200952 SP ENW

QUEST Trial Test Results & Analysis Report

By:	Smarter Grid Solutions Ltd.
Date issued:	22.10.2025
Document number:	63B

1. DOCUMENT ISSUE CONTROL

Document name: **QUEST Trial Test Results & Analysis Report**

Document number: **63B**

Version	Issue Date	Author	Reviewed by	Approved by	Description	DUR #
A	29/08/25	David Conkie	Mark Collins	Kiera J. Todd	A report comparing the results obtained from the trial tests live measurement and SGS digital twin simulations	9166
B	22/10/25	David Conkie	Mark Collins	Kiera J. Todd	Update to the report following partner feedback	

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2. EXECUTIVE SUMMARY

QUEST is an innovation project led by SP Electricity North West (SP ENW) and in collaboration with Smarter Grid Solutions (SGS), Schneider Electric (SE), Fundamentals Ltd, National Grid ESO and Impact Research. The QUEST system solution co-ordinates different network control methods, arbitrating between control decisions and avoiding undesirable conflict when delivering autonomous smart functions of Voltage Optimisation, Active Network Management (ANM)/Constraint Management and Conservation Voltage Reduction.

SGS, SE and SP ENW developed the use-cases and functional requirements to enable the delivery of the QUEST system as a deployed product live in the field. Schneider developed and delivered the live solution in line with the agreed QUEST system requirements. To support the delivery of the live system, SGS developed a Quasi-Dynamic time-series based solution where the QUEST control methods are emulated in python and the electrical environment is simulated using a steady-state load flow model. The result is a digital twin of the QUEST system that represents the live QUEST System and the electrical network. This is known as the *QUEST System Model* – this model allows for three areas of assessment to support project development and delivery:

1. Comparing and contrasting the existing control methods are functioning to required expectation, allowing for both the live system and the modelled system to confirm operational outcomes, and updating both to improve operation and fidelity between both systems.
2. Assessing future control methods, or operational situations more difficult to arrange on the live system. The QUEST system model allows for testing control methods not currently ready to deploy on the live system to help their development, and test outage conditions not often executed such as National Electricity System emergency conditions.
3. Finally, the QUEST system model allows for forecast of benefits into the future. The live system is limited to operational timeframes, whereas the QUEST system model can forecast out to greater time horizons, allowing for network behaviour and impacts to be assessed.

The objective of this report is to undertake the first two areas of assessment to:

1. Ensure the live system is functioning according to expectation- validating control methods and their conflict arbitration,
2. Validate the performance of the SGS QUEST system model against the live SE QUEST system to ensure fidelity between the two systems, and
3. Test control methods that can't be assessed in live trials to satisfy fitness for purpose of the QUEST solution as a whole.

During 2025, SP ENW undertook operational trials on the network under Whitegate GSP to test the live QUEST system under different configurations. A selection of the live trials has been used to compare and contrast the SGS QUEST system model and the live SE QUEST system for the purposes of confirming QUEST control methods and conflict arbitration functionality and validation of operational expectation. As part of these tests, the following control methods were tested:

- **CLASS:** Applies voltage control via the taps of transformers in the primary substations to decrease or increase network real power demand by leveraging voltage-demand relationships,
- **Network Efficiency Mode (NEM):** Increases 33kV system voltages by adjusting Bulk Supply Point (BSP) transformer target voltage settings via taps, enabling the reduction of I^2R losses.
- **Smart Street**: reduces (MW) real power demand via the Conservation Voltage Reduction (CVR) methodology at secondary/distribution substations by changing the taps of the transformers connected to secondary substations.

These functions were tested in isolation and as part of a priority ordering to determine whether their optimisation was being delivered correctly.

Additionally, three *simulation-only* tests have been completed by SGS, as these involved emergency protocols or functions which could not be tested on Schneider's live system. The following control methods were tested as part of the simulation only tests:

- **OC6:** Applied at primary substations as a method of reducing demand in an emergency situation. This can be achieved via two different methods:
  - Voltage Reduction (VR) – demand reduction is achieved by lowering voltage levels and leveraging the voltage/demand relationship,
  - Demand Disconnection (DD) – demand reduction is achieved by opening HV circuit breakers.
- **Low Frequency Demand Disconnection (LFDD):** Involves opening 33kV circuit breakers to reduce system demand in the case of a low frequency event on the network.
- **Tap Stagger:** Providing voltage support, by setting transformer pair tap imbalance creating circulating current that result in a reactive power absorption at the BSP Extra High Voltage (EHV) level. That is measurable as a change in reactive power at the Grid boundary (400/275/132kV transformers)

Completion of trials in both a live and modelled environment meant that the benefits of QUEST optimisation could be corroborated against both the measured data from site and the outputs of the SGS QUEST system model.

By simulating the trial tests and comparing resultant voltage and power metrics, it was found that, in general, the QUEST system model produces accurate results when comparing output trends to that of the live QUEST system. The QUEST system model optimises as expected and in-line with project functional specification and use cases. Throughout both sets of trials, there were some examples of behaviour that did not align between the two systems (live and modelled), however these results are explainable.

A brief overview of the comparison of each function in for both the live QUEST system and the QUEST system model is as follows:

- **CLASS:** CLASS results are broadly similar between the two systems, although the SGS QUEST system model often achieves the CLASS demand reduction target when the live QUEST system has not. This is because the QUEST system model often achieves a lower voltage result for each substation, and, therefore, will achieve the demand reduction target by applying CLASS less aggressively or at fewer substations.

- **NEM:** Results for NEM are broadly similar when there were no deviations from normal in the operational system. NEM on the live system tended to reach a slightly higher voltage, this is likely due to the SGS digital twin opting to select a conservative tap setting to prevent the 33 kV voltage going outside the statutory limits.
- **Smart Street:** Results for Smart Street were more difficult to compare, for which there are a few reasons:
    - Not all the smart street site data was available to be graphed, and some data was only available at 10 minute intervals,
    - Some secondary sites on the live system did not operate as expected when Smart Street was active, but this was due known limitation on the live network,
    - Smart Street was active throughout the whole QUEST trial period in the live system, whereas in the SGS model there are some cases where Smart Street was programmed to activate during the study window,
    - For aid of testing, Smart Street periodic calculations in the live system were extended to ensure a consistent output during specific QUEST tests. Therefore, a change to normal mode will not generate an automatic change to voltage set point and tap position.
- **OC6 VR/DD & LFDD:** OC6 VR/DD and LFDD were successfully simulated to showcase the demand reduction methods and the corresponding effects of CLASS, Smart Street and NEM.
- **Tap Stagger:** Tap Stagger was simulated successfully and demonstrates the level of reactive power absorption that can be achieved by creating a tap differential at a pair of transformers.

Overall, inaccuracies between power and voltage results between the live and modelled systems are due to known limitations on the live network during testing and differences between the live system measurements and simulated model measurements, rather than erroneous operation of the control methods and conflict arbitration these assessments are intended to prove.

Elements of the QUEST system model have been simplified to reduce modelling complexity, resulting in potential inaccuracies of power and voltage outputs for improved performance (solution convergence times). This model simplification has allowed for proving the live QUEST system is fit for purpose and that under future development or emergency conditions the live QUEST system should function as expected, achieving the project objectives.

The combination of simulated trial tests and live trial tests gave the opportunity to achieve the objectives of this report:

1. Confirmation that the live SE QUEST system operates as per the functional specification to perform QUEST control actions on the live network so that the benefits from QUEST can be realised. In some instances, differences between the two QUEST systems prompted questions regarding the response of the live QUEST system but these differences were generally because of known limitations on the live network.
2. Validation of the SGS QUEST system model, which has been shown via the trial tests outlined in this report to perform closely in line with the live SE QUEST system.
3. The simulated and live QUEST trials further support that Conservation Voltage Reduction is an effective technique for leveraging the voltage/demand relationship,

under operational situations hard to test in the live environment, namely OC6 and LFDD tests.

The trial tests show that QUEST can achieve control functionality for each method in isolation and as part of a multi-objective control requirement delivering the benefits relating to each individual control function and arbitrating the potential conflict between them. This has been shown in both the live QUEST system and the QUEST system model. The benefits of executing the trial tests in both these formats has allowed for functionality to be proven fit for purpose for the existing control functions. Furthermore, the QUEST system model has shown in the trial tests for functionality that does not currently exist or for non-testable scenarios the live QUEST system should perform as expected, achieving the benefits provided from these control functions.

In future work, a more complex model could improve accuracy and precision of the resulting power and voltage outputs for the QUEST system model. However, this would only be required where accuracy and precision have a material impact to proposed objectives.

3. INTRODUCTION

QUEST is an innovation project led by SP Electricity North West (SP ENW) and in collaboration with Smarter Grid Solutions (SGS), Schneider Electric (SE) Fundamentals Ltd, IMPACT Research and National Energy System Operator (NESO). The QUEST project solution co-ordinates different network control systems, arbitrating between control decisions and avoiding undesirable conflict when delivering autonomous smart functions of Voltage Optimisation, Active Network Management (ANM)/Constraint Management and Conservation Voltage Reduction.

SGS, SE, Fundamentals Ltd and SP ENW developed the use-cases and functional requirements to enable the delivery of the QUEST system as a deployed product live in the field. SE developed and delivered the live solution in line with the agreed QUEST system requirements.

To support the delivery of the live system, SGS developed a Quasi-Dynamic time-series based solution where the QUEST control methods are emulated in python and the electrical environment is simulated using a steady-state load flow model. The result is a digital twin of the QUEST system that represents the live QUEST System and the electrical network. This is known as the *QUEST System Model*, this model allows for different configurations of QUEST control inputs to be emulated upon different network operational conditions, utilising measured network data. Benefits of implementing a QUEST system model include:

- Allowing for testing of QUEST functionalities which are not yet available on the live QUEST system,
- Forecasting the QUEST system's behaviour on a network model which includes future upgrades,
- Optimising the QUEST system's response to unexpected changes in load/generation or network topology.

The objective of this report is to undertake the first two areas of assessment to:

1. Ensure the live system is functioning according to expectation- validating control methods and their conflict arbitration,
2. Validate the performance of the SGS QUEST system model against the live SE QUEST system to ensure fidelity between the two systems, and
3. Test control methods that can't be assessed in live trials to satisfy fitness for purpose of the QUEST solution as a whole.

During 2025, SP ENW undertook operational trials on the network under Whitegate GSP to test the live QUEST system under different configurations. A selection of the live trials has been used to compare and contrast the SGS QUEST system model and the live SE QUEST system for the purposes of confirming QUEST control method and conflict arbitration functionality and validation of operational expectation.

This report outlines the methodology used by the SGS QUEST system model and the results found from the SE live QUEST system trial tests, where all tests have been simulated in the system model and compared against the measurements from the live system. The tests support the achieving the first and second objective of this report.

Additionally, and in support of the third objective, three *simulation-only* tests have been completed by the SGS QUEST system model, as these involved emergency protocols or functions which could not be tested on the live QUEST system.

3.1. Summary of QUEST Functions

The voltage control functions which are managed by QUEST are:

- **CLASS Demand Reduction (DR):** Uses voltage control through the taps of Transformers in the primary substations to decrease network real power demand by leveraging voltage-demand relationships,
- **CLASS Demand Boost (DB):** Uses voltage control through the taps of Transformers in the primary substations to increase network real power demand by leveraging voltage-demand relationships,
- **Smart Street (SmSt):** reduces (MW) real power demand via the Conservation Voltage Reduction (CVR) methodology at secondary/distribution substations by changing the taps of the transformers connected to secondary substations.
- **Network Efficiency Mode (NEM):** increases 33kV system voltages by adjusting Bulk Supply Point (BSP) transformer target voltage settings via taps, enabling the reduction of I^2R losses.
- **Tap Stagger BSP:** Providing voltage support, by setting transformer pair tap imbalance creating circulating current that result in a reactive power absorption at the BSP Extra High Voltage (EHV) level. That is measurable as a change in reactive power at the Grid boundary (400/275/132kV transformer)
- **ANM Flexible Connections:** maintains network thermal flow limits by curtailing generation in real time, enabling quicker connection time and network investment deferral.
- **ANM Flexible Services:** is the forecasting of exceeding thermal flow limits, coupled with the procurement and dispatching of Distributed Energy Resource (DER) flexible demand and generation services to mitigate the forecast thermal flow exceedance.

Additionally, the live QUEST system can respond to emergency functions which are instructed by NESO. The set up of this can be tested in the live QUEST production system, but the delivery of these actions cannot be tested. In the SGS QUEST system model, both the set up and the delivery of the OC6 response can be tested. QUEST can be simulated as being active before moving to a preparation state in advance of OC6 being implemented. The emergency functions which have been tested on the SGS QUEST system are as follows:

- OC6**:** Applied at primary substations as a method of reducing demand in an emergency situation. This can be achieved via two different methods:
  - Voltage Reduction (VR) – demand reduction is achieved by lowering voltage levels and leveraging the voltage/demand relationship,
  - Demand Disconnection (DD) – demand reduction is achieved by opening HV circuit breakers.
- Low Frequency Demand Disconnection(LFDD): Involves opening 33 kV circuit breakers to reduce system demand in the case of a low frequency event on the network.

The live SE QUEST system and the SGS QUEST system model both support the delivery of providing fitness for purpose of the QUEST system for existing control functions, with the QUEST system model supporting the delivery of proving fitness for purpose of the functions in development and for emergency conditions. The results is that, between the live system and the model system, all project objectives can be achieved and the QUEST system proven as fit for purpose.

This document evidences the delivery of report's objectives in the following sections:

- Methodology: The methodology explains how the QUEST system model is constructed.
- Trial Tests: The trial tests define how the QUEST system is tested via the live system and modelled system to prove fitness for purpose.
- Trial Test Results: Each trial test results are presented and explained in the context of what they show and how it proves fitness for purpose.
- Conclusion: The results are concluded.

4. METHODOLOGY

The SGS QUEST system model is implemented in Python and interfaces with a load-flow model of the electrical network. The network area under test is the Whitegate GSP network area. The key inputs for the SGS QUEST system model are as follows:

- Load data – time series load values derived from system measurements provided by SP ENW,
- Load ZIP values – time series ZIP values derived from system measurements provided by SP ENW,
- QUEST config files – configuration files for each QUEST function which contain key information regarding each function's settings, such as relevant substations, function levels and voltage limits,
- System schedule – contains details of which functions are due to run during each simulation,
- Function Priorities – the order of QUEST function priorities, which impacts how control is applied.

The system model intakes the key information listed above and runs a time-series of load flows. The relevant QUEST control is applied in each time step and at the end of the control application a final load flow is run to recognise the final state of the system for each time step. Once each time step in the model had been run, a series of datasets is produced which contains relevant results for each QUEST control function. These datasets allow for voltage trends to be observed and key metrics such as change in demand and loss reduction to be calculated and compared with the live QUEST system.

4.1. Whitegate GSP Load-Flow Network Model

A load-flow network model of the Whitegate GSP area was provided by SP ENW for use in conjunction with the python-based QUEST control model, developed by SGS. The load-flow network model contained all the BSPs and primary substations in the Whitegate area, as well as a selection of secondary substations and aggregated equivalents of the LV network below.

Primary loads were modelled at the 6.6 kV or 11 kV busbars throughout the load-flow network model. If secondary sites were modelled, loads would be modelled at 415 V (240V p-n). Secondary loads were split up into 5, with 67% of the load being modelled at the LV busbar and the rest of the load being distributed across 2 LV feeders. This allows for end of feeder voltages to be observed during the application of Smart Street.

All transformer tap changers in the model are automatically controlled and target a voltage of 1 p.u, except from the secondary transformers which have their tap settings fixed. If QUEST is operational, this takes over the tap changer control.

4.2. Load and ZIP Data Processing

Load data was provided by SP ENW for each series of live trials which were run on the live network. A range of one second data was provided for BSPs and primaries, with 10 min average data for secondary transformers. While all this data was useful for the purpose of comparison, not all the data was required as inputs to the network model. As the load-flow model had some limitations with regards to the modelling of the 11kV and LV networks, the key loading information was the primary transformer measurements, with some secondary site loads also being directly modelled from the measurements. If there was a secondary site modelled in the load flow model, but the measurement data was not provided for this site, a conversion process was applied to the relevant primary dataset, which was broken down based on the number of feeders and secondaries supplied to model LV correctly. Additionally further processing was undertaken to model load at mid points and ends of LV feeders.

Some of QUEST's control functions are specifically focused on utilising the response between voltage and demand. Therefore, it is important that:

- The QUEST system model considers the demand response due to voltage control and,
- The input data that the QUEST system model uses does not already include this response due to live QUEST system controls applied to this data.

The QUEST system model is designed to induce the demand load-response due to the application of QUEST control on the system, so it did not make sense to directly apply loading data from the live system where QUEST had already been active. This is because the demand loading would be inclusive of the load response – potentially double counting the demand loading response from control application. Instead, loading data points from before and after the activation of QUEST were used to create a sensible loading estimate for the system model, and QUEST control was applied on the network to induce the expected load response.

The load-response Kp values were also provided by SP ENW. These measurements were taken at irregular intervals and so a process to interpolate these values and sample them at regular intervals was applied, so they can be used as an input to the QUEST system model. If Kp values for a certain primary were not available, an assumption was made that the site had a Kp value of 0, meaning that the load is not sensitive to voltage. Once the relevant Kp profile were created, the values were converted into ZIP values based on the following calculation:

$$K_{EXP} \leq 0 \rightarrow \begin{cases} K_Z = 0 \\ K_I = 0 \\ K_P = 1 \end{cases}$$

$$0 \leq K_{EXP} \leq 1 \rightarrow \begin{cases} K_Z = 0 \\ K_I = K_{EXP} \\ K_P = 1 - K_{EXP} \end{cases}$$

$$1 < K_{EXP} < 2 \rightarrow \begin{cases} K_Z = K_{EXP} - 1 \\ K_I = 2 - K_{EXP} \\ K_P = 0 \end{cases}$$

$$K_{EXP} \geq 2 \rightarrow \begin{cases} K_Z = 1 \\ K_I = 0 \\ K_P = 0 \end{cases}$$

[1]

The application of these processes meant that every load in the model was provided a time series profile and associated time series ZIP values which could be used to model the Voltage/Demand Relationship.

4.3. Application of QUEST Control

4.3.1. Individual Function Operation

A description of the functionality of each QUEST control method, considered under test, is as follows:

- **CLASS Demand Reduction (DR)** – achieved via the control of tap changers at primary transformers, with the goal to lower voltage and therefore reduce demand. This function is applied according to a function level which has an associated voltage target. There is also an associated demand reduction target which the control will aim for. If CLASS is applied to a function level below the maximum of 100% but the demand target is not reached, the control can opt to increase the function level further in an attempt to reach the target.

- **CLASS Demand Boost (DB)** – achieved via the control of tap changers at primary transformers, with the goal to raise voltage and therefore increase demand. This function operates similar to the CLASS Demand Reduction function described above.
- **Smart Street (SmSt)** – achieved via the control of tap changers at secondary transformers, with the goal to lower voltage and therefore reduce demand. This function is applied according to a function level which has an associated voltage target. There is no demand reduction target associated with Smart Street, but the control can opt to increase the function level to increase the benefit provided as long as there is not an adverse effect on other QUEST functions.
- **Network Efficiency Mode (NEM)** – achieved via the control of tap changers at BSP/Bulk transformers, with the aim to increase voltage to reduce 33 kV losses. This function is applied according to a function level which has an associated voltage target. There is no loss reduction target associated with NEM, but the control can opt to increase the function level to increase the benefit provided as long as there is not an adverse effect on other QUEST functions.
- **Tap Stagger (TS)** – achieved via the control of tap changers at BSP transformers, with the aim to achieve a transformer pair tap imbalance to create a reactive power sink which can be useful for voltage control at higher voltage levels.

The functions not exclusively tested in these specific trials are:

- **ANM Flexible Connections:** maintains network thermal flow limits by curtailing generation in real time, enabling quicker connection time and network investment deferral.
- **ANM Flexible Services:** is the forecasting of exceeding thermal flow limits, coupled with the procurement and dispatching of Distributed Energy Resource (DER) flexible demand and generation services to mitigate the forecast thermal flow exceedance.

These haven't been included as there is not, at present, enough connections and services to robustly test.

However, from a project objective perspective these functions have been integrated into the QUEST system model and were deemed to be fit for purpose in a prior report and published[1].

Furthermore, the communicative elements between the ANM systems that implement instruction from QUEST have been deemed to be fit for purpose in supporting work packages.

The remainder of this trial Test Results & Analysis Report will focus only on the aforementioned functions.

[1] Quest- an overarching control solution- July 2023IET Conference Proceedings 2023(6):496-500, Conference: 27th International Conference on Electricity Distribution (CIRED 2023)

4.3.2. QUEST Control – CLASS, NEM, Smart Street

When multiple control functions are applied via QUEST, they are given a priority order which effects how the control is applied. The SGS QUEST system model control co-ordination is based around the application of "Safe Mode", the details of which are given in the following:

Table 1: Safe Mode Function Level Settings

CLASS Setting	NEM Setting	Smart Street Setting
100	0	0
75	25	25
50	50	50
25	75	75
0	100	100

CLASS DR has a relationship with both NEM and Smart Street, however, NEM and Smart Street do not have a relationship with each other. If CLASS was the highest priority, then NEM and Smart Street would be given the corresponding function level according to the Safe Mode table, Table 1. For example, if CLASS was at 75% function level and in first priority, the NEM and Smart Street sites which interface with CLASS sites would be given a 25% function level. Similarly, if NEM or Smart Street were prioritised above CLASS and had a 75% function level, CLASS would be given a 25% function level.

The CLASS demand reduction target also influences the control. If CLASS is in first priority and is operating at a function level below 100% but the demand target has not been achieved, the function level will be progressed further until the demand target is achieved or all sites are at 100% function level. This target also has an impact on how NEM and Smart Street will act, so if CLASS is progressed to 100% function level, NEM and Smart Street would have a 0% function level according to Table 1. If NEM or Smart Street are prioritised ahead of CLASS, CLASS can still progress its function level to help achieve the demand reduction target as long as it is in accordance with Table 1.

NEM and Smart Street will also progress their function levels if possible, in accordance with Table 1. Although they do not have targets to hit, if the function level can be progressed without negatively impacting CLASS, the control will permit this.

The control for CLASS DB is very similar to CLASS DR, except there is no relationship between CLASS DB and NEM and only function levels 50% and 100% can be used for CLASS DB.

Application of safe mode settings are only applicable when CLASS and NEM/Smart Street are applied at sites which interface with each other. Sites which do not interface with each other can act independently of the safe mode settings.

The different function levels for QUEST function have corresponding target voltages which are shown in Table 2:

Table 2: Function Levels and Corresponding Target Voltages

Function Level (%)	CLASS DR Voltage Target (pu)	Smart Street Voltage Target (pu)	NEM Voltage Target (pu)	CLASS DB Voltage Target (pu)
0	1	1.01	1	1
25	0.9875	0.985	1.0143	N/A
50	0.975	0.96	1.0285	1.025
75	0.9625	0.935	1.0428	N/A
100	0.95	0.91	1.057	1.05

This logic has been applied in the SGS QUEST system model and is informed by the QUEST Functional Specification [2]. Similar logic is implemented in the live QUEST system but details of the implementation may differ which could lead to a divergence of results.

4.3.3. QUEST Control – Emergency Functions

The SGS QUEST system model not only allows for the comparison of QUEST in a preparation state for an emergency situation but also performs the calculation of a response from the implementation of that emergency situation.

4.3.3.1. OC6 Voltage Reduction & Demand Disconnection

OC6 Voltage Reduction (VR) and Demand Disconnection (DD) can be applied via the QUEST system. OCR VR reduces voltages by 3% or 6% at the primary substation level. This is applied in an attempt to decrease demand at these sites and is executed based on an instruction from NESO.

If demand reduction requirements are not met by OC6 VR alone, OC6 DD is also applied, which involves opening HV circuit breakers to meet the demand reduction target.

If OC6 is applied when other QUEST functions are operating, the QUEST functions must respond in a way that does not impede the OC6 functionality. This response is set out in [2], which gives details on how NEM and Smart Street should react for both OC6 VR and OC6 DD and is shown in Table 3:

Table 3: QUEST's behaviour in case of OC6 modes activation/deactivation [2]

Emergency condition/Affected techniques	ANM	NEM	Smart Street
OC6 VR Activated	**OC6-VR- Mitigation Mode**: Putting ANM in OC6-MM network-wide (preventing the release of the previously curtailed demand).	**OC6-VR- Mitigation Mode**: Switching off NEM at all the BSPs.	**OC6-VR- Mitigation Mode:** Fixing all the SMST transformers on their current tap positions.

Emergency condition/Affected techniques	ANM	NEM	Smart Street
OC6 DD Activated	**OC6-DD- Mitigation Mode:** Putting ANM in OC6-MM network-wide (preventing the release of the previously curtailed demand).	**OC6-DD- Mitigation Mode:** Locking NEM at all the BSPs in whatever voltage target setting the BSP transformers were in before SYSCON-4 was activated.	**OC6-DD- Mitigation Mode:** Locking all SMST transformers in whatever voltage target setting they were in before SYSCON-4 was activated.
OC6 modes deactivation	Returning ANM to a normal mode of operation	Returning NEM to a level of voltage increase determined under normal system operation in accordance with techniques' priorities and function levels (BLENDs).	Returning SMST transformers to a level of CVR determined under normal system operation in accordance with techniques' priorities and function levels (BLENDs).

4.3.3.2. Low Frequency Demand Disconnection

Low Frequency Demand Disconnection (LFDD) is another emergency function which can be instructed by NESO and involves opening 33 kV circuit breakers to reduce demand in the case of a low frequency event on the network. Again, active QUEST functions must respond accordingly if LFDD is activated, but it is only the NEM and ANM functions which have correspondence with this function. This is detailed in Table 4:

Table 4: QUEST's behaviour in case of LFDD mode activation/deactivation [2]

Emergency condition/Affected techniques	ANM	NEM
LFDD Activated	**LFDD-Mitigation Mode:** Putting ANM systems in LFDD-MM network-wide (preventing the release of the previously curtailed demand).	**LFDD- Mitigation Mode:** Switching off NEM on all the BSPs
LFDD Deactivated	Returning ANM to a normal mode of operation.	Returning NEM to a level of voltage increase determined under normal system operation in accordance with

Emergency condition/Affected techniques	ANM	NEM
		techniques' priorities and function levels (BLENDs).

5. TRIAL TESTS

The trial tests were designed to support delivery of the wider project objectives, proving fitness for purpose of the QUEST system.

5.1. Trial Selection

Fourteen (14) different tests were selected to be studied. These were selected as there is a wide range of functions, function levels and priority orders included, as well as some tests which are simulation only and some which are based on live measurements. The simulation only tests were tests that were unable to be tested on the live system, as this would have involved the application of emergency protocols or applications which are not yet fully available to execute via the live QUEST system.

Tap Stagger was tested manually, rather than through the centralised QUEST control, and the control of SP ENW's Active Network Management (ANM) system via QUEST has been tested separately outside of these trials.

Figure 1: QUEST Control Venn Diagram

Figure 1 shows the different types of services which can be provided by QUEST. Through these trials, a range of combinations and configurations of the top 3 circles have been tested.

The trial test summary, detailed in Table 5, has the following categories which define the tests undertaken:

- Test Number: The unique test reference.
- Test Type: Details whether the test has been completed on both the live system and SGS simulation or the SGS simulation only.
- NEM Function Level/Priority: If NEM is included in test, details the function level percentage setting, followed by the priority rank.
- CLASS Mode: If CLASS is included in test, details the mode which CLASS is in: Demand Reduction (DR) or Demand Boost (DB).
- CLASS Function Level/Priority: If CLASS is included in test, details the function level percentage setting, followed by the priority rank.
- Smart Street Function Level/Priority: If Smart Street is included in test, details the function level percentage setting, followed by the priority rank.
- OC6 Mode: If OC6 is included in test, details the mode OC6 is in: Voltage Reduction (VR) and Demand Disconnection (DD).
- LFDD: Details if LFDD is included in test.
- Tap Stagger: Details if Tap Stagger is included in test.

The following table, Table 5, shows a summary of the trial tests which were completed:

Table 5: QUEST Trial Tests Summary

Test Number	Test Type	NEM Function Level/Priority	CLASS Mode	CLASS Function Level/Priority	Smart Street Function Level/Priority	OC6 Mode	LFDD	Tap Stagger
01	Live & Simulation	25/2	DR	25/3	25/1	N/A	N/A	N/A
02	Live & Simulation	N/A	DR	100/1	0/2	N/A	N/A	N/A
03	Live & Simulation	N/A	DR	0/2	100/1	N/A	N/A	N/A
04	Live & Simulation	N/A	DR	75/1	25/2	N/A	N/A	N/A
05	Live & Simulation	N/A	DR	25/2	75/1	N/A	N/A	N/A
06	Live & Simulation	100/1	DR	100/2	100/3	N/A	N/A	N/A
07	Live & Simulation	100/2	DR	100/3	100/2	N/A	N/A	N/A
08	Live & Simulation	100/3	DR	100/2	100/1	N/A	N/A	N/A
09	Live & Simulation	50/1	DR	25/2	50/3	N/A	N/A	N/A
10	Live & Simulation	N/A	DB	100/1	0/2	N/A	N/A	N/A
11	Live & Simulation	50/2	DB	50/1	0/3	N/A	N/A	N/A
12	Simulation Only	25/2	DR	25/3	25/1	VR/DD	N/A	N/A
13	Simulation Only	25/2	DR	25/3	25/1	N/A	ON	N/A
14	Simulation Only	N/A	N/A	N/A	N/A	N/A	N/A	ON

In addition to providing load data and Kp values for the trials, SP ENW also provided supporting documents for each live trial which gave details of the following key points:

- The time periods during which QUEST was active,
- The relevant sites at which QUEST was implemented,
- The input function levels and priority orders,
- The resultant function levels,
- CLASS demand target and value achieved,
- NEM loss reduction value achieved.

This information was key for the trial set up and comparing outputs.

5.2. Voltage Control Hierarchy Expectation within the Live System QUEST Control

When Smart Street is operational, a periodic LV analysis is done to optimise LV voltage. Therefore, distribution voltages set point may be a random value at start of QUEST trial. Between QUEST trials the Smart Street units where often set to a default value, to ensure any customer feedback received during trials was QUEST related.

The voltage control hierarchy within SP ENW ensures voltage issues are resolved at the highest voltage first. This results in lower voltages having longer response times to maintain this hierarchy. This means distribution OLTCs can take up to 3 min to respond to a change in voltage set point (VSP) or measured voltage excursion from bandwidth around the voltage set point.

The live QUEST system optimises and prepares network, but the standard CLASS function requires to be prepared then activated. QUEST optimisation will immediately send NEM and Smart Street signals (with a delayed response to Smart Street on site). CLASS changes only when occur when activated (signal is sent from NESO in a real-world scenario) therefore real time data will show the system being optimised, followed by CLASS activation.

In some trial tests, function levels can be input as 0%, When this is the case, QUEST will still attempt to optimise the relevant function and so the resultant function level can raise above 0% provided this does not negatively impact any higher priority functions.

5.3. Trial Limitations

During the first test, which took place on 15/05/25, there were some system abnormalities which are evident in the Smart Street live measurement data. These were resolved for following tests.

During the trials, operational and telemetry issues may have resulted in some Smart Street tap changers defaulting to fixed tap / nominal voltage set point.

The initial network modelling for the trials was completed two years prior to the live trials and since then SP ENW have broadened the number of Smart Street sites on the network to support its operation, so for simulating Smart Street in the SGS QUEST system model, there were occasions where the site at which Smart Street had been applied in the live system was not modelled in the load-flow network model and therefore not considered within the SGS QUEST system model. In this case, an equivalent site that was available in the load-flow network model would be selected and so the effect of Smart Street at such a site could still be observed. An example of this is Pearley Banks, which was used in the SGS model in place of Goldsmith Ave (also fed from Heyside Primary), where Smart Street was applied in the live system.

Live measurement data for the Goldsmith Ave and Fold View Smart Street sites were only available at 10 minute intervals. This made comparison difficult for these sites, especially when the tests were performed over a short period of time. Due to this, some divergence of displayed results is expected here.

6. TRIAL TEST RESULTS

The following sections give the results of each trial test, all of which were conducted within the SGS QUEST system model. The trial tests have been divided into two types:

- 6.1. Live & Simulation Tests, the trial tests executed on both the live QUEST system and QUEST system model, with existing control functions, and
- 6.2. Simulation Only Tests, the trial tests executed on the QUEST System Model only.

For the live & simulation tests, graphs of measurement results from the live QUEST system have been included alongside the simulated results from the QUEST system for comparison.

For each trial, the reporting of results includes:

- Test number, name and date of live system test.
- Test QUEST Input Settings: Tabulated settings relating to the functions within the trial test
  - Function Level: the function level percentage at which each individual QUEST function was applied,
  - Voltage Target: the corresponding voltage target for each function level, for each individual QUEST function,
  - Demand Target: the demand reduction or demand boost target, only applicable to CLASS,
  - Active Time Period: the time period during which each function was active for in the SGS simulation.
- QUEST Sites: Tabulated Details of the substations available for each QUEST function in the SGS simulation.
- Load Details: Details on the source of load data.
- Trial Test Comments: Any additional comments which are relevant to the trial test.
- [Function] Results: Graphs and commentary for each QUEST function, with function specified in the title.

6.1. Live & Simulation Tests

6.1.1. Test 01 – Smart Street 25 + NEM 25 + CLASS 25 – 15/05/25

6.1.1.1. Test Input Details

Table 6: QUEST Input Settings for Test 01

	CLASS DR	CLASS DB	Smart Street	NEM
Priority	3	N/A	1	2
Function Level	25%	N/A	25%	25%
Voltage Target	0.9875 pu	N/A	0.985 pu	1.0143 pu
Target	2.45 MW	N/A	N/A	N/A
Active Time Period	12:37 - End	N/A	During whole trial	12:37 - End

Table 7: QUEST Sites

CLASS	Smart Street	NEM
Under Greenhill Grid: • Belgrave • St Mary • Werneth • Willowbank Under Royton Grid • Heyside • Shaw	Under Royton Primary: • Travis Court • Royton Centre • Oozewood Rd • Consort Ave • Beechwood Dr Under Heyside Primary: • Pearley Banks	Under Whitegate GSP: • Royton Grid • Greenhill Grid

Load Details

- From the trial information provided by SP ENW, QUEST became active between 12:16 and 13:41.
- Load values at 12:15 and 13:42 were recorded and linear interpolation between the values was used to get "non-QUEST-load".
- Trial was run from 12:15 to 13:10.

Trial Test Comments

- Limitations on the live system meant that Smart Street did not fully operate and Consort Avenue was the only site able to operate properly.
- Not all Smart Street sites had results data available.
- CLASS at Royton Primary was not available due to issues with the telemetry.

6.1.1.2. Smart Street Results

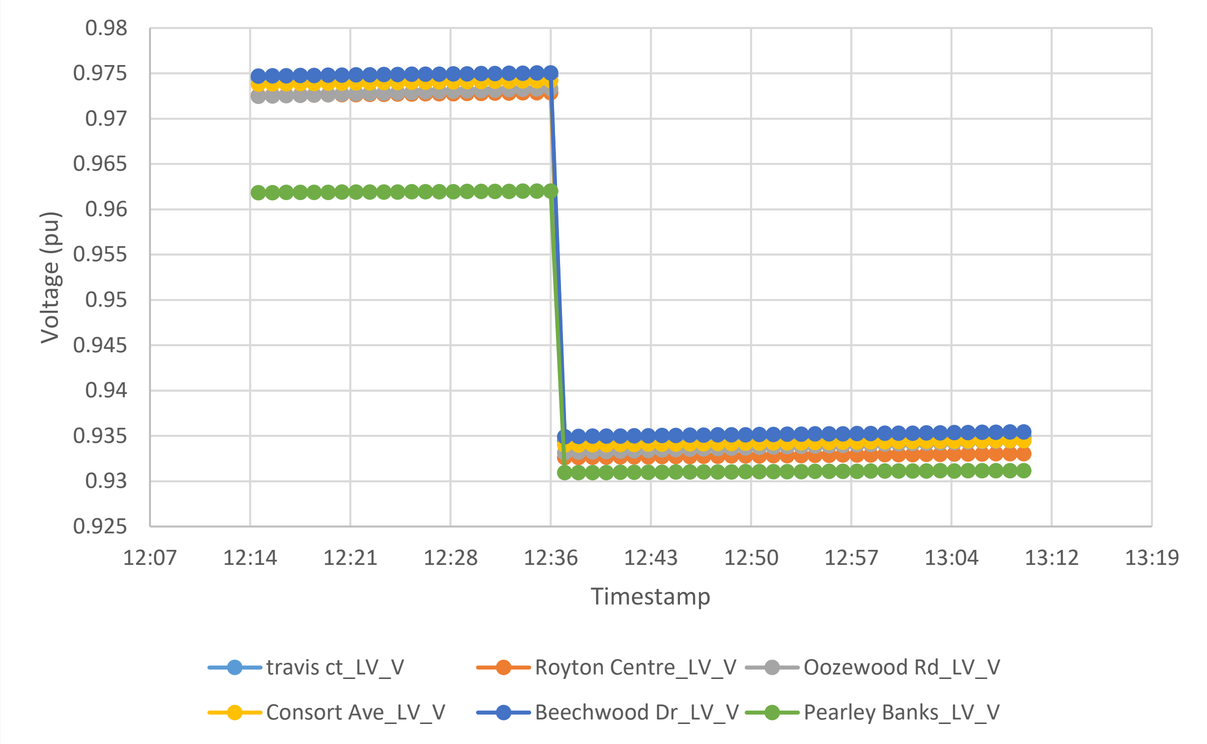

Figure 2: Smart Street Simulated Voltage Results from SGS QUEST System Model

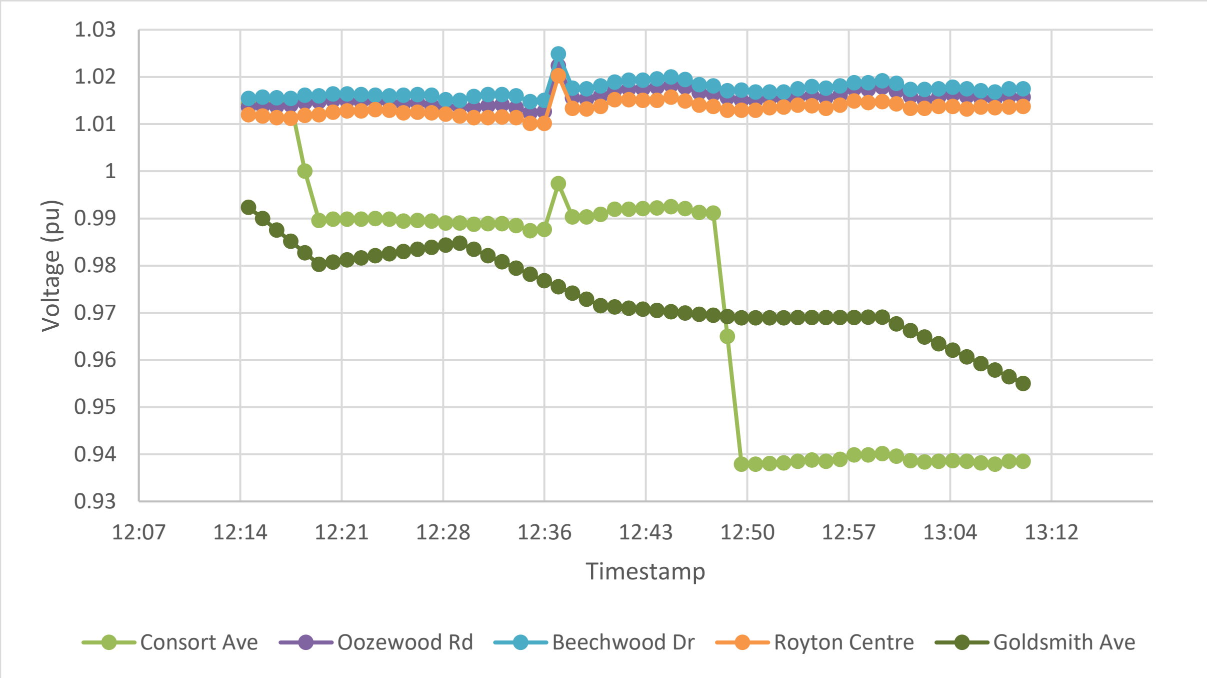

Figure 3: Smart Street Live Voltage Measurement Results from Live QUEST System

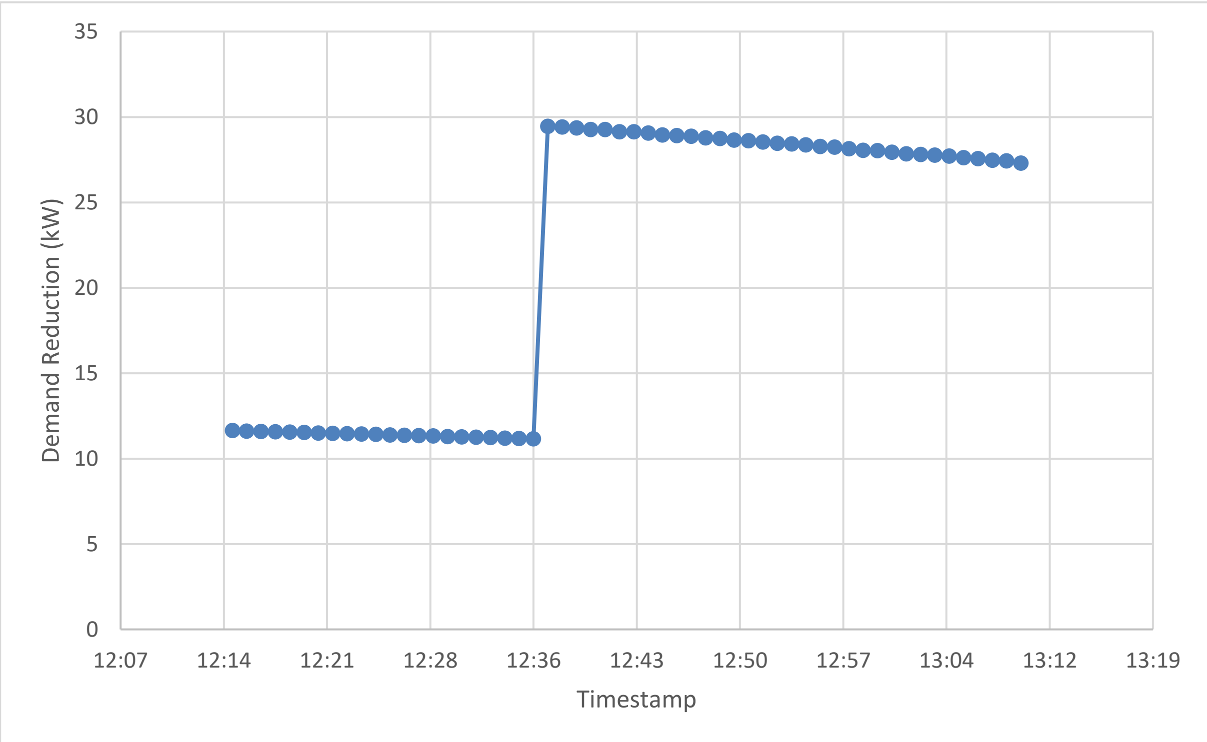

Figure 4: Smart Street Demand Reduction from SGS QUEST System Model

Figure 2 shows the voltage results for Smart Street from the SGS QUEST system model. Smart Street is implemented from the beginning and targets a voltage of at least 0.985 pu, which corresponds to the 25% function level. Pearley Banks substation is fed from a different primary substation (Heyside) than the rest of the Smart Street sites, so this voltage is a lower to start due to this. When CLASS and NEM are activated at 12:37, the Smart Street sites drop their voltage further. As CLASS is also given a 25% function level, Smart Street is able to progress to a 75% function level at sites which are fed by CLASS. In this trial, the only example of this is the Pearley Banks Site which is fed by Heyside. It is not obvious from Figure 2 that the Pearley Banks site is at a different function level from the rest of the Smart Street sites – this is because the other sites are on their maximum tap setting and so are unable to push their voltages lower to reach the 100% function level target of 0.91 pu.

When comparing the QUEST system model simulated results to the live system measurements, shown in Figure 3, only the Consort Ave and Goldsmith Ave substations act similarly to how the SGS QUEST system responded, as the other sites were unable to move their tap settings in the live system in this instance. At Consort Ave, the tap changer operates at 12:19 to lower the voltage in line with the 25% function level. At 12:36 the effect of NEM can be seen as a small raise in voltage, although this is brought back to the previous voltage due to the effect of the primary transformer tap changer. Shortly after this, a new voltage target is calculated based on Smart Street's 100% function level and the voltage drops further to around 0.94 per unit. Smart Street is able to go to 100% function level in this case as CLASS at Royton was not available. For Goldsmith Ave, only measurements at 10-minute intervals were available from the live system, but these appear to follow the same trend as Consort Ave which is expected.

Figure 4 shows the estimated demand reduction achieved by Smart Street in the SGS QUEST model, which starts around 11 kW and raises to 25 – 30 kW when the function level increases.

