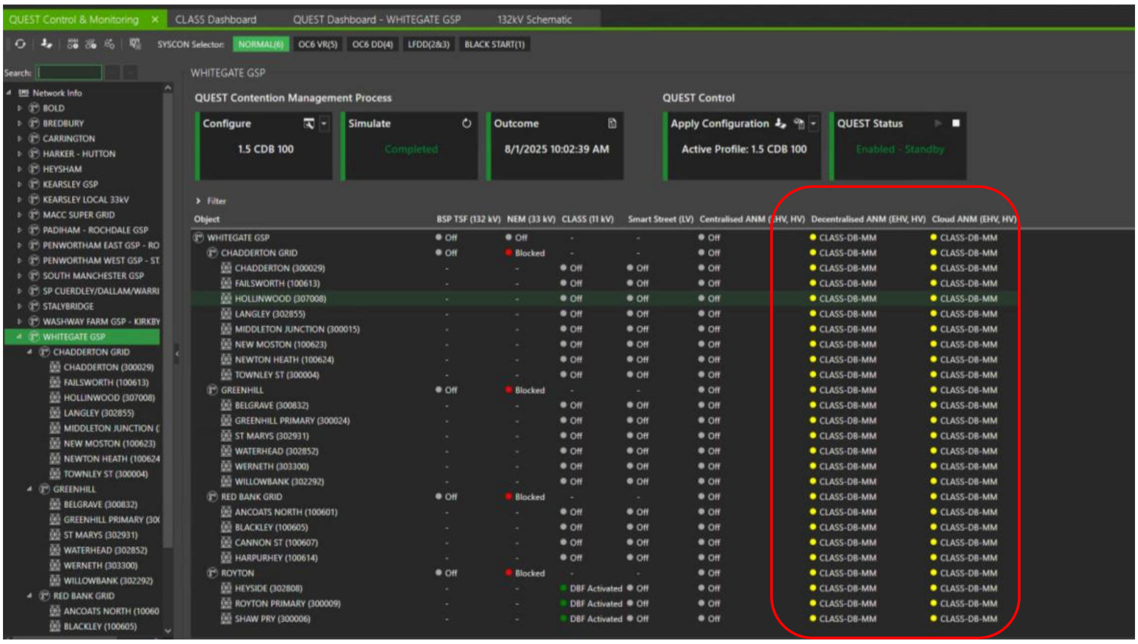


Figure 81 QUEST Dashboard showing DB Mitigation Mode Signals sent to ANM Systems

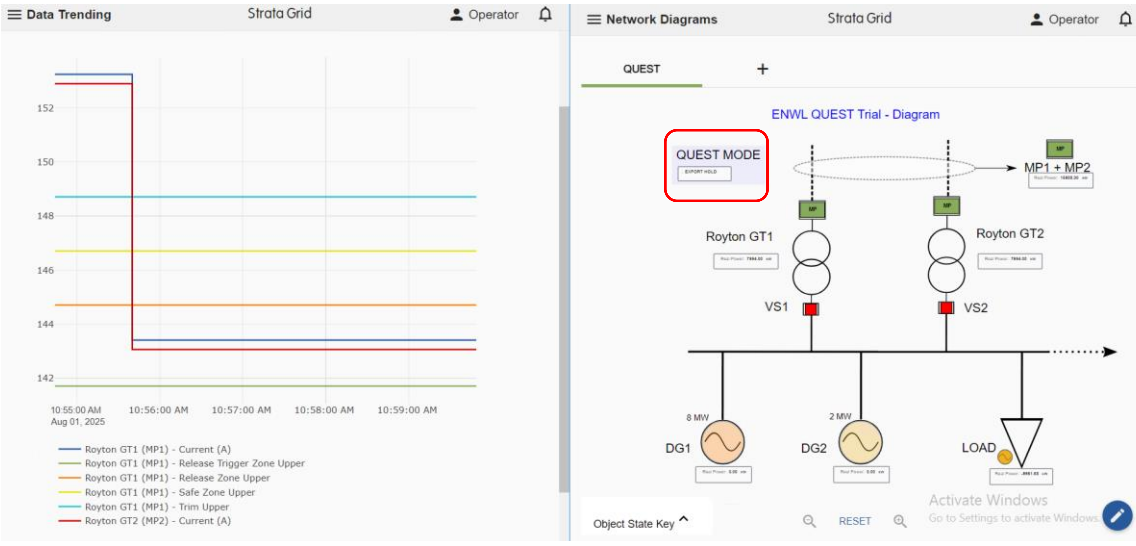


Figure 82 ANM Export Hold Mode received Preventing DER export during CLASS DB

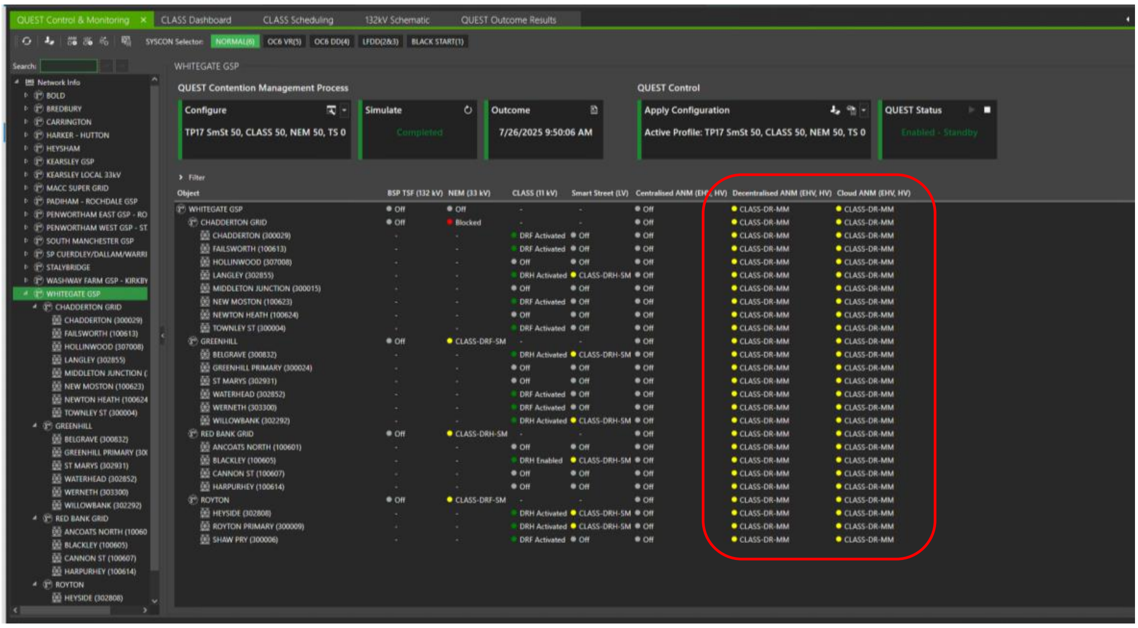


Figure 83 QUEST Dashboard showing DR Mitigation Mode Signals sent to ANM Systems

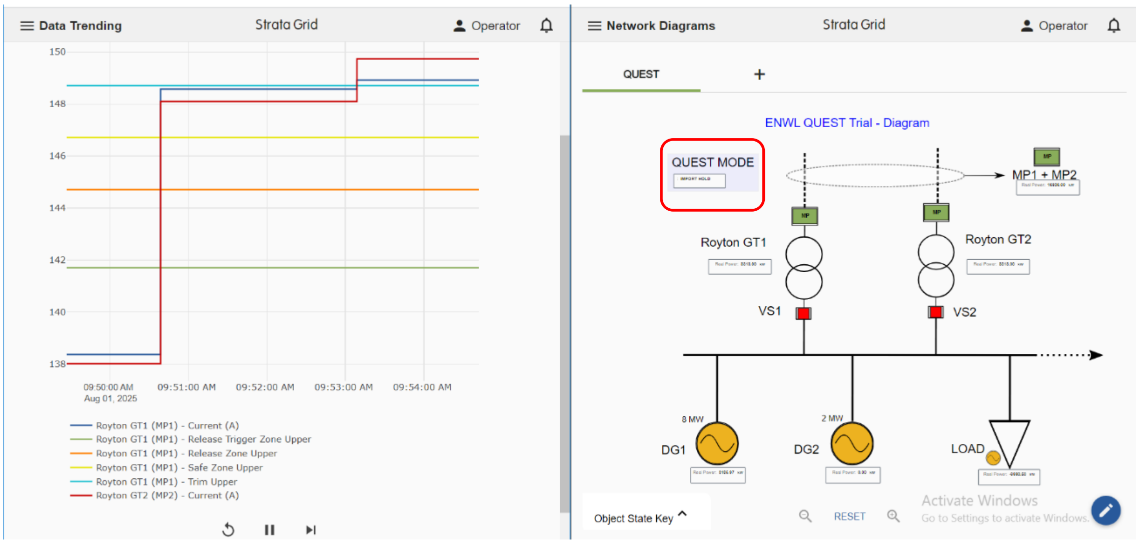


Figure 84 ANM Import Hold Mode Preventing DER import increase during CLASS DR

7.7.5. Observed Performance

When Hold Mode was active:

- ANM curtailed DER output as required for thermal constraints.
- During CLASS activation, ANM maintained DER at curtailed levels, avoiding counteraction.
- Upon CLASS deactivation, ANM resumed normal operation and released DER export/import in line with network conditions.

This behaviour demonstrated successful coordination between QUEST and ANM systems, ensuring voltage optimisation actions were not compromised by DER dispatch.

7.7.6. ANM Summary

The ANM trials confirmed:

- QUEST can issue mitigation commands to ANM systems via ICCP.
