QUEST

QUEST Functional Specification Architecture

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Revision History

Version	Authors	Date	Comments
1.0	Milena Jajčanin	10-May-2022	Initial version of the QUEST Functional Specification created based on requirements defined during the design for the QUEST Overarching Software application.
1.1	Gordana Simić	20-May-2022	Revision and update
1.2	ENWL, SGS, Fundamentals	30-May	Revision
1.3	Milena Jajčanin	8-June-2022	Update based on the comments received from ENWL and SGS
1.4	Gordana Simić	8-June-2022	Mock-ups update based on the comments received from ENWL and SGS

Final review and approval of the latest version:

	Date	Name & Surname	Business Role	Signature
Reviewer	10-June-2022	Gordana Simić	Product Owner	
Approver	21-June-2022	Marko Čomić	Senior Project Coordinator	

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1. REFERENCES

#	Title	Description
1.	QUEST an Overarching Control System, QUEST Initial Report - Use Cases	ENWL document "QUEST an Overarching Control System, QUEST Initial Report - Use Cases", Issue: 1, Submission Date: 30th July 2021", available at: https://www.enwl.co.uk/globalassets/innovation/quest/documents/quest-initial-report_use-cases-issue1.pdf.
2.	QUEST Architecture Options - Subphase 1 Report	Document providing the review of subphase 1 of the QUEST detailed design. Within this document, QUEST Use Cases are additionally clarified, and QUEST functionality is determined. Inputs from this document are crucial for determination of QUEST architecture options.
3.	QUEST Architecture Options – Subphase 2 Report	Document providing the review of subphase 2 of the QUEST detailed design. Within this document, QUEST Architecture Options are determined.
4.	Functional Specification for the Chosen Architecture – subphase 1 report	Document providing the review of subphase 1 of the Functional Specification for the Chosen Architecture phase of QUEST detailed design. Within this document, additional functionality introduced in QUEST architecture is described. Based on the agreements made during this subphase, this document is finalized.

1. ABBREVIATIONS

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

ENWL	Electricity North West Ltd.
ESO	Electricity System Operator
ESQCR	Electricity Safety, Quality and Continuity Regulations
HV	High Voltage
ICCP	Inter-Control Centre Communications Protocol
LCT	Low Carbon Technologies
LFDD	Low Frequency Demand Disconnection
LFDD-MM	Low Frequency Demand Disconnection Mitigation Mode
LV	Low Voltage
MW	Megawatt
NE	Network Efficiency
NEM	QUEST's Network Efficiency Mode
NMS	Network Management System
OC6	Grid operating code 6
OC6-MM	OC6 Mitigation Mode
OC6-VR-MM	OC6 Voltage Reduction Mitigation Mode
OC6-DD-MM	OC6 Demand Disconnection Mitigation Mode
SE	Schneider Electric
SGS	Smarter Grid Solutions
SMST	Smart Street
SYSCON	System Condition
TPL	Technique Priority List
TPS	Technique Priority Selector
TSF	Tap Stagger (CLASS Function)
UI	User Interface

2. INTRODUCTION

Effective control of system voltages is crucial to the safe and efficient operation of distribution networks and to provide optimum voltage to connected customers. Methods for controlling system voltages on distribution networks have evolved over time based largely on the historic passive nature of power flows – whereby power flows in one direction, from the transmission network through to demand customers connected to the distribution network – together with the predictable nature of customer demand profiles. The passive nature of the network meant that the design and operation of voltage control solutions, typically via use of transformer tap settings, could be kept simple, with local solutions acting independently with minimal need for overall co-ordination. This type of voltage control is applied at discrete layers on the distribution network. Many of the voltage control solutions are fixed systems, with local, manual adjustment of transformer tapping equipment, while others are fitted with Automatic Voltage Controllers (AVCs), which vary the voltage dynamically in response to local measurements.

In recent years, DNOs have introduced voltage optimisation and Conservation Voltage Reduction (CVR) to provide customers with optimum system voltages. Intelligent network devices and central software are used in combination to change system voltages dynamically. Furthermore, Active Network Management (ANM) has also been deployed to efficiently manage the connection of demand and generation on constrained networks. Usually, the ANM solution needs to address thermal constraints but sometimes voltage constraints may be present. This changing landscape results in more areas of the network becoming constrained due to voltage issues. Without significant reinforcement, historic solutions for distribution network voltage control are not well-suited to addressing these needs. Therefore, more economic techniques such as voltage optimisation and ANM are deployed.

Typically, these voltage management techniques are installed independently of one another and because of this they are not able to work collectively to provide voltage optimization benefits to the whole network. Additionally, as the solutions are not fully coordinated, there is potential for techniques to counteract one another, resulting in sub-optimal overall effectiveness. To mitigate this, DNOs currently design, configure and deploy these techniques with built-in safety margins that provide an operating 'buffer'. This could lead to a reduction in the effectiveness of each technique.

The changes to power flows and the unpredictability of demand, together with the proliferation of independent voltage optimization techniques, require network operators to review their approach to delivering safe and effective voltage control. To ensure that all techniques are operated optimally, it is necessary to investigate ways of integrating the various, discrete techniques to create a flexible and coordinated system.

In this regard, QUEST is envisioned as a part of the EcoStruxure ADMS functionality which is specifically designed to integrate the discrete voltage control techniques into one overarching, coordinated and optimized system. This will enable voltage optimisation for the whole distribution network. By viewing and controlling the whole network, QUEST co-ordinates the often-competing objectives of these existing systems to ensure optimised operation whilst maximising benefits for the customers.

In the rest of this document QUEST functionality is described.

3. OVERVIEW

To cater for the subsequent increase in electricity demand and generation associated with government decarbonisation targets, DNOs have investigated and deployed techniques such as Customer Load Active System Services (CLASS), Smart Street (SMST) and ANM optimisation systems. Whilst these systems have proven successful in helping DNOs to manage the network they do have limitations because they are often applied in isolation from one another and do not operate in a coordinated manner.

QUEST is a holistic, centralized optimization engine intended to demonstrate the use of an overarching optimization function to coordinate and control the above-mentioned existing systems. It endeavours to provide an optimum whole system voltage profile, at all times. QUEST is intended to demonstrate the benefits of running a holistic whole system voltage optimization program, allowing the concurrent operation of the discrete voltage dependent applications across the network.