6.1.1.3. NEM Results

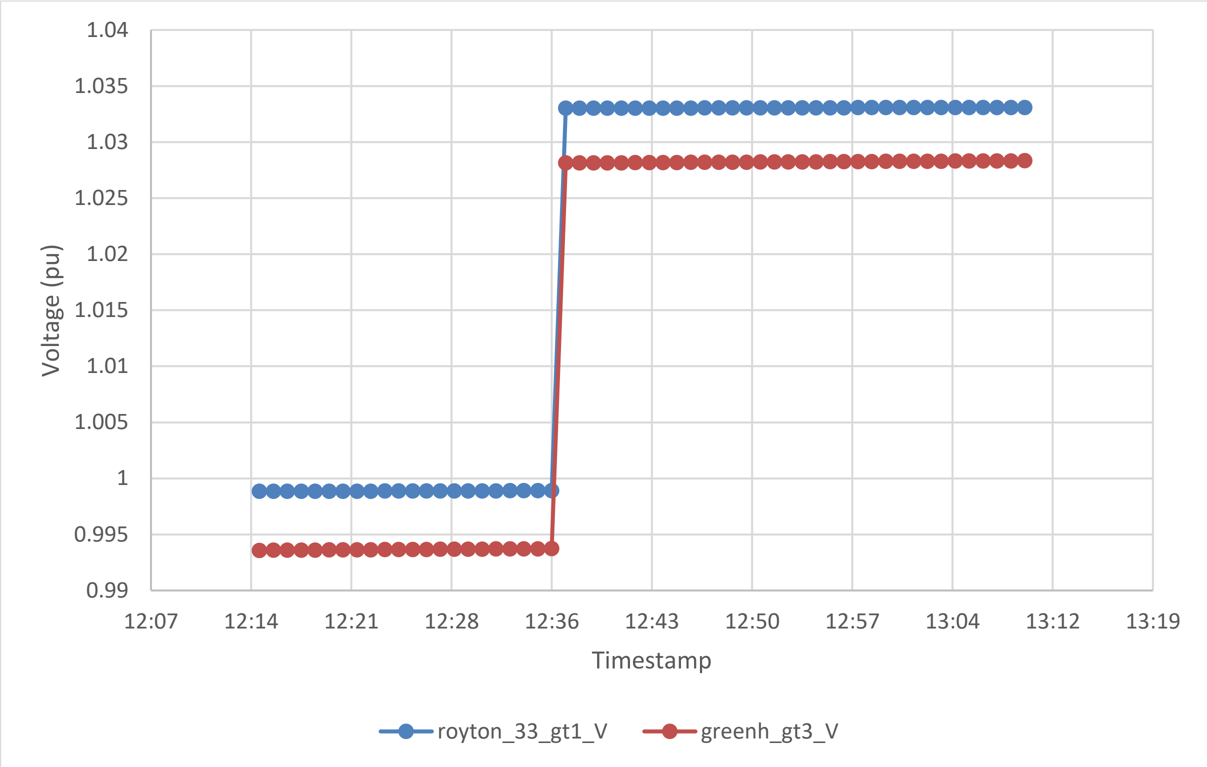

Figure 5: NEM Simulated Voltage Results from SGS QUEST System Model

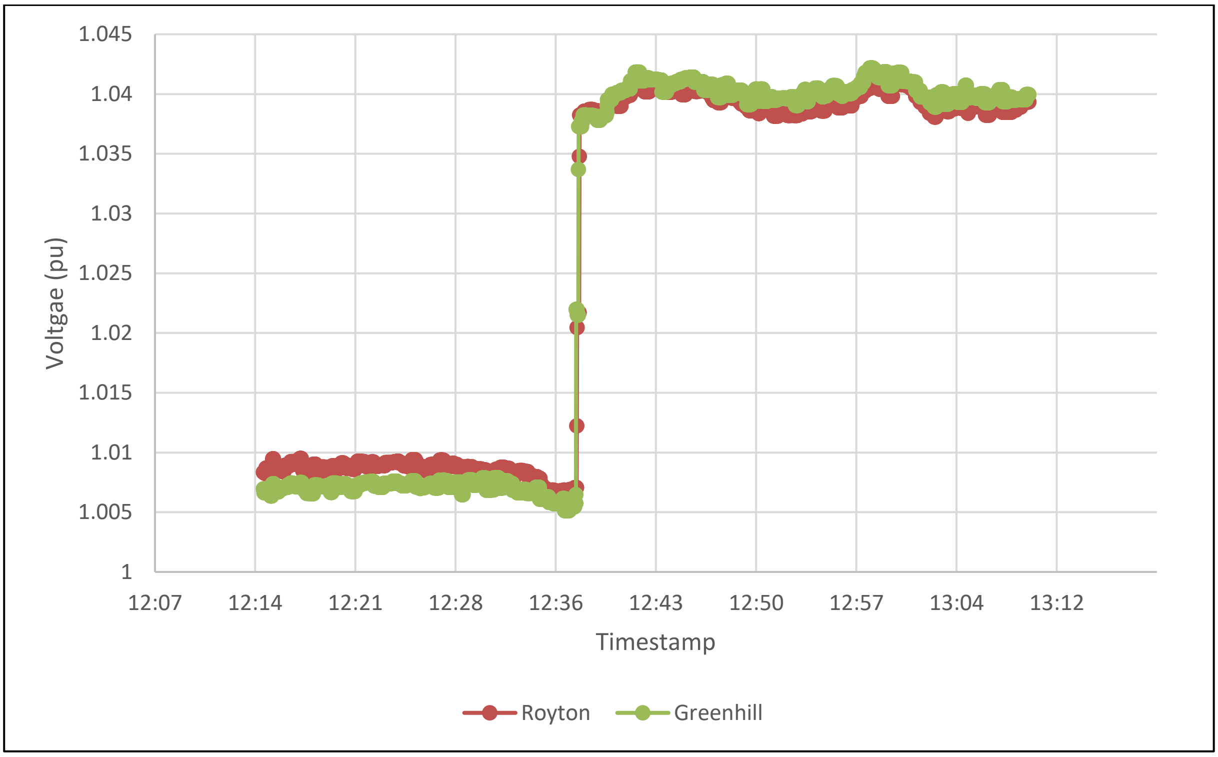

Figure 6: NEM Live Voltage Measurement Results from Live QUEST System

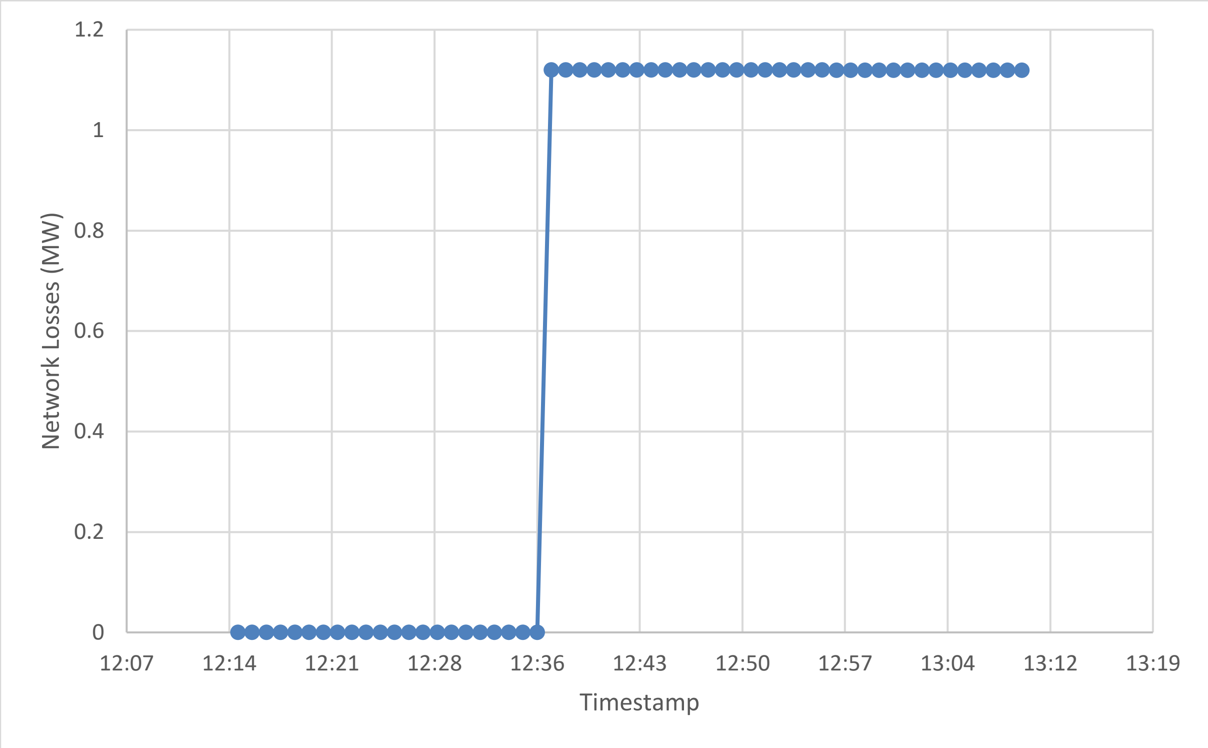

Figure 7: NEM Loss Reduction from SGS QUEST System Model

Figure 5 shows that both Royton and Greenhill BSPs have voltages close to 1 pu before NEM is active. Once NEM is activated, NEM is given a function level of 75% as this corresponds with the CLASS function level of 25%. The voltage target for the two BSPs becomes 1.0428 pu. The SGS simulation result shows the BSPs reaching a voltage of around 1.03 pu, slightly lower than the new voltage target. In this scenario, NEM was programmed to round down when considering tap selection, which is the reason a slightly lower voltage is achieved in the SGS results.

In the live measurements from the ENW system, the BSP voltages start slightly over 1 pu and then raise to close to the target voltage. The NEM response in the SGS model and the live QUEST system is similar for both BSPs.

The loss reduction in the SGS QUEST model is estimated to be around 1.1 MW. In the live QUEST system, this was estimated to be 3.48 MW. The difference in the loss reduction estimation could stem from differences in loss calculation between the two systems.

6.1.1.4. CLASS Results

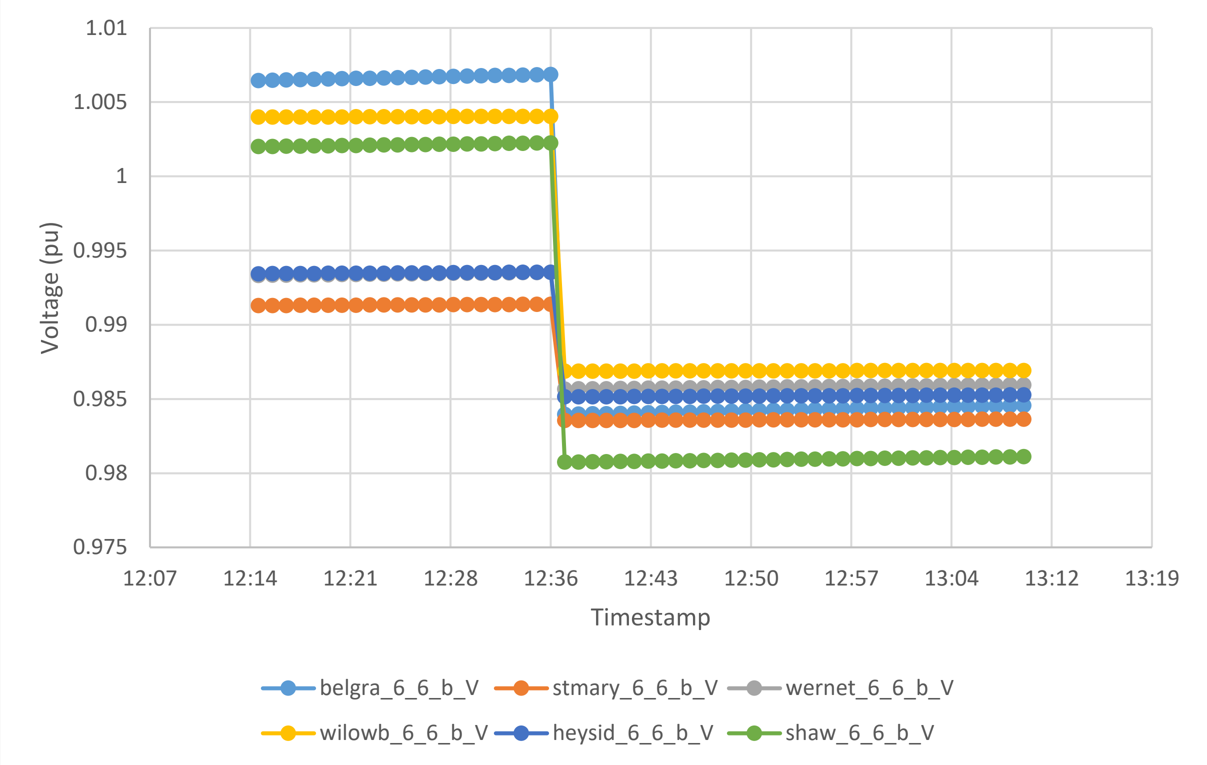

Figure 8: CLASS Simulated Voltage Results from SGS QUEST System Model

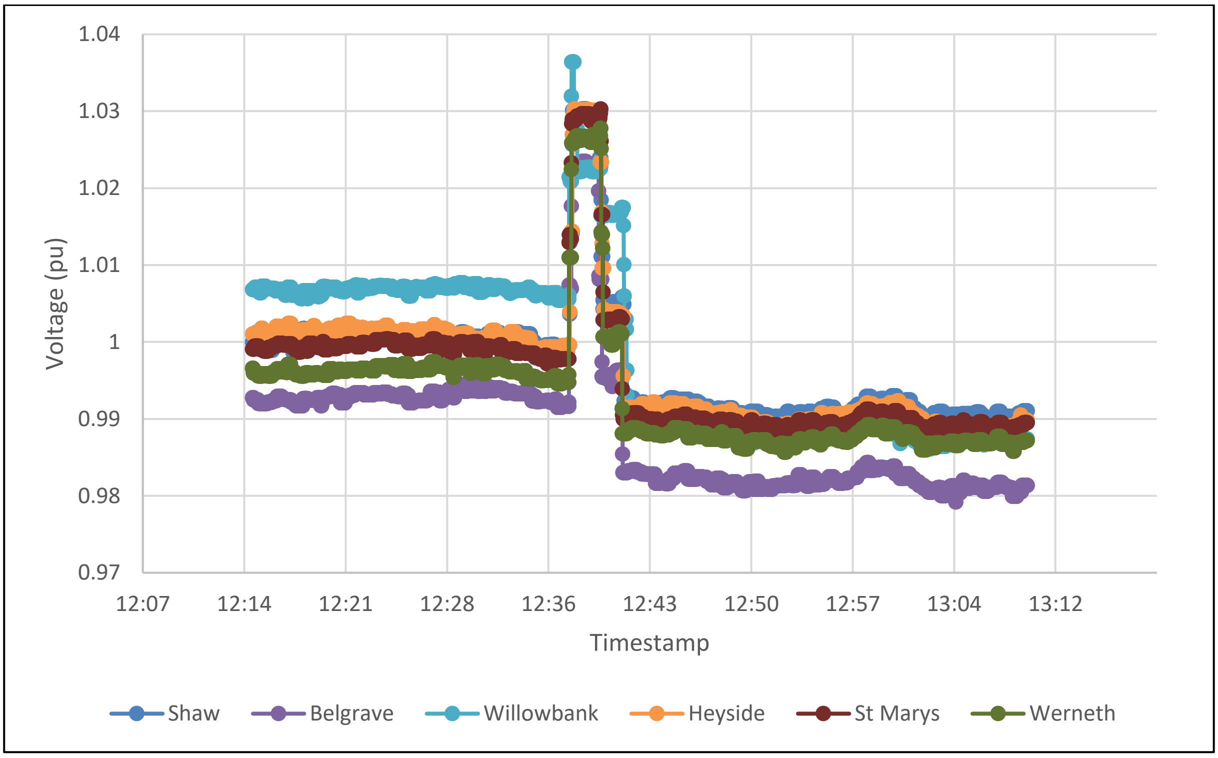

Figure 9: CLASS Live Voltage Measurement Results from Live QUEST System

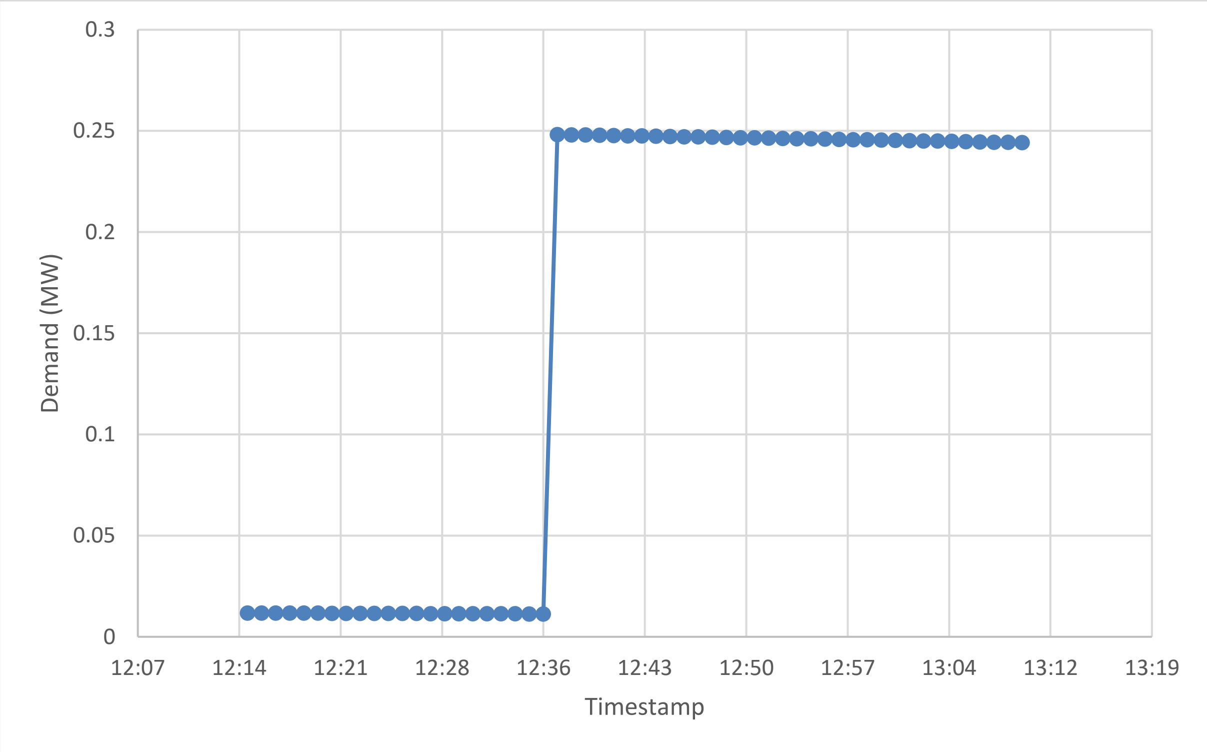

Figure 10: System Demand Reduction from SGS QUEST System Model

Figure 8 and Figure 9 show the results for CLASS sites in this trial for the SGS QUEST system model and live QUEST system respectively. In Figure 8, the CLASS site voltages drop at 12:37 to target 0.9875 pu, in correspondence with the 25% function level. As CLASS is the lowest priority QUEST function, it is not permitted to increase its function level even though the CLASS demand reduction target has not been achieved.

In Figure 9, the implementation of CLASS was delayed slightly on the live system due to the time taken to prepare then activate CLASS. There is a voltage rise at 12:37 which is due to the activation of NEM and so we see a voltage rise at 12:37, which is due to the activation of NEM at Royton BSP, which feeds the CLASS sites. The standard automatic voltage control at the primary then reduces the voltages to be around 1 pu before CLASS is activated and the voltages drop to around 0.98/0.99 pu.

The CLASS demand reduction target in this test was set to 2.45 MW, but Figure 10 shows that the SGS model only achieved a fraction of this, at around 0.25 MW. Results from the live QUEST system state that a reduction of 0.69 MW was achieved. A reason for this difference in result could be because NEM is active across other primaries which are not control by CLASS, these sites may have slight demand increases in the SGS model. As we are considering system demand reduction, any small increase in demand (due to slight increase in voltage at non-CLASS sites) may result in the figures for demand reduction being slightly lower.

6.1.2. Test 02 – CLASS 100 + Smart Street 0 – 17/06/25

Tests 02 & 03 are similar tests and so can be compared against each other.

6.1.2.1. Test Input Details

Table 8. QUEST Input Settings for Test 02

	CLASS DR	CLASS DB	Smart Street	NEM
Priority	1	N/A	2	N/A
Function Level	100%	N/A	0%	N/A
Voltage Target	0.95 pu	N/A	1.01 pu	N/A
Target	2.45 MW	N/A	N/A	N/A
Active Time Period	13:40 – 13:44	N/A	13:40 – 13:44	N/A

Table 9: QUEST Sites

CLASS Primaries	Smart Street Secondaries
Under Chadderton Grid: • Chadderton • Hollinwood • Langley • New Moston • Townley St Under Greenhill Grid: • Belgrave • St Mary • Werneth Under Redbank Grid • Blackley Under Royton Grid: • Royton • Shaw	Under Belgrave Primary: • Fold View • Rosary Cl Under Royton Primary: • Royton Centre • Oozewood Rd • Consort Ave • Beechwood Dr Under Heyside Primary: • Pearley Banks

Load Details

- From the trial information provided by SP ENW, QUEST became active between 13:03 and 13:59.

- Load values at 13:00 and 14:00 were recorded and linear interpolation between the values was used to get “non-QUEST-load”.
- Trial was run from 13:38 to 13:48.

Trial Test Comments

- The live SE QUEST system was configured with an additional primary in this test which was omitted from the SGS QUEST system model implementation.
- There were suspected issues with telemetry in the SE QUEST system which meant that 3 CLASS sites were not implemented

6.1.2.2. CLASS Results

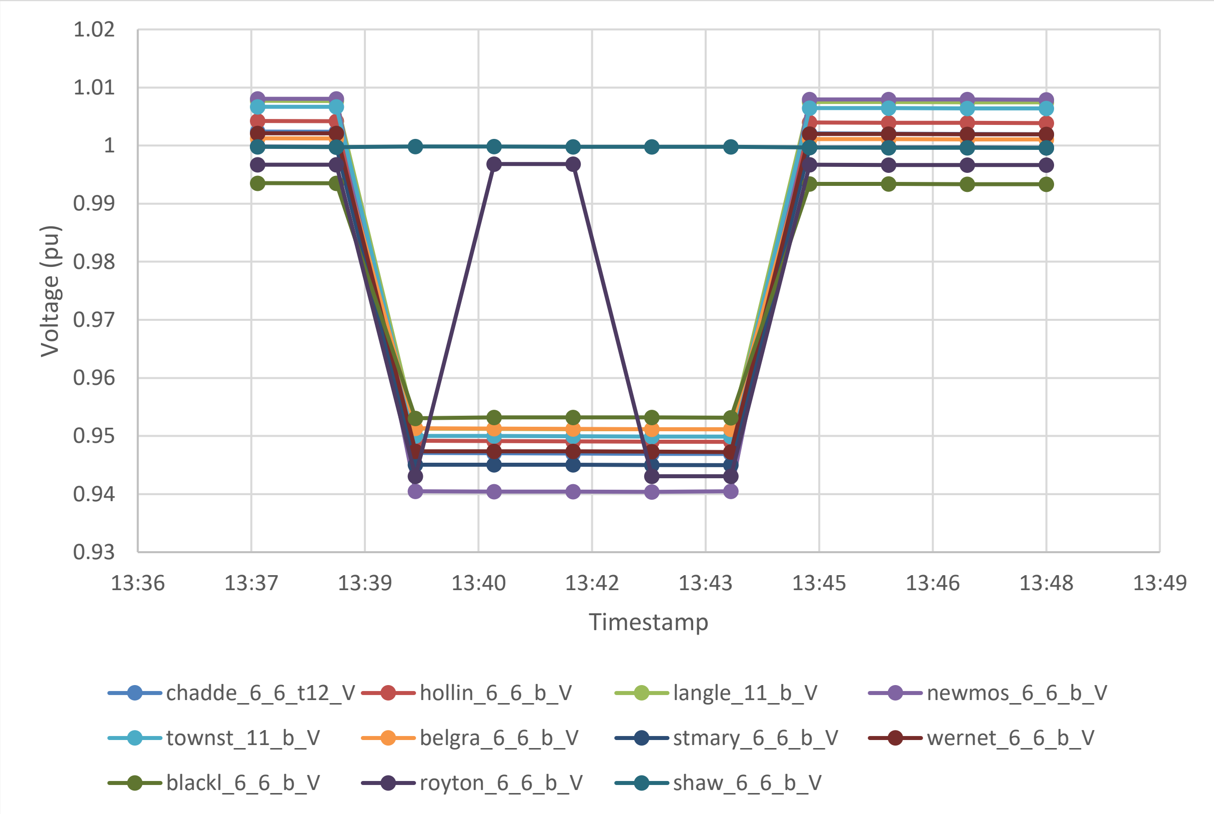

Figure 11: CLASS Simulated Voltage Results from SGS QUEST System Model

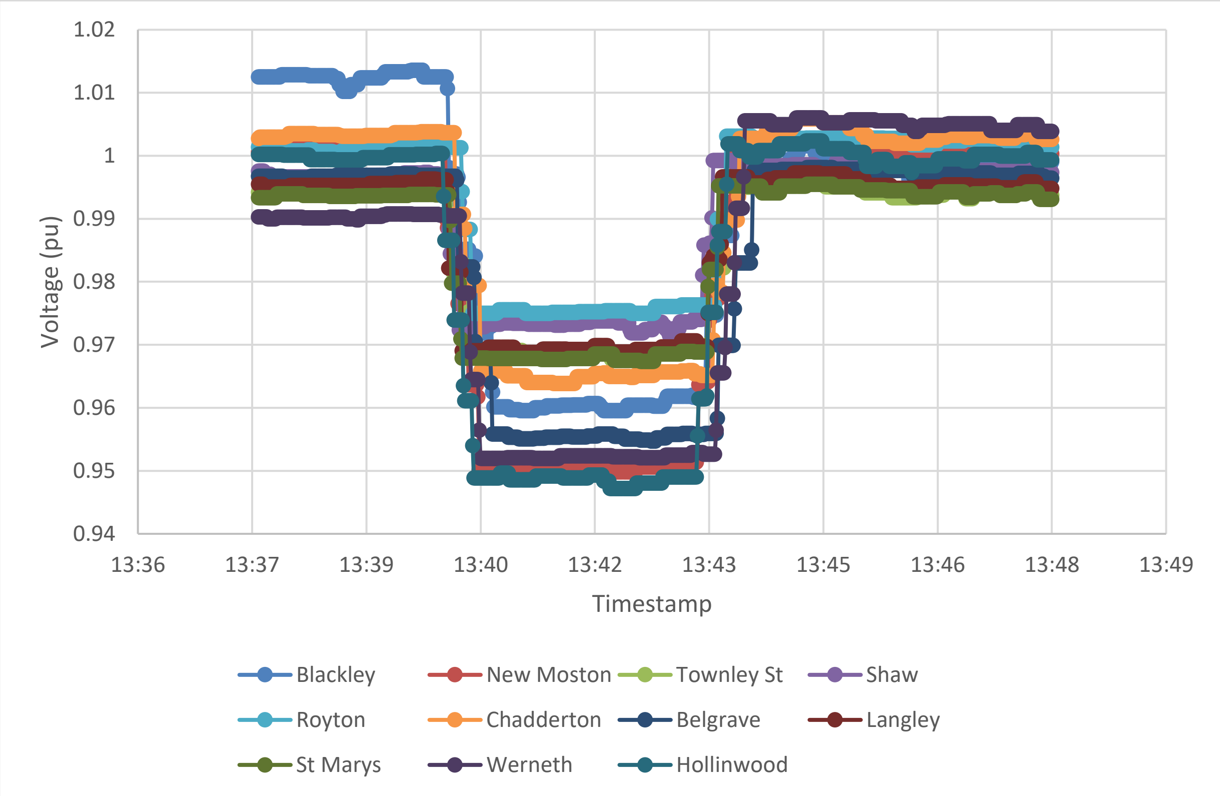

Figure 12: CLASS Live Voltage Measurement Results from Live QUEST System

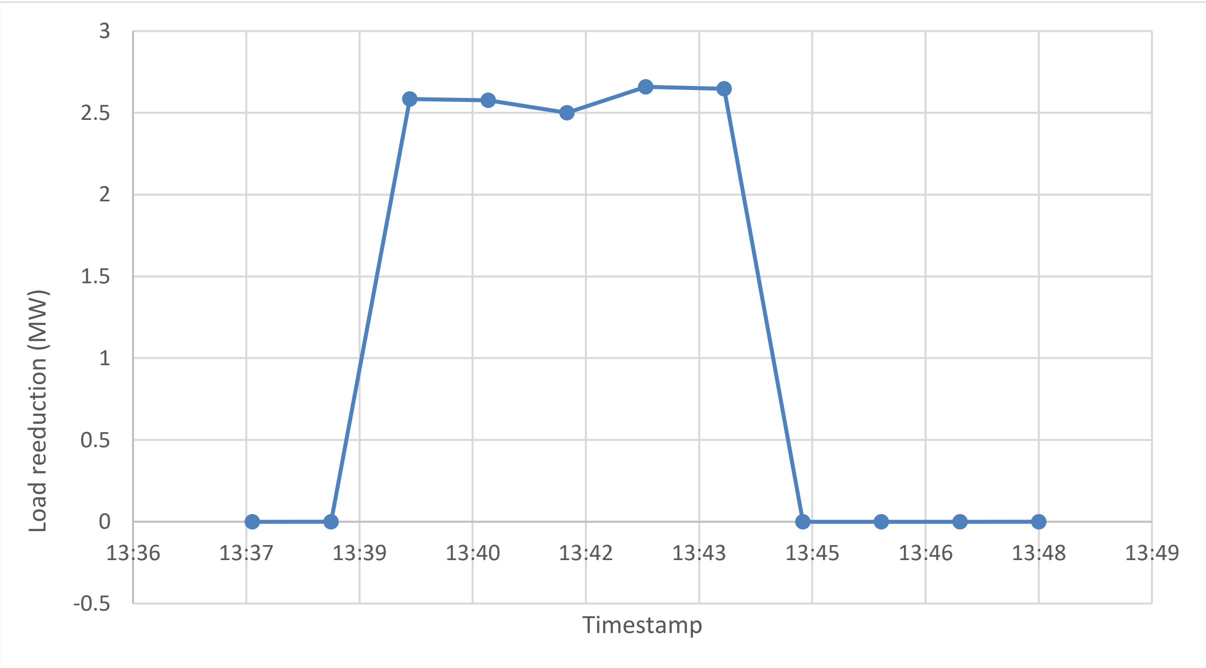

Figure 13: System Demand Reduction from SGS QUEST System Model

The CLASS responses from the SGS QUEST system model (Figure 11) and the live QUEST system (Figure 12) are similar in this trial but with some obvious differences. From the SP ENW results, it appears that all 11 CLASS sites have operated to achieve the CLASS demand reduction target of 2.45 MW, whereas in the SGS study, CLASS at Shaw Primary is not required to operate for the whole trial and CLASS at Royton Primary only partially operates. This is because in the SGS study, the demand reduction target has been achieved already and so additional reduction from these primaries are not needed.

Another difference between the studies is that the primaries in the SGS study achieve a lower voltage (while remaining above the statutory limit) than the primaries in the live system where the voltages range from 0.947 pu to 0.975 pu. This may be why the values for demand reduction are slightly off, as the SGS study will estimate more demand reduction per CLASS primary if the voltage reduction achieved is lower than what the live system achieved.

6.1.2.3. Smart Street Results

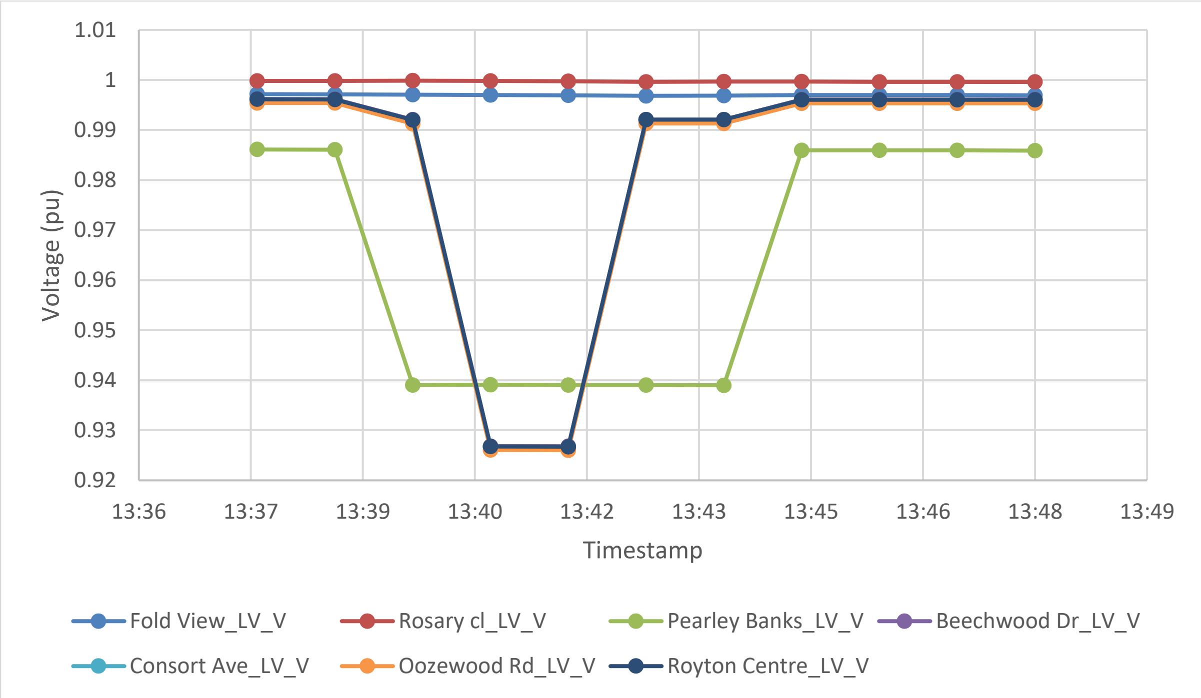

Figure 14: Smart Street Simulated Voltage Results from SGS QUEST System Model

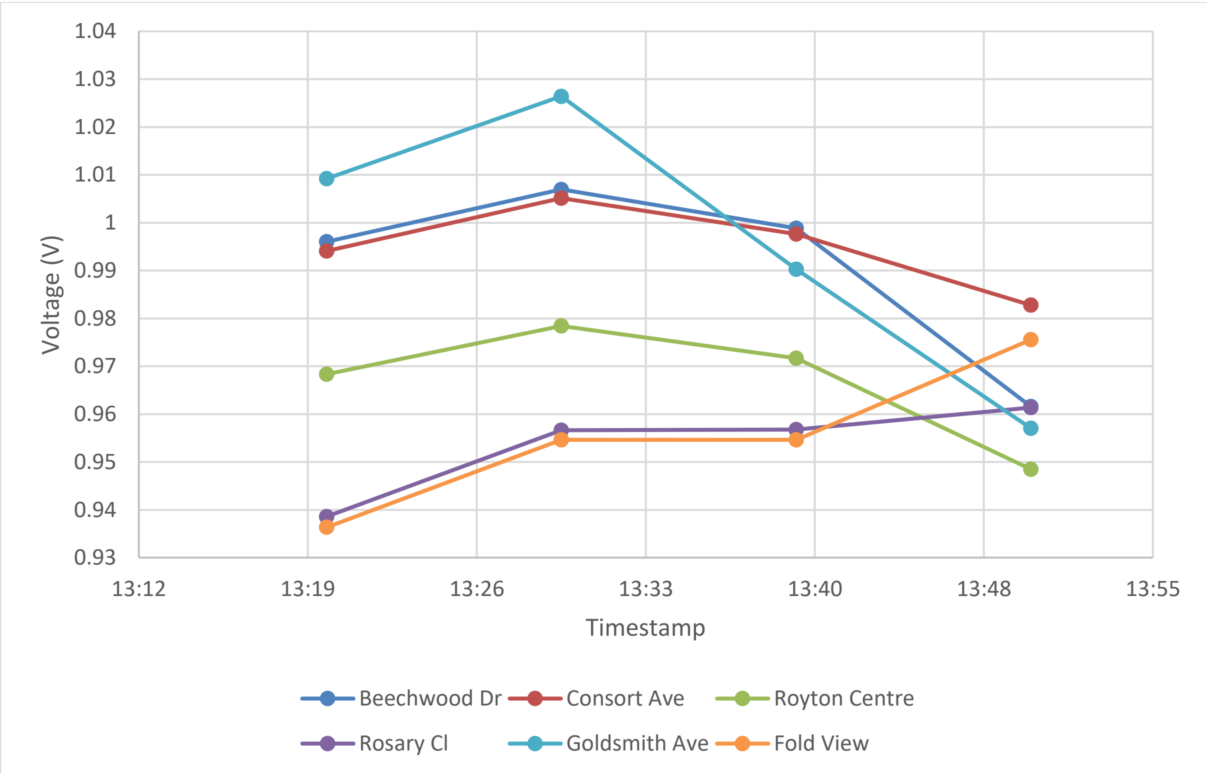

Figure 15: Smart Street Live Voltage Measurement Results from Live QUEST System

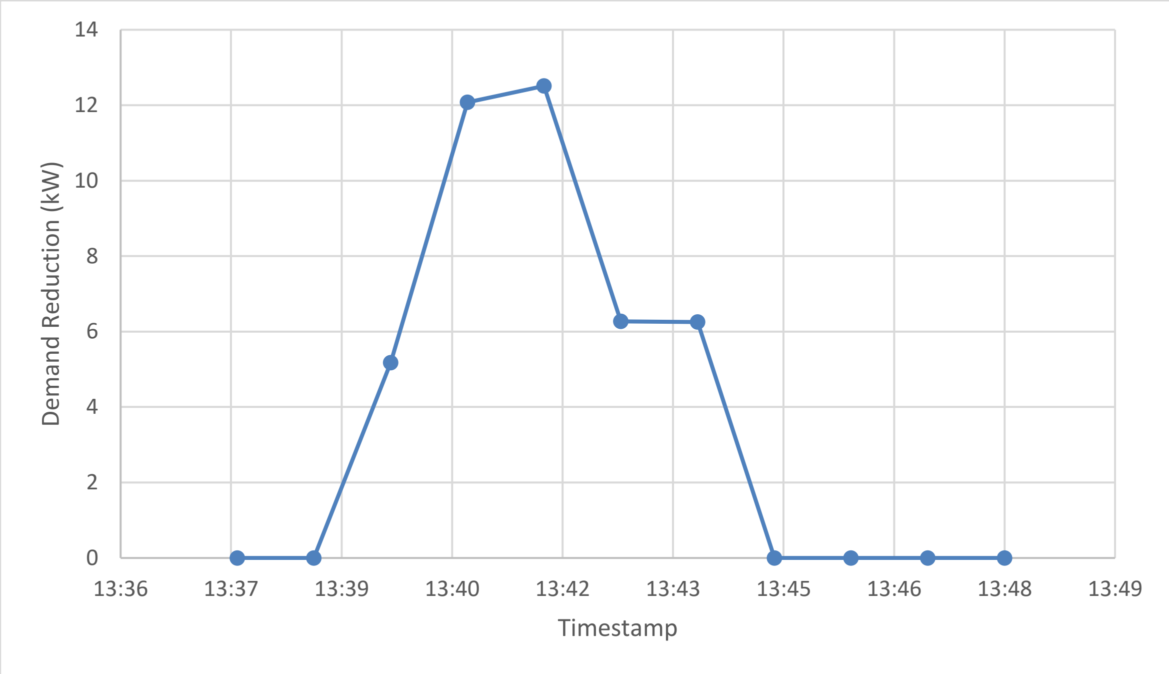

Figure 16: Smart Street Demand Reduction from SGS QUEST System Model

For the Smart Street sites in this trial, it is more difficult to compare the outputs from the QUEST systems as the live measurements for the secondary sites were only available on 10 minute intervals, meaning that the data resolution is poor in Figure 15. When considering Figure 14, there are three distinct trends to comment on:

- Both the Fold View and Rosary Cl sites remain at around 1 pu throughout the simulation. This is because they are fed by Belgrave Primary, where CLASS is active and so these Smart Street sites go into their corresponding safe mode function level, which is 0% and targets a voltage of 1.01 pu. A slight upward trend can be observed in Figure 15 for both of these site voltage measurements in the live system, which would be expected.
- The Pearley Banks site is not fed from a primary where CLASS is active, so this is given a function level of 100% and aims to target 0.91 pu.
- The remaining Smart Street sites are fed by Royton Primary, where CLASS is partially active in the SGS simulation. For the 2 timesteps where CLASS at Royton Primary is not required to meet the demand reduction target, Smart Street operates normally for the sites fed from Royton and targets a lower voltage. For the timesteps where CLASS at Royton Primary is active, the Smart Street sites go into safe mode, and their function level becomes 0%.

6.1.3. Test 03 – Smart Street 100 + CLASS 0 – 17/06/25

Tests 02 & 03 are similar tests and so can be compared against each other.

6.1.3.1. Test Input Details

Table 10. QUEST Input Settings for Test 03

	CLASS DR	CLASS DB	Smart Street	NEM
Priority	2	N/A	1	N/A
Function Level	0%	N/A	100%	N/A
Voltage Target	0.95 pu	N/A	0.91 pu	N/A
Target	2.45 MW	N/A	N/A	N/A
Active Time Period	13:51 – 13:59	N/A	13:51 – 13:59	N/A

Table 11: QUEST Sites

CLASS Primaries	Smart Street Secondaries
Under Chadderton Grid: • Failsworth • Hollinwood • New Moston Under Greenhill Grid: • Belgrave • Waterhead Under Royton Grid: • Royton	Under Belgrave Primary: • Fold View • Rosary Cl Under Royton Primary: • Royton Centre • Oozewood Rd • Consort Ave • Beechwood Dr Under Heyside Primary: • Pearley Banks

Load Details

- From the trial information provided by SP ENW, QUEST became active between 13:03 and 13:59.
- Load values at 13:00 and 14:00 were recorded and linear interpolation between the values was used to get “non-QUEST-load”.
- Trial was run from 13:48 to 14:00.