- ANM correctly applied Hold Mode to prevent DER release during CLASS actions.
- Conflict scenarios were effectively resolved, preserving QUEST benefits.

Mitigation modes are essential for integrated control of voltage and thermal constraints. Without these, ANM could inadvertently negate QUEST actions. The trials validated this functionality and demonstrated its importance for future whole-system optimisation.

8. Insights and Observations

The operational trials provided valuable insights into the behaviour, performance, and coordination capabilities of the QUEST system under a wide range of scenarios. These observations confirm the system's ability to manage complex interactions and highlight areas for refinement ahead of business-as-usual deployment.

8.1. Coordination Logic Performance

QUEST consistently applied the correct coordination logic in both proactive and responsive modes. Technique Priority Lists (TPLs) and Function Levels were respected, with adjustments made dynamically when system conditions changed. In multi-technique scenarios, QUEST successfully prevented conflicts by applying safe modes and mitigation modes, maintaining network stability throughout.

8.2. CLASS Demand Reduction and Boost

CLASS Demand Reduction operated as intended, delivering staged reductions across all configured levels, including newly introduced intermediate functions. Demand Boost trials confirmed the ability to increase demand safely without breaching voltage limits. In coordinated scenarios, QUEST adjusted CLASS function levels based on priority and target achievement, demonstrating flexibility in real-time operation.

8.3. Smart Street Behaviour

Smart Street performed reliably in isolation and when coordinated with other techniques. In standalone operation, CVR was applied effectively across the available sites. When CLASS was prioritised, Smart Street entered safe mode as expected, preventing excessive voltage reduction and maintaining compliance. In mixed-priority scenarios, QUEST enabled Smart Street where headroom allowed, balancing LV optimisation with HV requirements.