The objectives of QUEST, identified within the "QUEST an Overarching Control System, QUEST Initial Report - Use Cases" document [1], are:

- To introduce a distribution network-wide, fully coordinated, overarching system to manage voltages, with an appropriate balance between centralised and decentralised control hierarchy.
- To integrate discrete voltage management techniques into an overarching, coordinated and optimised system, enabling voltage optimisation for the whole distribution system, from the Electricity System Operator (ESO) intake to the interface with domestic customers.
- By viewing and controlling the distribution system as a whole, to coordinate the often-competing objectives of the various, discrete voltage control techniques to ensure an optimised operation, whilst maximising benefits for customers.
- To explore the coordinated operation of voltage management techniques to enable a reduction of the built-in operating margins, creating capacity for customers using existing circuit assets and thus facilitating the increased connection and use of low carbon technologies (LCT).
- By providing a means of command arbitration, to ensure that potential clashes are avoided, and overall benefits are maximised through coordination of previously discrete voltage techniques.
- Under normal operation, to ensure the network operates as efficiently as possible, optimising the system voltage to connected customers and minimising losses, based on the interaction of other discrete voltage systems on the network.
- To unlock benefits for National Grid Electricity System Operator (ESO) by providing improved visibility of real-time, embedded generators and other forms of Distribution Energy Resource (DER) and allowing "tuned" responses for demand control and OC6 (Grid Code Operating Code 6).
- To maintain statutory voltage limits as per Electricity Safety, Quality and Continuity Regulations (ESQCR) and ensure no disruption to system commercial contractual agreements, unless under emergency response situations.
- In the event of loss of system communication, to keep the system operating safely within its boundaries in order to maintain network stability and safety.

Based on the objectives stated above, QUEST core operational objectives have been determined for both normal and emergency system conditions:

- Normal conditions

  - Coordinate operation of system voltage control techniques by adjusting them in a way to gain as many benefits as possible from each voltage control technique, while preventing counteraction between them.
  - Enhance operational efficiency by minimizing the 33kV system losses.
  - Maintain statutory voltage limits as per ESQCR.
- Emergency conditions
  - Put the existing voltage control techniques in appropriate mitigation modes in order not to block provision of the emergency response to the ESO.

In order to satisfy its objectives, QUEST operates in real time.

QUEST is aware of the statuses of all the voltage control techniques and based on the all inputs provided, it performs appropriate coordination actions. QUEST coordination actions refer to putting the voltage control techniques into states that either prevents or resolves conflicts that happen between them. By doing so, QUEST reacts either proactively or responsively. If QUEST reacts proactively, the states into which voltage control techniques are referred to as “safe modes”. A “safe mode” is a state which proactively places a voltage control technique at a level which results in that part of the system staying within statutory voltage limits whilst still being physically achievable by the relevant network voltage control asset. If QUEST reacts responsively, the states in which voltage control techniques are put are referred to as “mitigation modes”. A “mitigation mode” is one which places a voltage control technique or active network management (ANM) system responsively into a state appropriate for an emergency or unplanned condition.

In the case of proactive coordination, QUEST considers the priorities of voltage control techniques that are predefined by the QUEST control engineer (CE). Based on the predefined priorities and desired function levels of each voltage control technique, QUEST performs appropriate coordination actions.

Another of QUEST’s core objectives is to enhance the operational efficiency, under normal system conditions, by minimizing the 33kV system losses. For that purpose, additional voltage control technique, Network Efficiency Mode technique, is introduced through the QUEST overarching software.

In addition to satisfying its defined objectives, QUEST also enhances the CLASS functionality. As an overarching software that has awareness of all other voltage control techniques operating in the network, QUEST can better adjust the CLASS primary substations in order to satisfy CLASS committed targets, but by trying to minimise its effect on other voltage control techniques. In order to facilitate this enhancement, QUEST introduces additional levels of voltage reduction for the CLASS primaries, as well as the Tap Stagger Functionality on a BSP level (BSP TSF).

More details regarding each topic mentioned in this section are provided in the remainder of this document through the detailed description of the agreed QUEST functionality and methodology.

3.1. Architecture

The main architecture diagram, displaying QUEST as an overarching software, is shown in Figure 3-1.

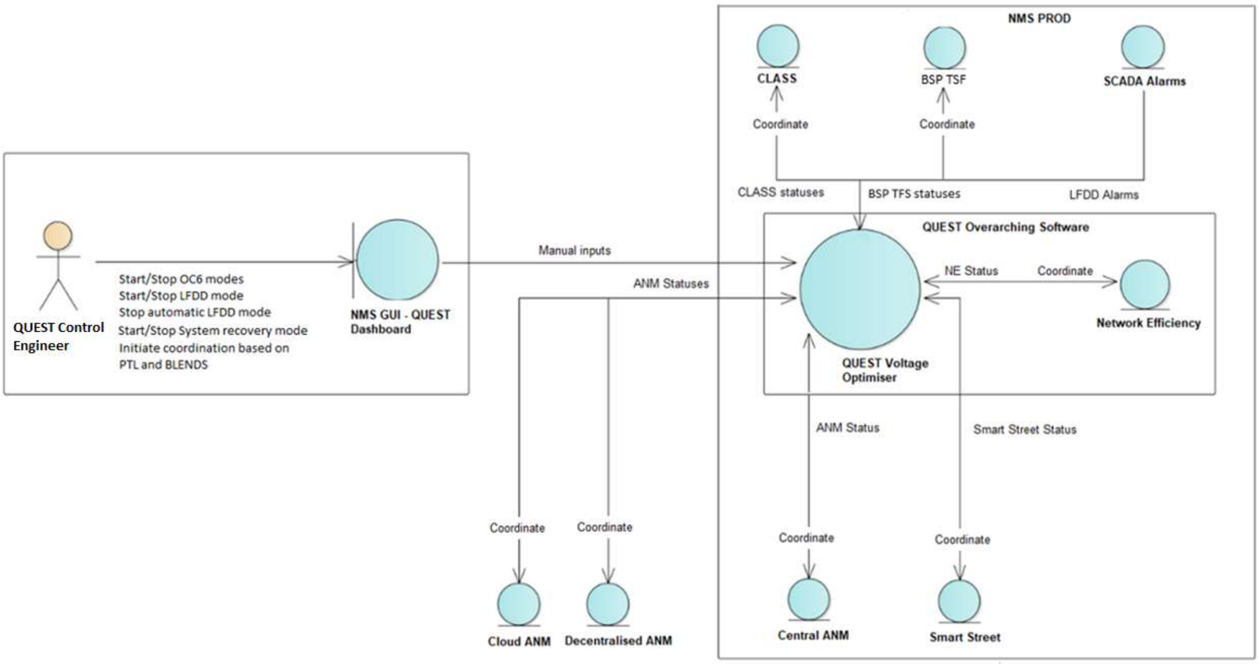


Figure 3-1 – QUEST – Main architecture diagram

On the right side of Figure 3-1, ENWL's NMS production system is shown with the QUEST Overarching Software in the centre. QUEST is built on the single ADMS Network Model containing all relevant network static data including that from the LV network. The network model is built from multiple data sources via the data interface built as part of the main NMS project and it is capable of fully modelling the distribution network including single customers, all conducting equipment, DERs, different types of load, and all the devices and their local automation.

Dynamic data provided to QUEST includes real-time data obtained from SCADA, such as the status of remotely controlled devices (including Bulk Supply Point (BSP) substation, primary substation and distribution substation transformer tap positions), monitored voltage values across the whole DNO network. It also takes in SCADA alarms, as well as the manually controlled device states, tags, temporary elements including jumper cuts, earths, temporary generators, temporary switches and temporary substations.