6.1.3.2. Smart Street Results

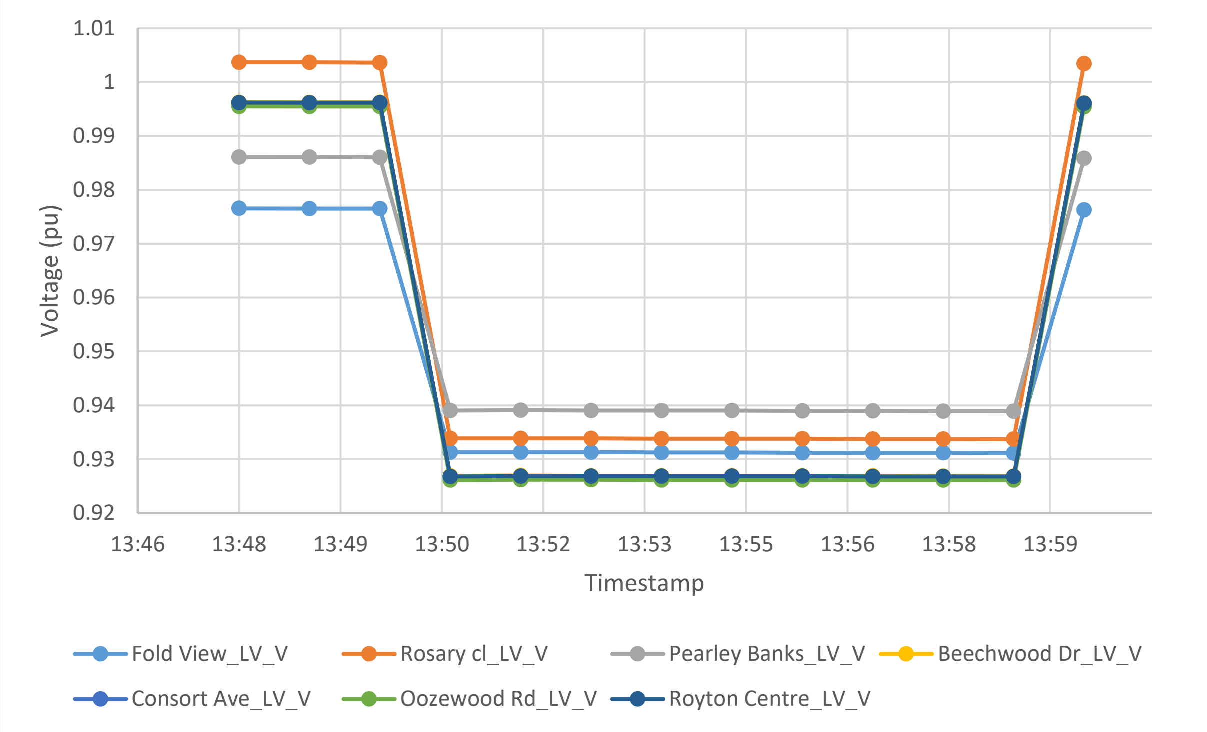

Figure 17: Smart Street Simulated Voltage Results from SGS QUEST System Model

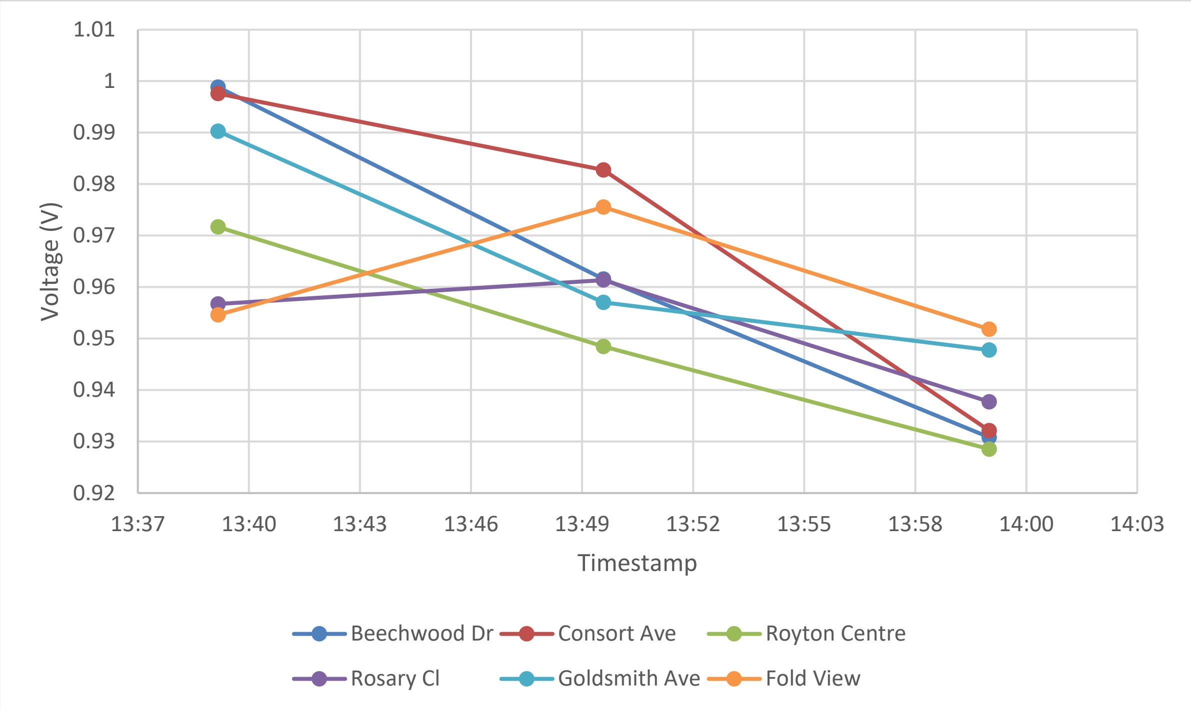

Figure 18: Smart Street Live Voltage Measurement Results from Live QUEST System

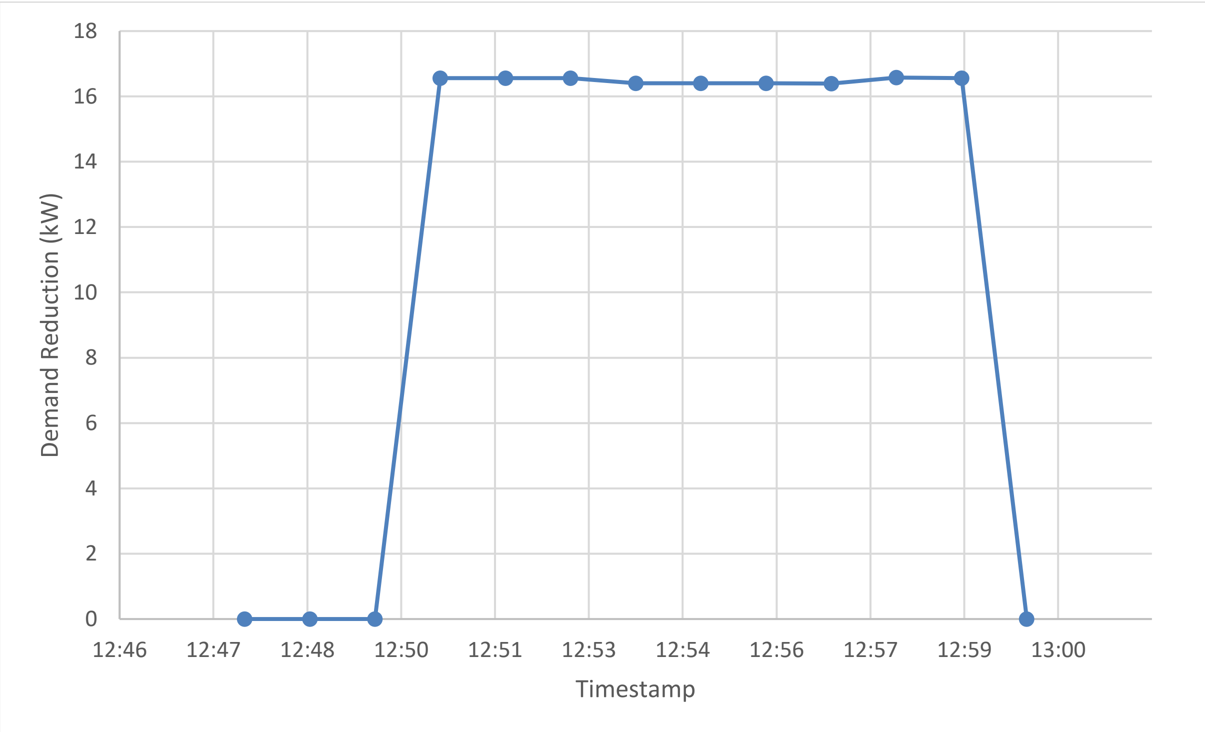

Figure 19: Smart Street Demand Reduction from SGS QUEST System Model

Again it is difficult to compare between the two QUEST systems for this trial as the live measurements available for the secondary sites where only available at 10 minute intervals, but it is evident there is a downward trend in Figure 18 towards ~0.93 pu for each of the Smart Street sites. In Figure 17 we can see that all Smart Street sites in the SGS simulation move to a lower voltage, which is to be expected as Smart Street is priority 1 in this trial and has a function level of 100%. Figure 19 shows the demand reduction achieved via Smart Street to be ~16.5 kW during the active period.

6.1.3.3. CLASS Results

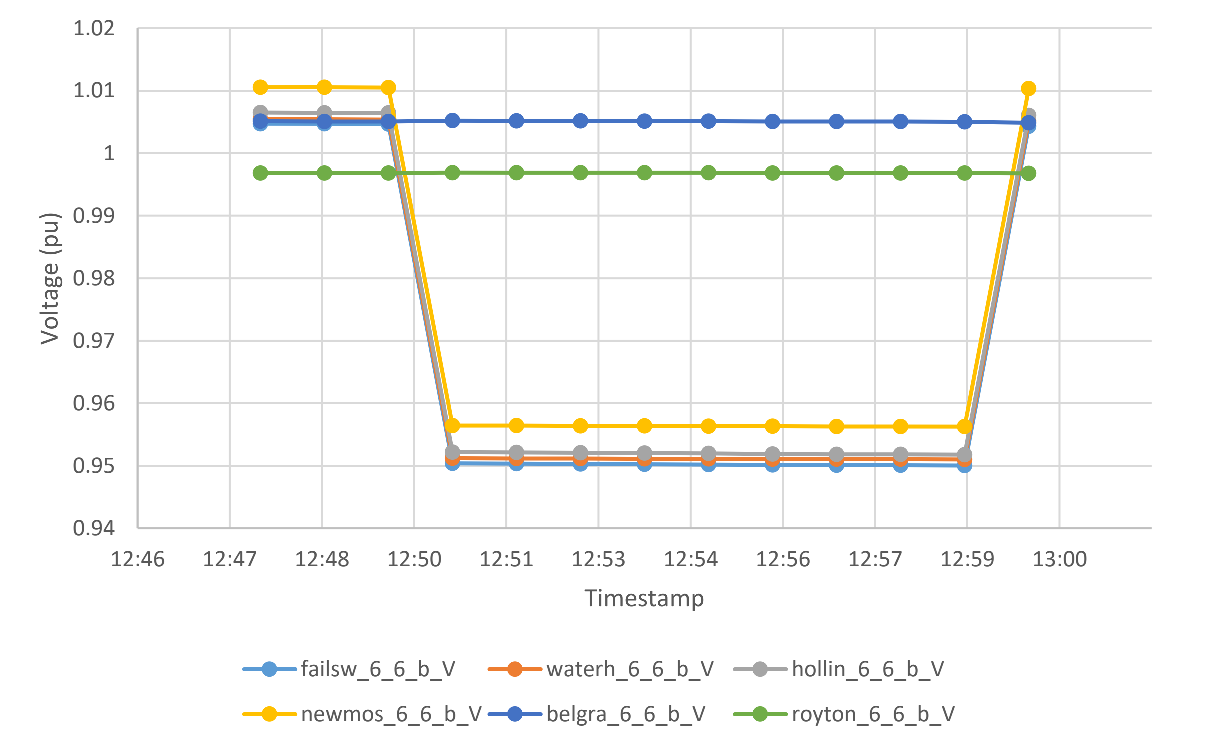

Figure 20: CLASS Simulated Voltage Results from SGS QUEST System Model

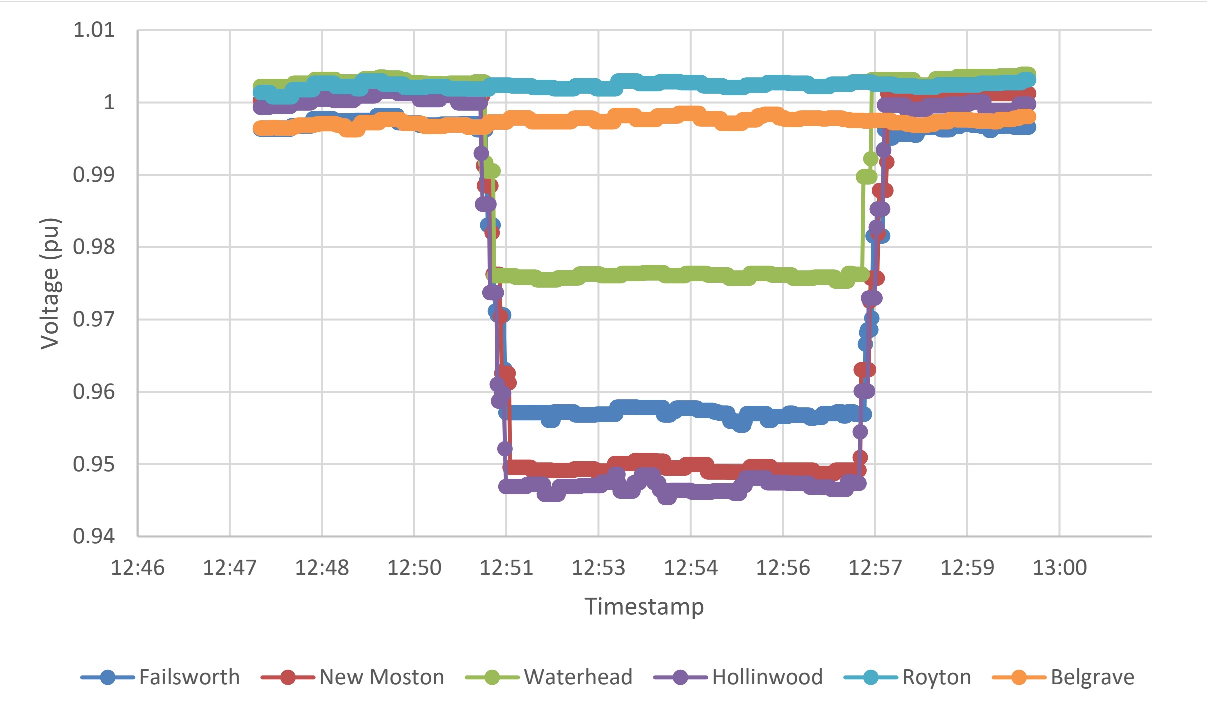

Figure 21: CLASS Live Voltage Measurement Results from Live QUEST System

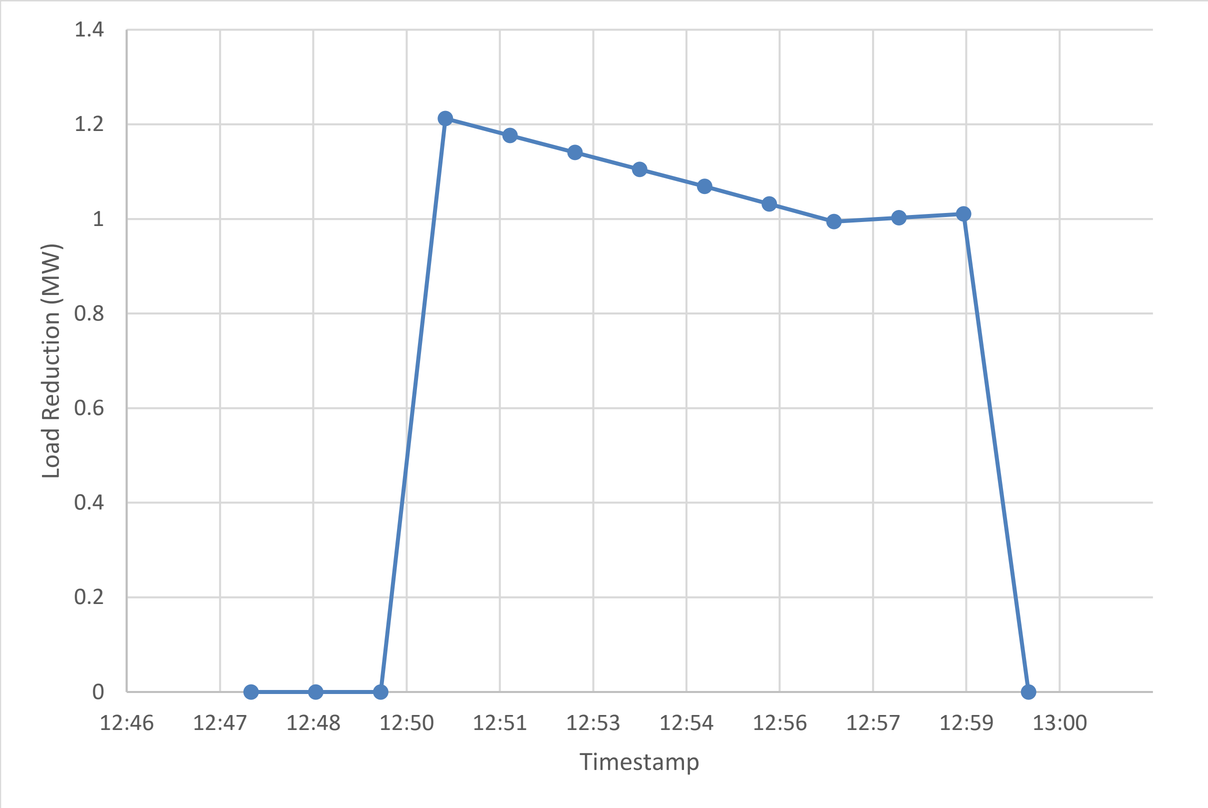

Figure 22: System Demand Reduction from SGS QUEST System Model

Comparison of Figure 20 and Figure 21 show that both QUEST systems have responded in similar ways for the CLASS function during this trial. In both cases, CLASS at Royton and Belgrave primaries does not operate. This is because both primaries are feeding Smart Street sites and as Smart Street is the priority 1 function with a function level of 100%, CLASS is given a function level of 0% for these corresponding primaries.

The remaining primaries have a similar response in both systems, with the exception of Waterhead Primary which only lowers to ~0.975 pu in the live system. As the function level for CLASS was 100% here, this site should have targeted 0.95 pu.

Comparing these results to the CLASS results in Test 02, we can see that the Royton and Belgrave primary voltages stay constant in Test 03, whereas in Test 02 they are permitted to target a lower voltage. This shows the effect of the prioritisation within QUEST and its ability to optimise accordingly.

A similar response can be observed when considering the Fold View and Rosary Cl Smart Street sites. In Test 03, their voltage drops as due to Smart Street, but in Test 02, this action is prevented due to the QUEST control and CLASS is active at Belgrave primary.

6.1.4. Test 04 – CLASS 75 + Smart Street 25 – 08/07/25

Tests 04 & 05 are similar tests and so can be compared against each other.

6.1.4.1. Test Input Details

Table 12. QUEST Input Settings for Test 04

	CLASS DR	CLASS DB	Smart Street	NEM
Priority	1	N/A	2	N/A
Function Level	75%	N/A	25%	N/A
Voltage Target	0.9625 pu	N/A	0.985 pu	N/A
Target	3 MW	N/A	N/A	N/A
Active Time Period	13:34 – 13:39	N/A	13:34 – 13:39	N/A

Table 13: QUEST Sites

CLASS Primaries	Smart Street Secondaries
Under Chadderton Grid: • Chadderton • Hollinwood • Langley • New Moston Under Greenhill Grid: • Belgrave • St Mary • Werneth • Waterhead • Willowbank Under Redbank Grid • Blackley Under Royton Grid: • Heyside • Shaw	Under Royton Primary: • Oozewood Rd • Consort Ave • Travis Ct Under Heyside Primary: • Pearley Banks

Load Details

- From the trial information provided by SP ENW, QUEST became active between 11:51 and 13:50 for a range of tests.

- Load values at 11:40 and 14:00 were recorded and linear interpolation between the values was used to get “non-QUEST-load”.
- Trial was run from 13:30 to 13:39.

6.1.4.2. CLASS Results

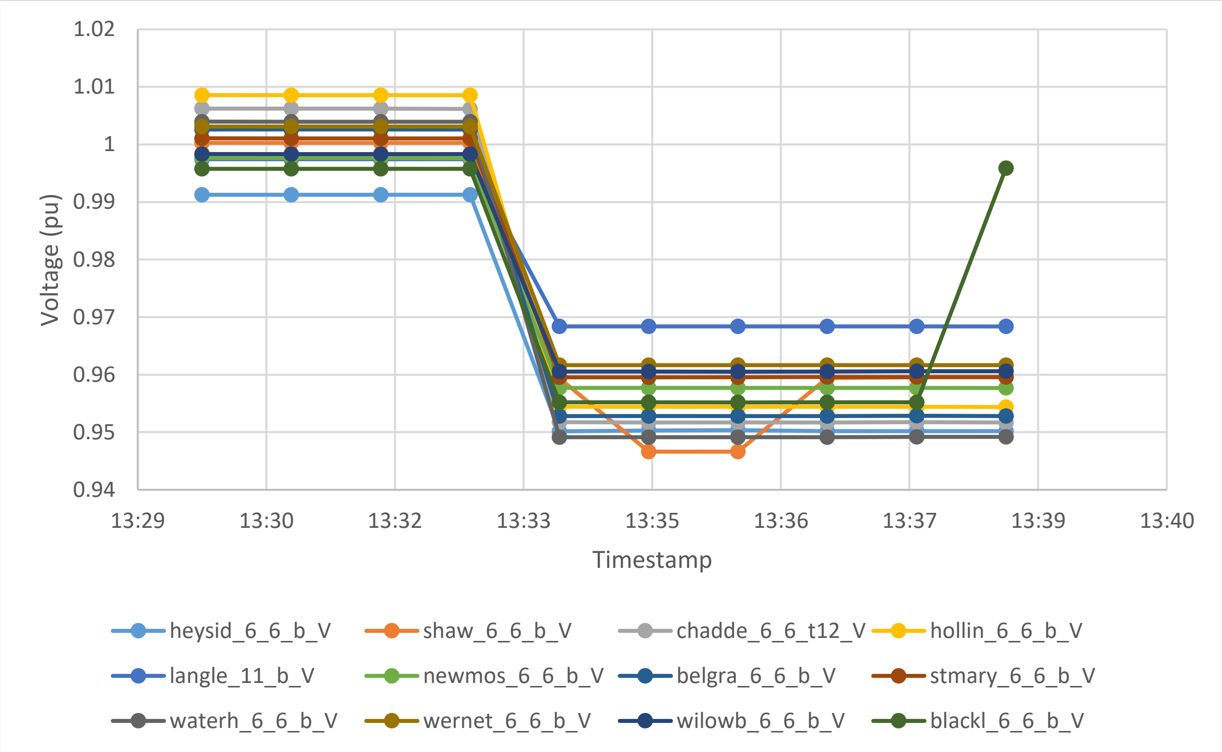

Figure 23: CLASS Simulated Voltage Results from SGS QUEST System Model

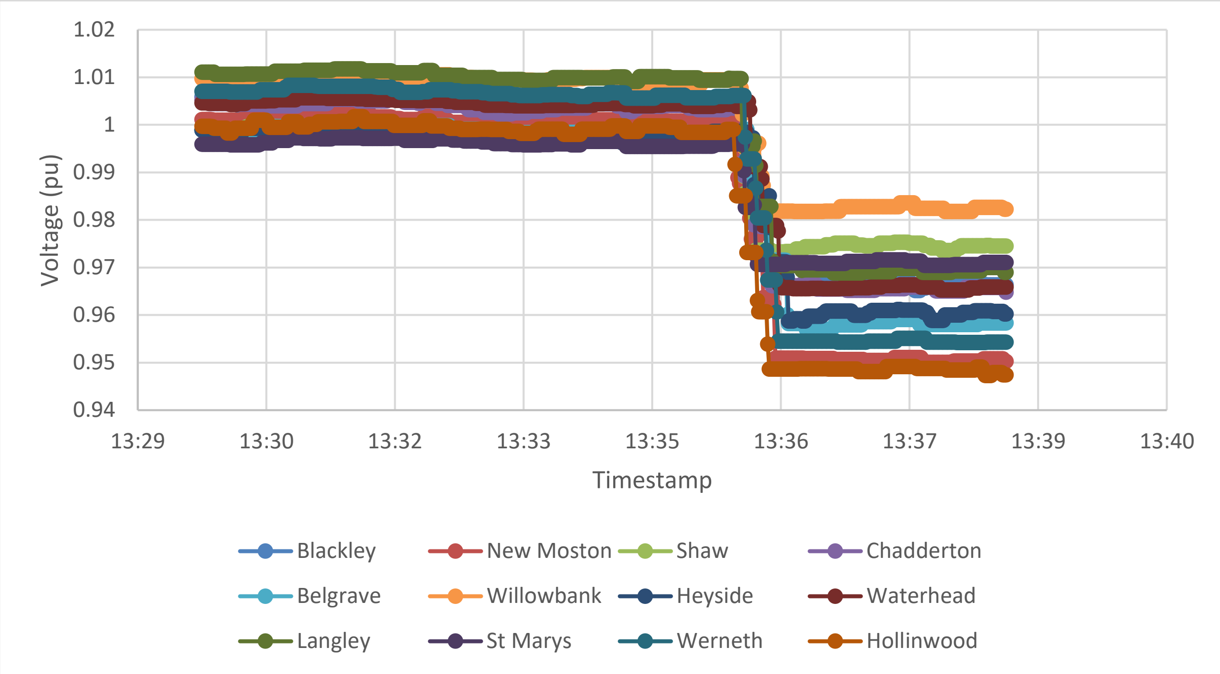

Figure 24: CLASS Live Voltage Measurement Results from Live QUEST System

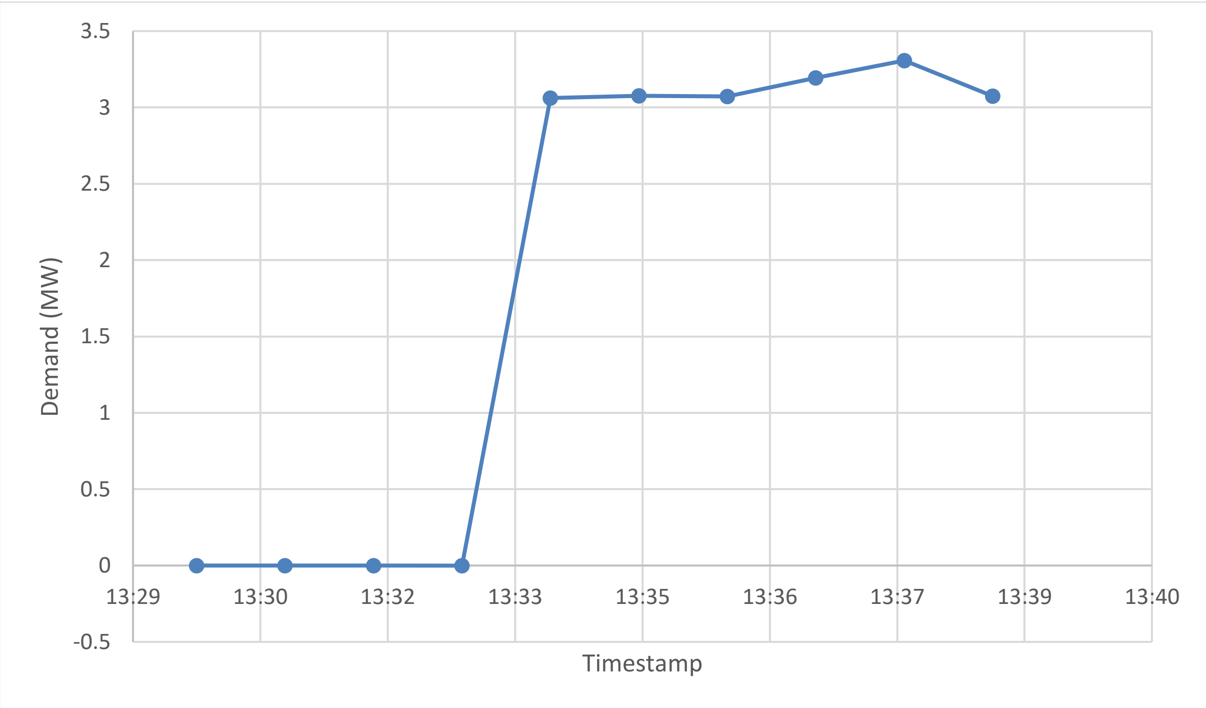

Figure 25: System Demand Reduction from SGS QUEST System Model

When comparing Figure 23 and Figure 24, the general trend of the CLASS site voltages is broadly similar, but with some key differences that influence how Smart Street functions in this trial. CLASS is given a 75% function level, but as CLASS is priority 1, QUEST will progress the CLASS function level up to 100% if the demand reduction target of 3 MW is not met. This occurs during the 13:35 and 13:36 timesteps for Shaw Primary and Heyside Primary, although the additional tap change at Heyside Primary is reversed as this moves the site voltage outwith the statutory limit if 0.94 pu. Additionally, in the last timestep, the CLASS demand target is reached in advance of CLASS 75% applied at Blackley Primary, so its voltage reverts to ~1 pu for this timestep in Figure 23. The system demand reduction in the SGS Simulation is shown in Figure 25.

In the live QUEST system, there is a slight delay in the CLASS implementation due to the need for it to be prepped and then activated. The 3 MW demand reduction target was not reached and so all available CLASS primaries were set to 100% function level, achieving a reduction of 2.88 MW. The reasoning for different demand reduction values between the two systems could be because some of the sites in the live system do not reach as low as voltage as they do in the SGS simulation. At least 3 sites in the live QUEST system still have a voltage greater than 0.97 pu when CLASS is active.

6.1.4.3. Smart Street Results

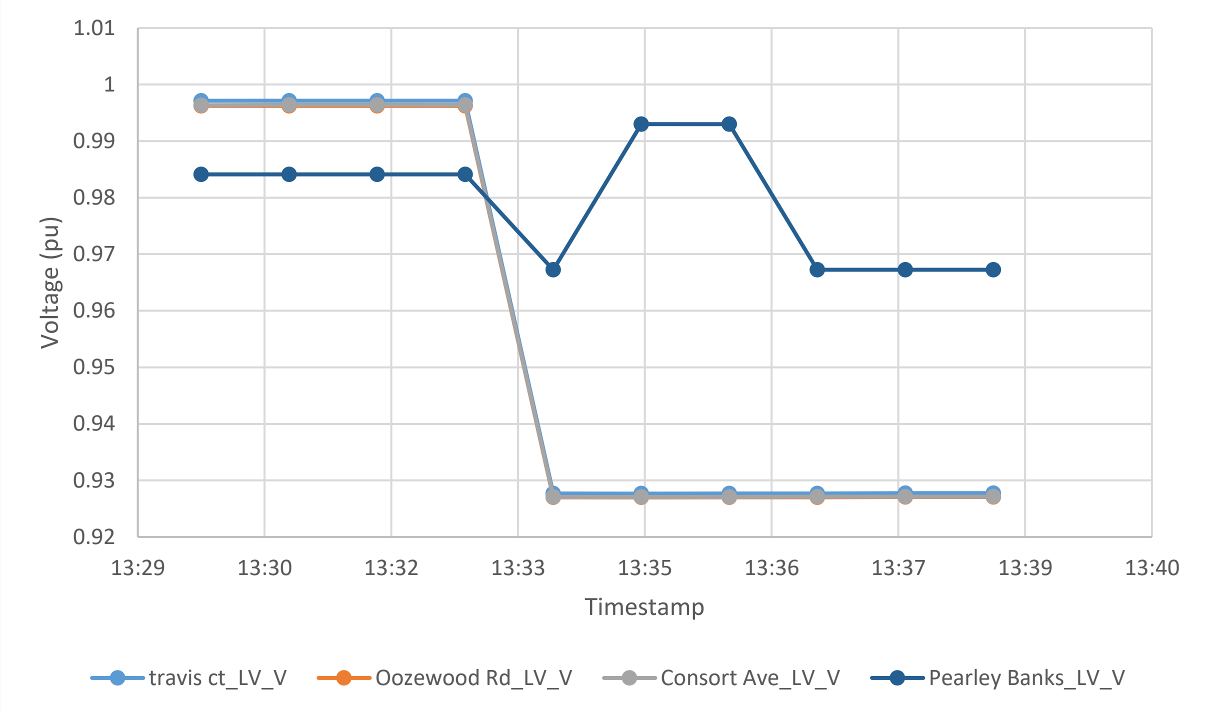

Figure 26: Smart Street Simulated Voltage Results from SGS QUEST System Model

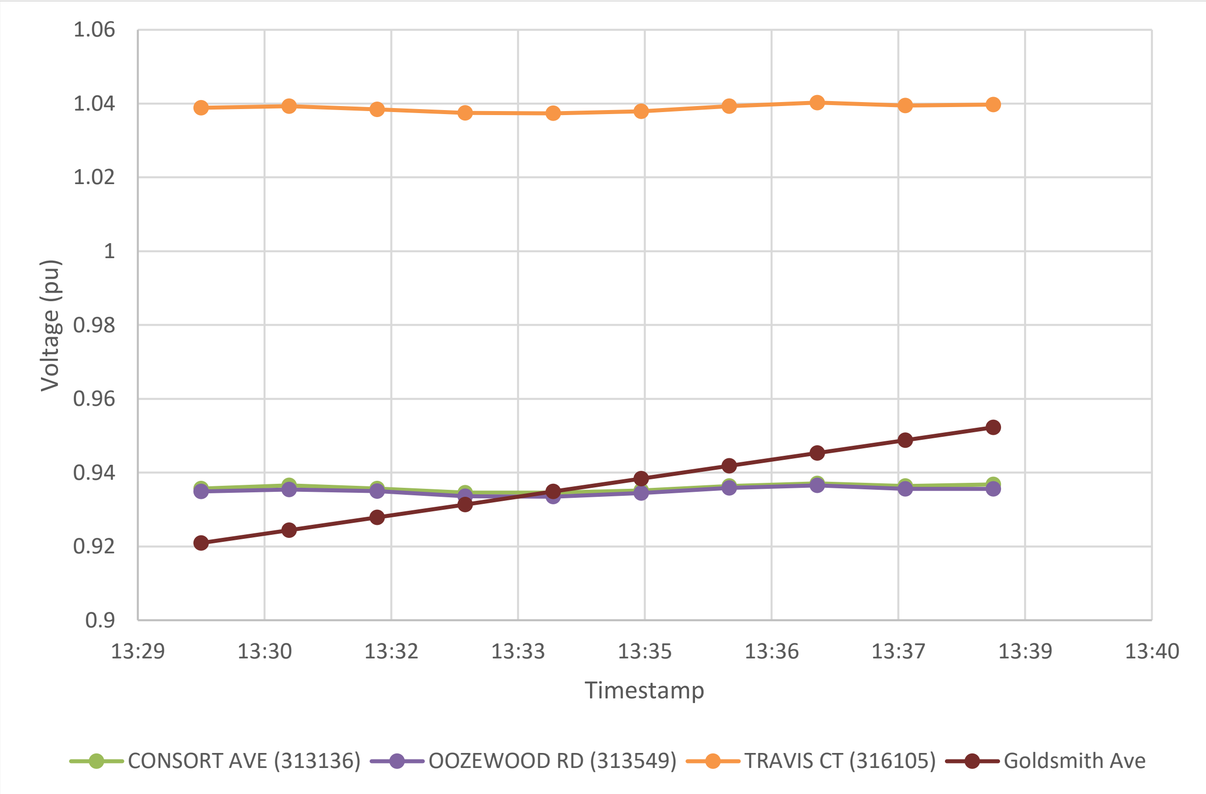

Figure 27: Smart Street Live Voltage Measurement Results from Live QUEST System

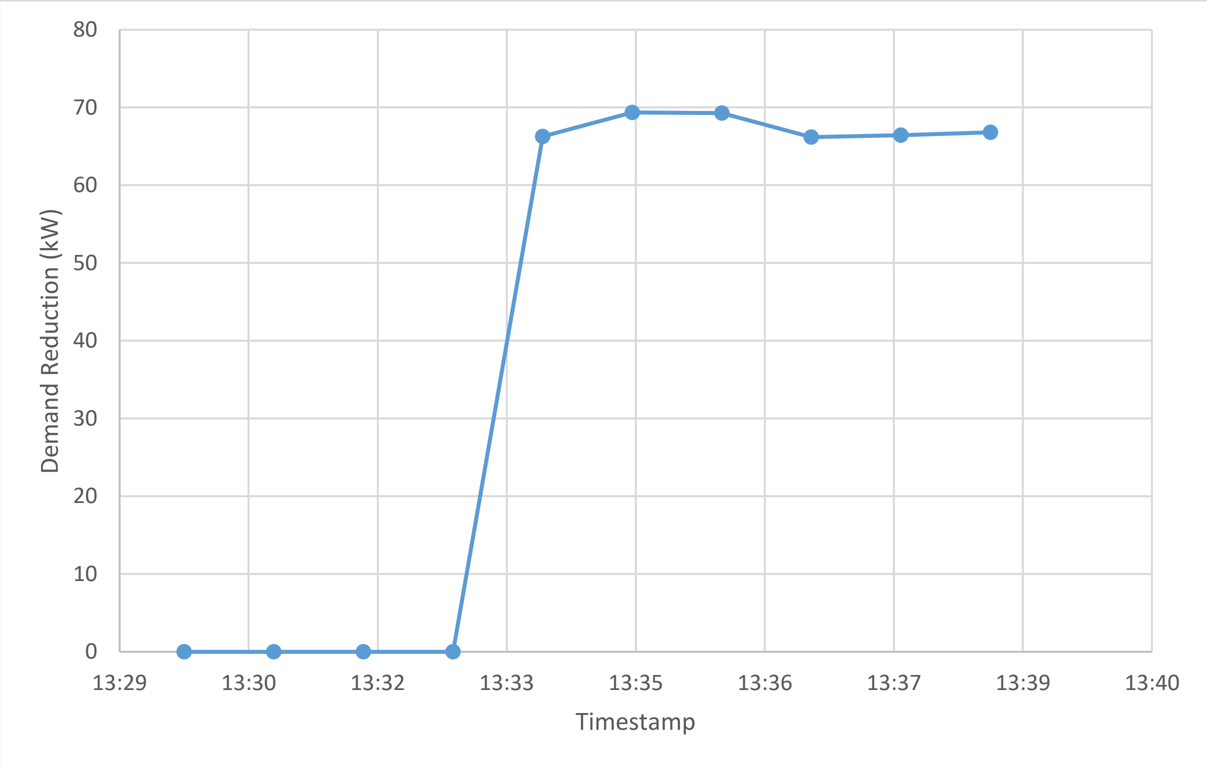

Figure 28: Smart Street Demand Reduction from SGS QUEST System Model

When considering Figure 26, all of the Smart Street sites are fed from Royton Primary except Pearley Banks, which is fed from Heyside Primary. As Royton Primary does not have CLASS active, the Smart Street sites fed by Royton are given a 100% function level and target a voltage of 0.91 pu.

CLASS is active at Heyside Primary and so the Pearley Banks site must respond accordingly. It initially is given a function level of 25% when QUEST is activated, but this changes to 0% for two timesteps (13:35 & 13:36) as the Heyside Primary function level increases to 100% for these timesteps.

In the live system, Smart Street is operational throughout this test and the effect is clearly observed at Consort Ave, Oozewood Rd and Goldsmith Ave. Goldsmith Ave has a slight upward trend, which would make sense if Smart Street had previously been active and was moving to a higher voltage due to the CLASS application at Heyside Primary. Other Smart Street sites under Royton Primary have not operated as expected, which is likely due to issues with local SCADA controls during the test according to SP ENW.

The function levels of a selection of CLASS and Smart Street sites are shown in Figure 29.

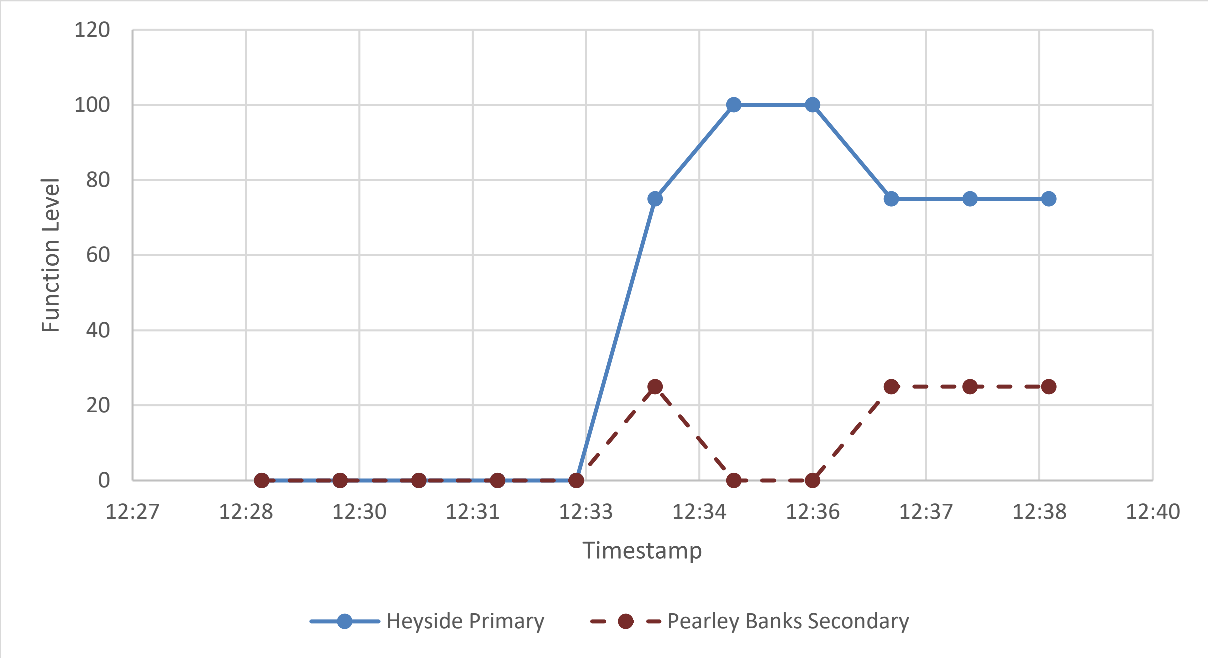

Figure 29: CLASS & Smart Street Function Levels from SGS QUEST System Model

This gives a graphical representation of how the function levels change across the trial period. The trends of Heyside Primary and Pearley Banks Secondary mirror each other, showing how QUEST applies its safe mode logic.

6.1.5. Test 05 – Smart Street 75 + CLASS 25 – 08/07/25

Tests 04 & 05 are similar tests and so can be compared against each other.

6.1.5.1. Test Input Details

Table 14. QUEST Input Settings for Test 05

	CLASS DR	CLASS DB	Smart Street	NEM
Priority	2	N/A	1	N/A
Function Level	25%	N/A	75%	N/A
Voltage Target	0.9875 pu	N/A	0.935 pu	N/A
Target	3 MW	N/A	N/A	N/A
Active Time Period	13:43 – 13:50	N/A	13:43 – 13:50	N/A

Table 15: QUEST Sites

CLASS Primaries	Smart Street Secondaries
Under Chadderton Grid: • Chadderton • Hollinwood • Langley • New Moston Under Greenhill Grid: • Belgrave • St Mary • Werneth • Waterhead • Willowbank Under Redbank Grid • Blackley Under Royton Grid: • Heyside • Shaw	Under Royton Primary: • Oozewood Rd • Consort Ave • Travis Ct Under Heyside Primary: • Pearley Banks

Load Details

- From the trial information provided by SP ENW, QUEST became active between 11:51 and 13:50 for a range of tests.

- Load values at 11:40 and 14:00 were recorded and linear interpolation between the values was used to get “non-QUEST-load”.
- Trial was run from 13:40 to 13:50.

Trial Test Comments

- The SGS model did not have representations of Smart Street sites at Willowbank or Langley in the IPSA model, but the effects of voltage reduction due to these sites were simulated.
- Issues with telemetry to Royton in the live system have caused come Smart Street sites not to operate.

6.1.5.2. Smart Street Results

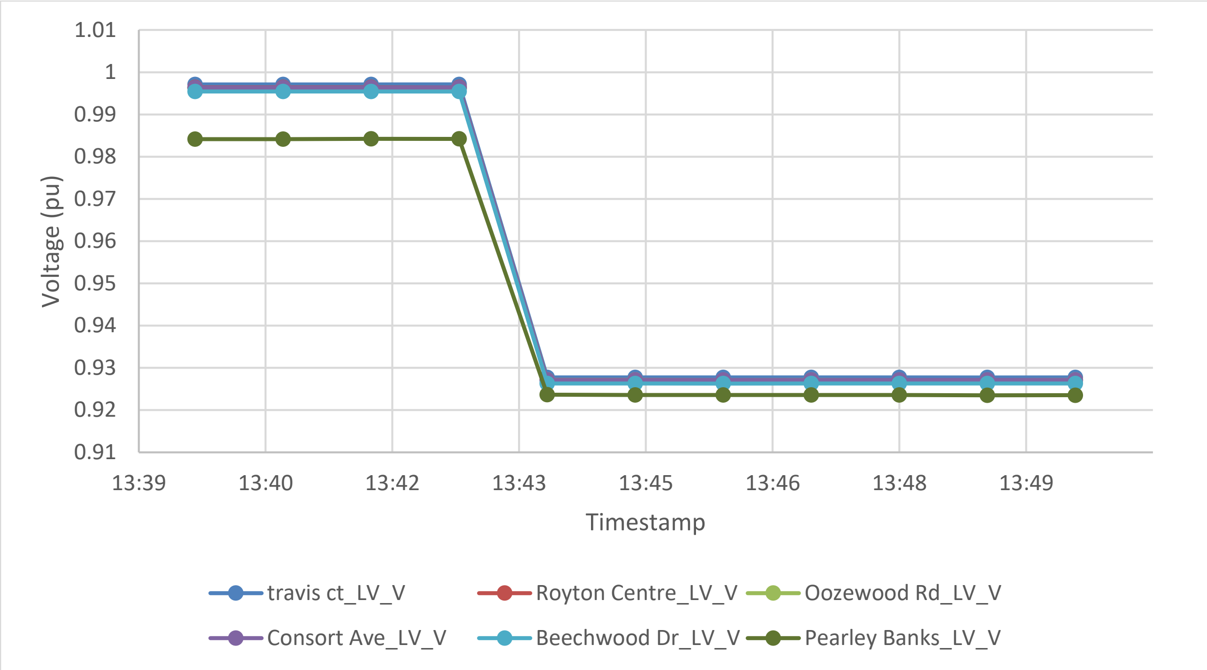

Figure 30: Smart Street Simulated Voltage Results from SGS QUEST System Model

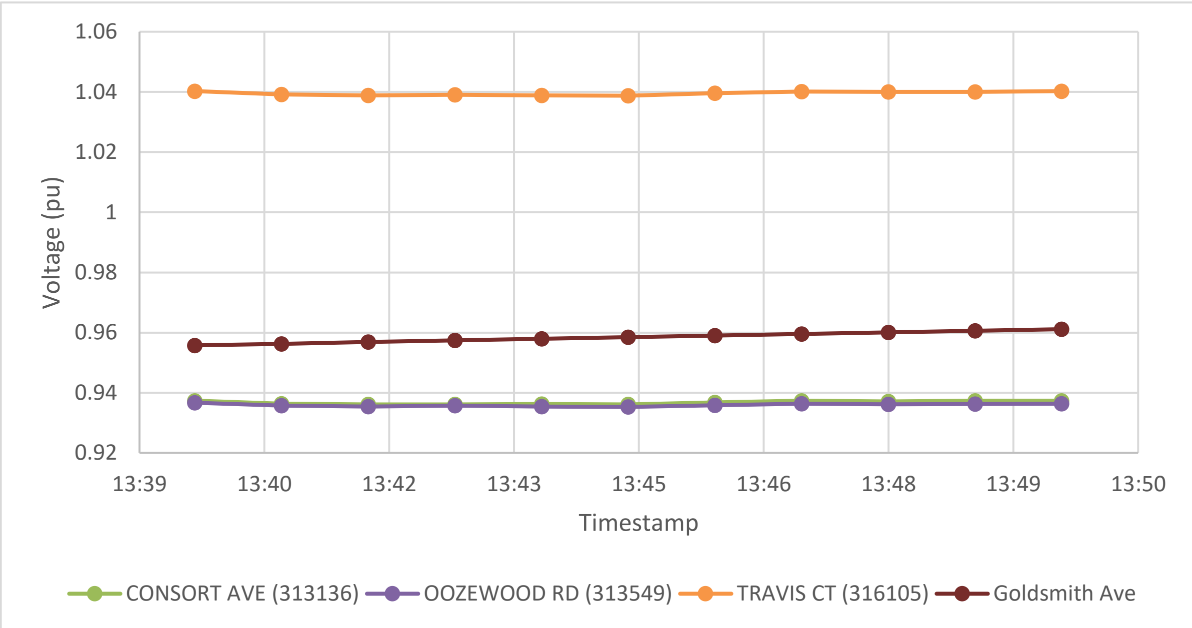

Figure 31: Smart Street Live Voltage Measurement Results from Live QUEST System

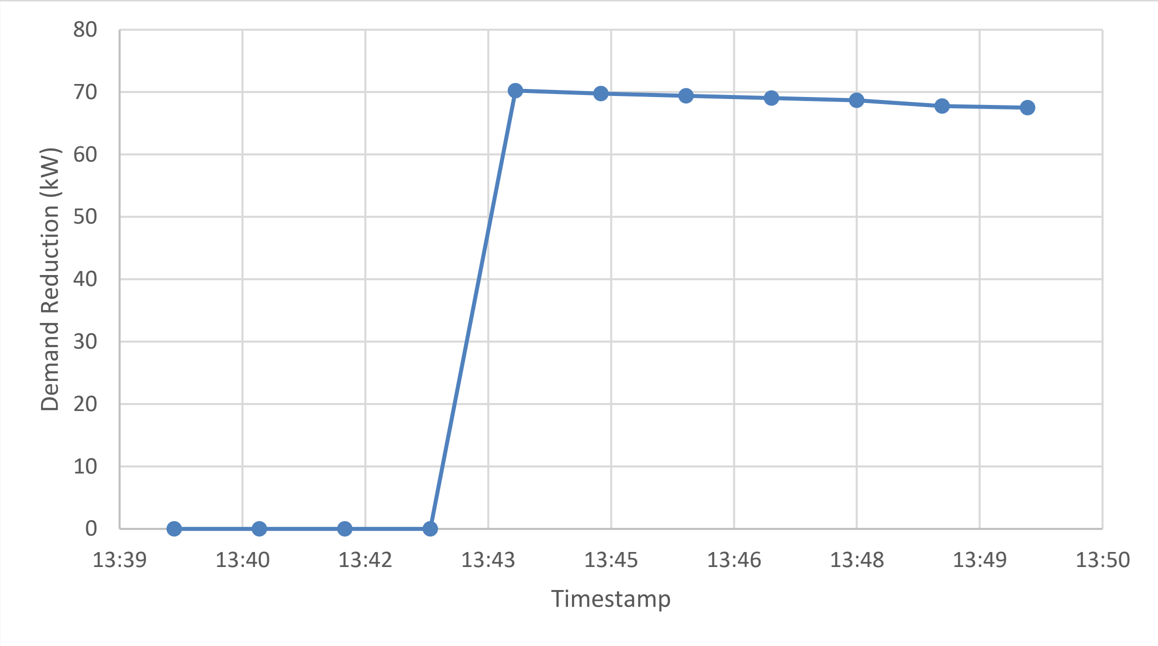

Figure 32: Smart Street Demand Reduction from SGS QUEST System Model

Figure 30 shows the Smart Street site voltage during this trial. Similarly to the trial set up in the previous trial, all Smart Street primaries are fed from Royton Primary except from Pearley Banks, which is fed from Heyside Primary. This results in the primaries fed from Royton being given a progressed function level of 100% - as CLASS is not affecting Smart Street operation here, the function level can be increased. The Pearley Banks site maintains its prescribed function level of 75%, as this is being fed by a site where CLASS is active.