8.4. NEM Loss Reduction

NEM contributed to loss reduction at the 33kV level, applying voltage increases at BSPs in line with coordination logic. In emergency conditions, NEM was correctly inhibited, ensuring compliance with operational protocols. Variations between simulation and live trials were observed, primarily due to transformer availability and tap range constraints, but overall behaviour aligned with expectations.

8.5. Emergency Function Response

QUEST responded appropriately to system state changes, applying mitigation modes during OC6 and LFDD events. Tap positions were locked, and ANM systems held in mitigation mode to prevent unintended dispatch. The system transitioned back to normal operation promptly after emergency states were cleared, restoring configured function levels without manual intervention.

8.6. Tap Stagger Functionality

Tap Stagger trials confirmed the ability to absorb reactive power through controlled tap imbalance at grid transformers. The function operated independently and did not interfere with other techniques, validating its compatibility within the QUEST coordination framework.

8.7. System Integration and Operator Experience

The QUEST Dashboard and Event Summary provided clear visibility of system actions and coordination status. Manual transitions between system states were executed reliably, with appropriate responses observed. Operator feedback highlighted the importance of training and familiarity with the interface, particularly during emergency scenarios, and suggested enhancements for real-time performance monitoring.

9. Lessons Learnt

The QUEST operational trials provided valuable insights into system behaviour, coordination logic, and operational readiness. While the majority of trials met their success criteria, several key lessons emerged that will inform future deployments and refinements.

The basis of system design was that of a business as usual system responsive to real time network configuration. This was proven by testing, however that responsiveness added complexity to the repeatability of trails and outcomes. E.g. One asset becoming unavailable (e.g. fault, maintenance, loss of comms) would result in a different optimisation solution being delivered for the same scenarios settings.

The testing was performed within the SP ENWL control centre, with both QUEST and the production system being open at the same time. This quickly identified that additional time was taken between the sending and receipt of controls between the systems (with QUEST being slower due to the communications route, using ICCP, and the smaller my DMS system.

On an intermittent basis, this extended comms time breached QUEST Control/Confirmation system checks, resulting in QUEST assuming NON operation of devices and triggering another optimisation cycle. This is what a BaU system should do but resulted in a number of tests being invalidated. This was resolved by a QUEST system wide review and reset of a number of key timers, to ensure consistency. A Bau system would not require these changes.

Building on trial learning, the use of Smart Street sites other than supplied from Royton Primary was developed to fully capture the breadth of optimisation being performed by QUEST. In broadening the number of sites being used additional timing issues where uncovered due to the use of the cellular network for these comms.

The trials being performed in unison by an Innovation engineer and a control engineer brought forward a rapid understanding of QUEST and the Real Time system, and generated additional monitoring and tracking to support the trial and analysis process. By having a number of control engineers on the project, also resulted in a wider breadth of learning and observations to be captured for a BaU rollout.

As widely communicated, the required IT changes for essential security (cyber) concerns also generated some lessons for the project, that should not impact an integrated BaU solution but did impact trials.

The ICCP/ Infrastructure issues impacted signal response times (as noted above)

The timeframes required for IT business change, resulted in the decision for a small number of changes not to be applied to the QUEST system whilst the core system proving was ongoing. The most significant change that being with the BSP SCADA/ICCP set up, where physical TS operation had to be performed via the real time system.

The secure QUEST system required a chain of "remote access" systems to be up and running to both populate certain data sets that are auto generated in the production system and to provide system access to perform the trials. Trial delays where experienced when these systems or access to them was unavailable.

The infrastructure to support the QUEST system also started to suffer memory capacity issues as the data from multiple trials incremented. In a BaU system this would be managed by the system centrally, for QUEST the majority of the impacts could be managed by enhanced manual system maintenance. Towards the end of the trial the memory issue impacted yield summery reporting. As the volume of trial data already collected was sufficient, and the appropriate fix time consuming to deliver this lack of data was accepted.