By combining the static data with the dynamic data, the "as-operated" state of the network is determined, and it is provided to QUEST so it can perform its coordination based on the "as-operated" network topology.

Since it is located within the NMS system, QUEST is aware of the status of all the other existing systems in the NMS system (CLASS, SMST and Central ANM).

By using ICCP (Inter-Control Centre Communications Protocol) communication links, QUEST is also integrated with the external ANM systems: Decentralised ANM and Cloud ANM and is aware of their statuses.

Having visibility of all the existing systems in the QUEST trial area, as well as the voltages across the whole DNO network, QUEST Overarching Software is able to provide full distribution network coordination. By performing full coordination, voltage profiles are managed with an appropriate balance between centralised and decentralised control hierarchy (QUEST Voltage Optimiser circle in the main architecture diagram is in charge for coordination of all voltage control techniques).

In addition to coordinating the operation of the existing voltage control techniques in the network, QUEST Overarching Software tries to increase the 33kV network efficiency whenever possible, by increasing the voltages on the 33kV parts of the distribution network. Network efficiency (NE) is displayed in the main architecture diagram as an additional voltage control technique which is provided through QUEST Overarching Software and is also coordinated by the QUEST Voltage Optimiser.

Based on the inputs provided to QUEST, QUEST determines and automatically performs appropriate coordination actions.

3.1.1. Main inputs

The input data required for QUEST calculations contains the internal model, state model and execution options. The internal model is a bus-branch-shunt model, which contains the information about the as-built and as-operated state of the network. The state model contains variables that are independent of the topology, such as the customer loads, generator productions and source voltages so that the network state may be obtained within QUEST.

Beside these models, the input for QUEST includes:

- Execution options (see section 4.2.1 “QUEST ”),
- Network of interest (‘Whitegate’ trial area),
- System condition (SYSCON): (see section 4.1 “SYSCON Selector”),
- Status of the existing voltage control techniques (CLASS, SMST, Central ANM, Decentralised ANM, Cloud ANM),
- CLASS demand reduction (DR) and demand boost (DB) half an hour target,
- SCADA alarms (based on which automatic low frequency demand disconnection (LFDD) activation is detected),
- Exclusion List.

3.1.1.1. Exclusion list

The Exclusion List (Figure 3-) contains devices which should not be considered by any ADMS application engine that generates a switching sequence as a part of its functionality (there is only one exclusion list visible to all applications). The information about the excluded devices is used only during the creation of the list of the available resources, and it is not used during the execution. The intent of the Exclusion List is to ensure that QUEST does not propose an action on a device which is not operating correctly. This mechanism essentially ensures that the system does not continuously loop, attempting to use the same failure prone device creating needless alarms and interruptions to the operational staff. Another use case is that the user does not want a device to be automatically controlled by the system and therefore manually adds the device to the Exclusion List.

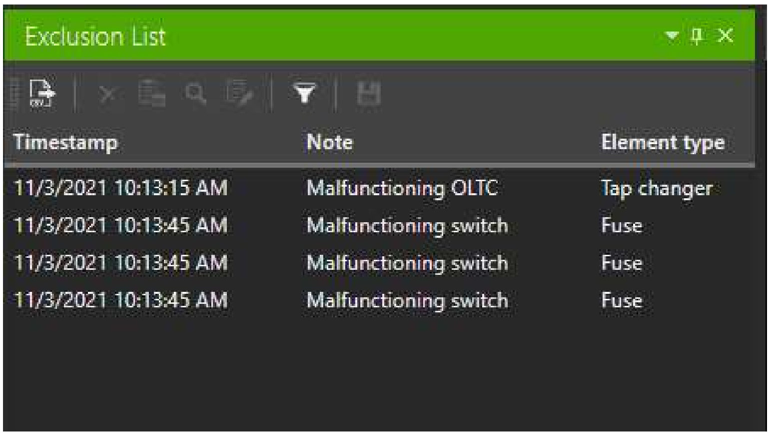


Figure 3-2 – Exclusion list

3.1.2. Main outputs

Output data of the QUEST application is the following:

- Generated and automatically executed sequence of switching operations (target voltage settings) for SMST transformers and BSP transformers,
- The enablement of CLASS primaries to satisfy CLASS DR/CLASS DB targets,
- NEM activation,
- Alternative modes for Central ANM, Decentralised ANM and Cloud ANM upon each CLASS activation/deactivation or emergency state activation,
- Calculation results and benefit analysis presented in the form of a Dashboard.

Additionally, QUEST application generates event and alarm messages. Usually, the events are used to perform the post analysis of the application's activity or to track the current activity of the application. An alarm is reported when the CE's attention is needed. Each alarm is followed with the same event, so it can be found later, in the event's list (note: alarms and events are logged into an NMS wide single Alarm and Event Summary within which sorting functionality is available). A list of QUEST messages is given in the Appendix, section 6.1 ”QUEST messages”.

3.1.3. Triggering

When performing coordination in real time, QUEST is triggered only when it is needed to readjust the levels of coordinated voltage control techniques (NEM, CLASS, SMST) and ANM systems. The situations where a QUEST trigger is needed are the following:

- The change of CLASS half-an-hour targets,
- The change of CLASS primary substation's availability status (inhibited, test, contribution is zero),
- The change of CLASS function status (e.g. CLASS status changes from Enabled to Activated),
- On emergency SYSCON selection,
- On enablement of BSP TSF.

Each of these situations can affect the previous adjustment of voltage control techniques performed by QUEST or a voltage control techniques' targets, so in these situations QUEST's automatic intervention is expected.

More details regarding QUEST’s operation in real time is provided in the section 5.3 "QUEST coordination under normal operating conditions”.

4. FUNCTIONALITY

The central window from which QUEST operation is configured and monitored is the **QUEST Control & Monitoring** window. The window is presented in Figure 4-1.