Once Smart Street is activated, all sites arrive at close to the same voltage, despite Pearley Banks having a different function level from the rest of the sites. This is because Pearley Banks has a slightly lower voltage to start with, and so it takes less tap movements to lower the voltage than the Royton sites. Additionally, the Royton sites are placed on their maximum tap setting due to the 100% Smart Street function level. If possible, the tap setting would have changed further to reach the target of 0.91 pu, but as the sites are at their tap limit this is not possible.

Again, Smart Street in the Live System was operational throughout this trial, and the effect can be observed at Consort Ave, Oozewood Rd and Goldsmith Ave in Figure 31, but other sites do not operate as anticipated due to limitations on the live system.

6.1.5.3. CLASS Results

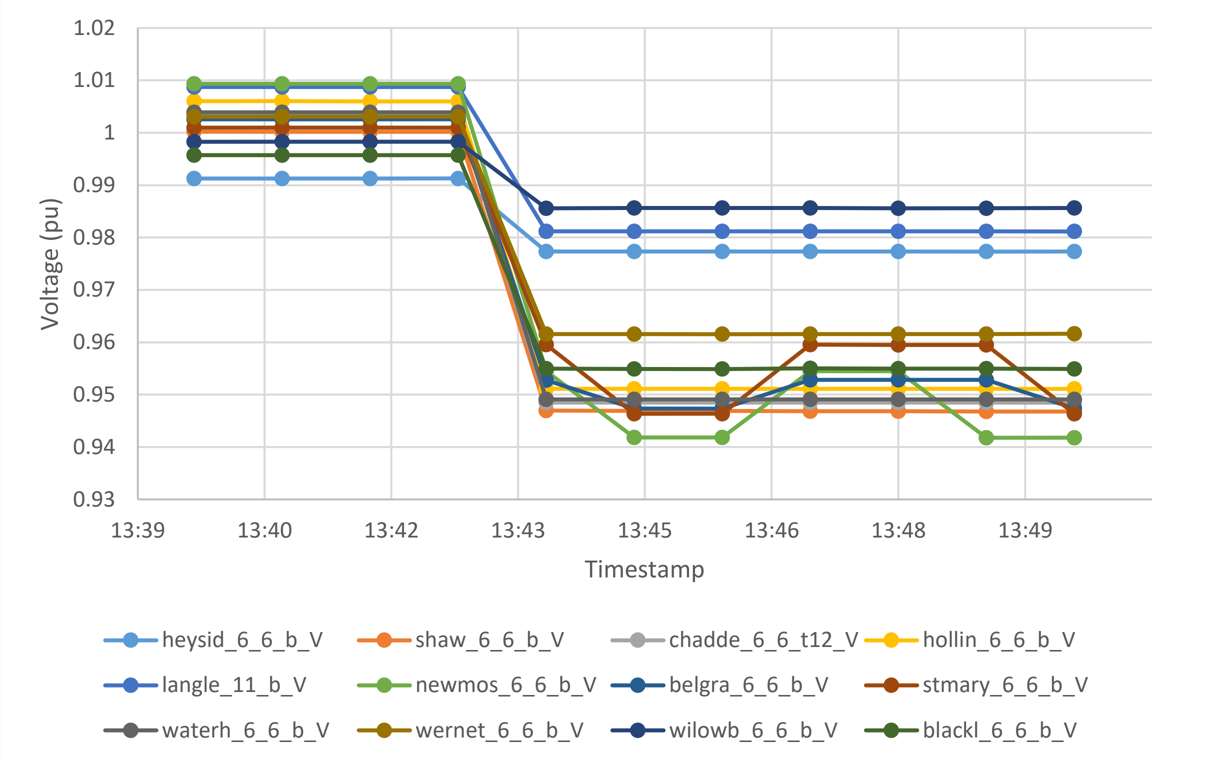

Figure 33: CLASS Simulated Voltage Results from SGS QUEST System Model

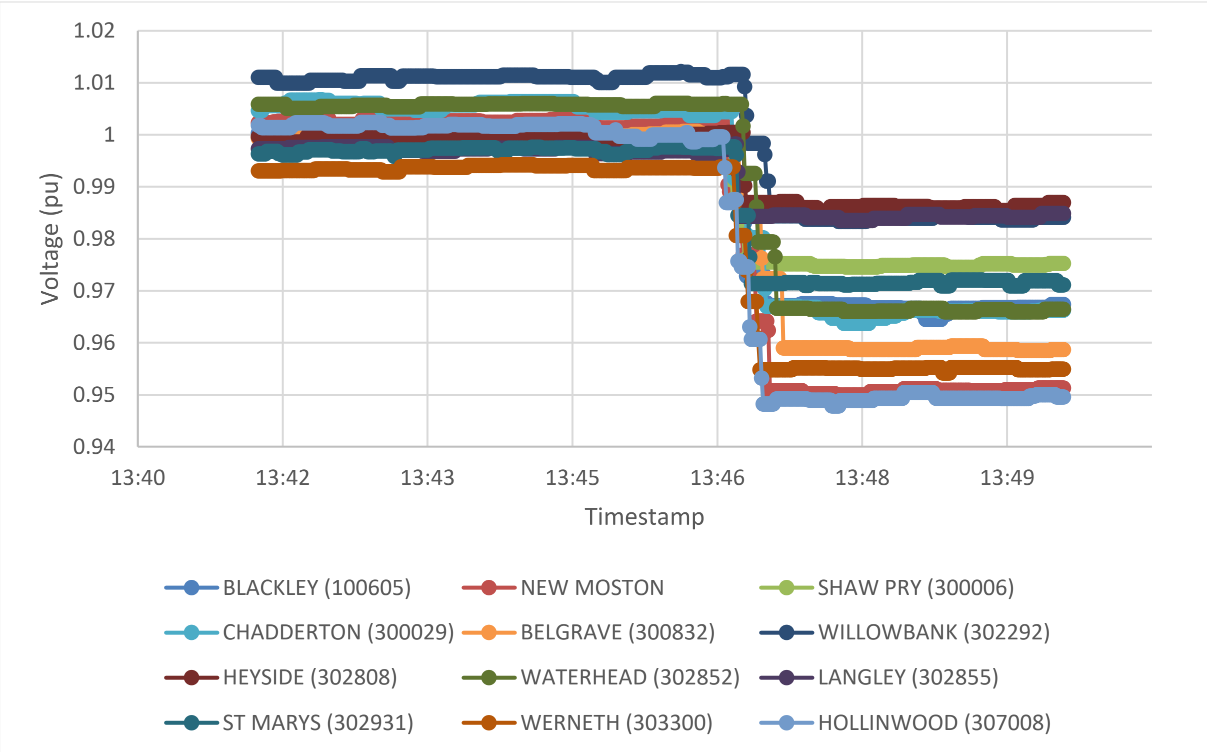

Figure 34: CLASS Live Voltage Measurement Results from Live QUEST System

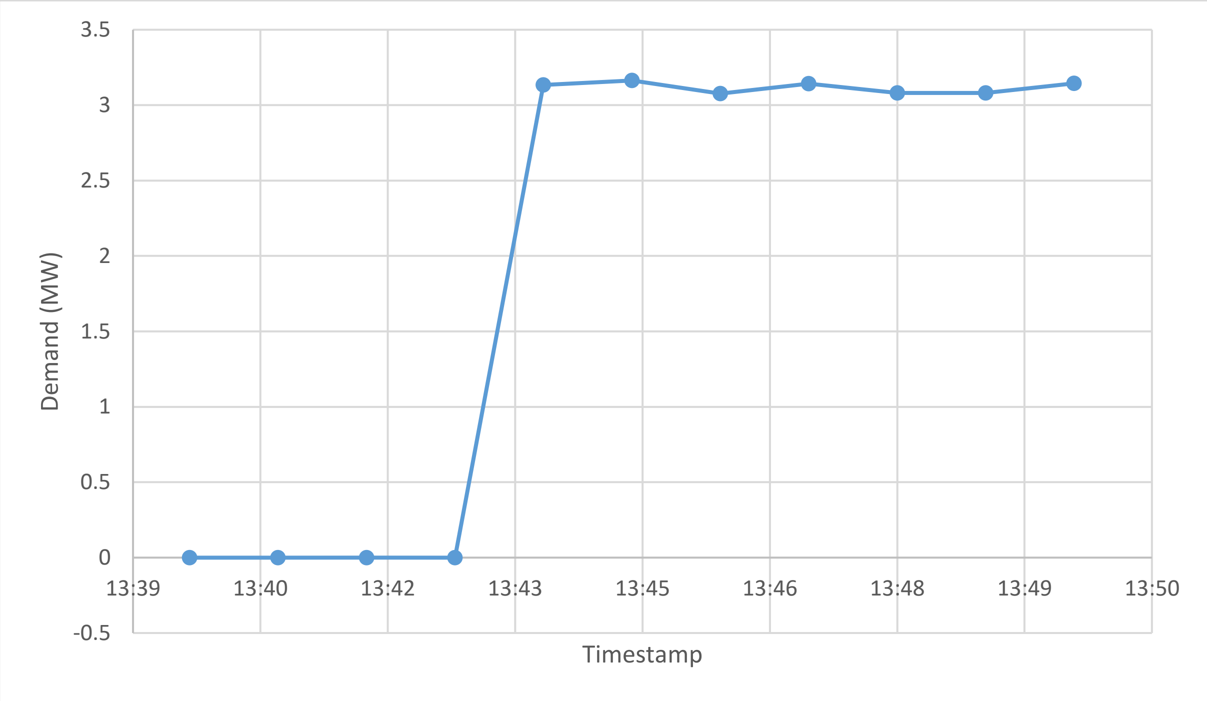

Figure 35: System Demand Reduction from SGS QUEST System Model

When comparing the results in Figure 33 and Figure 34 it is shown that the primaries which fed Smart Street sites remain at a higher voltage when CLASS is active. This is because they have been limited to a 25% function level due to Smart Street's 75% function level. The remaining CLASS sites are permitted to increase their function level to reach the CLASS target. In the SGS simulation, the CLASS target is reached as the remaining CLASS sites end up at either 75% or 100% function levels. In the live QUEST system, the demand reduction achieved is 2.51 MW / 3 MW. Despite the remaining CLASS sites progressing to a function level of 100%, the voltages of these sites are not as low as the sites in the SGS simulation, which could be a reason for the difference in demand reduction between the two systems.

6.1.6. Test 06 – NEM 100 + CLASS 100 + Smart Street 100 – 15/07/25

Tests 06, 07, 08 & 09 are similar tests and so can be compared against each other.

6.1.6.1. Test Input Details

Table 16. QUEST Input Settings for Test 06

	CLASS DR	CLASS DB	Smart Street	NEM
Priority	2	N/A	3	1
Function Level	100%	N/A	100%	100%
Voltage Target	0.95 pu	N/A	0.91 pu	1.057 pu
Target	3 MW	N/A	N/A	N/A
Active Time Period	09:23 - End	N/A	09:19 - End	09:19 - End

Table 17: QUEST Sites

CLASS	Smart Street	NEM
Under Chadderton Grid: • Chadderton • Hollinwood • Langley • New Moston • Failsworth Under Greenhill Grid: • Belgrave • St Mary • Werneth • Willowbank • Waterhead Under Royton Grid • Heyside • Shaw	Under Royton Primary: • Travis Court • Royton Centre • Oozewood Rd • Consort Ave • Beechwood Dr Under Heyside Primary: • Pearley Banks Under Belgrave Primary: • Fold View Under New Moston Primary: • Blandford Dr	Under Whitegate GSP: • Royton Grid • Red Bank Grid • Chadderton Grid

Load Details

- From the trial information provided by SP ENW, QUEST became active between 08:50 and 13:36.
- As this section of tests were longer, load values at different points were used to create a load profile without the effects of QUEST. For this trial, load values at 09:10 and 11:00

were recorded and linear interpolation between the values was used to get "non-QUEST-load".

- Trial was run from 09:15 to 09:31.

Trial Test Comments

- In the live system, NEM was only available on one grid transformer at Chadderton.
- CLASS service not available at Royton Primary
- NEM service not available at Greenhill Grid

6.1.6.2. NEM Results

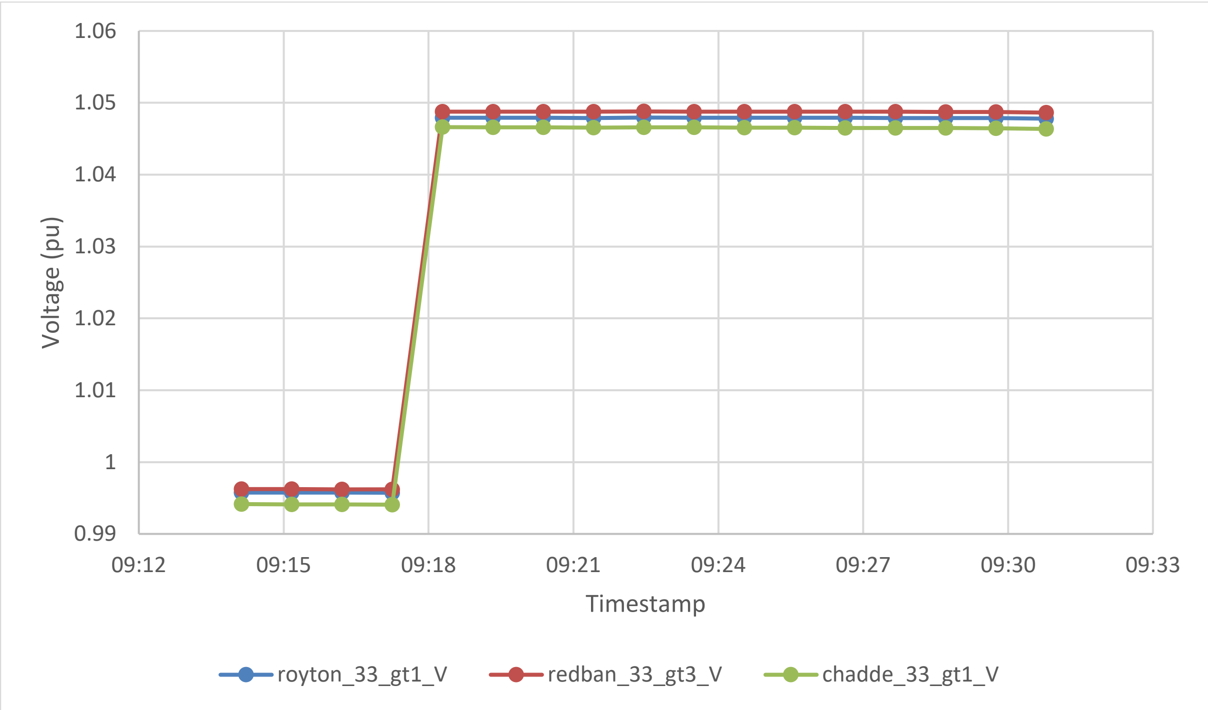

Figure 36: NEM Simulated Voltage Results from SGS QUEST System Model

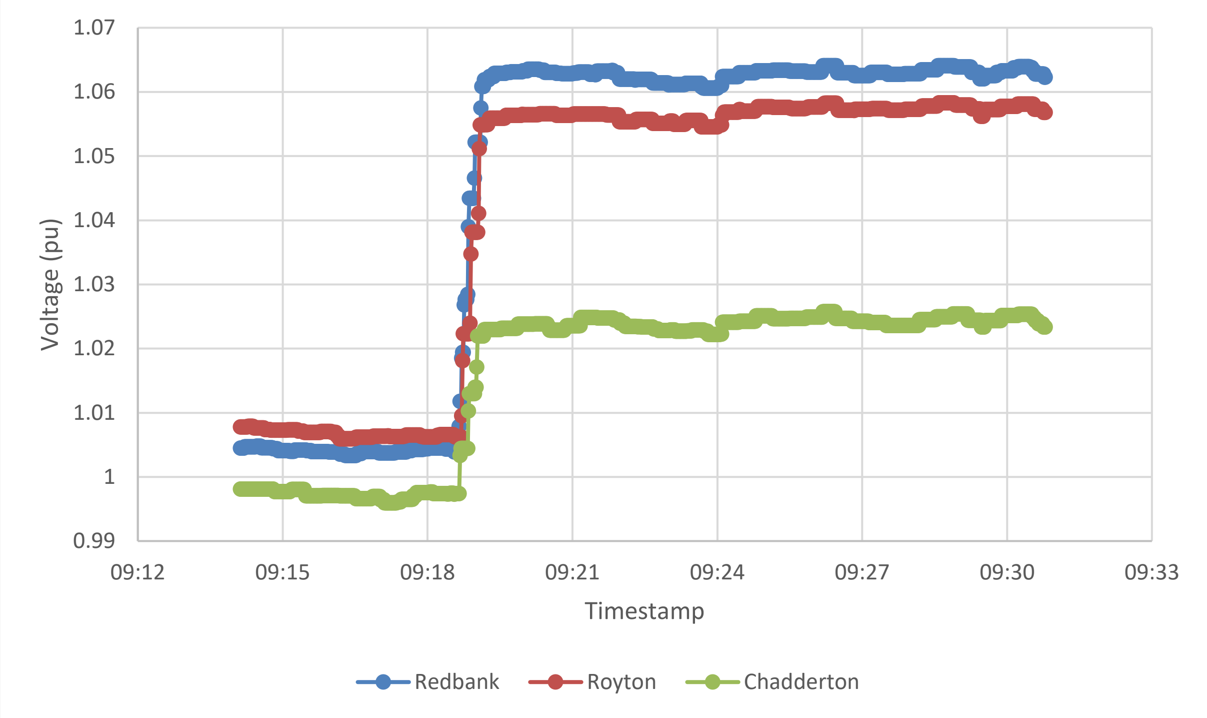

Figure 37: NEM Live Voltage Measurement Results from Live QUEST System

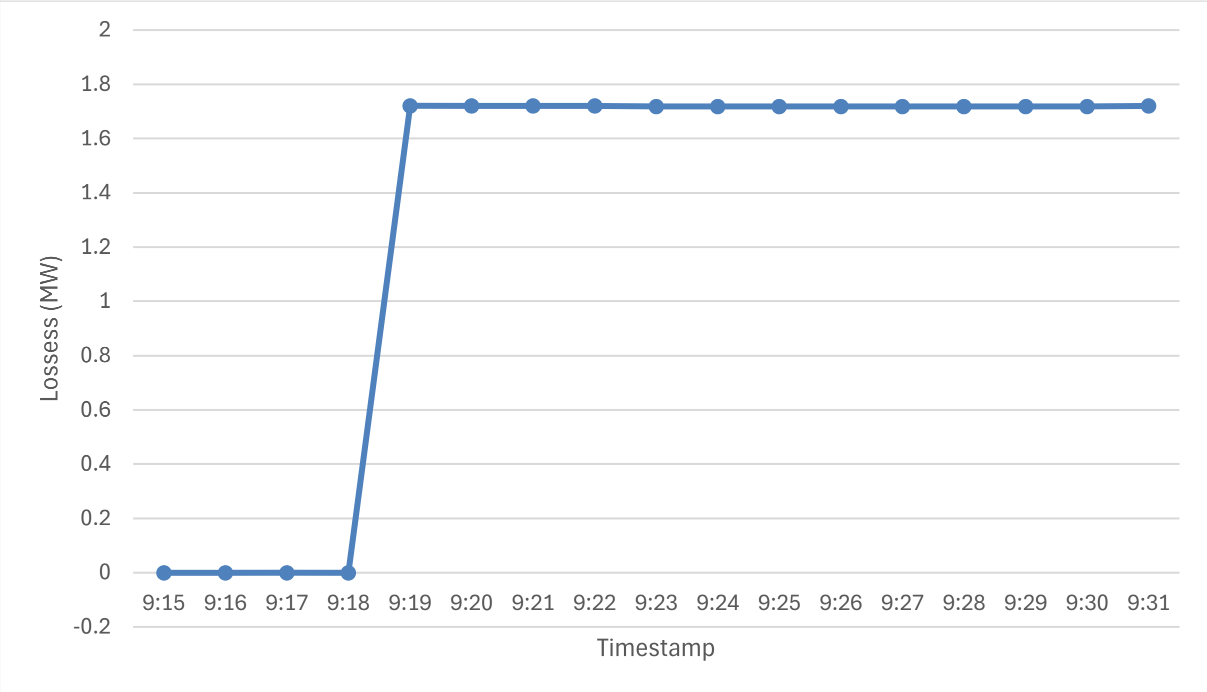

Figure 38: NEM Loss Reduction from SGS QUEST System Model

In the SGS simulation, all three BSP voltages raise to around 1.05 pu as shown in Figure 36. The target is 1.057 pu, but if one tap movement further would push them beyond 1.06 pu then the model will amend the tap setting by 1 to prevent this. In Figure 37, the measurements from the live system show that Royton and Red Bank BSPs have amended their tap settings to achieve a voltage of close to 1.057 pu. The Chadderton BSP voltage has been raised, but only to around 1.025 pu. This is to be expected from the live system as one of the Chadderton GTs had its tap setting fixed. As the 33 kV sides of the Chadderton GTs are connected via a bus coupler, is it expected that the resultant voltage would be somewhere between 1 pu and 1.057 pu.

6.1.6.3. CLASS Results

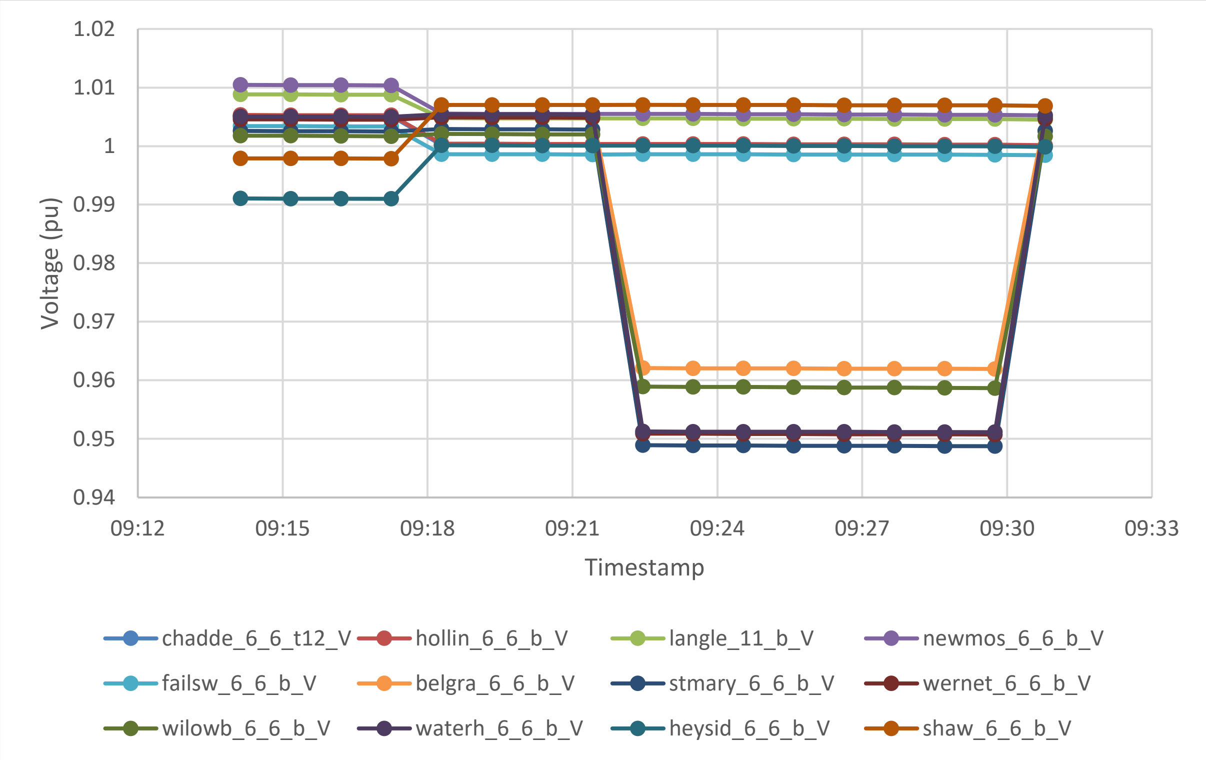

Figure 39: CLASS Simulated Voltage Results from SGS QUEST System Model

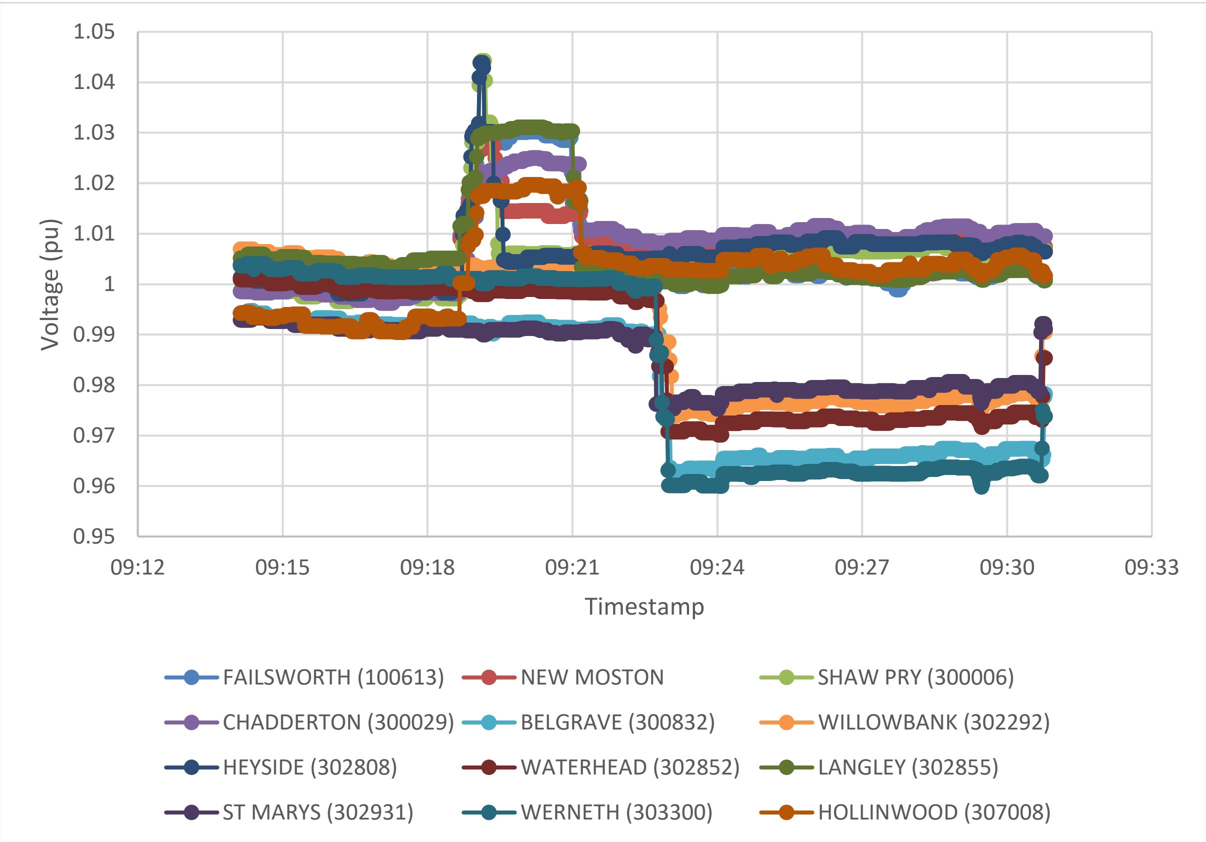

Figure 40: CLASS Live Voltage Measurement Results from Live QUEST System

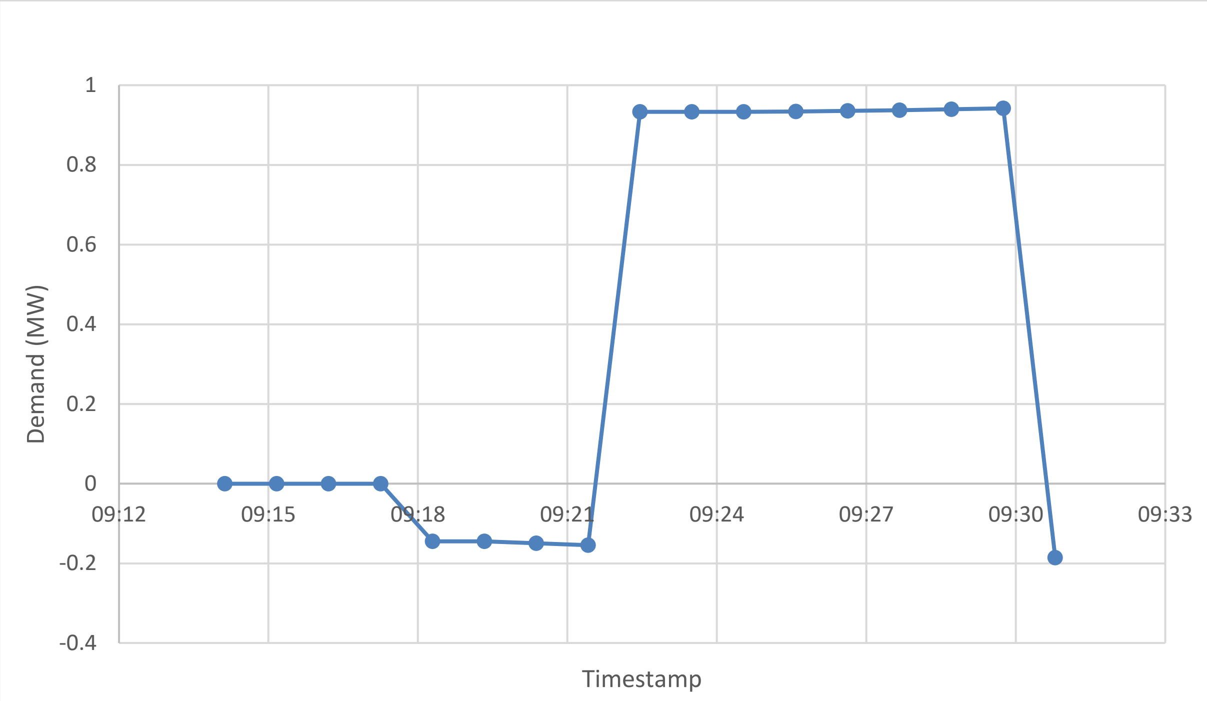

Figure 41: System Demand Reduction from SGS QUEST System Model

The results in Figure 39 and Figure 40 are fairly similar, however one obvious difference is the raised voltages in the live system measurements from 09:19 – 09:21. This is due to the operation of NEM – the primary transformers take a few minutes to return to 1 pu before CLASS is activated. The Primaries that initially remain at 1pu are those fed from Greenhill, which is not available for NEM so does not increase 33kV volts.

When CLASS is activated at 09:23, some sites lower there voltage whereas others target 1 pu. Sites fed from Greenhill are available for CLASS and are selected by QUEST and activated. Sites fed from remaining NEM sites are blocked to CLASS and therefor stay at 1pu

This is because NEM is priority 1 and has a function level of 100%. The corresponding CLASS function level for this setting is 0%, so CLASS sites which are fed by active NEM sites maintain a voltage target of 1 pu. Sites which are fed by Greenhill BSP, which does not have NEM active, are permitted to operate CLASS at a function level of 100%. In both versions of QUEST, these site voltages reduce to target 0.95 pu.

In the SGS model, CLASS achieves a system demand reduction of ~0.94 MW when CLASS is active, as shown in Figure 41. This is close to the report demand reduction achieved via the real system, which is 1.07 MW.

6.1.6.4. Smart Street Results

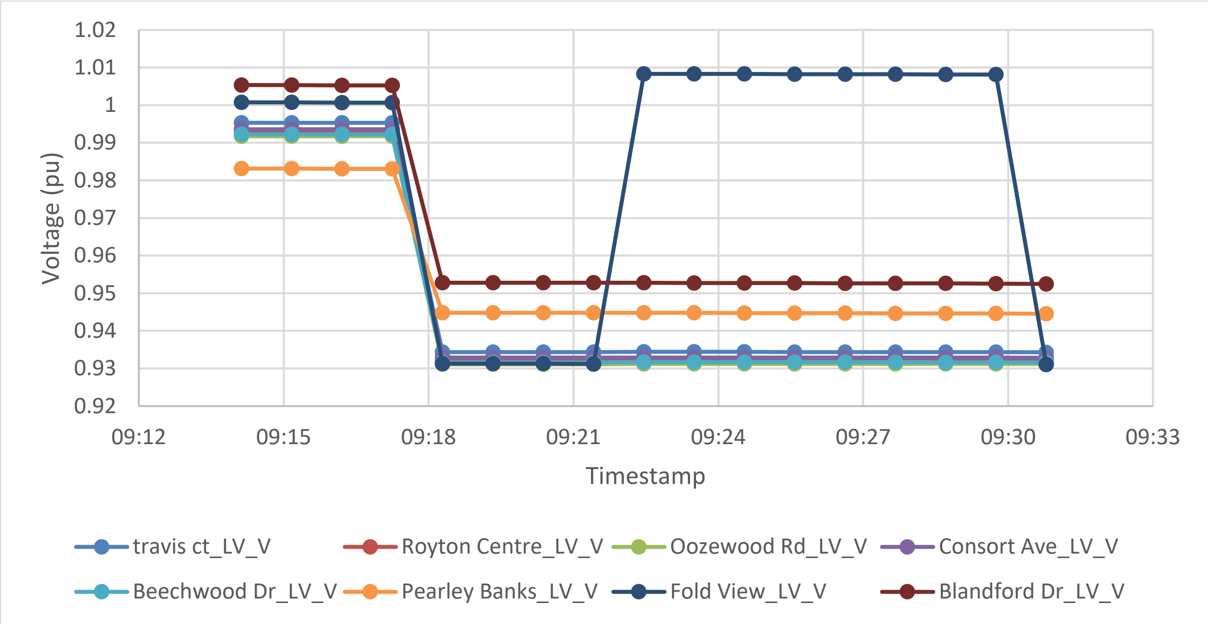

Figure 42: Smart Street Simulated Voltage Results from SGS QUEST System Model

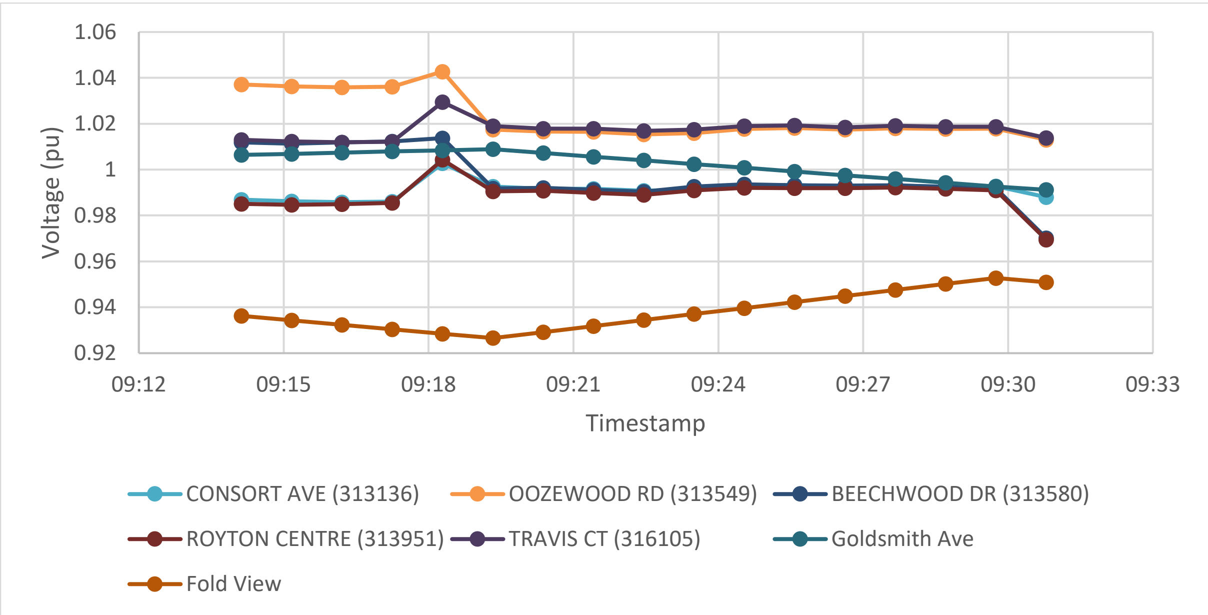

Figure 43: Smart Street Live Voltage Measurement Results from Live QUEST System

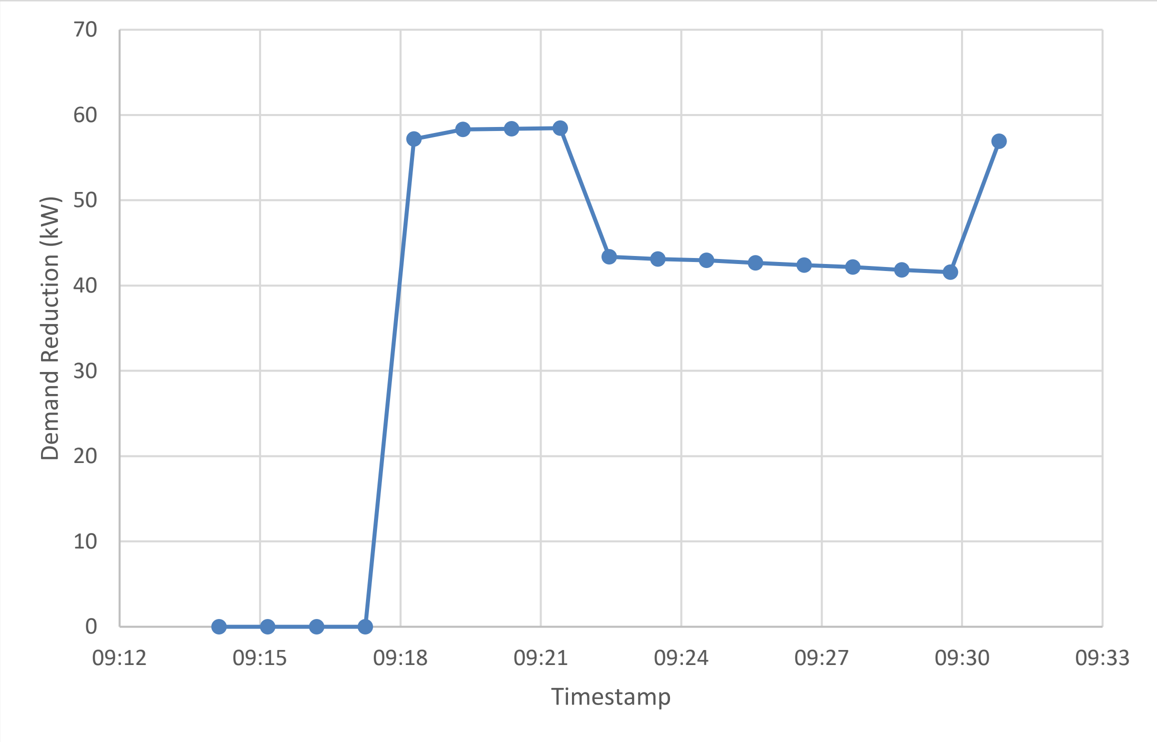

Figure 44: Smart Street Demand Reduction from SGS QUEST System Model

It is difficult to draw similarities between the Smart Street results in Figure 42 and Figure 43, which is likely due to the operational constraints around the operation of Smart Street in the live system.

Where NEM is used, CLASS is not and where OLTC assets are available they are allowed to optimise as normal. Smart Street reoptimizes at a configurable period, however, to prove QUEST optimisation is obliterated by other activity, the Smart Street Optimisation window had been extended. So whilst in Normal operation, if an optimisation cycle does not occur the units are left at the initial VSP.

In the SGS model, Smart Street is operated alongside NEM at 09:19. All voltages target 0.91 pu as expected until CLASS is activated. When CLASS is activated, the voltage for Fold View raises to target 1.01 pu. This is the Smart Street safe mode voltage for when CLASS is active at 100% function level. As CLASS is active at Belgrave (because Belgrave is not fed by a NEM site), this results in Fold View site targeting the safe mode voltage. The remainder of the Smart Street sites are not fed by sites where CLASS is operational, and so Smart Street is permitted to operate normally.

6.1.7. Test 07 –CLASS 100 + NEM 100 + Smart Street 100 – 15/07/25

Tests 06, 07, 08 & 09 are similar tests and so can be compared against each other.

6.1.7.1. Test Input Details

Table 18. QUEST Input Settings for Test 07

	CLASS DR	CLASS DB	Smart Street	NEM
Priority	1	N/A	3	2
Function Level	100%	N/A	100%	100%
Voltage Target	0.95 pu	N/A	0.91 pu	1.057 pu
Target	3 MW	N/A	N/A	N/A
Active Time Period	09:39 – 09:45	N/A	09:38 – 09:46	09:38 – 09:46

Table 19: QUEST Sites

<table>
<tr><th>CLASS</th><th>Smart Street</th><th>NEM</th></tr>
<tr>
<td>Under Chadderton Grid:
Chadderton
Langley
New Moston
Under Red Bank Grid:
Blackley Primary
Under Greenhill Grid:
Belgrave
St Mary
Werneth
Willowbank
Waterhead
Under Royton Grid
Heyside
Shaw</td>
<td>Under Royton Primary:
Travis Court
Royton Centre
Oozewood Rd
Consort Ave
Beechwood Dr
Under Heyside Primary:
Pearley Banks
Under Belgrave Primary:
Fold View
Under New Moston Primary:
Blandford Dr</td>
<td>Under Whitegate GSP:
Royton Grid
Red Bank Grid
Chadderton Grid</td>
</tr>
</table>

Load Details

- From the trial information provided by SP ENW, QUEST became active between 08:50 and 13:36.