9.1. Configuration Accuracy

Accurate setup of Technique Priority Lists (TPLs) and Function Levels (BLENDs) is essential. Trials showed that even minor misconfigurations could lead to suboptimal coordination or unintended interactions between techniques. Profiles must be carefully reviewed before activation to ensure alignment with trial objectives and system conditions.

9.2. Communication Reliability

Reliable data exchange between QUEST and field devices is critical. ICCP link stability and transformer telemetry availability directly impacted coordination performance, it is however, envisaged for BaU these will not be as applicable since it would be integrated into the main NMS system. Trials highlighted the need for robust fallback mechanisms and clear alerting when communication issues arise.

9.3. Operator Training and Interface Familiarity

Control engineers who were familiar with the QUEST Dashboard, SYSCON selector, and Event Summary tools executed trials more effectively. Emergency transitions and manual overrides require confidence and clarity—scenario-based training should be included in future rollout plans.

9.4. Integration with External Systems

Coordination with external platforms such as ANM dispatch, and Smart Street relays requires careful timing and configuration. Trials confirmed that integration is achievable but sensitive to asset availability, tap limits, and optimisation cycles.

9.5. Smart Street Optimisation Behaviour

Smart Street's periodic optimisation cycles can be affected by other active techniques. In some trials, extended optimisation windows were used to isolate Smart Street behaviour. Tap availability and transformer constraints influenced voltage targets and demand reduction outcomes.

9.6. Emergency Response Readiness

QUEST correctly transitioned techniques into mitigation modes during OC6 and LFDD events. Tap lockouts and transformer availability influenced the system's ability to fully meet NESO instructions. Clear mitigation logic and asset readiness are essential for reliable emergency response.

10. Conclusion

The QUEST trials have successfully demonstrated the operational capability, flexibility, and optimisation potential of the QUEST system across a wide range of voltage management scenarios. Through both simulation and real-time testing, the trials validated the core functionality of QUEST as defined in the project's design and functional specification.

Across emergency system states (SYSCON 2–5), QUEST reliably transitioned voltage control techniques into appropriate mitigation modes, ensuring compliance with NESO requirements and maintaining system stability. The trials confirmed that QUEST correctly responded to manual and automatic activations of OC6 VR, OC6 DD, and LFDD, sending the expected commands to ANM, NEM, and Smart Street systems while maintaining CLASS in its designated state.

In normal operating conditions, QUEST demonstrated its ability to coordinate multiple voltage control techniques—CLASS DR, CLASS DB, Smart Street, NEM, and BSP Tap Stagger—both in isolation and in combination. The trials showed that QUEST could prioritise techniques according to predefined profiles, apply safe mode logic where conflicts existed, and dynamically adjust function levels to meet demand reduction or loss reduction targets.

Notably, the trials confirmed that:

- CLASS DR and DB could be activated at varying levels (25%–100%) and achieve their forecasted targets.
- Smart Street operated effectively under QUEST control, delivering measurable demand reduction while avoiding voltage violations.
- NEM delivered consistent loss reduction benefits, with coordination logic ensuring it did not conflict with other active techniques.
- BSP Tap Stagger functionality was successfully triggered and measured, validating its integration into the QUEST control framework.

Multi-technique coordination trials further demonstrated QUEST's ability to optimise across competing objectives. Whether CLASS was prioritised over Smart Street and NEM, or vice versa, QUEST maintained voltage compliance and delivered benefits in line with expectations. The system's responsiveness to changing priorities and its ability to reconfigure control actions in real time were key strengths observed throughout the trial programme. The trials also highlighted areas for refinement, including the impact of external constraints such as manual inhibits, blocked transformers, and optimisation cycle timing. These insights will inform future enhancements to QUEST along with its integration into business-as-usual operations.

In summary, the QUEST trials have validated the system's design, confirmed its operational readiness, and demonstrated its value in delivering coordinated, optimised voltage control across the distribution network. QUEST has proven to be a robust and intelligent platform capable of supporting SP ENW's strategic objectives for network efficiency, customer benefit, and system resilience.