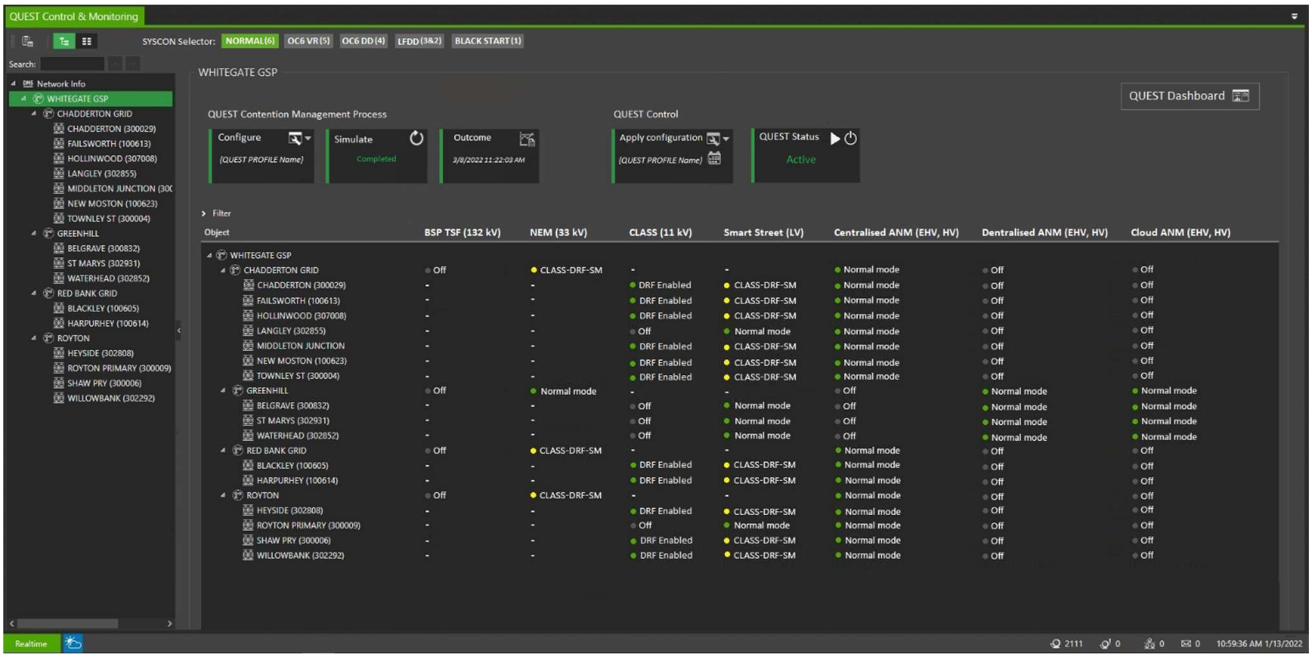


Figure 4-1 – QUEST Control & Monitoring window

In the left part of the window, the network tree is provided. The QUEST CE can navigate through the different parts of the network, down to the primary substations to monitor QUEST's operation.

The right part of the window consists of four parts related to QUEST control and/or monitoring described in the following sub sections.

4.1. SYSCON Selector

As defined within QUEST objectives, QUEST performs appropriate coordination actions for each voltage control technique in both, normal and emergency system conditions.

At the top of the QUEST Control & Monitoring window, in the toolbar, a SYSCON Selector is available. The SYSCON Selector is presented in Figure 4-2.

Figure 4-2 – QUEST Control & Monitoring – SYSCON Selector

The QUEST SYSCON states are set according to national electricity system conditions:

- SYSCON-1 = System Recovery [Black Start] State (Grid Code OC9),
- SYSCON-2 = LFDD Automatic Activation State (Grid Code OC6.6),
- SYSCON-3 = LFDD Manual Activation State (Grid Code OC6.7),

- SYSCON-4 = OC6 stages 3 to 5 State (Grid Code OC6.5, Demand Disconnections),
- SYSCON-5 = OC6 stages 1 & 2 State (Grid Code OC6.5, 3% & 6% Voltage Reductions),
- SYSCON-6 = Normal System Operating State.

Through this part of the window, the QUEST CE can observe the system states, but can also select some other state as an input for QUEST operation. SYSCON-2 is activated automatically (Automatic Low Frequency Demand Disconnection). All other SYSCONs require the QUEST CE to manually select them as a part of a business process (SYSCON 1, 3, 4, 5 and 6). Only one SYSCON at a time can be selected as an input for QUEST. Also, an appropriate warning message is provided upon changing the selection of the SYSCON where the CE is asked to confirm their decision to change the SYSCON state. This is especially important in the case of selecting emergency system states.

SYSCON-1 to SYSCON-5 all refer to emergency situations.

SYSCON-6 refers to the normal system state which will be active for 99%+ of the time. In this state QUEST coordination is performed based on the QUEST configuration that considers priorities among different voltage control techniques. In the case of one of the emergency states being selected, QUEST intervenes in a way that prevents its voltage management techniques from acting against the requirements and, if required, assists in the provision of the emergency response to the ESO. More details regarding QUEST coordination in normal and emergency situation are provided in sections “QUEST coordination under normal operating conditions” and “QUEST operation in case of emergency condition”.

4.2. QUEST Contention Management Process

This part of the window is related to configuration and control of QUEST’s operation in the normal operating system state. Since QUEST coordination is performed for the Whitegate GSP area, this part of the window is not dependent on the network selection in the network tree. It always refers to a GSP level of the network.

Prior to starting QUEST’s automatic operation, the QUEST CE performs offline analysis to determine what is the most suitable QUEST configuration. For that purpose, the QUEST Contention Management Process (CMP) section is introduced. The QUEST CMP section is shown in Figure 4-3.

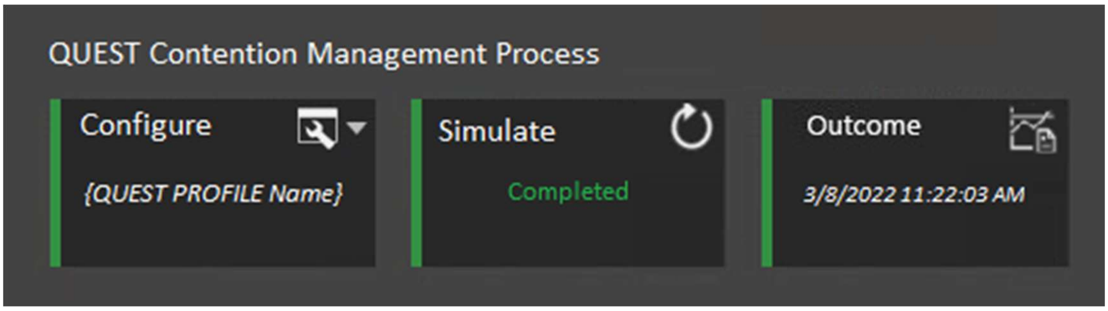


Figure 4-3 – QUEST Control & Monitoring - QUEST Contention Management Process

The CMP section contains three tiles: Configure, Simulate and Outcome. The Configure tile enables the QUEST CE to create different QUEST PROFILEs. Each created QUEST PROFILE should be named differently in order to easily distinguish it when it is later considered. Configuring and assigning the QUEST

PROFILES is allowed only for the users with adequate permissions[1]. Through the selection or construction of a QUEST PROFILE all parameters related to QUEST coordination are configured. These include the definition of type of coordination performed by QUEST, as well as the definition of voltage control techniques' priorities and desired function levels (BLENDs) during the coordination. The QUEST PROFILEs are described in section 4.2.1 "QUEST ".

After a QUEST PROFILE is created, and assigned within the Configure tile, the simulation can be performed through the Simulation tile. The name of the QUEST PROFILE that is chosen for simulation process is displayed in the Configuration tile. Upon starting the simulation, QUEST simulates coordination actions according to the previously selected priorities and BLENDs. After the simulation process is finished, the outcome of QUEST's calculation is available within the Outcome tile. The Outcome report has a similar look to the QUEST Dashboard. All details regarding the results presented in the Dashboard are provided in the section 4.5 "QUEST Dashboard".