- As this section of tests were longer, load values at different points were used to create a load profile without the effects of QUEST. For this trial, load values at 09:10 and 11:00 were recorded and linear interpolation between the values was used to get "non-QUEST-load".
- Trial was run from 09:35 to 09:50.

Trial Test Comments

- In the live system, NEM was only available on one grid transformer at Chadderton.
- CLASS service not available at Royton Primary
- NEM service not available at Greenhill Grid

6.1.7.2. CLASS Results

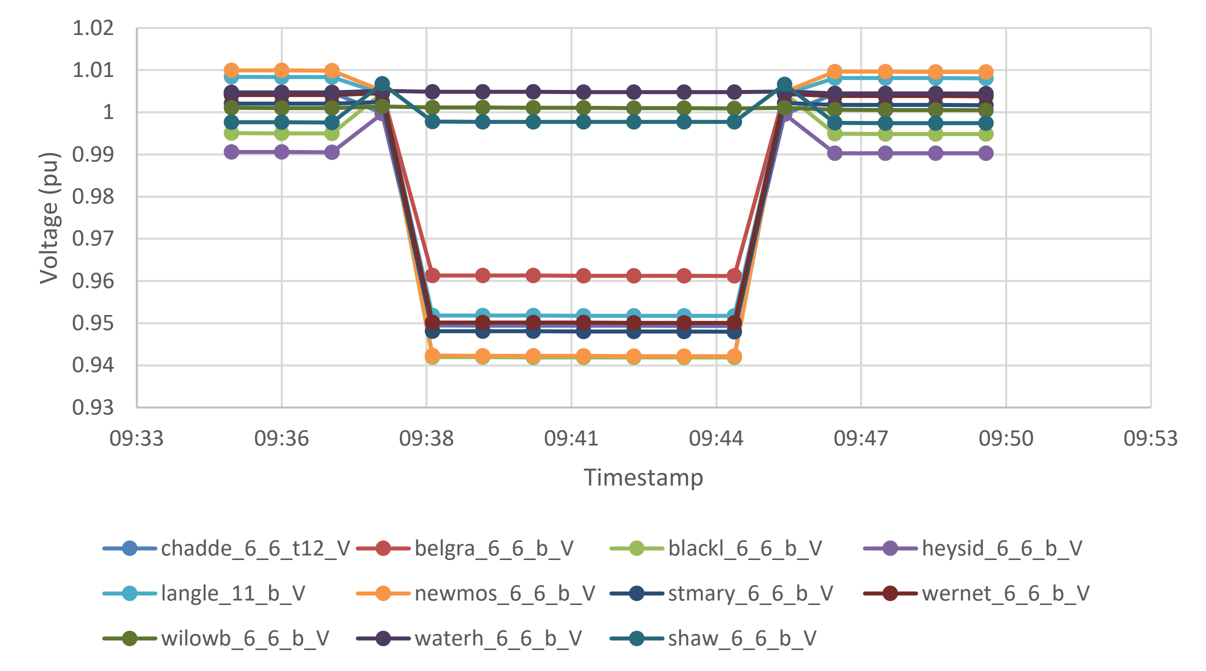

Figure 45: CLASS Simulated Voltage Results from SGS QUEST System Model

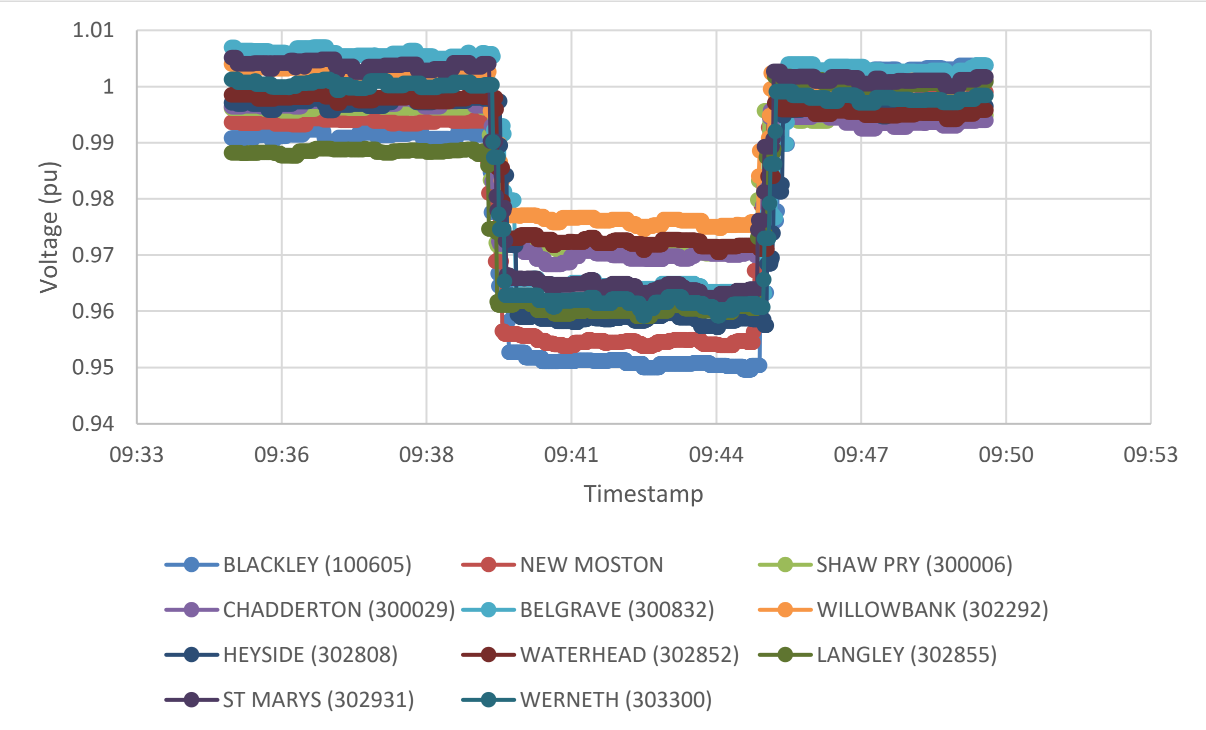

Figure 46: CLASS Live Voltage Measurement Results from Live QUEST System

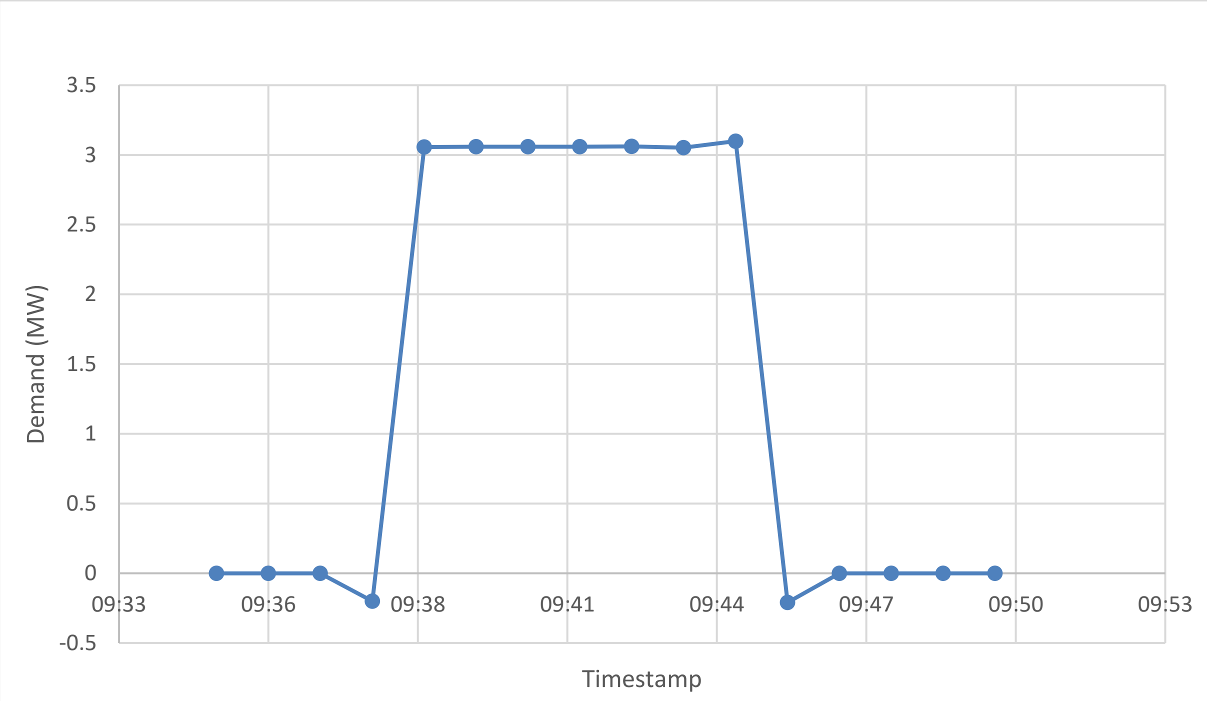

Figure 47: Smart Street Demand Reduction from SGS QUEST System Model

From comparing Figure 45 and Figure 46, the results share similarities but there is a key difference in that three of the CLASS sites in the SGS simulation remain at 1 pu. This is because the demand reduction target of 3 MW has been achieved, whereas in the live system CLASS achieved 2.70 MW, meaning all of the available CLASS sites had a function level of 100%.

The reasoning for this difference in demand reduction could be that the CLASS site voltages in the SGS simulation reach lower values than in the real system. The voltages in the SGS system range from around 0.94 pu – 0.96 pu, whereas in the real system they range from around 0.95 pu – 0.975 pu.

6.1.7.3. NEM Results

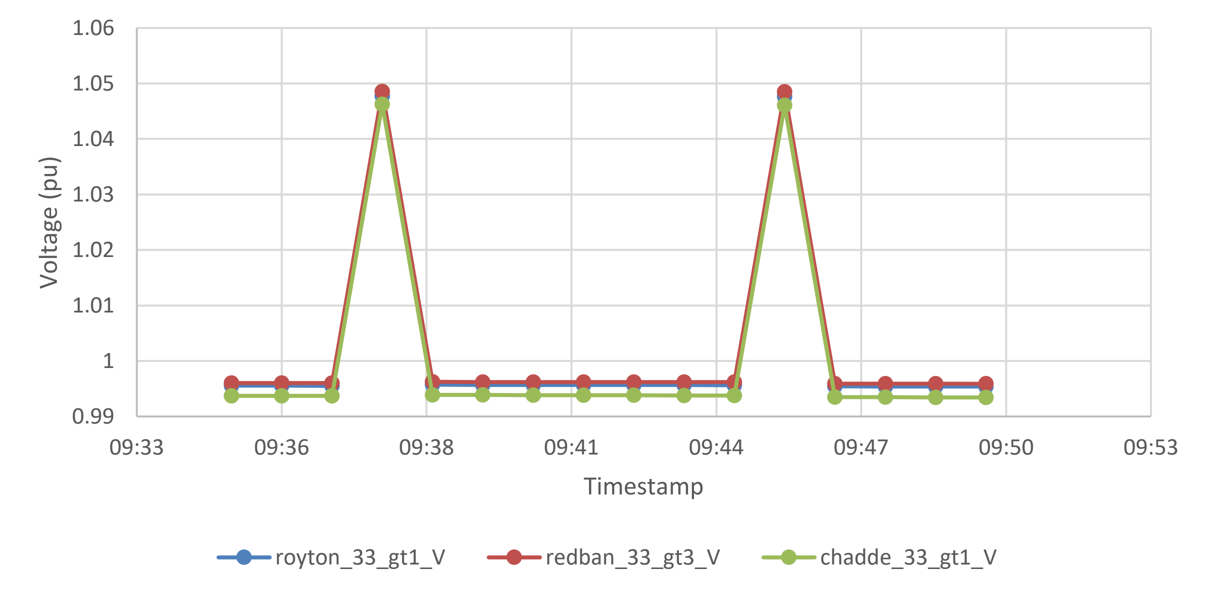

Figure 48: NEM Simulated Voltage Results from SGS QUEST System Model

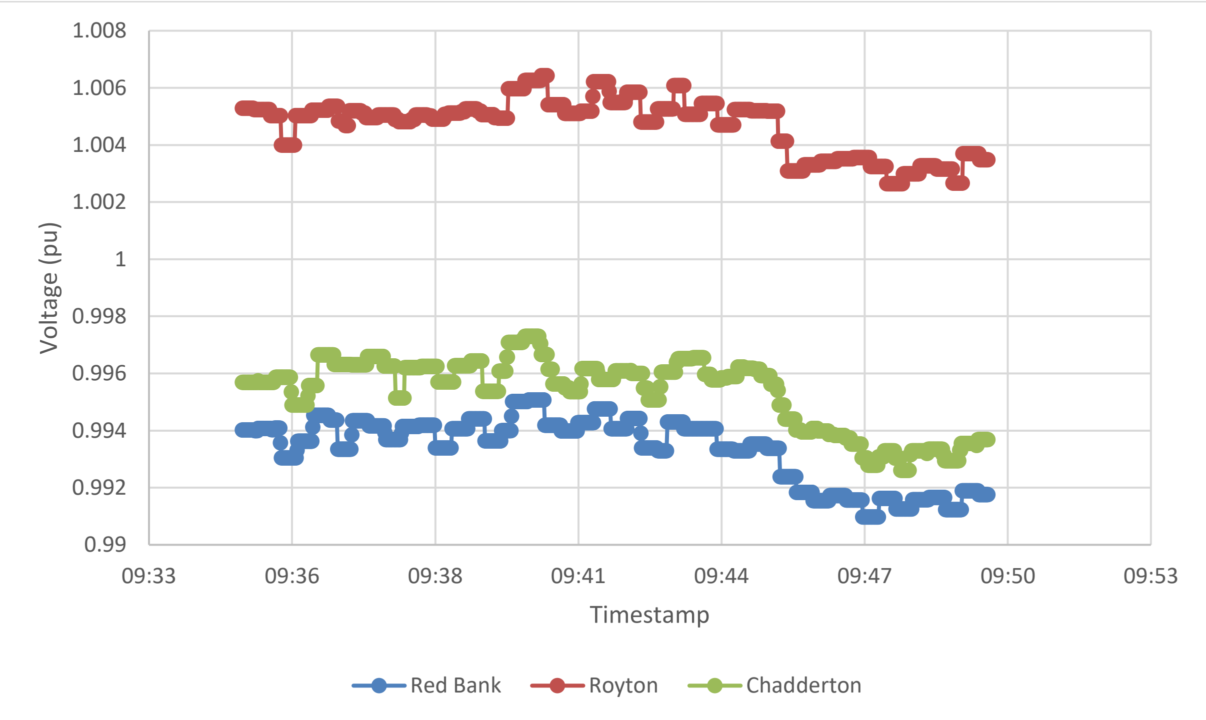

Figure 49: NEM Live Voltage Measurement Results from Live QUEST System

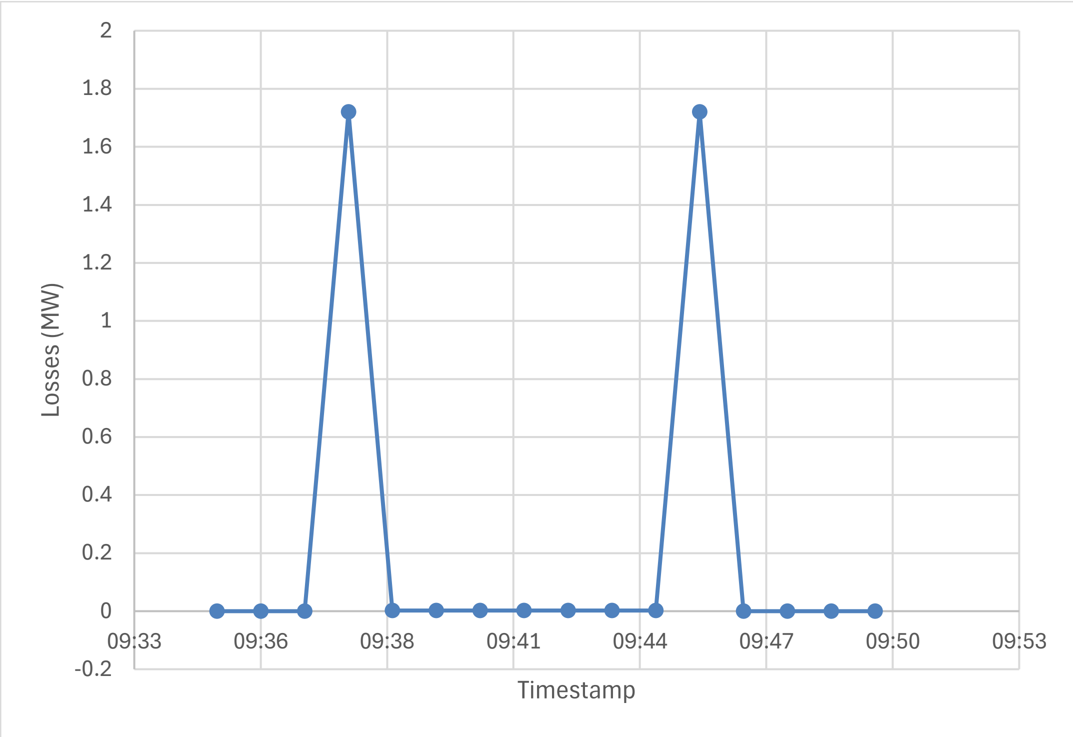

Figure 50: NEM Loss Reduction from SGS QUEST System Model

The results in Figure 48 and Figure 49 have one key difference in that the SGS results show two large spikes. This is because NEM is programmed to come on 1 minute before and 1 minute after CLASS. As the SGS model recalculates the QUEST system in each timestep, these spikes are observed as CLASS is not active during these minutes and so NEM can act as normal. In reality, these spikes are not observed and the voltage stays around 1 pu.

This is an example of the application of the QUEST functional spec in a slightly different manner. The live system version of QUEST is a "one off" optimisation at the point of use, whilst the SGS QUEST more regularly refreshes.

6.1.7.4. Smart Street Results

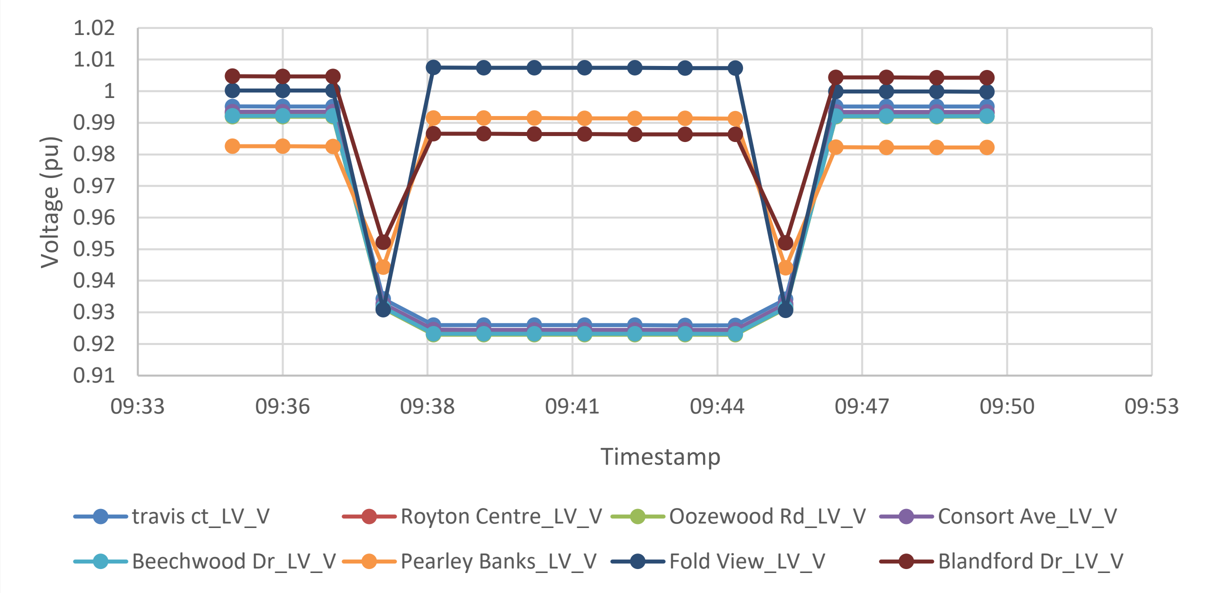

Figure 51: Smart Street Simulated Voltage Results from SGS QUEST System Model

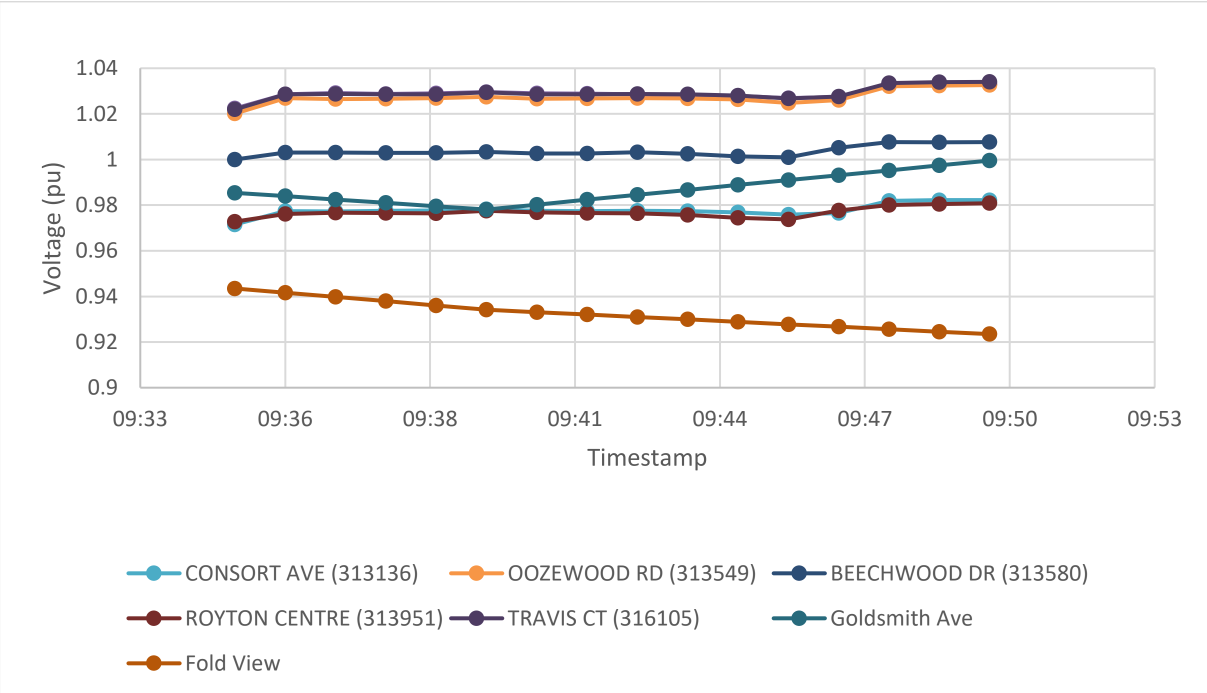

Figure 52: Smart Street Live Voltage Measurement Results from Live QUEST System

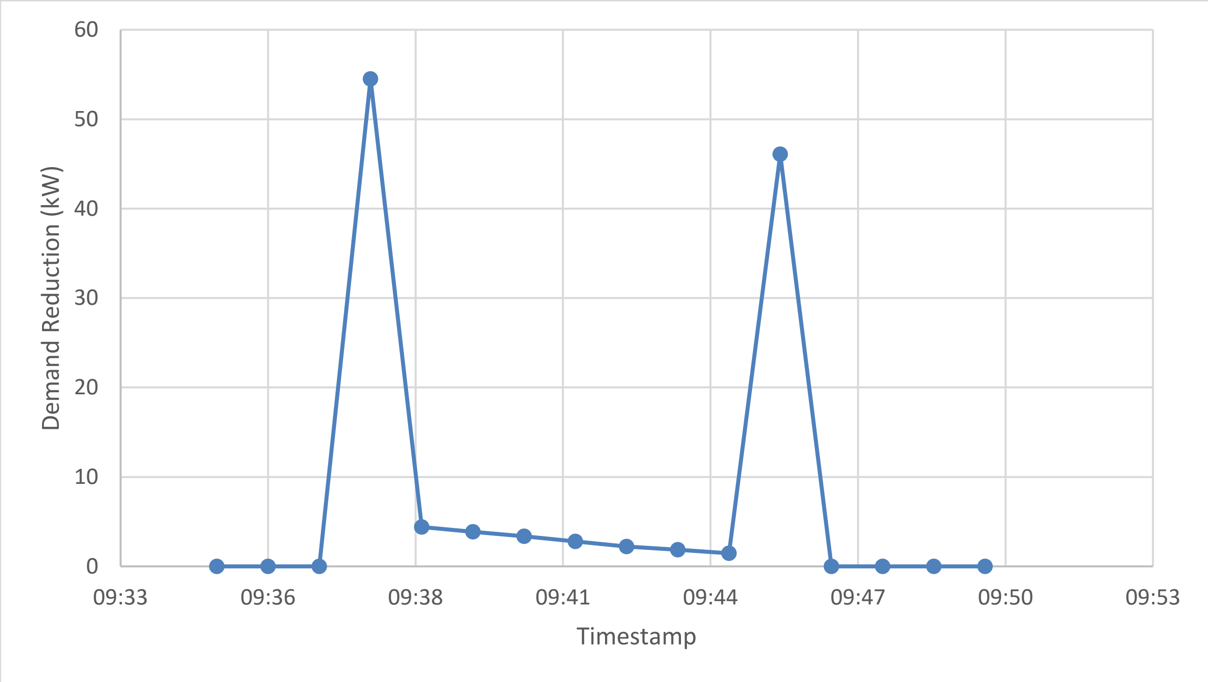

Figure 53: Smart Street Demand Reduction from SGS QUEST System Model

Again, it is difficult to draw similarities between the Smart Street results in Figure 51 and Figure 52, which is likely due to the operational constraints around the operation of Smart Street in the live system. In the live system, voltages at Royton Centre and Consort Ave are slightly lower than the nominal voltage. It would be expected that all sites fed by Royton Primary are at a lower voltage and should be targeting 0.91 pu as Smart Street is on the 100% function level.

Smart Street reoptimizes at a configurable period, however, to prove QUEST optimisation is obliterated by other activity, the smart street Optimisation window had been extended. So whilst in Normal operation, if an optimisation cycle does not occur the units are left at the initial VSP. In the SGS simulation, all Smart Street sites lower their voltage initially before CLASS becomes active. Once CLASS is active, three Smart Street sites raise their voltage to target 1.01 pu. This is because these three sites are fed by CLASS sites, so the corresponding Smart Street sites go into safe mode operation.

Figure 53 shows the demand reduction due to Smart Street. As three of the sites go into safe mode, this actually introduces a slight demand rise and so the Smart Street demand reduction is very low when CLASS is active.

6.1.8. Test 08 – Smart Street 100 + CLASS 100 + NEM 100 – 15/07/25

Tests 06, 07, 08 & 09 are similar tests and so can be compared against each other.

6.1.8.1. Test Input Details

Table 20. QUEST Input Settings for Test 08

	CLASS DR	CLASS DB	Smart Street	NEM
Priority	2	N/A	1	3
Function Level	100%	N/A	100%	100%
Voltage Target	0.95 pu	N/A	0.91 pu	1.057 pu
Target	3 MW	N/A	N/A	N/A
Active Time Period	09:51 – 10:01	N/A	09:50 – 10:02	09:50 – 10:02

Table 21: QUEST Sites

CLASS	Smart Street	NEM
Under Chadderton Grid: • Chadderton • Langley • New Moston Under Red Bank Grid: • Blackley Primary Under Greenhill Grid: • Belgrave • St Mary • Werneth • Willowbank • Waterhead Under Royton Grid • Heyside • Shaw	Under Royton Primary: • Travis Court • Royton Centre • Oozewood Rd • Consort Ave • Beechwood Dr Under Heyside Primary: • Pearley Banks Under Belgrave Primary: • Fold View Under New Moston Primary: • Blandford Dr	Under Whitegate GSP: • Royton Grid • Red Bank Grid • Chadderton Grid

Load Details

- From the trial information provided by SP ENW, QUEST became active between 08:50 and 13:36.

- As this section of tests were longer, load values at different points were used to create a load profile without the effects of QUEST. For this trial, load values at 09:10 and 11:00 were recorded and linear interpolation between the values was used to get "non-QUEST-load".
- Trial was run from 09:48 to 10:05.

Trial Test Comments

- In the live system, NEM was only available on one grid transformer at Chadderton.
- CLASS service not available at Royton Primary
- NEM service not available at Greenhill Grid

6.1.8.2. Smart Street Results

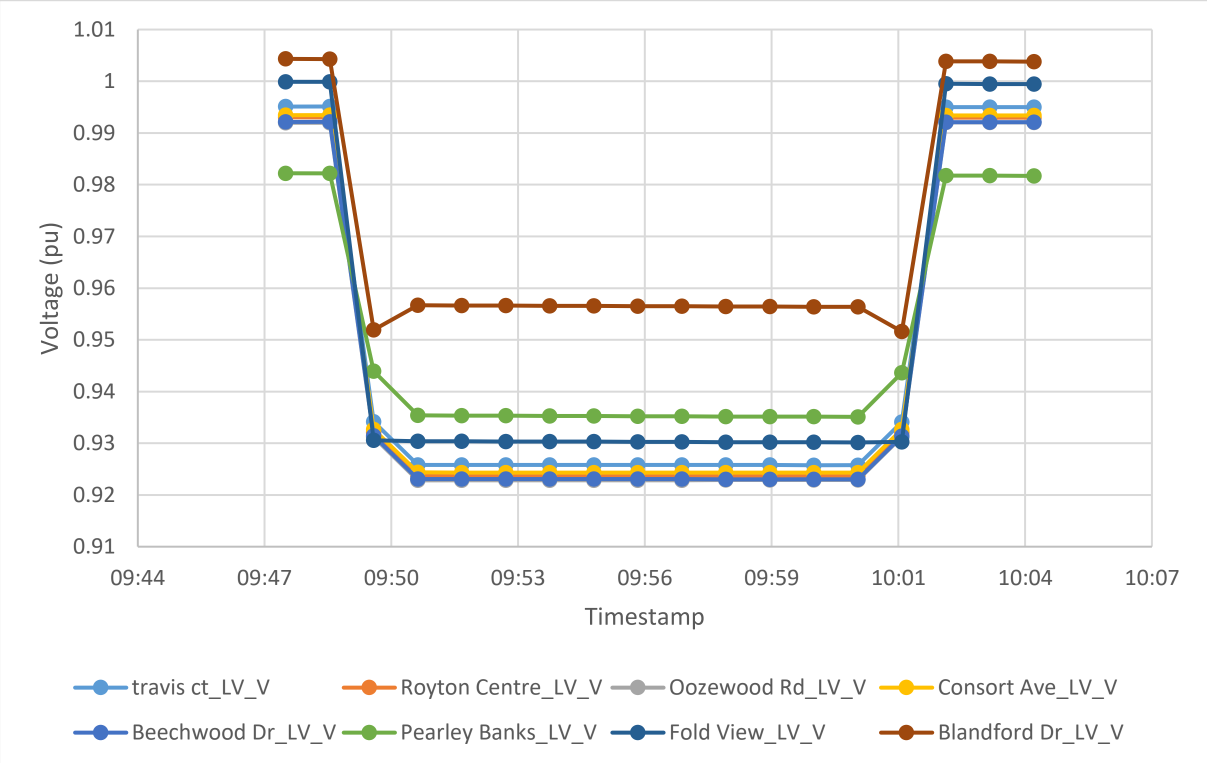

Figure 54: Smart Street Simulated Voltage Results from SGS QUEST System Model

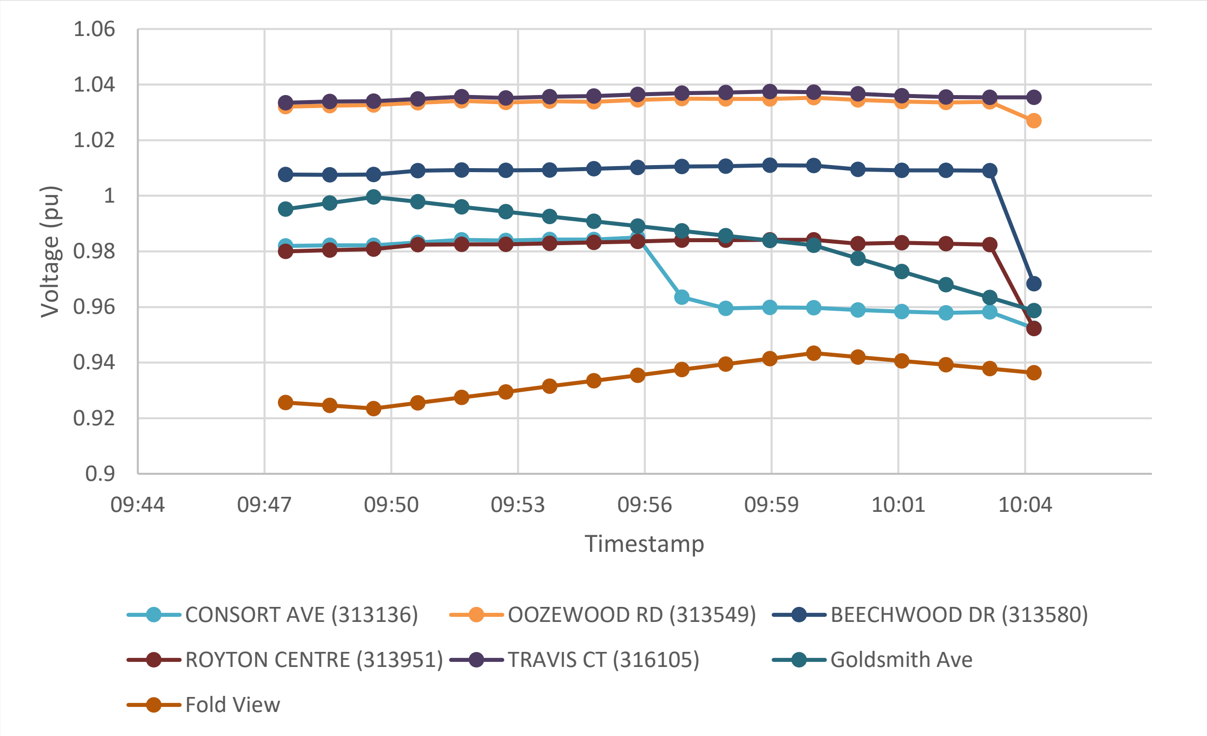

Figure 55: Smart Street Live Voltage Measurement Results from Live QUEST System

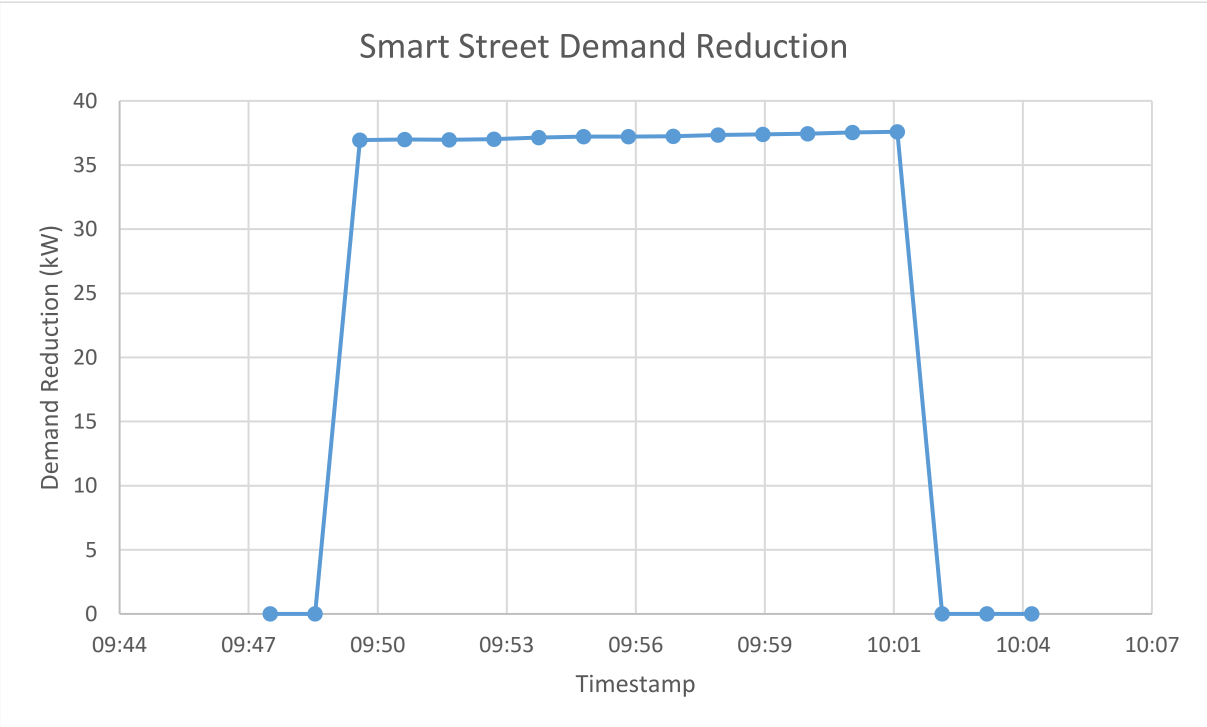

Figure 56: Smart Street Demand Reduction from SGS QUEST System Model

Again, it is difficult to draw similarities between the Smart Street results in Figure 54 and Figure 55, which is likely due to the operational constraints around the operation of Smart Street in the live system. Trends on Figure 55 start to drop towards the end, which could indicate delayed activation of Smart Street.

In the SGS simulation, the Smart Street voltages drop when Smart Street is made active, targeting the 100% function level voltage of 0.91 pu. The Blandford Dr voltage is slightly higher than the rest of the sites, but it is still on its lowest tap setting in an attempt to target 0.91 pu.

Smart Street reoptimizes at a configurable period, however, to prove QUEST optimisation is obliterated by other activity, the Smart Street Optimisation window had been extended. So whilst in Normal operation, if an optimisation cycle does not occur the units are left at the initial VSP.

6.1.8.3. CLASS Results

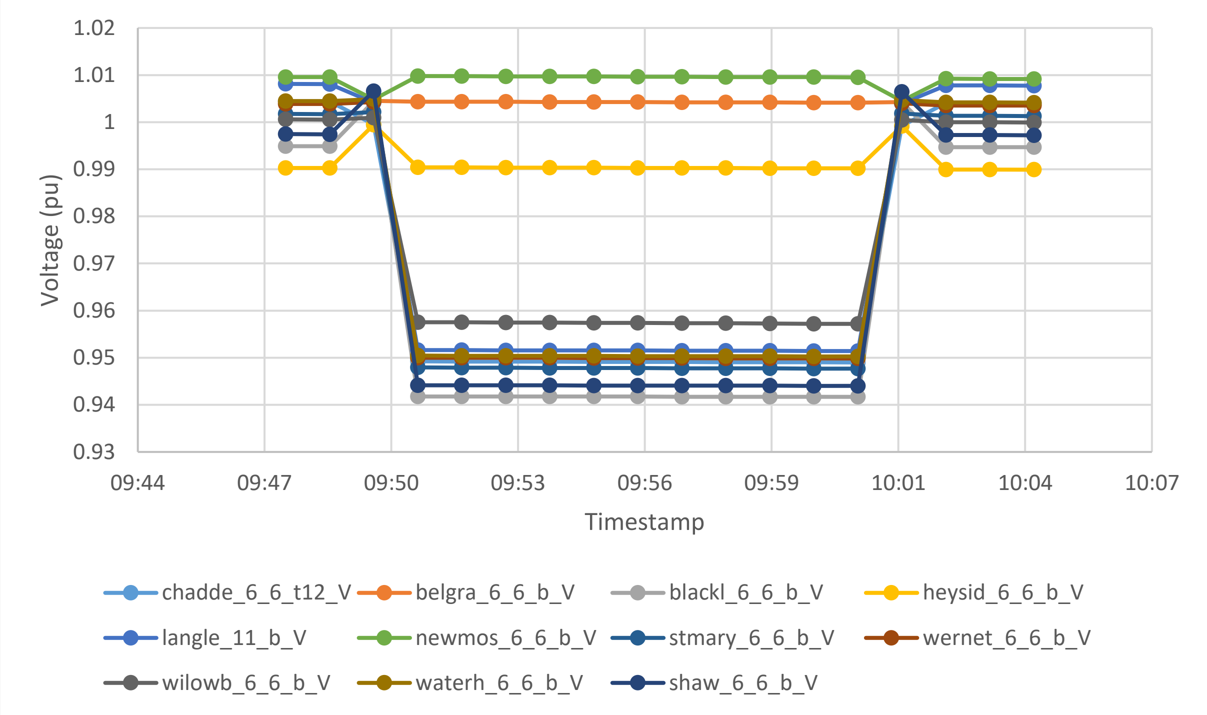

Figure 57: CLASS Simulated Voltage Results from SGS QUEST System Model

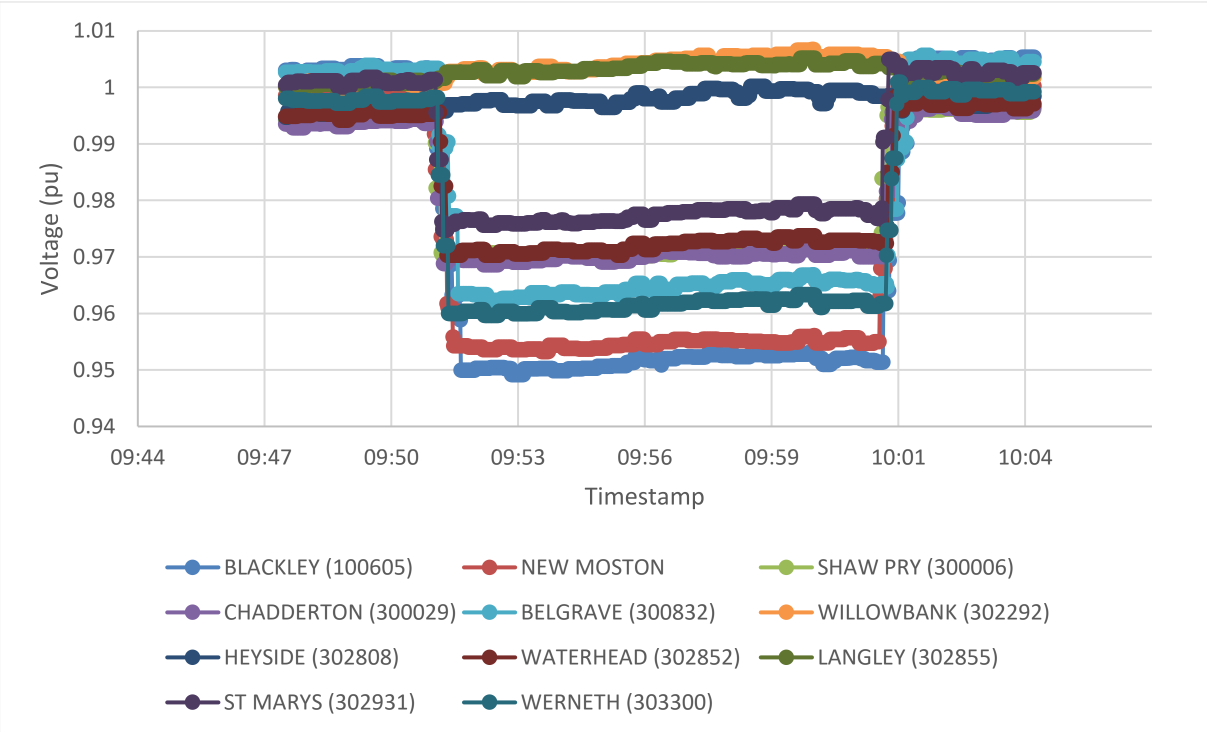

Figure 58: CLASS Live Voltage Measurement Results from Live QUEST System

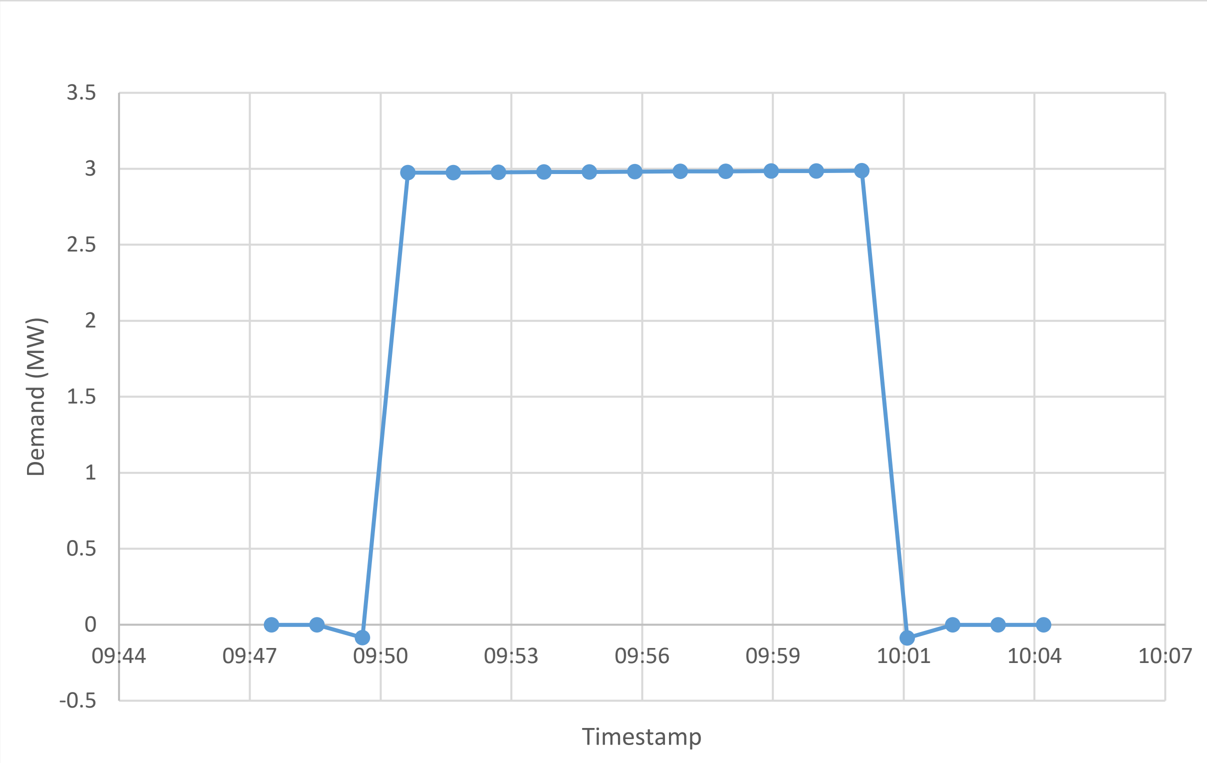

Figure 59: System Demand Reduction from SGS QUEST System Model

There are clear similarities between Figure 57 and Figure 58, with most CLASS sites dropping their voltages but three sites maintaining a voltage target of 1 pu. This is because Smart Street is in priority 1 and is at 100% function level, so the corresponding CLASS sites which feed these Smart Street sites are put into safe mode operation and target a voltage of 1 pu. The sites which target a voltage of 1 pu during CLASS operation are different, this decision was made based on what Smart Street sites were available to model in the SGS system.