By observing the achieved benefits for each of the voltage control techniques compared to the configured adjustment of the selected priorities and BLENDs, the CE can conclude whether the QUEST Configuration is acceptable, or if some fine-tuning of the BLENDs should be performed through another CMP cycle.

It is important to note that the QUEST CMP does not affect QUEST's operation in real time. Even after QUEST is activated with one configuration, QUEST CMP can be performed in parallel to provide the possibility for the CE to create (off-line) additional configurations which can be applied to the real time operation subsequently.

4.2.1. QUEST PROFILE

A QUEST PROFILE represents one set of coordination parameters based on which QUEST coordination is performed. The QUEST PROFILEs are displayed in Figure 4-4 and Figure 4-5.

[1] It will be a business procedure to define which users will be in charge of QUEST PROFILEs creation and approval and which ones will only be able to assign a previously created PROFILE to a part of the network and to start QUEST in real time with the previously approved PROFILE. It is assumed that the QUEST CE engineer will be the one in charge for QUEST PROFILE creation and approval and that the other CEs will be the ones allowed to choose one from the approved PROFILEs, assign them to a trial area and run QUEST in real time with the chosen PROFILE.

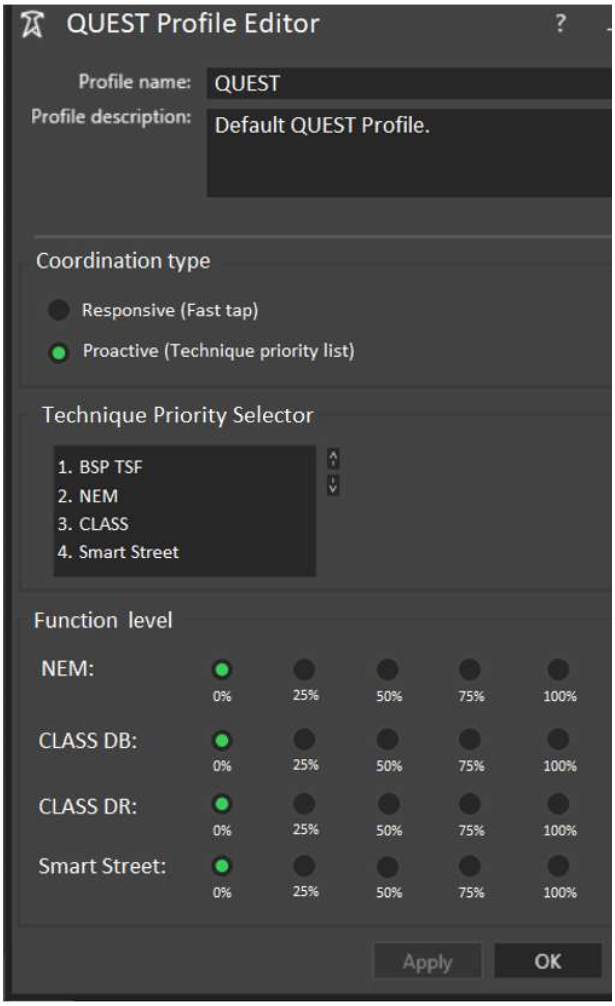


Figure 4-4 – QUEST PROFILE – Proactive coordination type

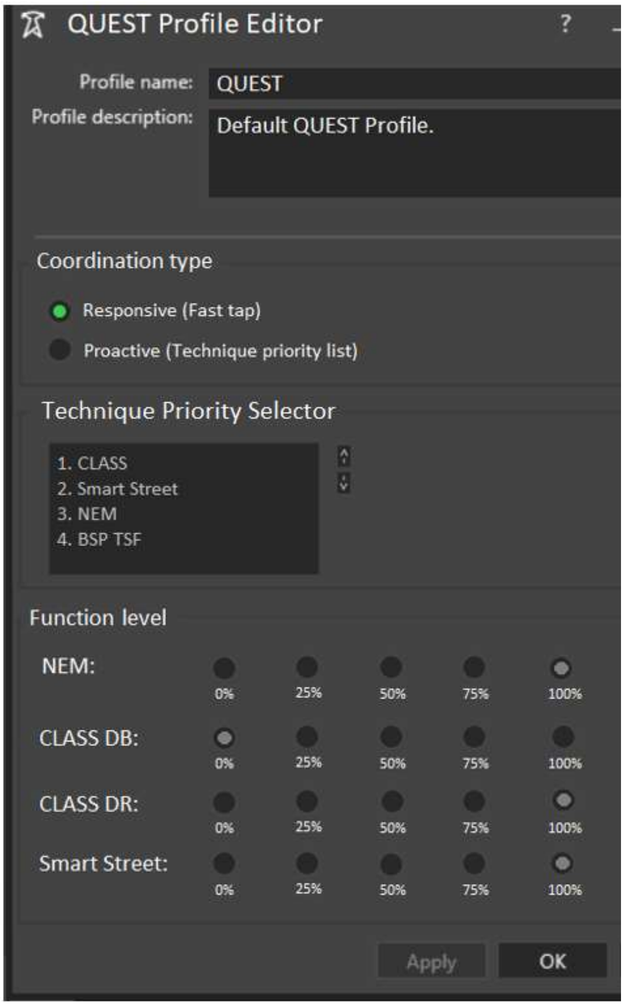


Figure 4-5 – QUEST PROFILE – Responsive coordination type

As it can be seen from the figures, there are two types of QUEST coordination that can be set through QUEST PROFILE:

- Proactive (Technique priority list),
- Responsive (Fast tap) coordination.

When proactive coordination type is selected, the QUEST CE can define the (voltage control) techniques' in priority order and their desired function levels (BLENDs). Within the Technique Priority Selector (TPS), the Technique Priority List (TPL) is created. By selecting the voltage control technique and using the arrows displayed in TPS section, the CE can order the voltage control techniques by desired priority. The priorities are ordered in descending order, meaning that the techniques selected as first in the list is treated as the highest priority technique.

In the Function level section, desired function levels or BLENDs (the combination of all the selected function levels) can be adjusted. The function levels are presented in the form of percentages. Each percentage represents the level that will be applied for that voltage control technique in order to try to satisfy its objectives. For example, if CLASS DR 50% is chosen as a desired function level, that means that QUEST will try to satisfy the CLASS committed targets by applying the DRH voltage reduction on CLASS primaries. It doesn't mean that CLASS should try to satisfy only 50% of the total CLASS committed target MW reduction delivery yield.

For each of the displayed percentages appropriate tooltip functional descriptions (acronyms) for the function level is provided. Also, appropriate UI validation is introduced for situations where the CE tries to set the function level for CLASS DB different than 0, while CLASS DR level is already configured to a value different than zero (and vice versa). This is because CLASS DB and DR levels are mutually exclusive.