In the live system, QUEST achieved a demand reduction of 2.07 MW, whereas in the SGS simulation it hits its target of 3 MW. Again, this difference could be due to the increased voltage reduction in the SGS simulation. An additional reason in this case could be that different Smart Street sites were simulated, which led to differences in which CLASS sites went into safe mode. These sites will have different loadings and voltage/demand relationships, so this will also cause a difference in demand reduction.

6.1.8.4. NEM Results

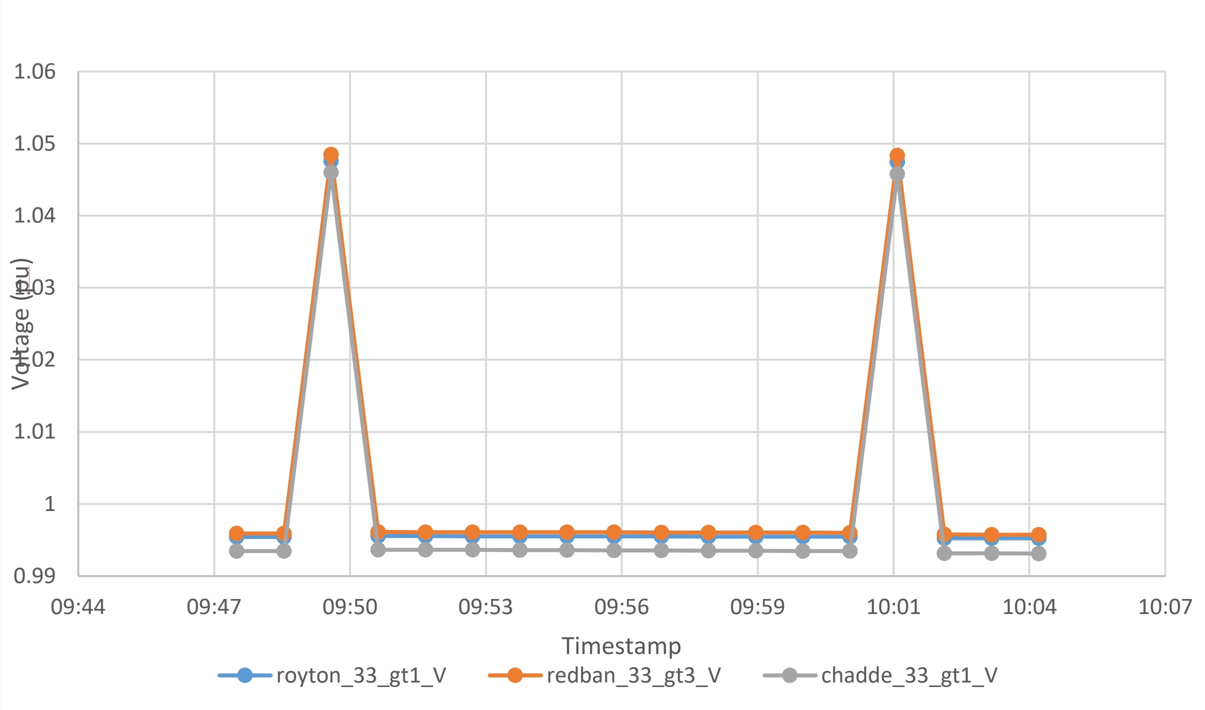

Figure 60: NEM Simulated Voltage Results from SGS QUEST System Model

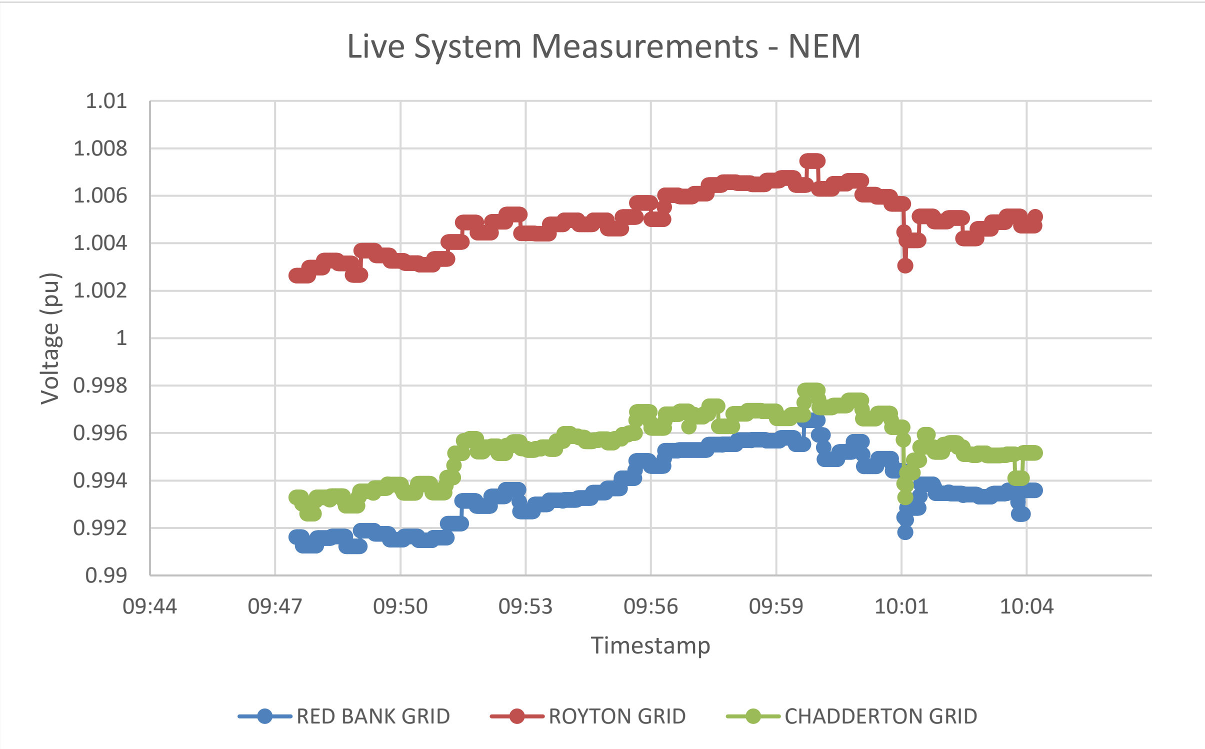

Figure 61: NEM Live Voltage Measurement Results from Live QUEST System

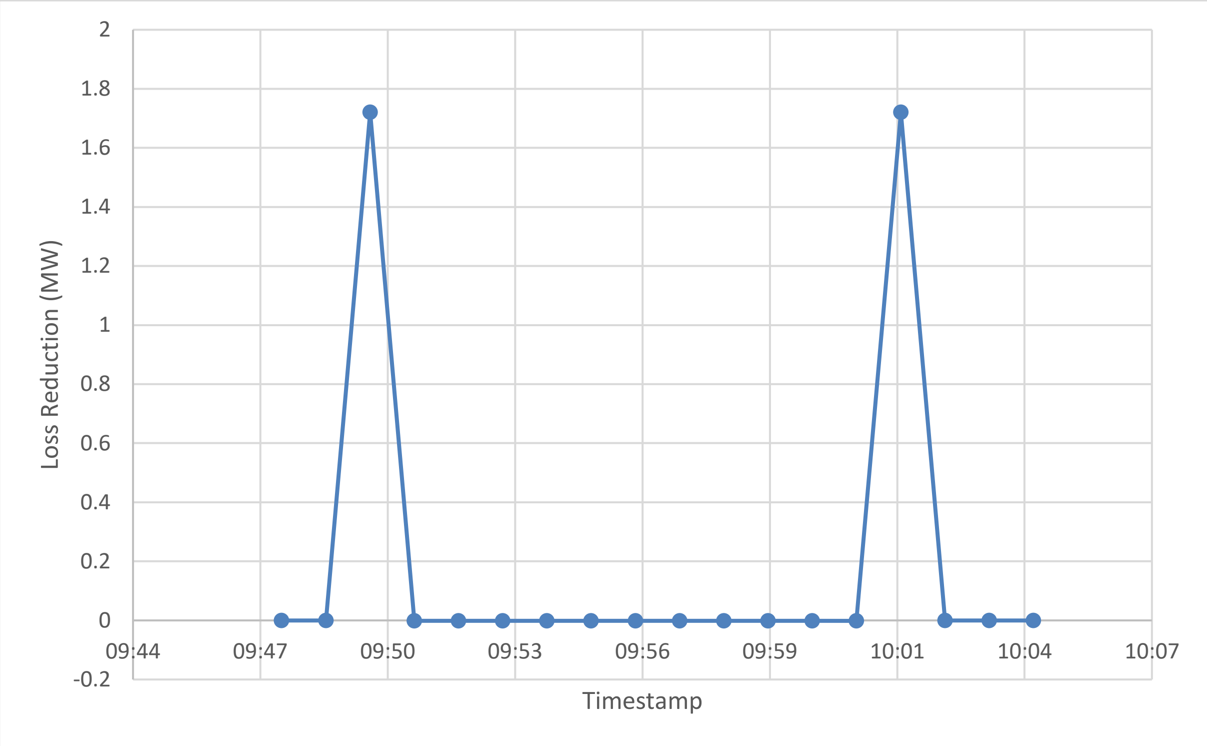

Figure 62: NEM Loss Reduction from SGS QUEST System Model

Similarly to the previous trial, the results in Figure 60 and Figure 61 have one key difference in that the SGS results show two large spikes. This is because NEM is programmed to come on 1 minute before and 1 minute after CLASS. As the SGS model recalculates the QUEST system in each timestep, these spikes are observed as CLASS is not active during these minutes and so NEM can act as normal. In reality, these spikes are not observed and the voltage stays around 1 pu.

This is an example of the application of the QUEST functional spec in a slightly different manner. The live system version of QUEST is a “one off” optimisation at the point of use, whilst the SGS QUEST more regularly refreshes.

6.1.9. Test 09 – NEM 50 + CLASS 50 + Smart Street 50 – 15/07/25

Tests 06, 07, 08 & 09 are similar tests and so can be compared against each other.

6.1.9.1. Test Input Details

Table 22. QUEST Input Settings for Test 09

	CLASS DR	CLASS DB	Smart Street	NEM
Priority	2	N/A	3	1
Function Level	50%	N/A	50%	50%
Voltage Target	0.975 pu	N/A	0.96 pu	1.0285 pu
Target	3 MW	N/A	N/A	N/A
Active Time Period	10:36 – 10:44	N/A	10:36 – 10:45	10:36 – 10:45

Table 23: QUEST Sites

<table>
<tr><th>CLASS</th><th>Smart Street</th><th>NEM</th></tr>
<tr>
<td>Under Chadderton Grid:
• Chadderton
• Hollinwood
• Langley
• New Moston

Under Red Bank Grid:
• Blackley Primary

Under Greenhill Grid:
• Belgrave
• St Mary
• Werneth
• Willowbank
• Waterhead

Under Royton Grid
• Heyside
• Shaw</td>
<td>Under Royton Primary:
• Travis Court
• Royton Centre
• Oozewood Rd
• Consort Ave
• Beechwood Dr

Under Heyside Primary:
• Pearley Banks

Under Belgrave Primary:
• Fold View

Under New Moston Primary:
• Blandford Dr</td>
<td>Under Whitegate GSP:
• Royton Grid
• Red Bank Grid
• Chadderton Grid</td>
</tr>
</table>

Load Details

- From the trial information provided by SP ENW, QUEST became active between 08:50 and 13:36.

- As this section of tests were longer, load values at different points were used to create a load profile without the effects of QUEST. For this trial, load values at 09:10 and 11:00 were recorded and linear interpolation between the values was used to get "non-QUEST-load".
- Trial was run from 10:30 to 10:47.

Trial Test Comments

- In the live system, NEM was only available on one grid transformer at Chadderton.
- CLASS service not available at Royton Primary
- NEM service not available at Greenhill Grid

6.1.9.2. NEM Results

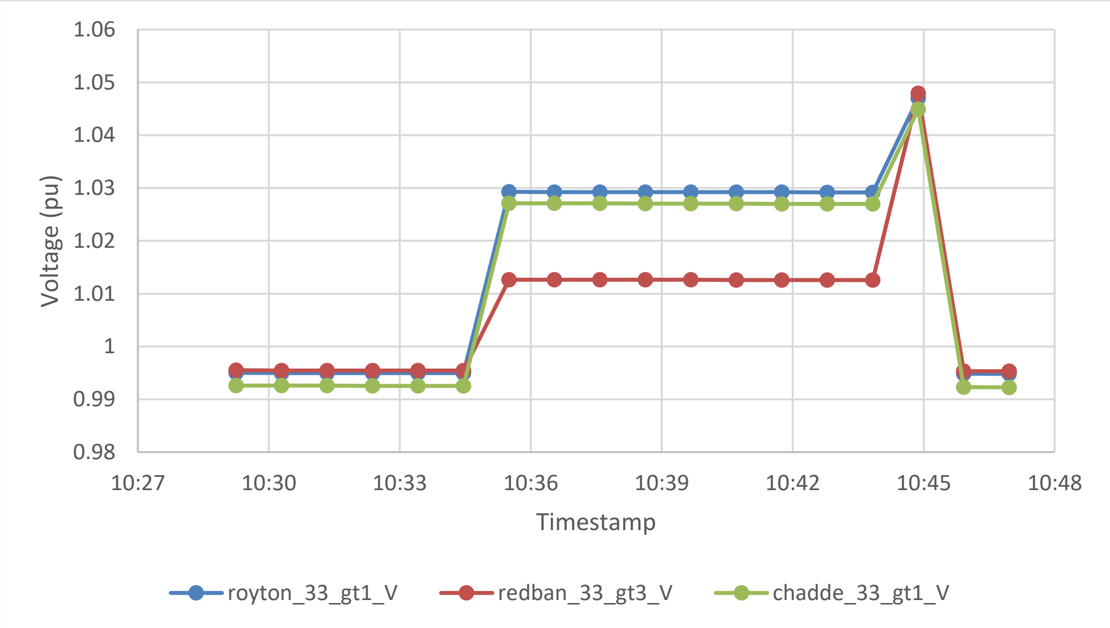

Figure 63: NEM Simulated Voltage Results from SGS QUEST System Model

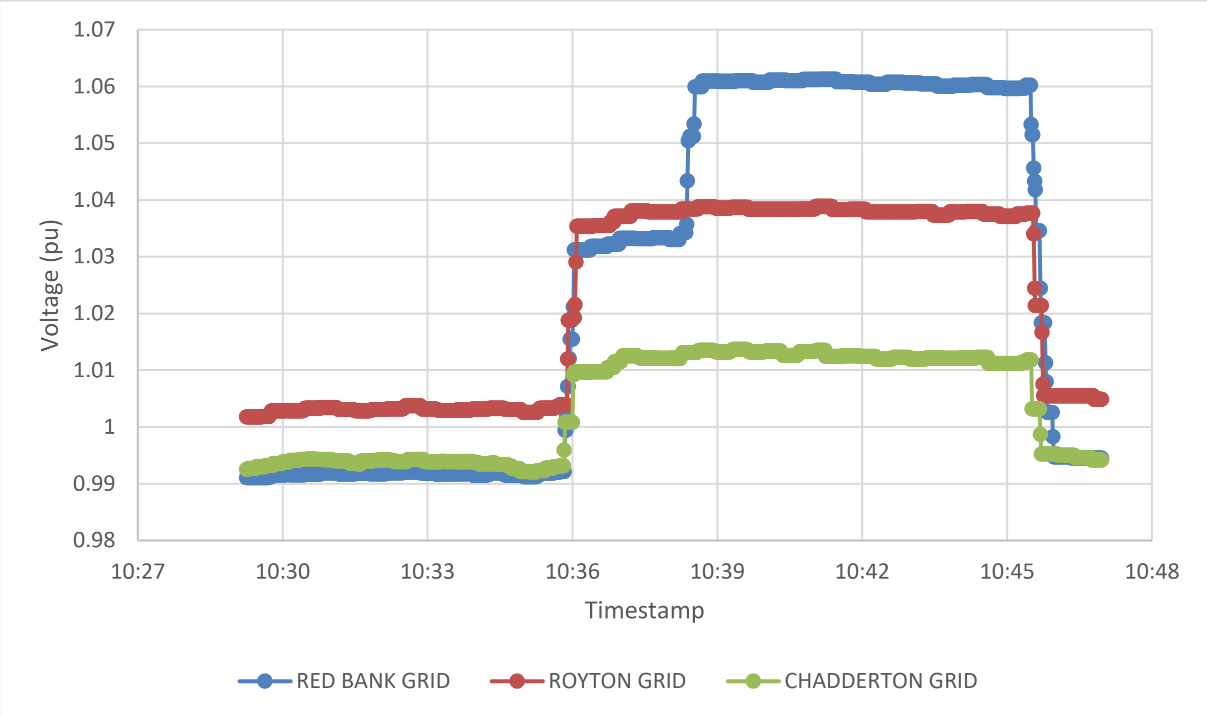

Figure 64: NEM Live Voltage Measurement Results from Live QUEST System

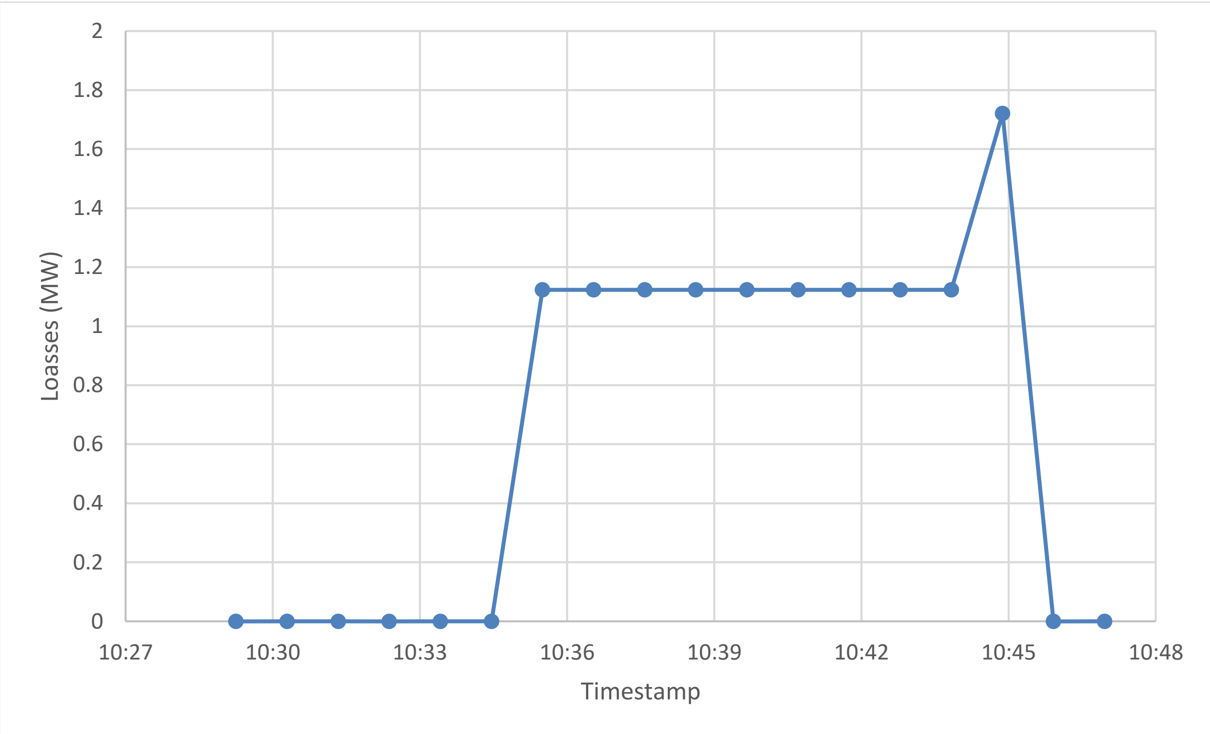

Figure 65: NEM Loss Reduction from SGS QUEST System Model

The results in Figure 63 and Figure 64 are similar but have key differences:

- The Chadderton Grid voltage does not reach as high as in the live system as it does in the SGS simulation. This is because one of the Chadderton GTs was not operating under QUEST in reality.

- Red Bank Grid reaches a higher voltage in the live system than it does in the SGS simulation. On investigating this, it appears that CLASS at Blackley Primary did not operate due to a suspected comms/telemetry issue. Due to this, and because there were no other CLASS sites under Red Bank Grid, QUEST permits this site to move to 100% function level, therefore targeting a voltage of 1.057 pu instead of 1.0285 pu. Additionally, in the SGS QUEST system, QUEST has calculated that Red Bank Grid should only move one tap position, rather than two, and so it ends up on a lower voltage than the other two NEM sites. The cause of this is due to small differences in voltage, and this causing the calculation in the model logic to only move Red Bank one tap position, when it is on the fringes of being moved two positions.
- In the SGS simulation, the NEM voltages spike at 10:45. This is because CLASS deactivates at 10:44, and as the SGS QUEST recalculates every timestep, NEM is able to progress to 100% function level for this timestep.

6.1.9.3. CLASS Results

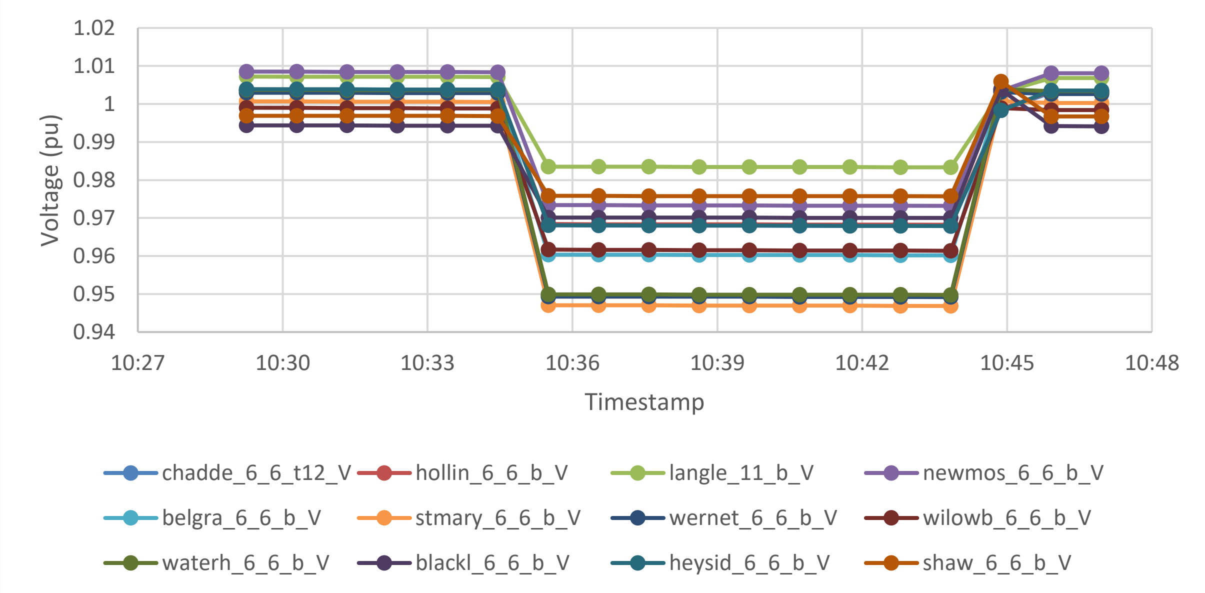

Figure 66: CLASS Simulated Voltage Results from SGS QUEST System Model

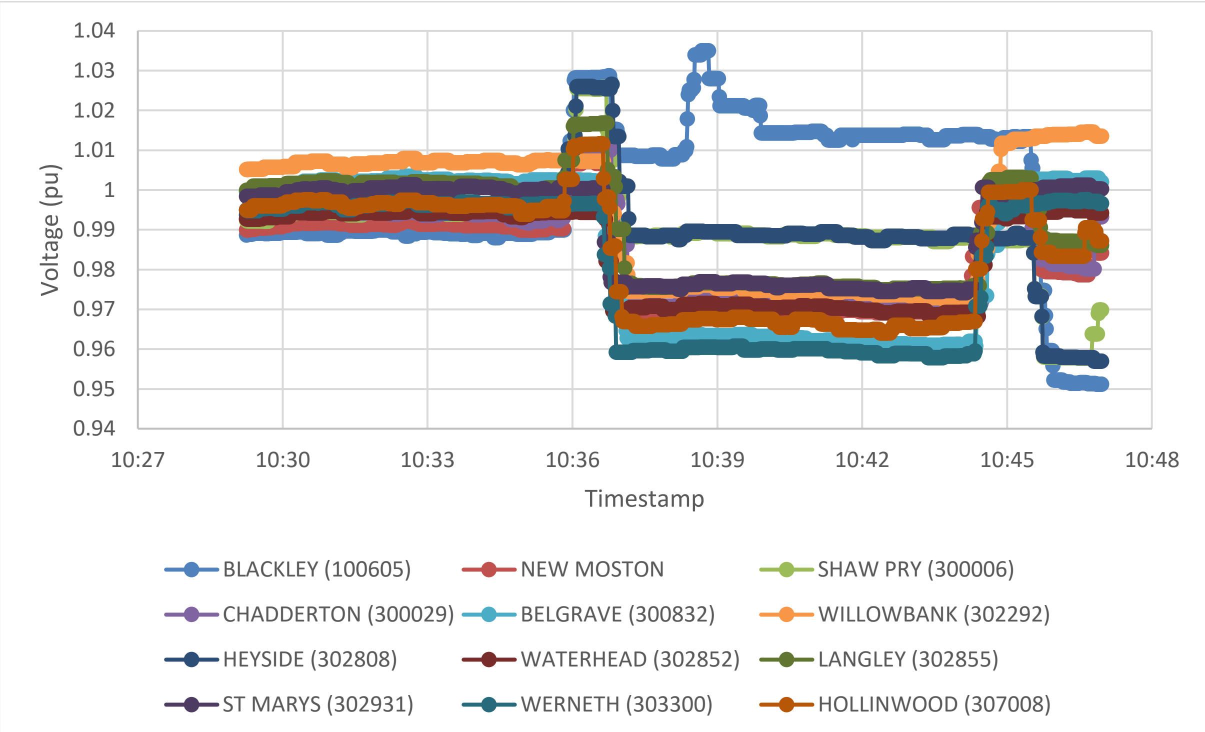

Figure 67: CLASS Live Voltage Measurement Results from Live QUEST System

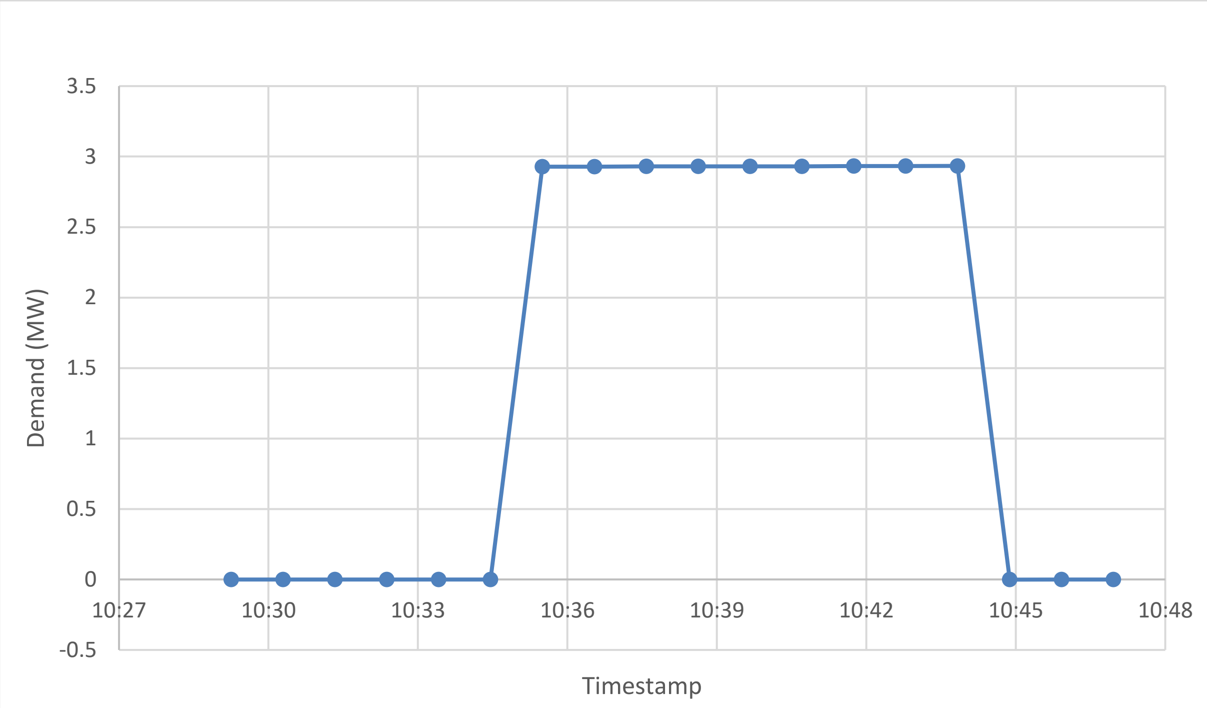

Figure 68: Smart Street Demand Reduction from SGS QUEST System Model

From comparing Figure 66 and Figure 67, the key difference is the voltage results for Blackley Primary, for which CLASS did not operate in the live system as previously discussed. The rest of the CLASS sites have a similar response between the two QUEST systems. Similarly to other trials, the SGS QUEST system achieves the demand reduction target, whereas the real system does not, likely due to the difference in voltage reduction levels between the two systems.

In the live system, the 50% function level is progressed to 100% for sites which are not fed by NEM BSPs. In the SGS system, the same occurs except that not all sites are needed at 100% function level, some are only progressed to 75% - this is because the demand target is hit in advance of this.

In the live system results, there are some further voltage deviations after 10:45, because QUEST has been stopped and NEM has returned to normal causing a voltage reduction at the non-CLASS sites which have then started to respond.

6.1.9.4. Smart Street Results

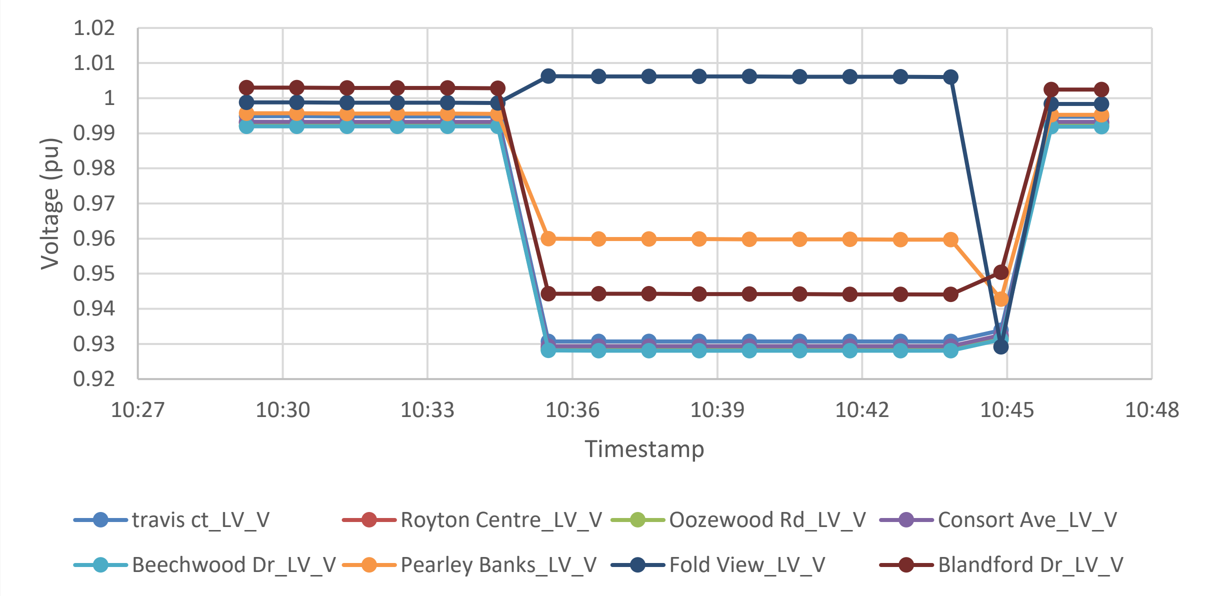

Figure 69: Smart Street Simulated Voltage Results from SGS QUEST System Model

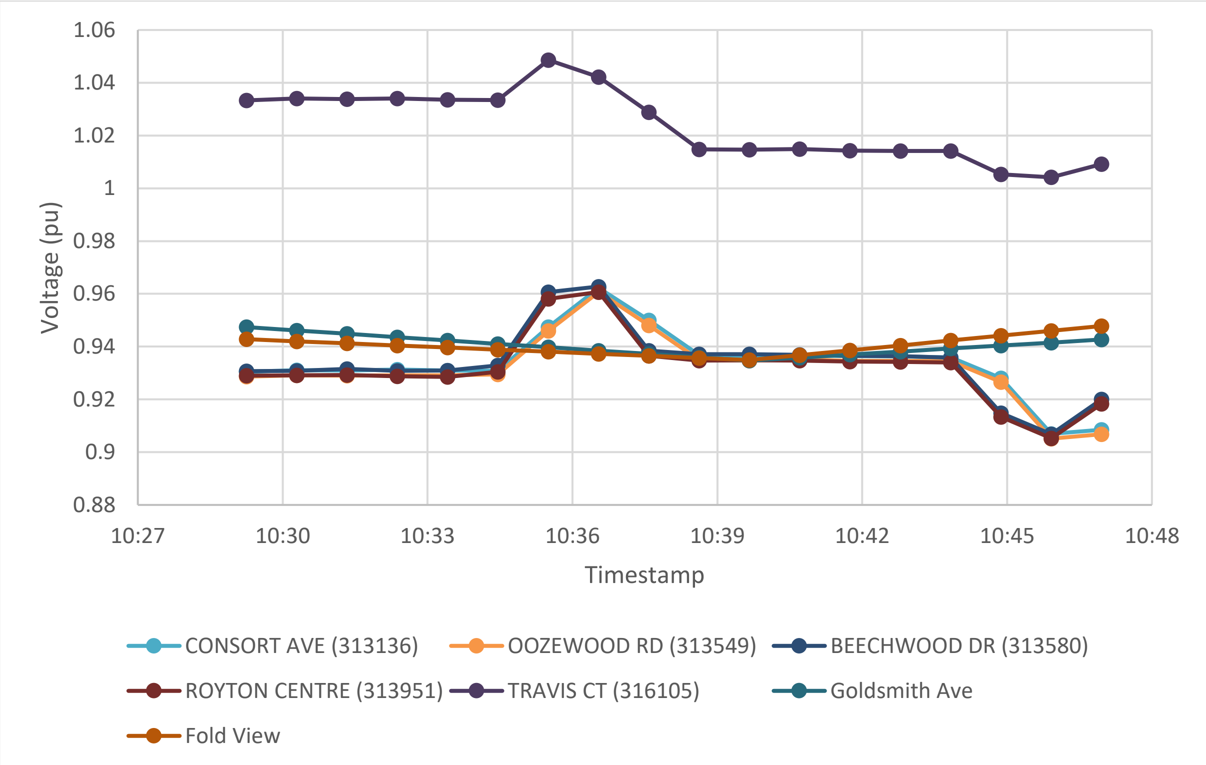

Figure 70: Smart Street Live Voltage Measurement Results from Live QUEST System

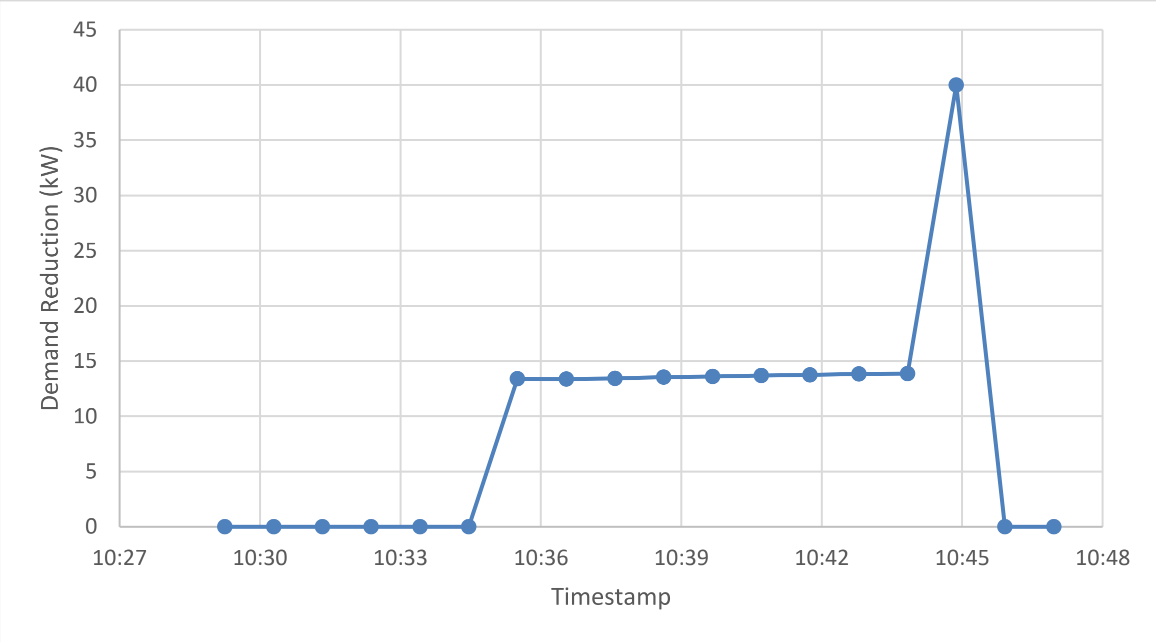

Figure 71: Smart Street Demand Reduction from SGS QUEST System Model

Again, it is difficult to draw similarities between the Smart Street results in Figure 69 and Figure 70, which is likely due to the operational constraints around the operation of Smart Street in the live system, but it is evident that three of the sites under Royton Primary achieve a reduced voltage in Figure 70, as well as Goldsmith Ave and Fold View.

Where NEM is used, CLASS is not and where OLTC assets are available they are allowed to optimise as normal. Smart Street reoptimizes at a configurable period, however, to prove QUEST optimisation is obliterated by other activity, the Smart Street Optimisation window had been extended. So whilst in Normal operation, if an optimisation cycle does not occur the units are left at the initial VSP.

In Figure 69, when Smart Street is initiated, the sites fed by Royton Primary target 0.91 pu as their function level is 100% since Royton Primary does not have CLASS active. Blandford Dr and Pearley Banks are fed by New Moston and Heyside Primaries respectively, which have CLASS active at 50% function level, meaning the corresponding Smart Street function level is 50% for each of these sites, resulting in a partially reduced voltage. Fold View is fed by Belgrave Primary, which is at 100% function level and so the Smart Street safe mode function level is 0%, results in a target voltage of 1.01 pu.

Figure 71 shows the demand reduction due to Smart Street in the SGS Simulation. There is a spike in this trend which corresponds with the timestep in which CLASS deactivates but NEM and Smart Street are still active.

Comparison across Trial Tests 06, 07, 08 and 09 show the effect of the optimisation that QUEST applies relative to priority order and function level. For each of the tests it can be observed that when NEM or Smart Street is higher priority than CLASS, they are allowed to operate to the specified input parameters. When NEM or Smart Street are lower priority than CLASS, they have to operate to the relevant safe mode level for the prescribed CLASS function level.

The difference in function level between Trial Tests 06 and 09 show the effect of this input parameter. In Test 06, as NEM is at 100% function level, the CLASS sites fed by these NEM sites go to 0% function level, whereas other CLASS sites are able to go to the 100% function level. This has a knock-on effect to the Smart Street sites, where function levels are decided depending on how CLASS has functioned. In Test 09, the configuration of QUEST with the 50% function levels allows for a more diverse result from the QUEST functions. As the NEM sites are at 50%, CLASS sites are permitted to go to 50% function level (or higher, if not being fed by a NEM site). Again, the Smart Street site function levels depend on how CLASS functioned.

6.1.10. Test 10 – CLASS DB 100 – 15/07/25

6.1.10.1. Test Input Details

Table 24. QUEST Input Settings for Test 10

	CLASS DR	CLASS DB	Smart Street	NEM
Priority	N/A	1	2	N/A
Function Level	N/A	100%	0%	N/A
Voltage Target	N/A	1.05	0.91 pu	N/A
Target	N/A	3 MW	N/A	N/A
Active Time Period	N/A	08:50 – 9:06	Full time period	N/A

Table 25: QUEST Sites

CLASS Primaries	Smart Street Secondaries
Under Chadderton Grid: • Chadderton • Hollinwood • Langley • New Moston • Failsworth Under Greenhill Grid: • Belgrave • St Mary • Werneth • Willowbank • Waterhead Under Royton Grid: • Heyside • Shaw	Under Royton Primary: • Travis Court • Royton Centre • Oozewood Rd • Consort Ave • Beechwood Dr Under Heyside Primary: • Pearley Banks Under Belgrave Primary: • Fold View Under New Moston Primary: • Blandford Dr

Load Details

- From the trial information provided by SP ENW, QUEST became active between 08:50 and 13:36.
- As this section of tests were longer, load values at different points were used to create a load profile without the effects of QUEST. For this trial, load values at 08:45 and 09:10

were recorded and linear interpolation between the values was used to get “non-QUEST-load”.

- Trial was run from 08:45 to 09:10.

6.1.10.2. CLASS Results

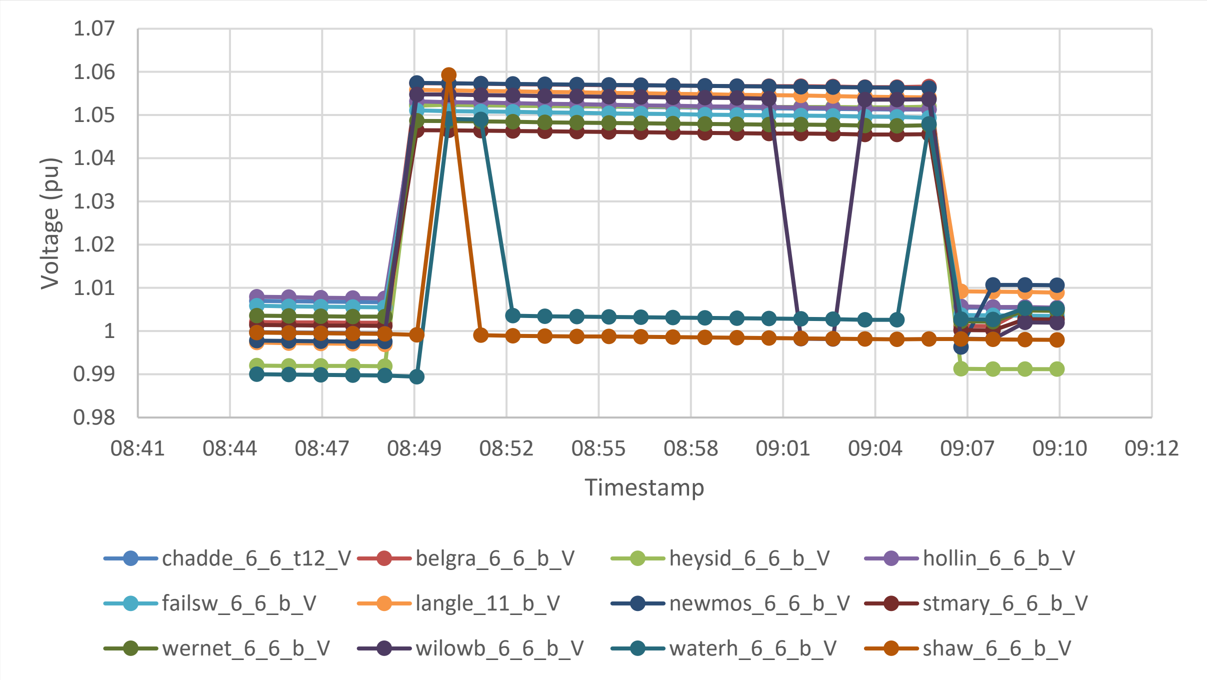

Figure 72: CLASS Simulated Voltage Results from SGS QUEST System Model

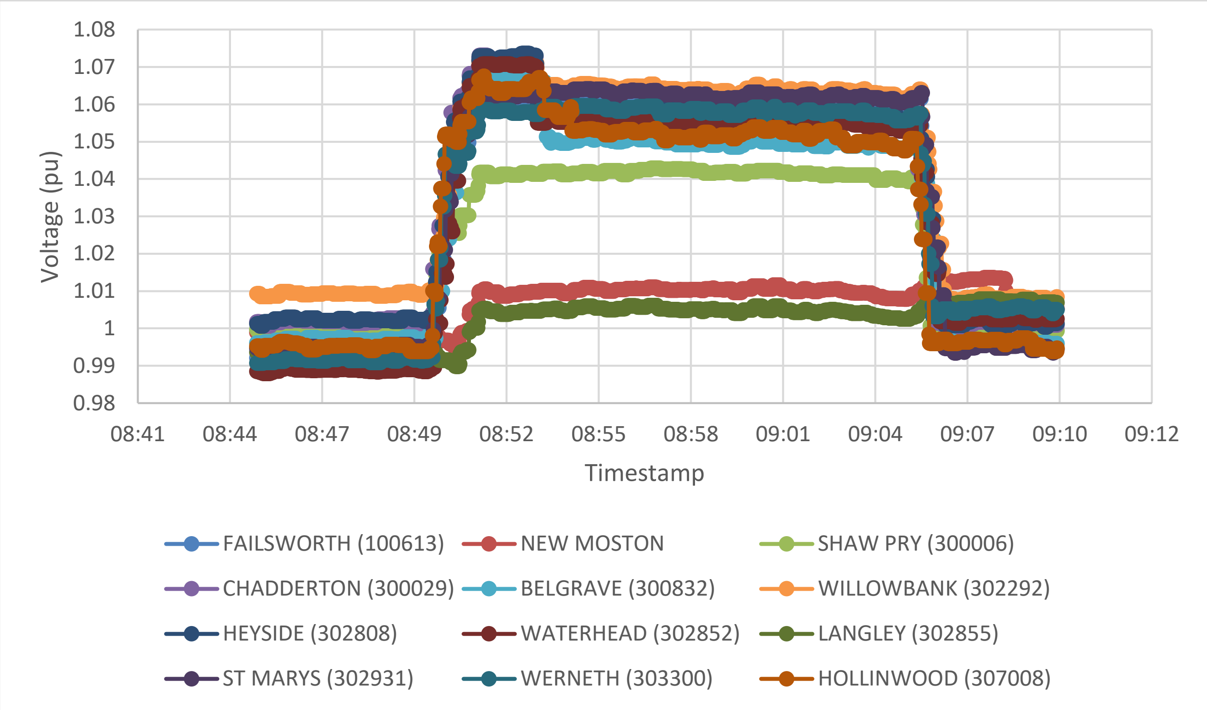

Figure 73: CLASS Live Voltage Measurement Results from Live QUEST System

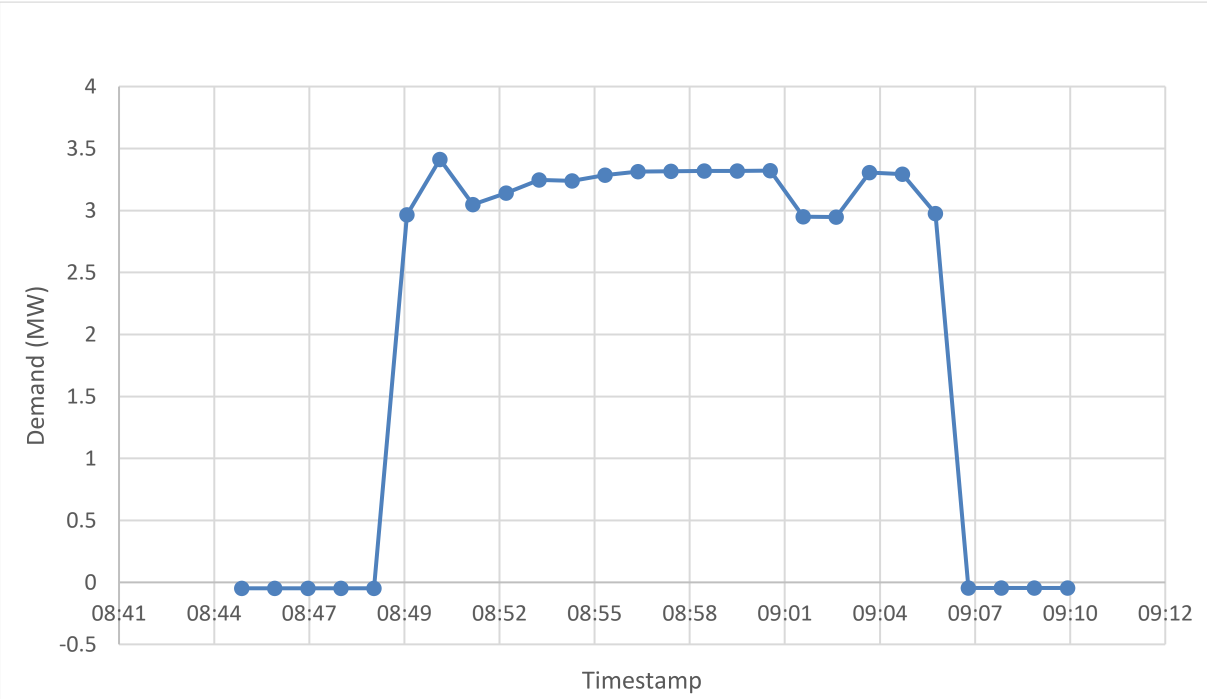

Figure 74: System Demand Reduction from SGS QUEST System Model

Figure 72 and Figure 73 show the CLASS site voltages in the two QUEST systems. In the SGS QUEST system, not every CLASS site is required to hit the demand increase target of 3 MW, which is successfully achieved throughout the simulation. In the live QUEST system, an increase of 2.89 MW is achieved. As the demand increase target is not hit here, all sites should be at 100% function level, although it New Moston and Langley do not reach as high a voltage.

6.1.10.3. Smart Street Results

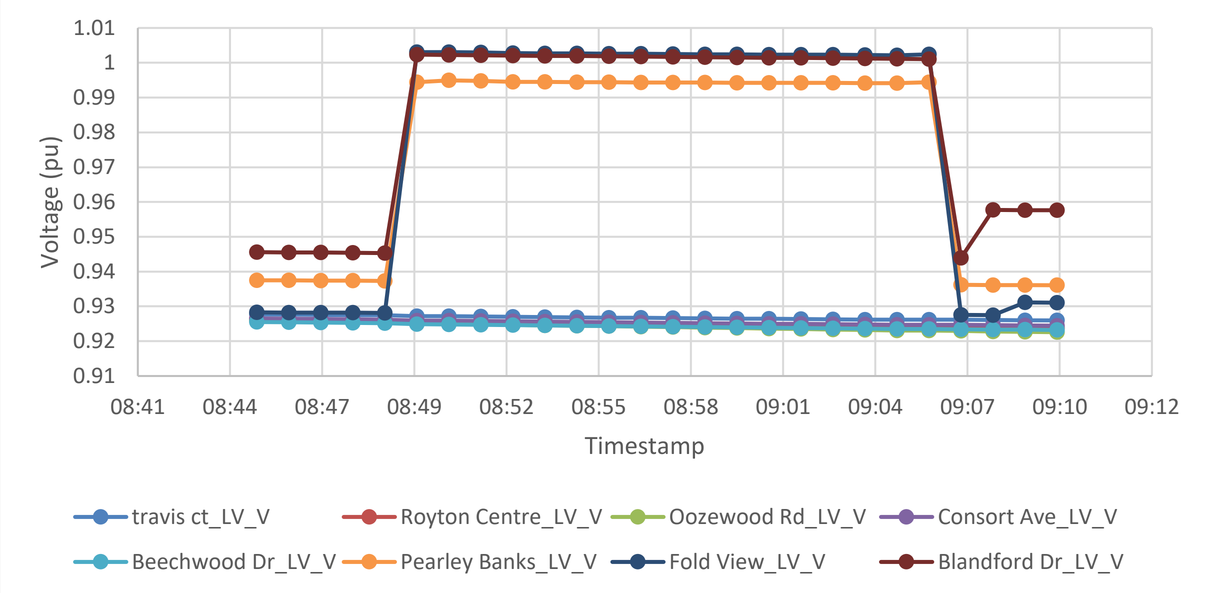

Figure 75: Smart Street Simulated Voltage Results from SGS QUEST System Model

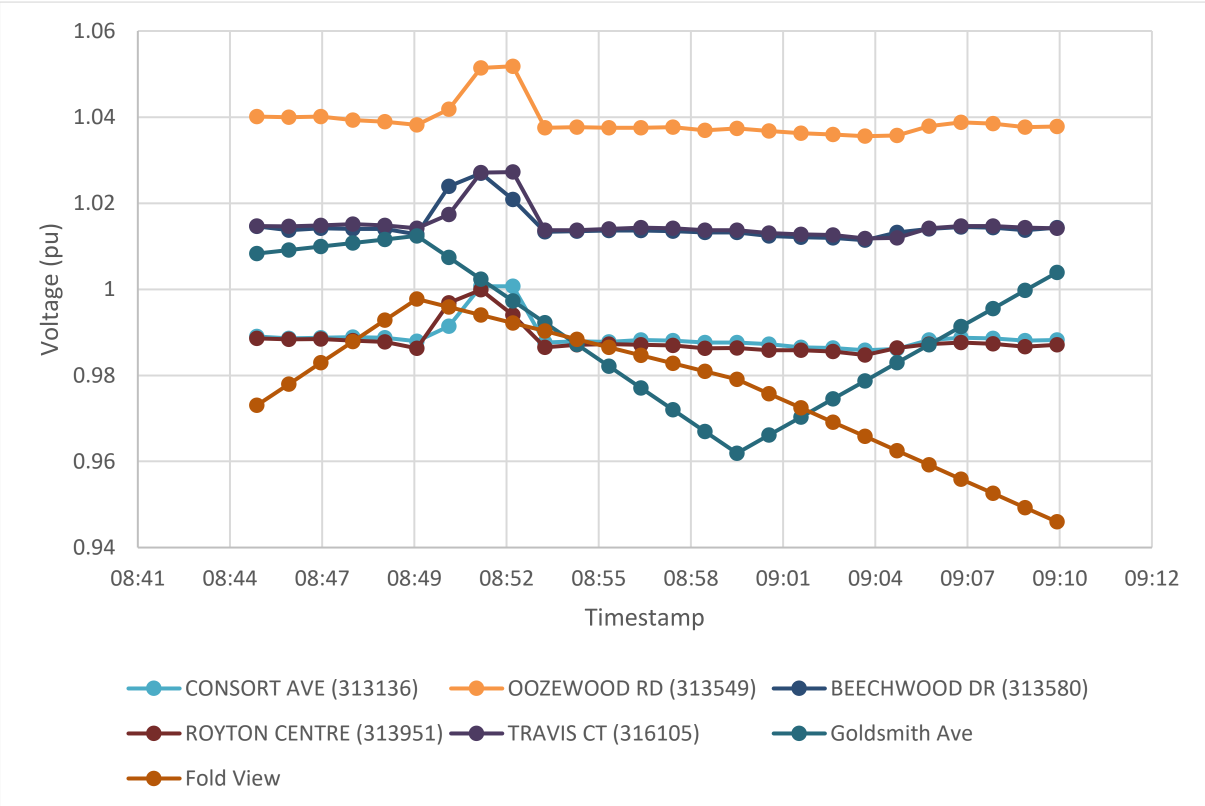

Figure 76: Smart Street Live Voltage Measurement Results from Live QUEST System

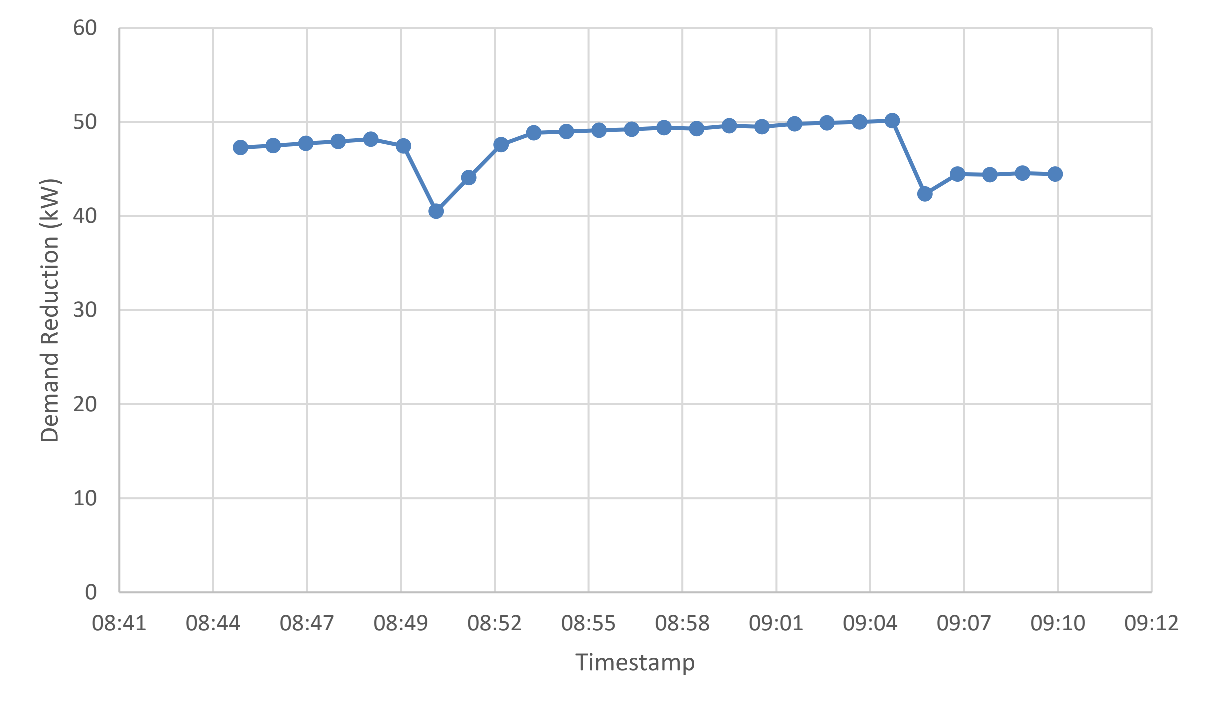

Figure 77: Smart Street Demand Reduction from SGS QUEST System Model

It is difficult to draw similarities between the Smart Street results in Figure 75 and Figure 76, which is likely due to the operational constraints around the operation of Smart Street in the live system.

Smart Street is active for the full trial in this SGS Simulation. When CLASS DB is activated, the sites under Royton Primary maintain their 100% function level due to the telemetry issue at Royton. The sites fed from CLASS sites now target 1.01 pu as part of the safe mode, which is shown in Figure 75. Figure 77 shows the demand reduction due to Smart Street. It may be surprising that there is no large dip in this graph when CLASS is active and three of the Smart Street sites compromise due to this – this is because the measure of demand reduction for this period is taken when the effect of CLASS DB on the Smart Street sites would have been an increase in voltage, so the Smart Street demand reduction figure across the trial stays consistent.

Smart Street reoptimizes at a configurable period, however, to prove QUEST optimisation is obliterated by other activity, the Smart Street Optimisation window had been extended. So whilst in Normal operation, if an optimisation cycle does not occur the units are left at the initial VSP.

6.1.11. Test 11 – CLASS DB 50 + NEM 50 – 15/07/25

6.1.11.1. Test Input Details

Table 26. QUEST Input Settings for Test 11

	CLASS DR	CLASS DB	Smart Street	NEM
Priority	N/A	1	3	2
Function Level	N/A	50%	100%	50%
Voltage Target	N/A	1.025	0.91 pu	1.0285 pu
Target	N/A	1.4	N/A	N/A
Active Time Period	N/A	13:33 – 13:36	During whole trial	13:30 – 13:37

Table 27: QUEST Sites

CLASS	Smart Street	NEM
Under Chadderton Grid: • Chadderton • New Moston • Hollinwood • Langley Under Greenhill Grid: • Belgrave • St Mary • Werneth Under Red Bank Grid: • Blackley Under Royton Grid • Heyside • Shaw	Under Royton Primary: • Travis Court • Royton Centre • Oozewood Rd • Consort Ave • Beechwood Dr Under Heyside Primary: • Pearley Banks Under Belgrave Primary: • Fold View Under New Moston Primary: • Blandford Dr	Under Whitegate GSP: • Royton Grid • Red Bank Grid

Load Details

- From the trial information provided by SP ENW, QUEST became active between 08:50 and 13:36.
- As this section of tests were longer, load values at different points were used to create a load profile without the effects of QUEST. For this trial, load values at 13:26 and 13:40

were recorded and linear interpolation between the values was used to get "non-QUEST-load".

- Trial was run from 13:26 to 13:40.

6.1.11.2. CLASS Results

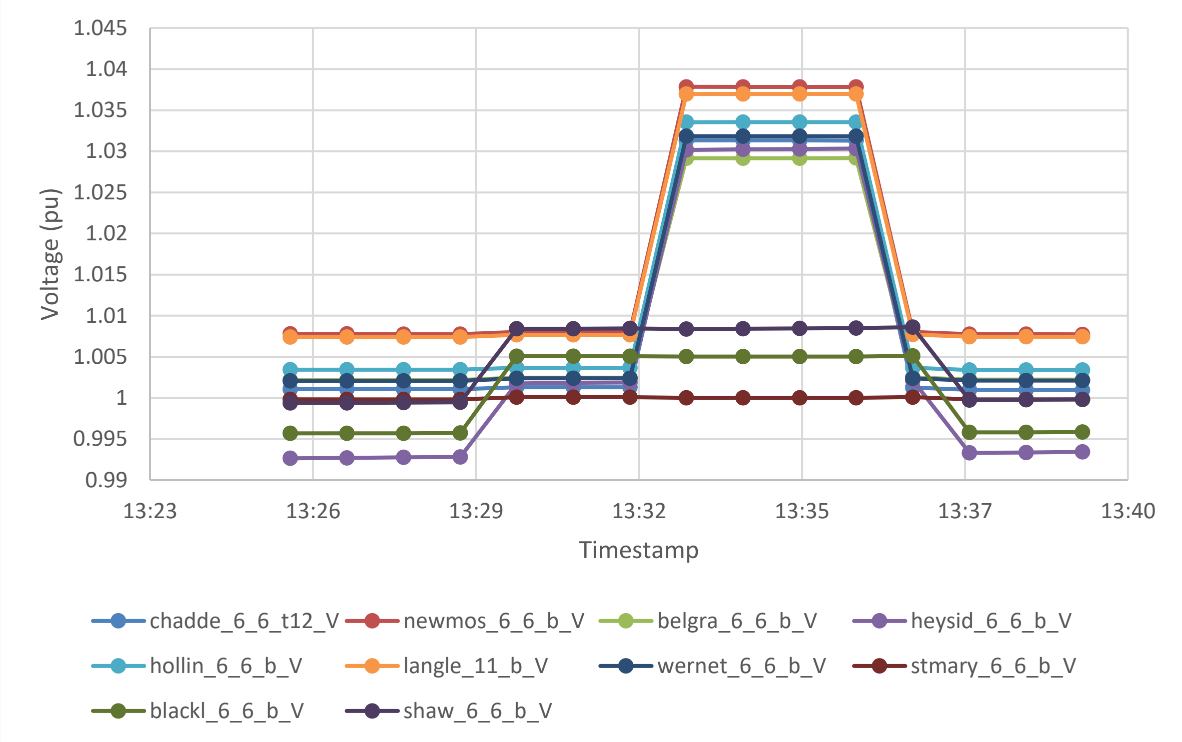

Figure 78: CLASS Simulated Voltage Results from SGS QUEST System Model

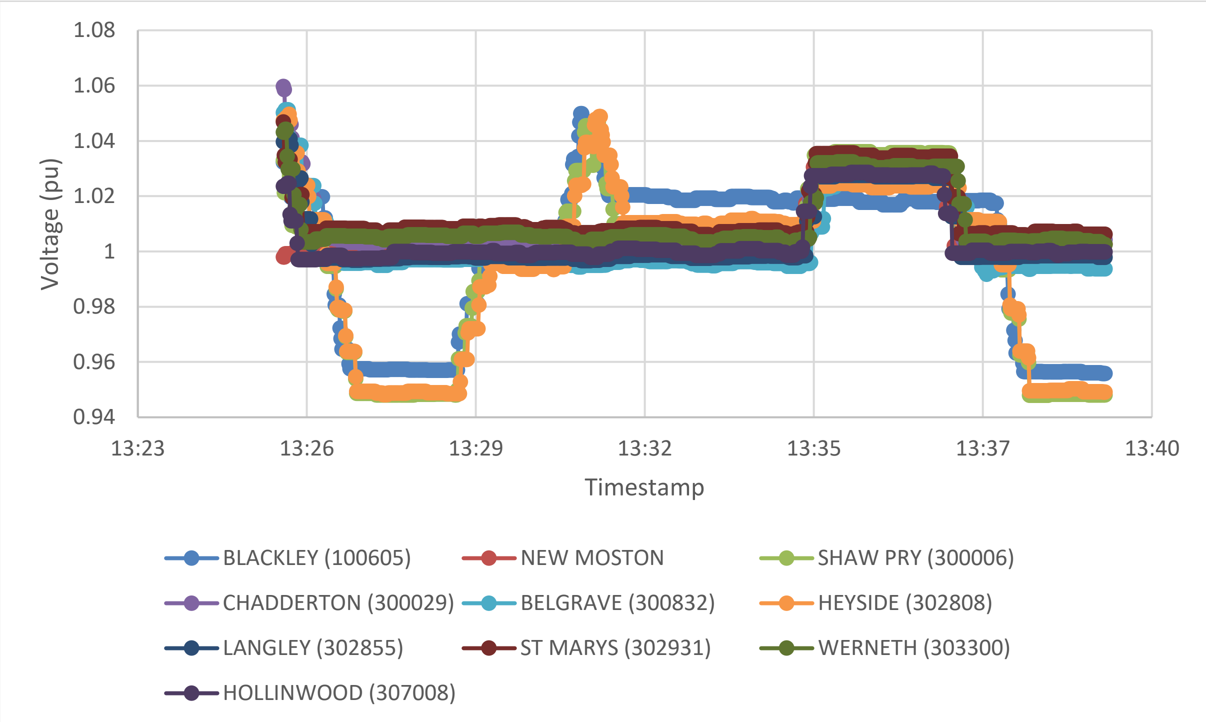

Figure 79: CLASS Live Voltage Measurement Results from Live QUEST System

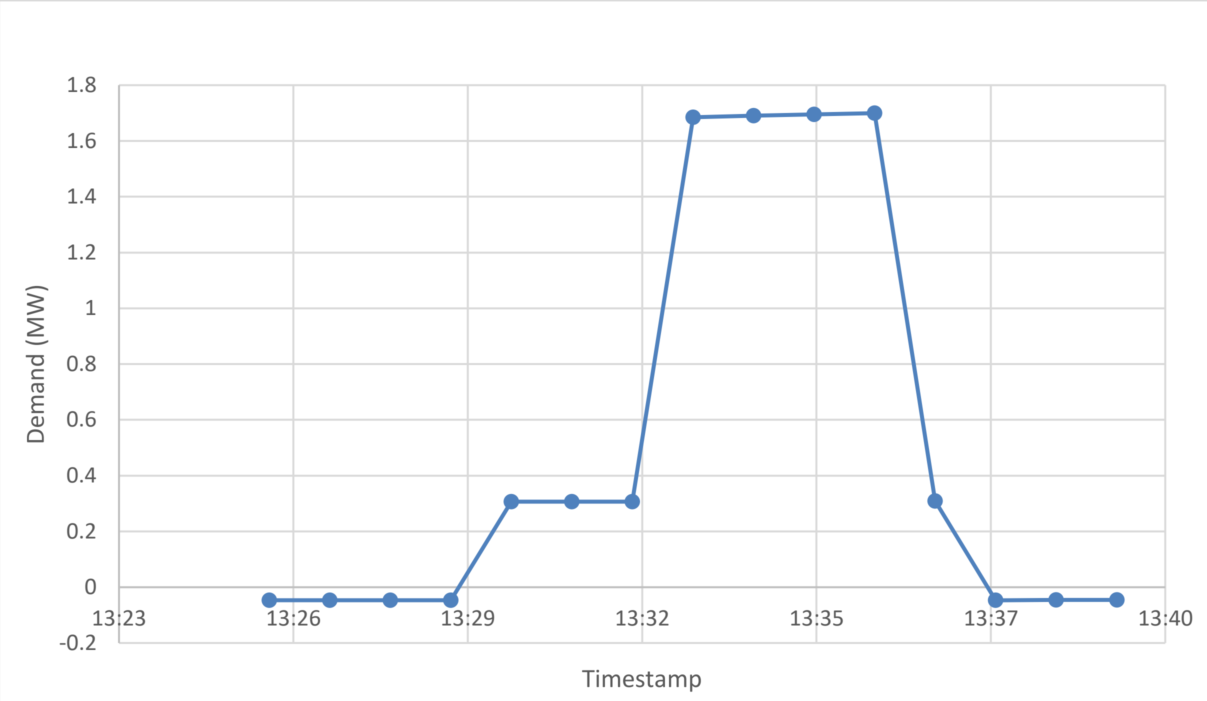

Figure 80: System Demand Reduction from SGS QUEST System Model

Figure 78 and Figure 79 appear to show different trends at first but the start of the graph in Figure 79 is voltage response carried over from the previous trial. NEM operates at 13:30, responses from which can be seen in both graphs. When CLASS operates at 13:30, voltages in the SGS system raise to between 1.03 pu and 1.04 pu, which is slightly higher than the 1.025 pu target. Not all CLASS sites have to operate in the SGS simulation, with 3 sites remaining unoperated to achieve the target of 1.4 MW. The target is also achieved in the live QUEST system, but the demand increase has to be spread across 10 sites rather than 7. This could be due to the slightly lower voltage increase achieved for some of the sites in the live system.

6.1.11.3. NEM Results

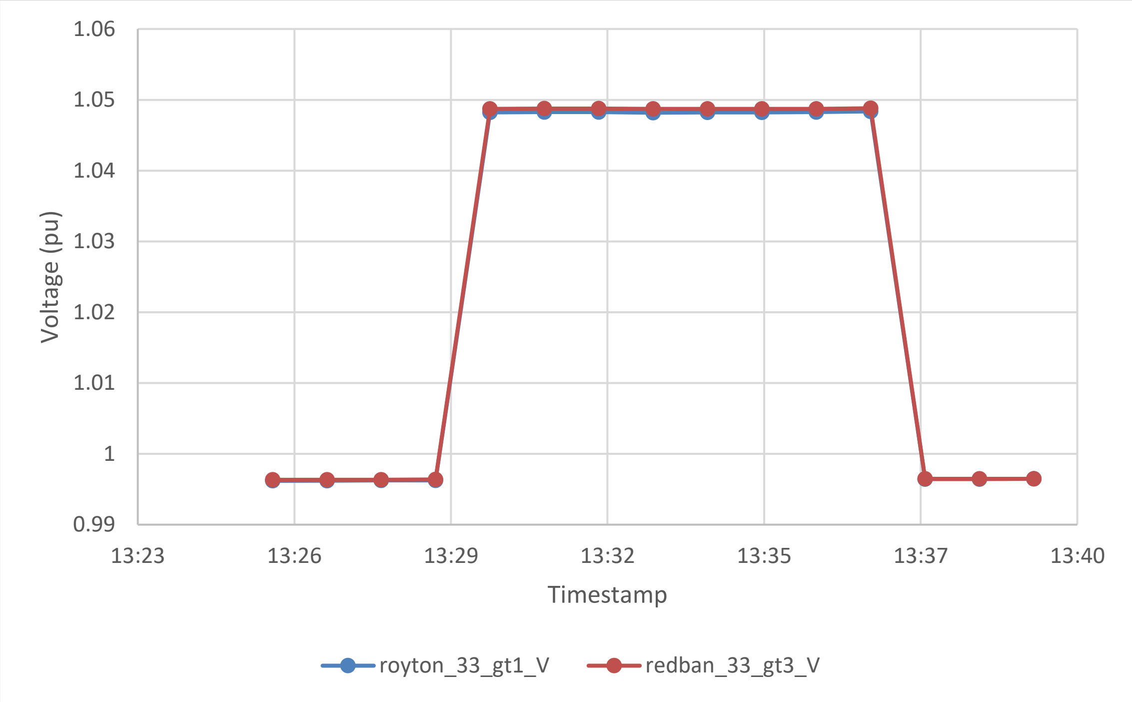

Figure 81: NEM Simulated Voltage Results from SGS QUEST System Model

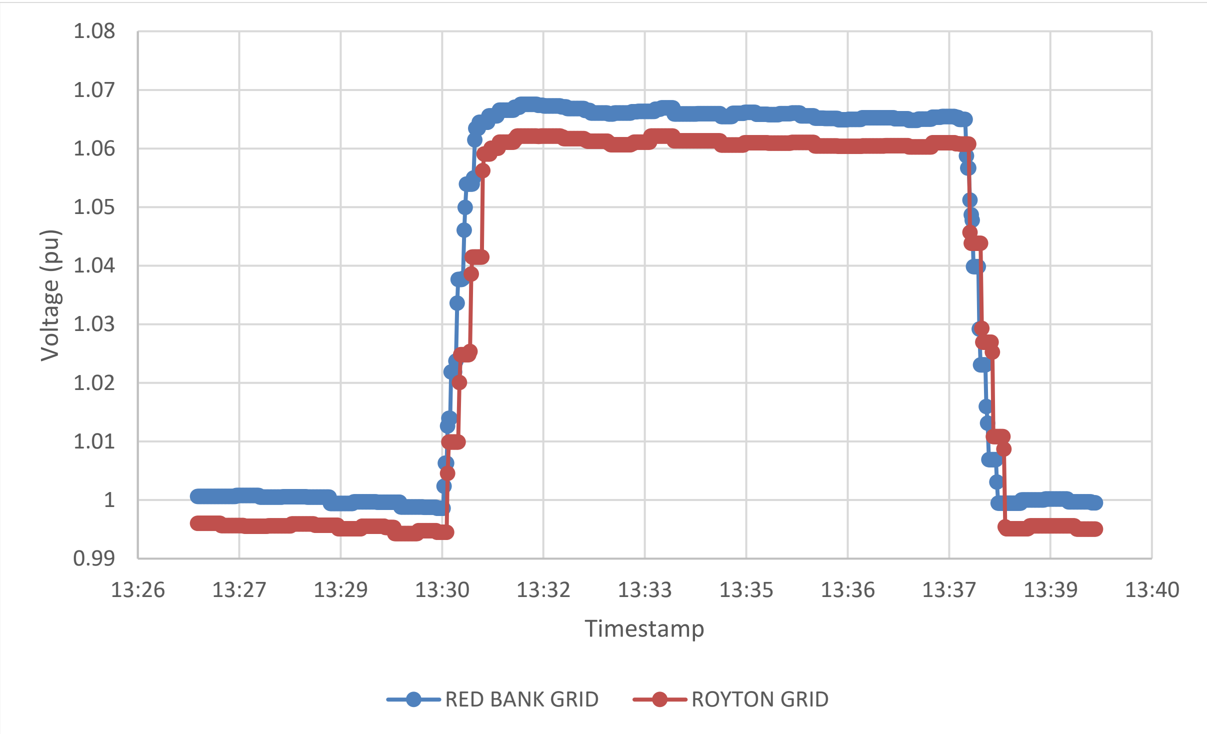

Figure 82: NEM Live Voltage Measurement Results from Live QUEST System

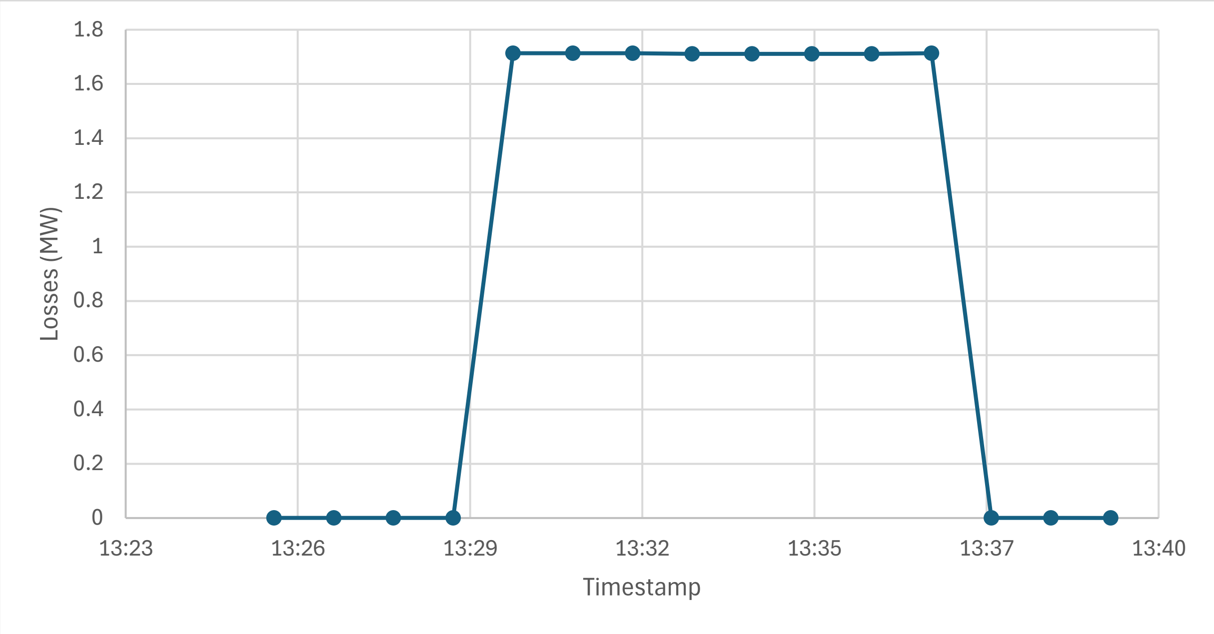

Figure 83: NEM Loss Reduction from SGS QUEST System Model

The NEM service is not impacted by CLASS demand boost, so the function level is progressed to 100% for both NEM sites. This is the case in both Figure 81 and Figure 82. There is a difference in voltage magnitude between the figures, this is likely due to the SGS QUEST system selecting a more conservative tap to prevent exceeding the statutory limit.

6.1.11.4. Smart Street Results

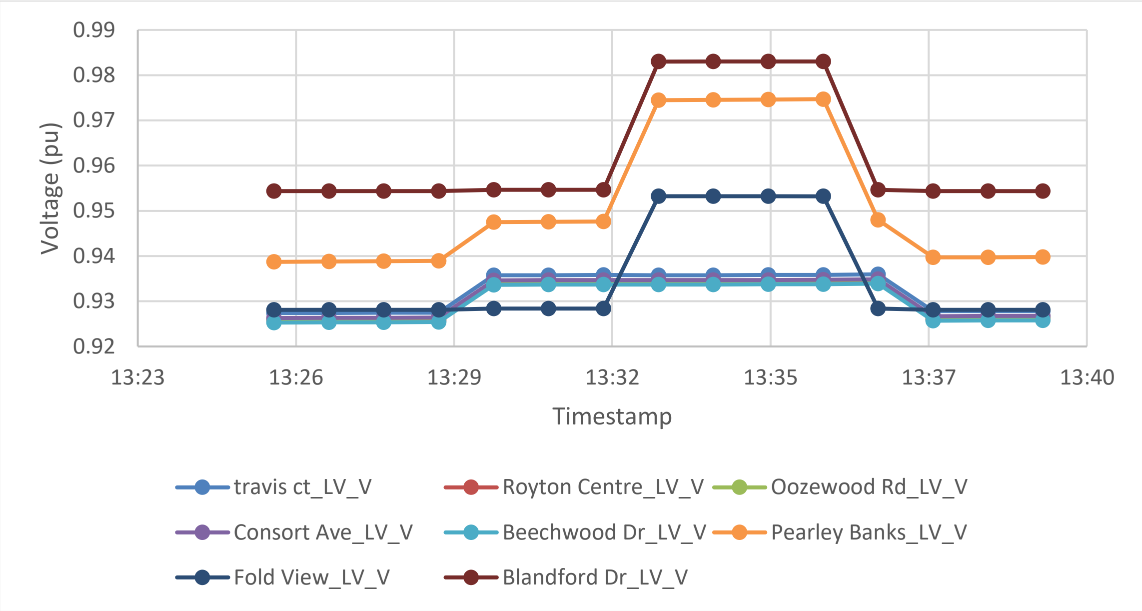

Figure 84: Smart Street Simulated Voltage Results from SGS QUEST System Model

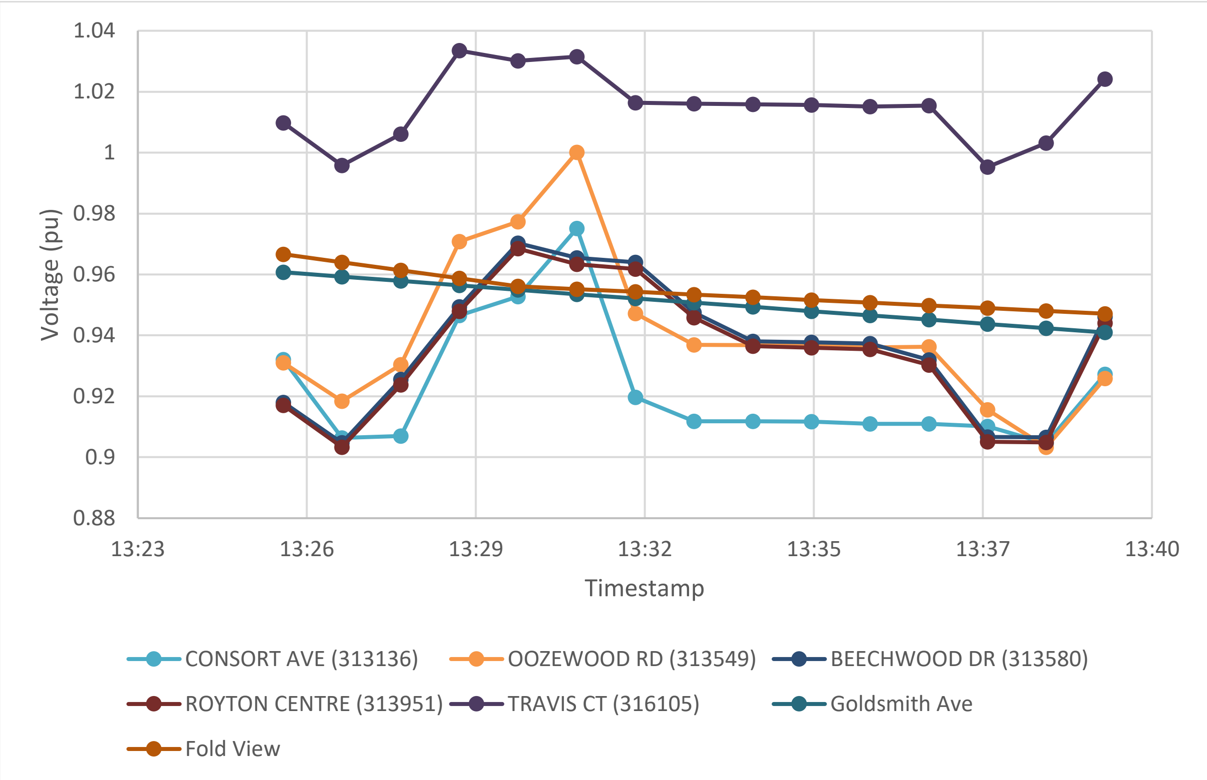

Figure 85: Smart Street Live Voltage Measurement Results from Live QUEST System

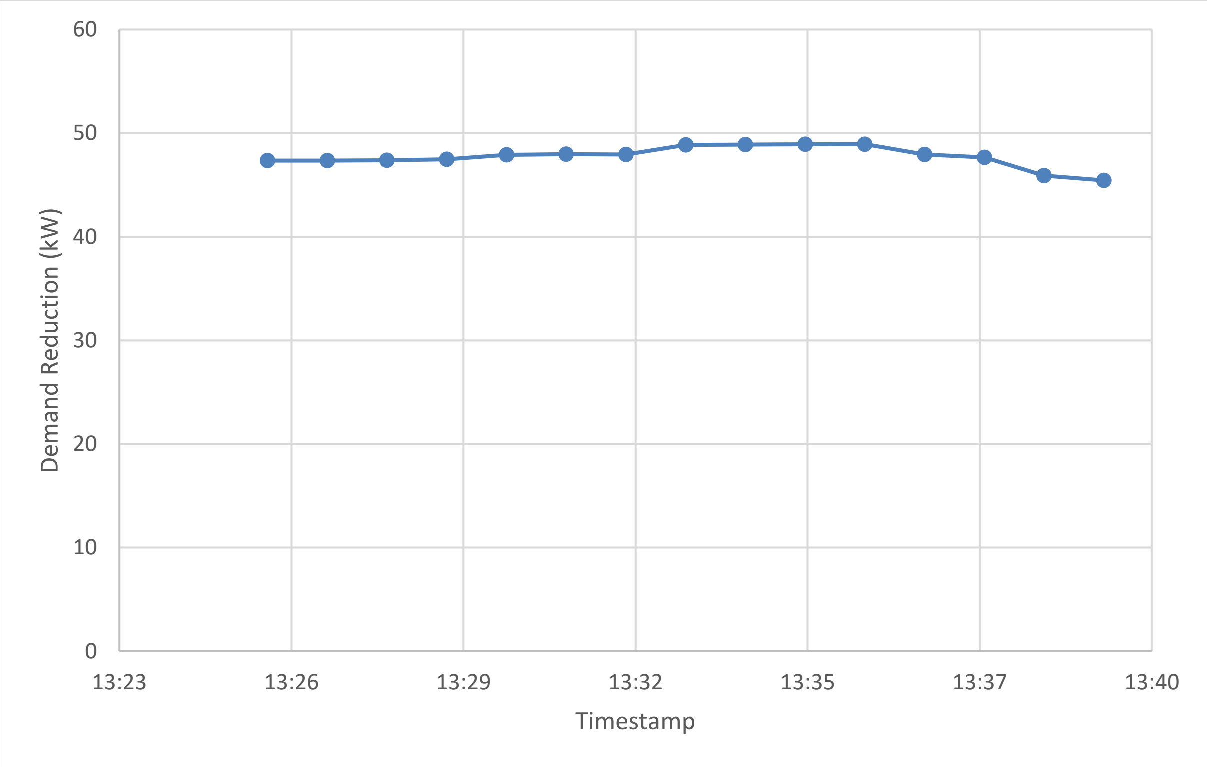

Figure 86: Smart Street Demand Reduction from SGS QUEST System Model

Smart Street remains operational throughout the trial. In Figure 84, it can be observed that when CLASS becomes active, the Smart Street sites which are fed by CLASS sites revert to their safe mode function level, which is 50% in this case. It is difficult to draw comparisons against the results of the live QUEST system in Figure 85, but it can be observed that some of the sites fed from Royton maintain a reduced voltage value.

Smart Street reoptimizes at a configurable period, however, to prove QUEST optimisation is obliterated by other activity, the Smart Street Optimisation window had been extended. So whilst in Normal operation, if an optimisation cycle does not occur the units are left at the initial VSP.

The demand reduction due to Smart Street in Figure 86 appears constant throughout the trial. This is again because the measure of demand reduction during the period when CLASS is active is taken when the effect of CLASS DB on the Smart Street sites would have been an increase in voltage, so the Smart Street demand reduction figure across the trial stays consistent.

6.2. Simulation Only Tests

The tests in this section involve the following functions:

- OC6: Applied at primary substations as a method of reducing demand in an emergency situation. This can be achieved via two different methods:
  - Voltage Reduction (VR) – demand reduction is achieved by lowering voltage levels and leveraging the voltage/demand relationship,
  - Demand Disconnection (DD) – demand reduction is achieved by opening HV circuit breakers.
- LFDD: Involves opening 33 kV circuit breakers to reduce system demand in the case of a low frequency event on the network.
- Tap Stagger BSP: Providing voltage support, by setting transformer pair tap imbalance creating circulating current that result in a reactive power absorption at the BSP High Voltage (HV) level. That is measurable as a change in reactive power at the Grid boundary (400/275 : 132kV transformer)

The application of OC6 and LFDD in conjunction with QUEST is further explained in Section 4.3.3. Tap Stagger is simulated in Test 14 in isolation.