In Figure 4-5 presented above, this is an example where responsive type of coordination is selected within the QUEST PROFILE. Responsive coordination uses the fast tap capability of the SMST transformers. In case of this coordination type, TPL and BLENDS are predefined and cannot be changed (explanation why these cannot be changed is provided in the section 5.3.6 "Responsive coordination type"). The CE can only observe the predefined priorities and BLENDs that are considered within this coordination type. As can be seen from the Figure 4-5, for this coordination type, CLASS is set as a primary technique, SMST and NEM are secondary and tertiary techniques and BSP TSF has the lowest priority. Function levels are also predefined and put to 100% for CLASS DR, SMST and NEM. As CLASS DB and CLASS DR are mutually exclusive, CLASS DB function level is put to 0%.

More details regarding QUEST operation, using both proactive and responsive coordination type, are provided in section 5.3 "QUEST coordination under normal operating conditions".

4.3. QUEST Control

After the offline studies are performed and the most suitable configuration is determined, QUEST can be started per GSP area. For that purpose, the QUEST Control section is introduced. The QUEST Control section is displayed in Figure 4-6.

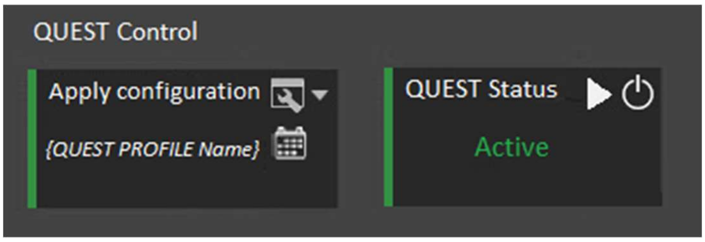


Figure 4-6 – QUEST Control & Monitoring - QUEST Control

This section consists of two tiles: Apply configuration and QUEST Status. By using the Apply Configuration tile, the QUEST CE can choose the configuration previously created through the CMP and apply it. The configuration can be applied from the moment of QUEST activation, or it can be scheduled. The QUEST Status tile provides the ability to start and stop QUEST's automatic operation in real time[2]. It also provides

[2] It was mentioned during the design that an improvement of the QUEST functionality could be to introduce a QUEST semi-automatic mode of operation. The purpose of this mode would be to gain trust in the QUEST functionality prior running it in automatic mode. As a preparation for running QUEST in automatic mode in real time, CMP would be performed to fine tune the QUEST PROFILEs, QUEST would then be run in a 'semi-automatic' mode. This mode refers to running QUEST in real time where QUEST suggests the adjustment of voltage control techniques but without applying that adjustment in the field. After observing the QUEST operation in semi-automatic mode and gaining trust in its operation, the next step would be to run it

the status of QUEST's operation. As it can be seen from the example provided in Figure 4-6 – QUEST Control & Monitoring - QUEST Control, the QUEST status is Active.

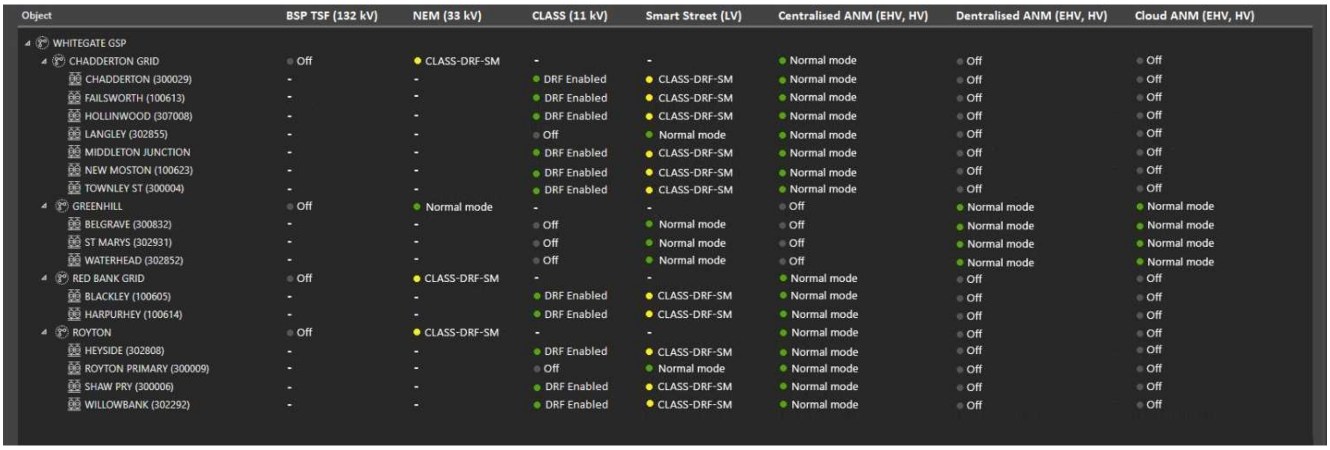
After it is activated, QUEST continues to automatically perform the coordination based on the configured BLENDs and TPL. The situations in which QUEST is triggered to readjust the voltage control techniques are stated in the "Triggering" section.

It is important to note that although the QUEST operation is activated, the QUEST CE can apply a different configuration and activate QUEST again in order to apply the newly assigned configuration.

Upon deactivating QUEST operation, the most important thing is to leave the system in a safe operating condition. That means that voltage control techniques cannot be returned in a normal operating mode, because that could lead to a potential conflict between voltage control techniques, or even to a situation with voltage values outside of the ESQCR limits. Having that in mind, after QUEST is deactivated, it considers which voltage control technique takes priority and based on the priority list QUEST performs the appropriate actions. For example, if CLASS has priority, upon turning QUEST off, CLASS remains enabled, but SMST is switched off in order to prevent low voltage violations in case of CLASS activation. On the other hand, if SMST has priority over CLASS, then SMST is returned to a CVR mode (normal mode of operation), and all CLASS primaries that supply SMST transformers are inhibited. It is then up to the CE to determine what are the next steps regarding the operation of each voltage control technique, whether CLASS scheduling mechanism should be enabled to continue scheduling CLASS primaries or whether SMST should continue operating in CVR mode or it should be switched off, etc. The only task for QUEST is to leave the system in a safe operating condition.

4.4. QUEST Monitoring

The bottom part of the QUEST Control & Monitoring window is intended for monitoring the statuses of each voltage control technique that QUEST is coordinating. This part is displayed in Figure 4-7.