6.2.1. Test 12 – Smart Street 25 + NEM 25 + CLASS 25 + OC6 VR/DD

6.2.1.1. Test Input Details

Table 28. QUEST Input Settings for Test 12

	CLASS DR	CLASS DB	Smart Street	NEM
Priority	3	N/A	1	2
Function Level	25%	N/A	25%	25%
Voltage Target	0.9875 pu	N/A	0.985 pu	1.0143 pu
Target	2.45 MW	N/A	N/A	N/A
Active Time Period	12:25 onwards	N/A	12:25 onwards	12:25 onwards

Table 29: QUEST Sites

CLASS	Smart Street	NEM
Under Greenhill Grid: • Belgrave • St Mary • Werneth • Willowbank Under Royton Grid • Heyside • Shaw	Under Royton Primary: • Travis Court • Royton Centre • Oozewood Rd • Consort Ave • Beechwood Dr Under Heyside Primary: • Pearley Banks	Under Whitegate GSP: • Royton Grid • Greenhill Grid

OC6 Details

- OC6 Voltage Reduction uses two different voltage target levels to reduce system demand:
    - 0.97 pu
    - 0.94 pu
- OC6 Demand Disconnection was assigned the following loads to disconnect:
    - Waterhead Primary (fed from Greenhill Grid)
    - Royton Primary (fed from Royton Grid)
    - Hollinwood Primary (fed from Chadderton Grid)
    - Chadderton Primary (fed from Chadderton Grid)

Load Details

- From the trial information provided by SP ENW, QUEST became active between 12:16 and 13:41.
- So load values at 12:15 and 13:42 were recorded and linear interpolation between the values was used to get “non-QUEST-load”.
- Trial was run from 12:15 to 13:42.

6.2.1.2. OC6 Results

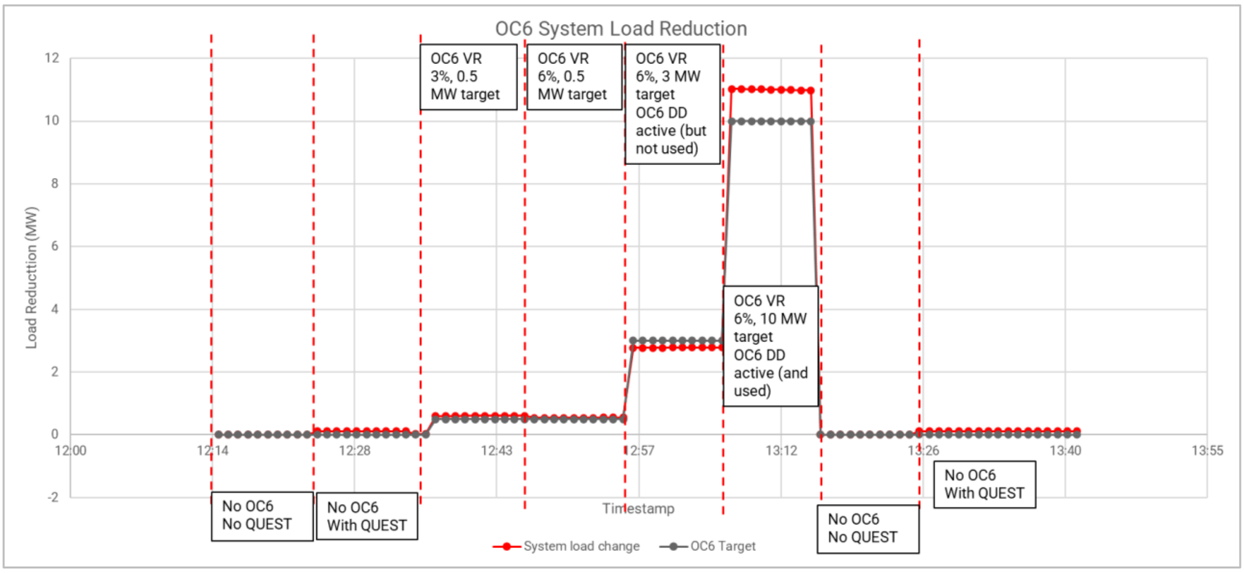

Figure 87: OC6 Load Reduction Results

Figure 87 shows the system load reduction and the OC6 reduction target. OC6 is not activated until 12:37, where it is given a 3% voltage reduction instruction (voltage target = 0.97 pu) and a demand reduction target of 0.5 MW. The system is able to achieve the target by implementing OC6 VR at 3 primaries. The system configuration changes so that OC6 is given a 6% voltage reduction instruction (voltage target = 0.94 pu), with the same previous demand reduction target. The demand target can is achieved by implementing OC6 at 2 primaries, as there is higher demand reduction per primary with a lower voltage target.

At 12:57 the demand reduction target is raised to 3 MW, and OC6 DD is enabled but is not required, as the target is satisfied by implementing OC6 VR at 12 primaries across the Whitegate network. When the target is increased to 10 MW at 12:57, OC6 VR is used at all primaries across the Whitegate network and OC6 DD is implemented, disconnecting 2 out of the 4 assigned loads to achieve the demand reduction target.

At 13:16 all OC6 instructions are removed, and the system operates normally until 13:26 when QUEST is reactivated.

6.2.1.3. Smart Street Results

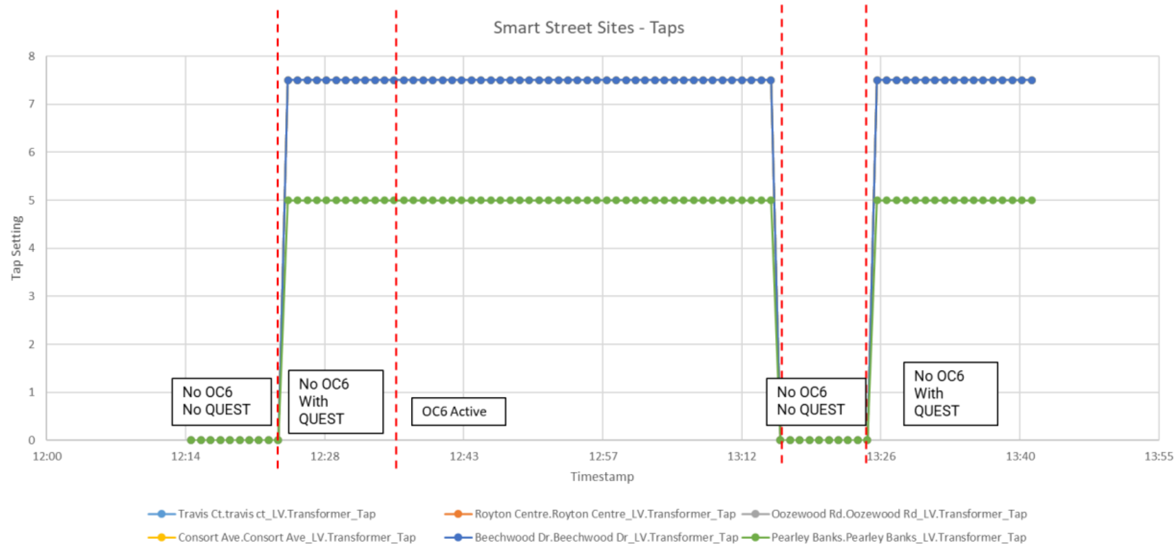

Figure 88: Smart Street Tap Settings from SGS Simulation

QUEST activates at 12:25, making Smart Street, NEM and CLASS active. For Smart Street, it is observed that the tap settings change at this time, which lowers the voltage of the sites to close to the target voltage. The Pearley Banks site taps to a lower setting than the rest of the sites as this secondary has a lower tap range.

OC6 activates at 12:37 and from this point on the tap settings for the Smart Street sites are fixed until OC6 is deactivated. This is in accordance with the QUEST logic for the OC6 functions. QUEST reactivates at 13:26 and the Smart Street site tap settings return to the same points as previously.

6.2.1.4. NEM Results

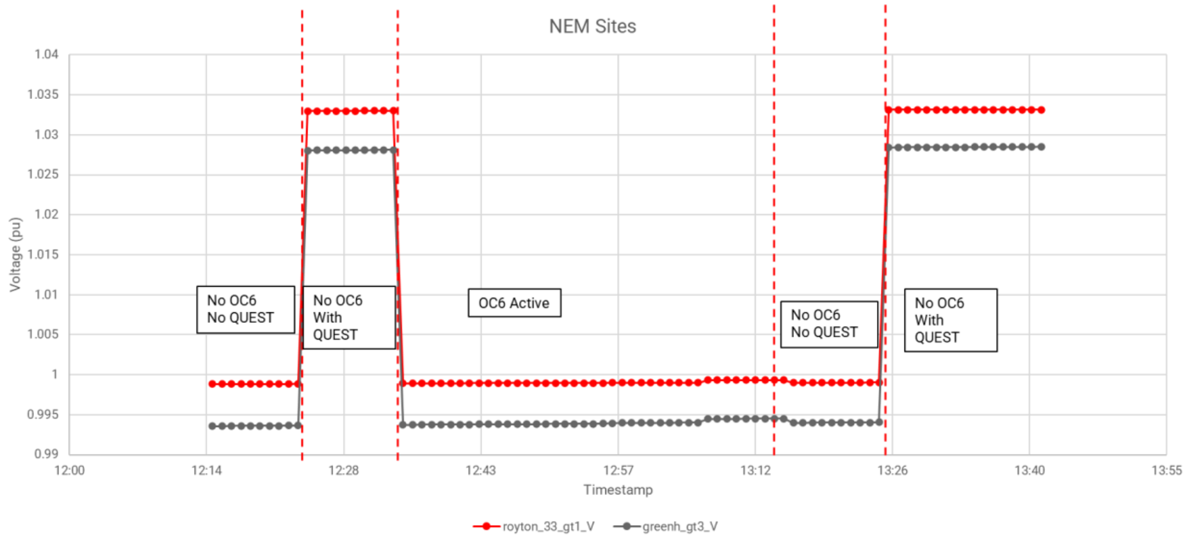

Figure 89: NEM Voltage Results from SGS Simulation

Figure 89 shows the voltage results for NEM in this trial. When NEM is activated, the voltage of the corresponding BSPs raises accordingly. When OC6 VR is activated, NEM is deactivated and the voltage for both BSPs drops back to around 1 pu. This continues through to when OC6 DD is activated and so NEM is continually left deactivated in accordance with the QUEST logic for OC6. NEM reactivates once the OC6 instruction is removed and QUEST becomes activated again.

6.2.1.5. CLASS Results

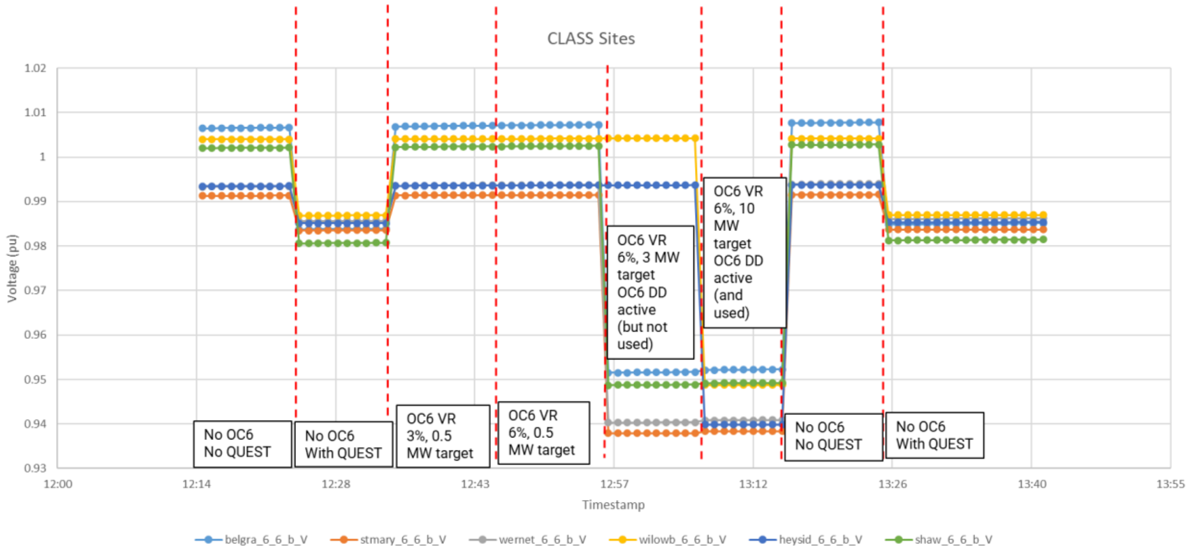

Figure 90: CLASS Voltage Results from SGS Simulation

Figure 90 shows the voltage results for the CLASS sites. When QUEST activates, the voltage for each class sites drops as expected. When OC6 activates, the CLASS sites return to targeting 1 pu. This is because although OC6 VR is active, the demand reduction target is low and none of the CLASS sites have been required to lower their voltage to contribute to achieving the 0.5 MW target as this is covered by other primaries in the Whitegate area. At 12:57, the OC6 demand reduction target increases to 3 MW and it can be observed that all but two of the CLASS sites target a lower voltage to help achieve this reduction. When the target is raised to 10 MW, all of the CLASS sites are now required to lower their voltage to contribute towards achieving the demand reduction target.

When OC6 deactivates, the CLASS site voltages return to around 1 pu. When QUEST reactivates, the CLASS voltages all drop in accordance with the 25% function level prescribed.

6.2.2. Test 13 – Smart Street 25 + NEM 25 + CLASS 25 + LFDD

Low Frequency Demand Disconnection (LFDD) is another emergency function which can be instructed by NESO and involves opening 33 kV circuit breakers to reduce demand in the case of a low frequency event on the network. Again, active QUEST functions must respond accordingly if LFDD is activated, but it is only the NEM and ANM functions which have correspondence with this function.

6.2.2.1. Test Input Details

Table 30. QUEST Input Settings for Test 13

	CLASS DR	CLASS DB	Smart Street	NEM
Priority	3	N/A	1	2
Function Level	25%	N/A	25%	25%
Voltage Target	0.9875 pu	N/A	0.985 pu	1.0143 pu
Target	2.45 MW	N/A	N/A	N/A
Active Time Period	12:37 onwards	N/A	12:15 onwards	12:37 onwards

Table 31: QUEST Sites

CLASS	Smart Street	NEM
Under Greenhill Grid: • St Mary • Werneth • Willowbank Under Royton Grid • Shaw	Under Royton Primary: • Travis Court • Royton Centre • Oozewood Rd • Consort Ave • Beechwood Dr Under Heyside Primary: • Pearley Banks	Under Whitegate GSP: • Royton Grid • Greenhill Grid

LFDD Details

LFDD was configured with the following circuit breakers to disconnect:

1. Circuit Breakers that connect Greenhill –Belgrave T11 and T12 to Greenhill Substation
2. Circuit Breakers that connect Heyside – Royton T11 and T12 to Royton Substation
3. Circuit Breakers that connect Chadderton T11 and T12 to Chadderton Substation
4. Circuit Breaker that Redbank – Anchor North Lines to Redbank Substation

LFDD demand reduction target has been set as follows:

- 5 MW target between 12:43 and 12:49
- 10 MW target between 12:50 and 12:58
- 20 MW target between 12:59 and 13:09

Load Details

- From the trial information provided by SP ENW, QUEST became active between 12:16 and 13:41.
- So load values at 12:15 and 13:42 were recorded and linear interpolation between the values was used to get "non-QUEST-load".
- Trial was run from 12:15 to 13:42.

6.2.2.2. LFDD Results

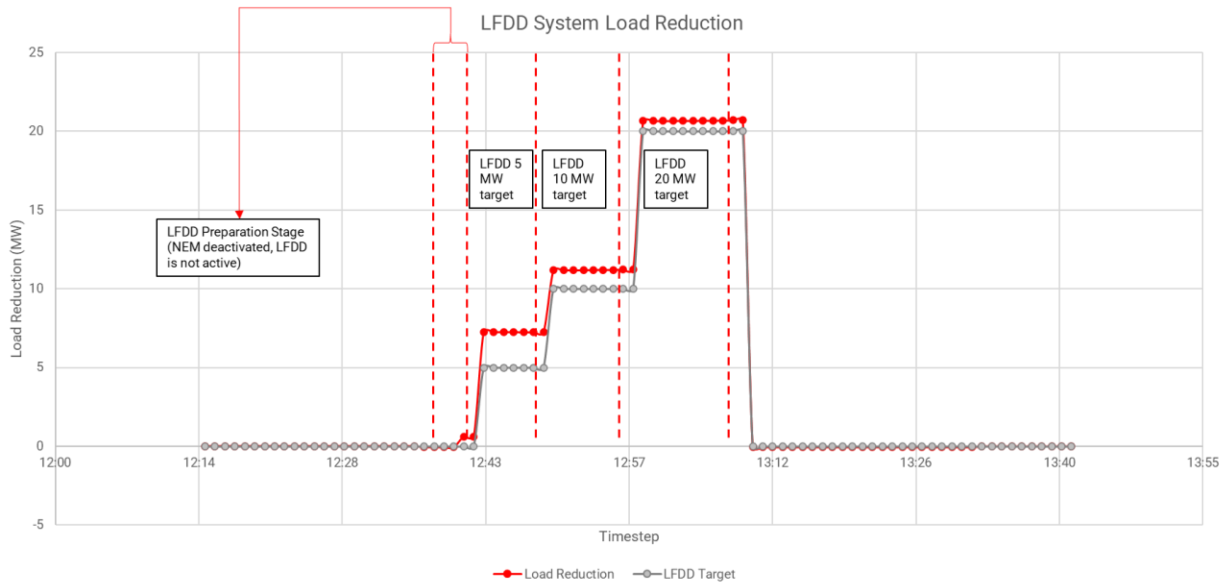

Figure 91: LFDD Load Reduction Results

Figure 91 shows the system load reduction and the LFDD load reduction target. LFDD is not activated until 12:43, where it is given a 5 MW load reduction instruction. The system is able to achieve the target of 5 MW by disconnecting the first circuit breaker couple (Circuit Breakers that connect Greenhill – Belgrave T11 and T12 to Greenhill Substation). Then, the LFDD target is updated to 10 MW at 12.50. The system is able to achieve the target of 5 MW by additionally disconnecting the second circuit breaker couple (Circuit Breakers that connect Heyside – Royton T11 and T12 to Royton Substation). Then, the LFDD target is updated to 20 MW at 12.59. The system is able to achieve the target of 20 MW by additionally disconnecting the third and fourth circuit breaker couple (Circuit Breakers that connect Chadderton T11 and T12 to Chadderton Substation, Circuit Breaker that Redbank – Anchor North Lines to Redbank Substation). At 13:10 all LFDD instructions are removed, and the system operates normally until the end of the trial period.

6.2.2.3. Smart Street Results

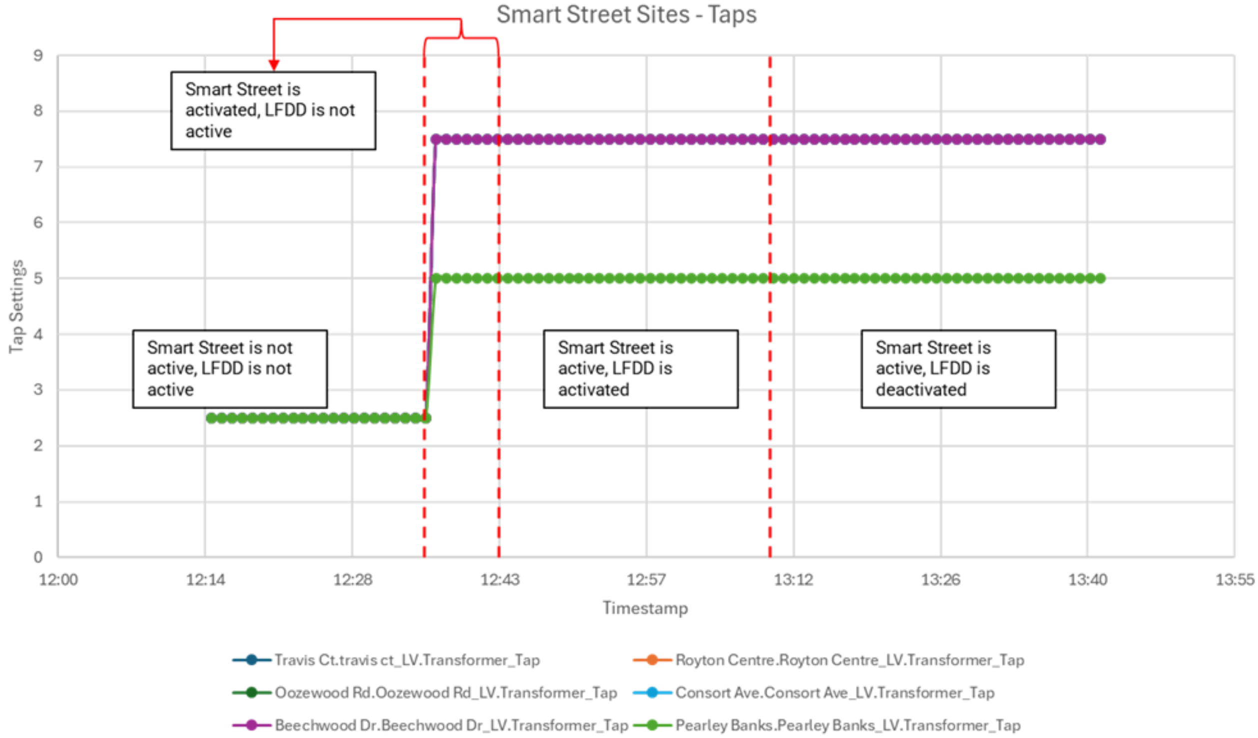

Figure 92: Smart Street Tap Settings from SGS Simulation

Smart Street is being continuously activated during the trial period. For Smart Street, it is observed that the tap settings change at this time, which lowers the voltage of the sites to close to the target voltage, and when CLASS is activated at 12:37, the smart street lowers the voltage lowers the voltage of the sites. Then, this continues until the end of the trial period. LFDD does not impact the application of Smart Street.

6.2.2.4. NEM Results

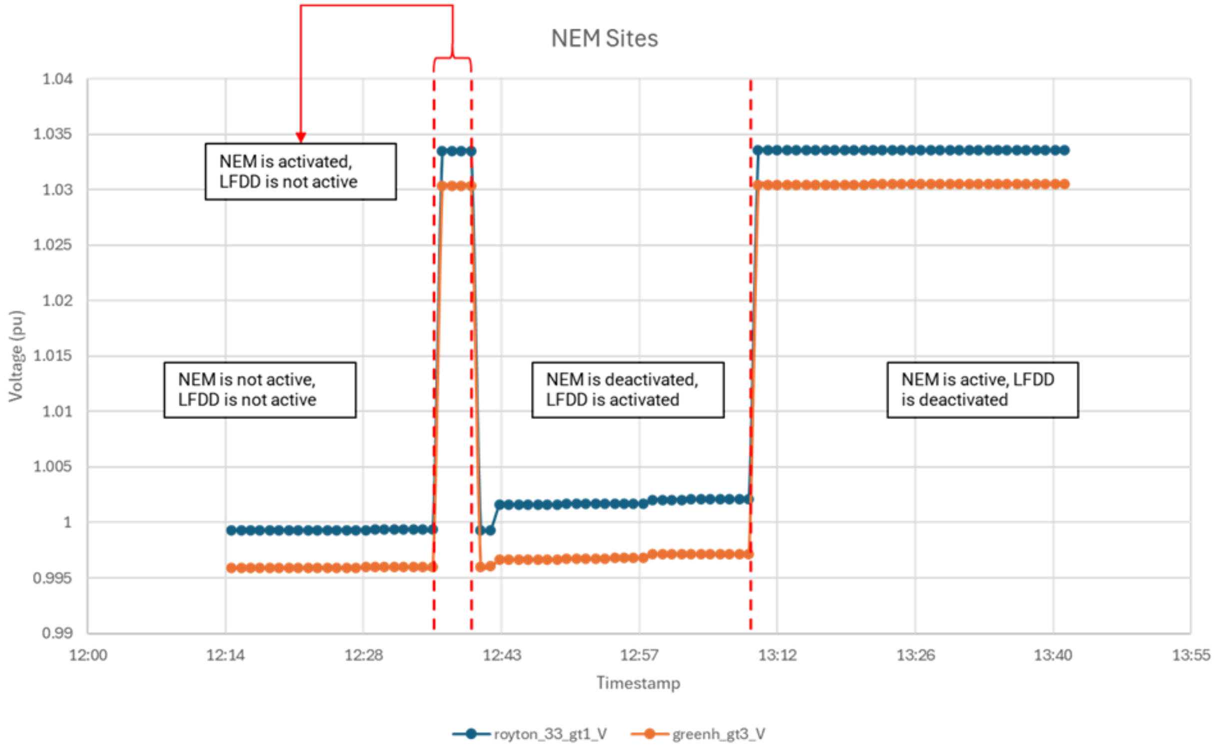

Figure 93: NEM Voltage Results from SGS Simulation

Figure 93 shows the voltage results for NEM in this trial. When NEM is activated at 12:37, the voltage of the corresponding BSPs raises accordingly. When LFDD is activated at 12:41, NEM is deactivated and the voltage for both BSPs drops back to around 1 pu. This continues until LFDD is deactivated at 13:10, and NEM reactivates once the LFDD instruction is removed and QUEST becomes activated again.

6.2.2.5. CLASS Results

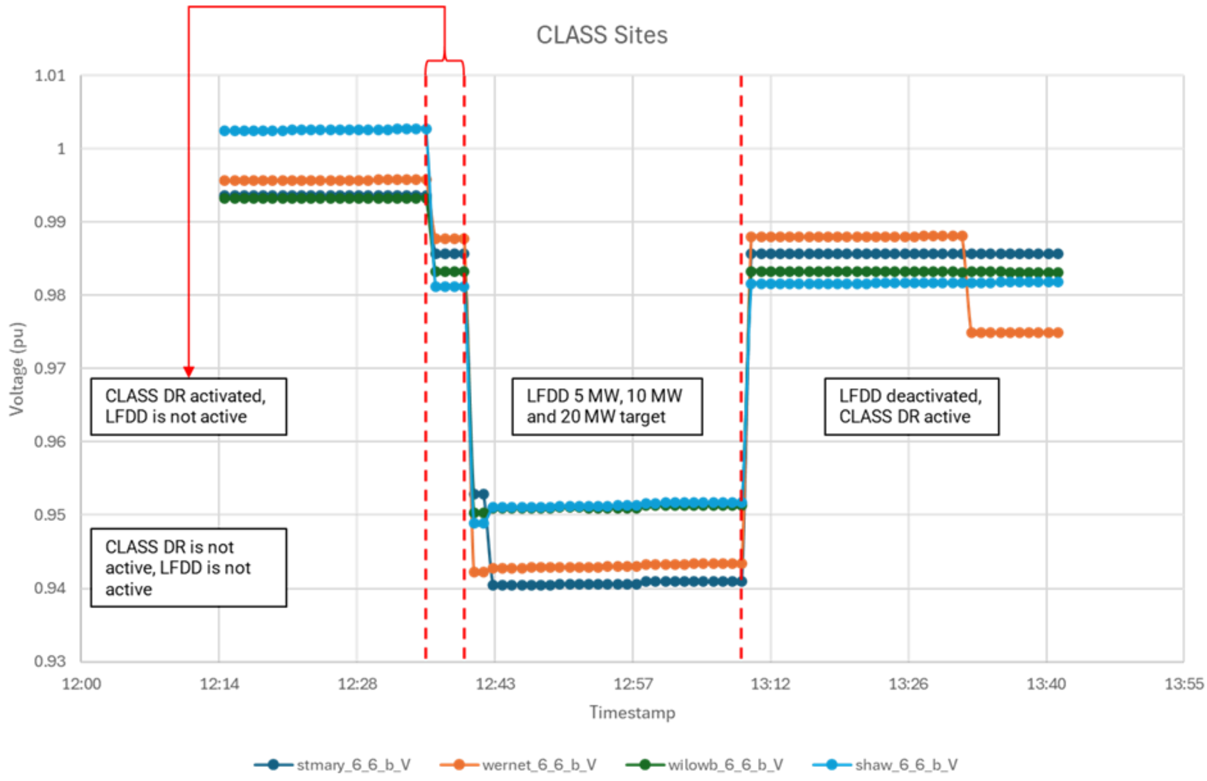

Figure 94: CLASS Voltage Results from SGS Simulation

Figure 94 shows the voltage results for the CLASS sites. When CLASS DR is activated at 12:37, for each class sites drop as expected. When LFDD is activated at 12:41, the CLASS lowers the voltage for each class sites more. This is because these CLASS sites were being restricted by the operation of NEM, but as NEM has been switched off due to LFDD, CLASS can achieve a lower voltage. When LFDD is deactivated at 13:10, the voltages at each class site increases back to the value at 12:37 (CLASS activated and LFDD deactivated) – this is because NEM is back online due to the deactivation of LFDD.

6.2.3. Test 14 – Tap Stagger

6.2.3.1. Test Input Details

In this simulation only test, the only function involved is the Tap Stagger function. This has been made active at the four BSPs in Whitegate: Royton, Greenhill, Red Bank and Chadderton. The function level used was 75% (creating a 6-tap difference between transformer pairs) and tap stagger is active between 13:30 and 13:36.

Load Details

- Load details have been used from 15/07/25 for this simulation test.
- From the trial information provided by SP ENW, QUEST became active between 08:50 and 13:36.
- As this section of tests were longer, load values at different points were used to create a load profile without the effects of QUEST. For this trial, load values at 13:26 and 13:40 were recorded and linear interpolation between the values was used to get “non-QUEST-load”.
- Trial was run from 13:26 to 13:40.

6.2.3.2. Tap Stagger Results

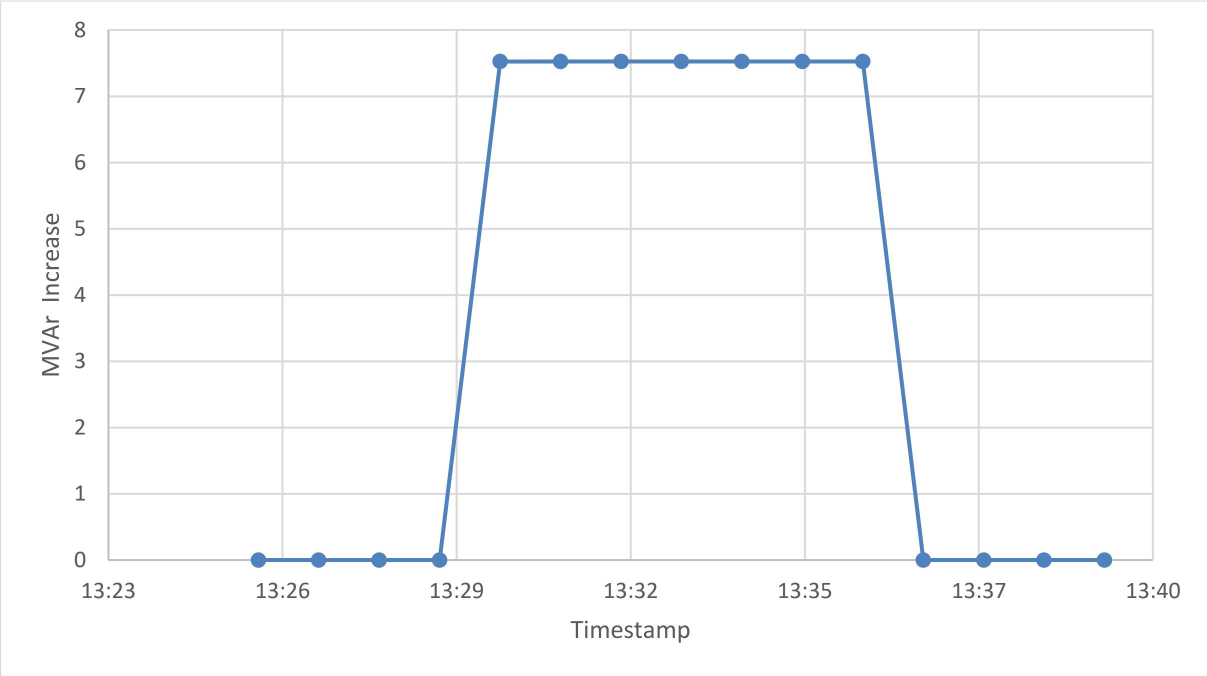

Figure 95: Whitegate SGT MVAr Increase

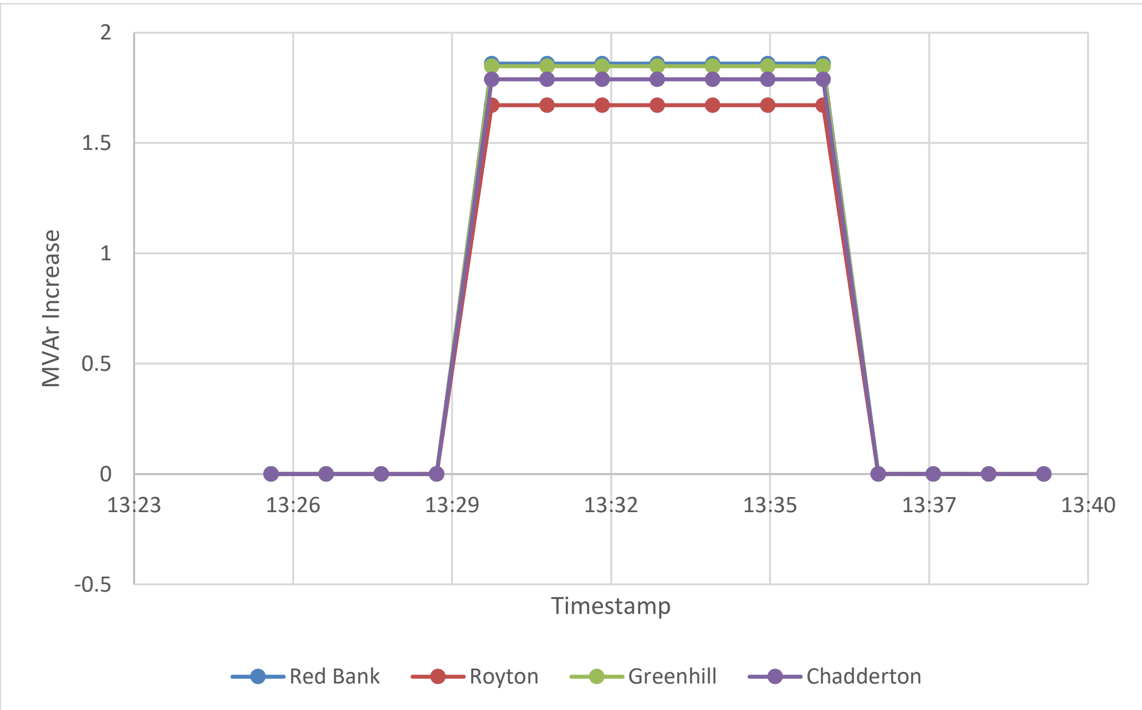

Figure 96: Whitegate BSP MVAr Increase

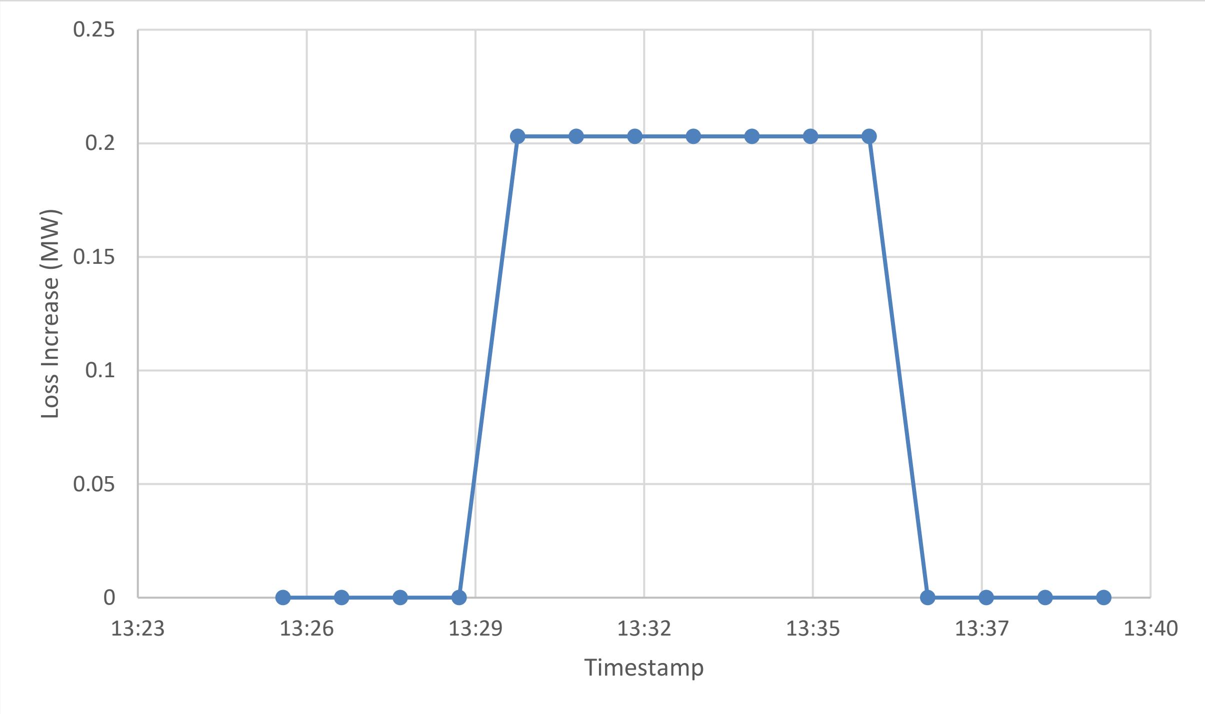

Figure 97: Total GT Loss Increase (Sum of the 4 BSPs)

Figure 95 shows the increase in MVAr flow through the Whitegate SGTs during the trial. When Tap Stagger is activated, there is an increased power draw of up to around 7.5 MVAr in the system, due to the circulating reactive current from the transformer tap differential. This is broken down per BSP in Figure 96.

Additionally, Tap Stagger causes increased losses in the Grid Transformers, the cumulative value of which is shown in Figure 97. This is due to increased copper losses from the increased current flowing through the transformer.

Although this was a Simulation Only test, SP ENW performed their own Tap Stagger test on the live system (without the application of QUEST). Figure 98 shows the MVAr flows from individual transformers. The mirrored nature of the MVAr values is due to the circulating reactive current between the transformer pairs, proving that Tap Stagger is an effective way of creating a reactive power sink.

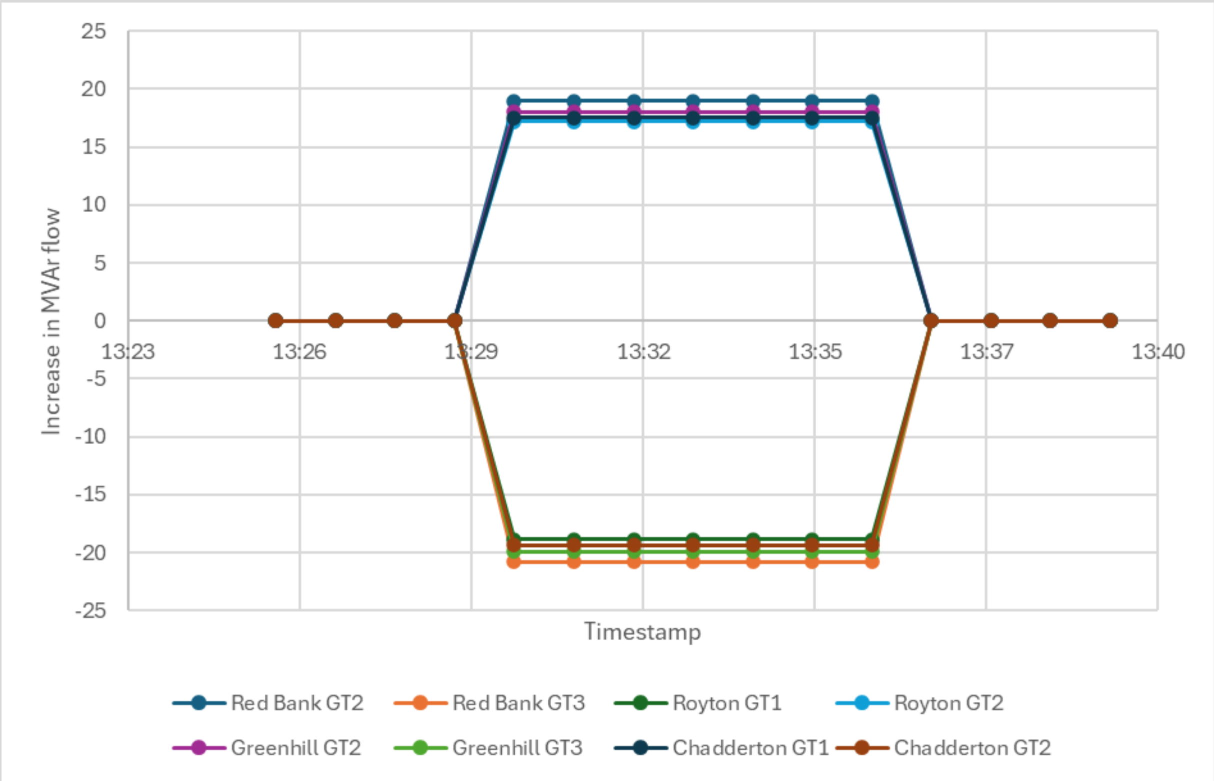

Figure 98: MVAr GT Flows from Live System during Tap Stagger test

7. CONCLUSION

Completion of trials in both a live and modelled environment meant that the benefits of QUEST optimisation could be corroborated against both the measured data from site and the outputs of the SGS QUEST system model.

By simulating the trial tests and comparing resultant voltage and power metrics, it was found that, in general, the QUEST system model produces accurate results when comparing output trends to that of the live QUEST system. The QUEST system model optimises as expected and in-line with project functional specification and use cases. Throughout both sets of trials, there were some examples of behaviour that did not align between the two systems (live and modelled), however, these results are explainable.

An overview of the comparison of each function in for both the live QUEST system and the QUEST system model is as follows:

- **CLASS:** CLASS results are broadly similar between the two systems, although the SGS QUEST system model often achieves the CLASS demand reduction target when the live QUEST system has not. This is because the QUEST system model often achieves a lower voltage result for each substation, and, therefore, will achieve the demand reduction target by applying CLASS less aggressively or at fewer substations.
- **NEM:** Results for NEM are broadly similar when there were no deviations from normal in the operational system. NEM on the live system tended to reach a slightly higher voltage, this is likely due to the SGS digital twin opting to select a conservative tap setting to prevent the 33 kV voltage going outside the statutory limits.
- **Smart Street:** Results for Smart Street were more difficult to compare, for which there are a few reasons:
    - Not all the smart street site data was available to be graphed, and some data was only available at 10-minute intervals,
    - Some secondary sites on the live system did not operate as expected when Smart Street was active, but this was due known limitation on the live network,
    - Smart Street was active throughout the whole QUEST trial period in the live system, whereas in the SGS model there are some cases where Smart Street was programmed to activate during the study window,
    - For aid of testing, Smart Street periodic calculations in the live system were extended to ensure a consistent output during specific QUEST tests. Therefore, a change to normal mode will not generate an automatic change to voltage set point and tap position.
- **OC6 VR/DD & LFDD:** OC6 VR/DD and LFDD were successfully simulated to showcase the demand reduction methods and the corresponding effects of CLASS, Smart Street and NEM.
- **Tap Stagger:** Tap Stagger was simulated successfully and demonstrates the level of reactive power absorption that can be achieved by creating a tap differential at a pair of transformers.

Overall, inaccuracies between power and voltage results between the live and modelled systems are due to known limitations on the live network during testing and differences between the live system measurements and simulated model measurements, rather than erroneous operation of the control methods and conflict arbitration these assessments are intended to prove.

The combination of simulated trial tests and live trial tests gave the opportunity to achieve the objectives of this report:

1. Confirmation that the live SE QUEST system operates as per the functional specification to perform QUEST control actions on the live network so that the benefits from QUEST can be realised. In some instances, differences between the two QUEST systems prompted questions regarding the response of the live QUEST system but these differences were generally because of known limitations on the live network.
2. Validation of the SGS QUEST system model, which has been shown via the trial tests outlined in this report to perform closely in line with the live SE QUEST system.
3. The simulated and live QUEST trials further support that Conservation Voltage Reduction is an effective technique for leveraging the voltage/demand relationship, under operational situations hard to test in the live environment, namely OC6 and LFDD tests.

The trial tests show that QUEST can achieve control functionality for each method in isolation and as part of a multi-objective control requirement delivering the benefits relating to each individual control function and arbitrating the potential conflict between them. This has been shown in both the live QUEST system and the QUEST system model. The benefits of executing the trial tests in both these formats has allowed for functionality to be proven fit for purpose for the existing control functions. Furthermore, the QUEST system model has shown in the trial tests for functionality that does not currently exist or for non-testable scenarios the live QUEST system should perform as expected, achieving the benefits provided from these control functions.

Area for improvement / next steps include the following:

- Further fidelity between the two models could be achieved by amending how often the SGS model re-calculates the QUEST solution (it currently does so on a minute-by-minute basis),
- Improvements around the load modelling process, which is currently based on linear interpolation,
- Expansion to other network areas to identify the potential benefits of a QUEST solution,
- Enhanced modelling of the LV network,
- Expand trial area to give broader representation of interaction when QUEST deliveries and optimised solution of varied solutions per BSP.

A more complex model could improve accuracy and precision of the resulting power and voltage outputs for the QUEST system model. However, this would only be required where accuracy and precision have a material impact to proposed objectives.

8. REFERENCES

[1] M. Collins, T. Rafferty and e. Al, “Voltage demand relationship modelling for future energy scenarios,” 27th International Conference on Electricity Distribution (CIRED 2023), 2023.

[2] Schneider Electric, “QUEST Functional Specification,” 2023.