Object	BSP TSF (132 kV)	NEM (33 kV)	CLASS (11 kV)	Smart Street (LV)	Centralised ANM (EHV, HV)	Dentralised ANM (EHV, HV)	Cloud ANM (EHV, HV)
WHITEGATE GSP							
CHADDERTON GRID	Off	CLASS-DRF-SM	-	-	Normal mode	Off	Off
CHADDERTON (300029)	-	-	DRF Enabled	CLASS-DRF-SM	Normal mode	Off	Off
FAILSWORTH (100613)	-	-	DRF Enabled	CLASS-DRF-SM	Normal mode	Off	Off
HOLLINWOOD (307008)	-	-	DRF Enabled	CLASS-DRF-SM	Normal mode	Off	Off
LANGLEY (302855)	-	-	Off	Normal mode	Normal mode	Off	Off
MIDDLETON JUNCTION	-	-	DRF Enabled	CLASS-DRF-SM	Normal mode	Off	Off
NEW MOSTON (100623)	-	-	DRF Enabled	CLASS-DRF-SM	Normal mode	Off	Off
TOWNLEY ST (300004)	-	-	DRF Enabled	CLASS-DRF-SM	Normal mode	Off	Off
GREENHILL	Off	Normal mode	-	-	Off	Normal mode	Normal mode
BELGRAVE (300832)	-	-	Off	Normal mode	Off	Normal mode	Normal mode
ST MARYS (302931)	-	-	Off	Normal mode	Off	Normal mode	Normal mode
WATERHEAD (302852)	-	-	Off	Normal mode	Off	Normal mode	Normal mode
RED BANK GRID	Off	CLASS-DRF-SM	-	-	Normal mode	Off	Off
BLACKLEY (100605)	-	-	DRF Enabled	CLASS-DRF-SM	Normal mode	Off	Off
HARPURHEY (100614)	-	-	DRF Enabled	CLASS-DRF-SM	Normal mode	Off	Off
ROYTON	Off	CLASS-DRF-SM	-	-	Normal mode	Off	Off
HEYSIDE (302808)	-	-	DRF Enabled	CLASS-DRF-SM	Normal mode	Off	Off
ROYTON PRIMARY (300009)	-	-	Off	Normal mode	Normal mode	Off	Off
SHAW PRY (300006)	-	-	DRF Enabled	CLASS-DRF-SM	Normal mode	Off	Off
WILLOWBANK (302292)	-	-	DRF Enabled	CLASS-DRF-SM	Normal mode	Off	Off

Figure 4-7 – QUEST Control & Monitoring – Coordinated Techniques Monitoring

In the monitoring section, each technique that QUEST is coordinating is displayed in a separate column. Voltage control techniques are ordered by the voltage level on which they operate. At the end, ANM systems

in automatic mode. This was mentioned only as potential enhancement that could be provided within some future version of QUEST overarching software.

are presented. As can be seen from Figure 4-7, on parts of the network where the Centralised ANM is configured and running, the Decentralised ANM is switched off and vice versa. This is in accordance with the agreement that the Centralised and Decentralised ANM will be configured on different parts of the Whitegate area.

If QUEST didn't perform any coordination action for a voltage control technique on some part of the network, the status of that technique is coloured in green and it states Normal operation. For example, for SMST that means that it operates in full CVR mode on that part of the network, or for NEM it means that the maximum level of 33kV voltage increase is applied on that part of the network. On the other hand, if QUEST did perform some coordination actions for a voltage control technique, the status of that technique for that part of the network where coordination is performed, indicates which safe or mitigation mode is applied by QUEST (more details regarding safe and mitigation modes are provided in section 5.3 "QUEST coordination under normal operating conditions"). If a technique is put in a safe mode or mitigation mode, its status is coloured in yellow. As it can be seen from the Figure 4-7, since CLASS DRF is enabled on X CLASS primaries, on all the BSPs supplying those CLASS primaries, NEM is put in a CLASS-DRF-SM. SMST on all the distribution transformers supplied from X CLASS primaries is put in a CLASS-DRF-SM, as well.

Tooltips providing more details regarding possible safe/mitigation modes for each technique are available on mouse hovering over each column representing particular voltage control technique.

Please note that QUEST is aware of all primary substations, regardless of the CLASS installation. All primary substations are displayed in the monitoring section and for the ones that do not have CLASS installed, CLASS status is represented with a "-". Within QUEST these primaries are treated the same as inhibited CLASS primary substations.

In addition to monitoring the statuses of voltage control techniques, this part of the window provides the possibility to control NEM operation. As a voltage control technique introduced through the QUEST Overarching Software, NEM is automatically started on all BSP transformers upon starting QUEST real time operation and stopped when QUEST operation is deactivated. Through this part of the window, the QUEST CE is able to manually exclude a particular BSP from NEM consideration by choosing the "Block for NEM" command from the context menu. The process of blocking NEM per a BSP is displayed in Figure 4-8.

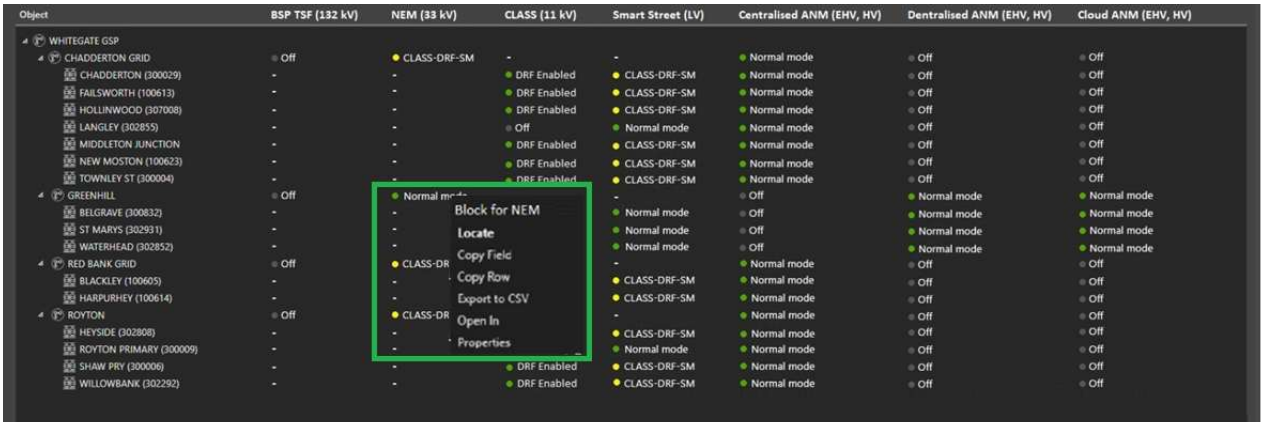


Figure 4-8 – QUEST Control & Monitoring – Blocking NEM on a BSP

After blocking NEM for a particular BSP, its status is displayed as "Blocked" (see Figure 4-9).

Figure 4-9 - QUEST Control & Monitoring –NEM blocked on a particular BSP

4.5. QUEST Dashboard

After QUEST is activated, a shortcut to the QUEST Dashboard is available from QUEST Control & Monitoring window. This is displayed in Figure 4-10.

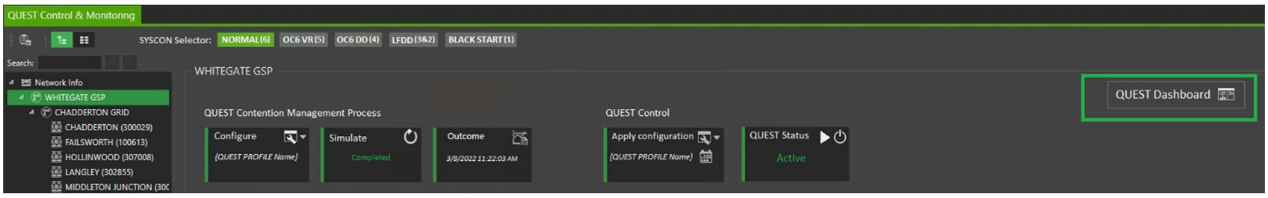


Figure 4-10 – QUEST Control & Monitoring – A shortcut to QUEST Dashboard

The QUEST dashboard displays all the relevant information regarding QUEST's operation in real time.

Figure 4-11 – QUEST Dashboard

In the left part of the window, a summary of the QUEST configuration (QUEST input) is displayed. The TPL showing the techniques' priorities, as well as the configured function levels can be observed. This part of the window can be collapsed to a vertical text representation along the left side of the window. Collapsing that part of the Dashboard, causes only QUEST results to be shown (Figure 4-12 – QUEST Dashboard –).

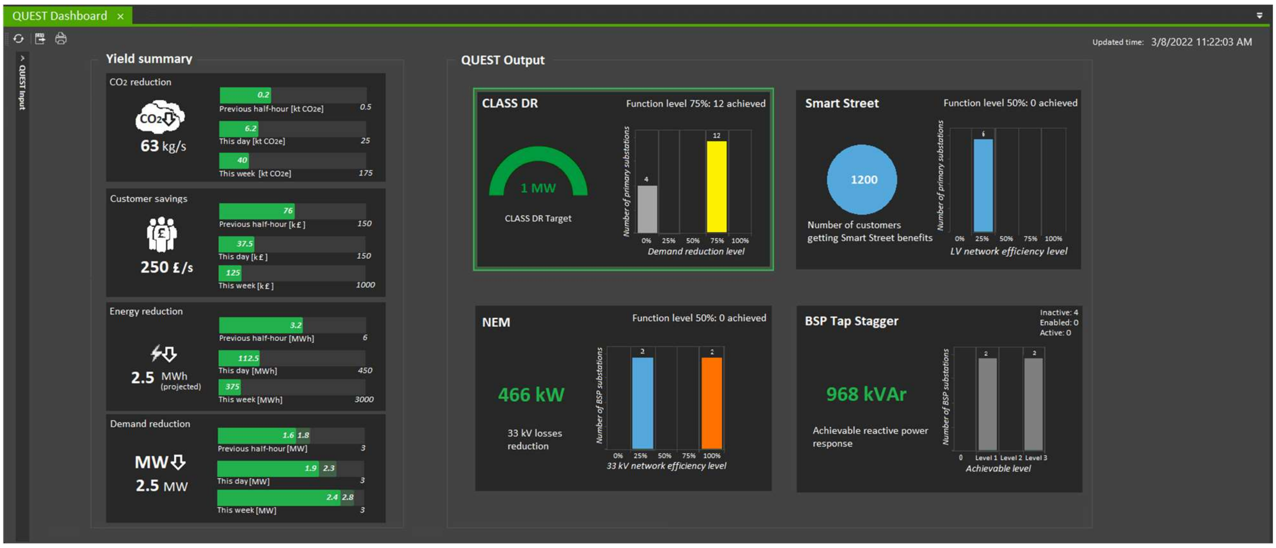


Figure 4-12 – QUEST Dashboard – Displaying only results

The results are divided into two sections: 'Yield summary' and 'QUEST Output'.

The Yield summary represents the key performance indicators through which the benefits of QUEST's real time operation can be observed. These data displays are determined based on the real time measured data representing the achieved network state and the simulated (counter factual) network state that is likely to have occurred without QUEST operating in real time.

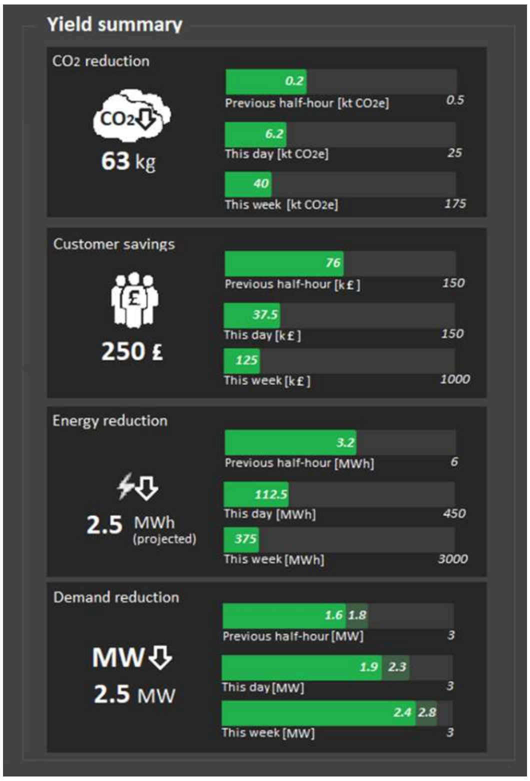


Figure 4-13 – QUEST Dashboard – Yield summary section

As it can be seen in Figure 4-13, within the Yield summary, four types of yields, over four temporal domains, are shown, each in separate tile.

The four types of yields are:

- CO_2 reduction,
- Customer savings,
- Energy reduction,
- Demand reduction.

The four temporal domains are:

- Present (or projected in case of energy reduction),
- Previous half hour,
- This day (since start of day (00:00:00)),
- This week (since Monday morning (00:00:00)).

The present value for each yield is shown in the left part of the tile, together with the appropriate icon (graphical representation of the yield). The present demand reduction refers to the total demand reduction that is achieved through NEM, CLASS and SMST operation. Energy reduction for the present temporal domain is a projection of the present demand reduction value over one hour, so the value is equivalent to the present demand reduction, but the unit is displayed as MWh (projected). Since the present CO_2 reduction and customer savings are calculated based on the present demand reduction, their units for present values are shown in kg and £.

Historical values for previous half-hour, this day, and this week, are represented through the bar charts, in the right part of the tiles. Each bar has a range value defined that is shown in the right end of the bar. The range values are set by the CE through the QUEST Dashboard window options. Bar charts representing three temporal domains for demand reduction, are displaying the average and peak MW demand reduction within that period. The first value in the bar represents the average value of demand reduction, and the second value (darker green) represents the peak demand reduction over a period. Temporal domain values for energy reduction refer to the amount of the energy reduced over each period. Customer savings and CO_2 reduction temporal domain bars represent the overall customer savings and carbon reduction over each period.

In the right part of the QUEST Dashboard window, the outcome of the QUEST coordination is provided (QUEST Output section). For each voltage control technique that QUEST coordinates the relevant data sets are presented in graphical/numerical form. The relevant data refers to the configured function level and whether it is achieved or not. QUEST Output section is displayed in Figure 4-14.

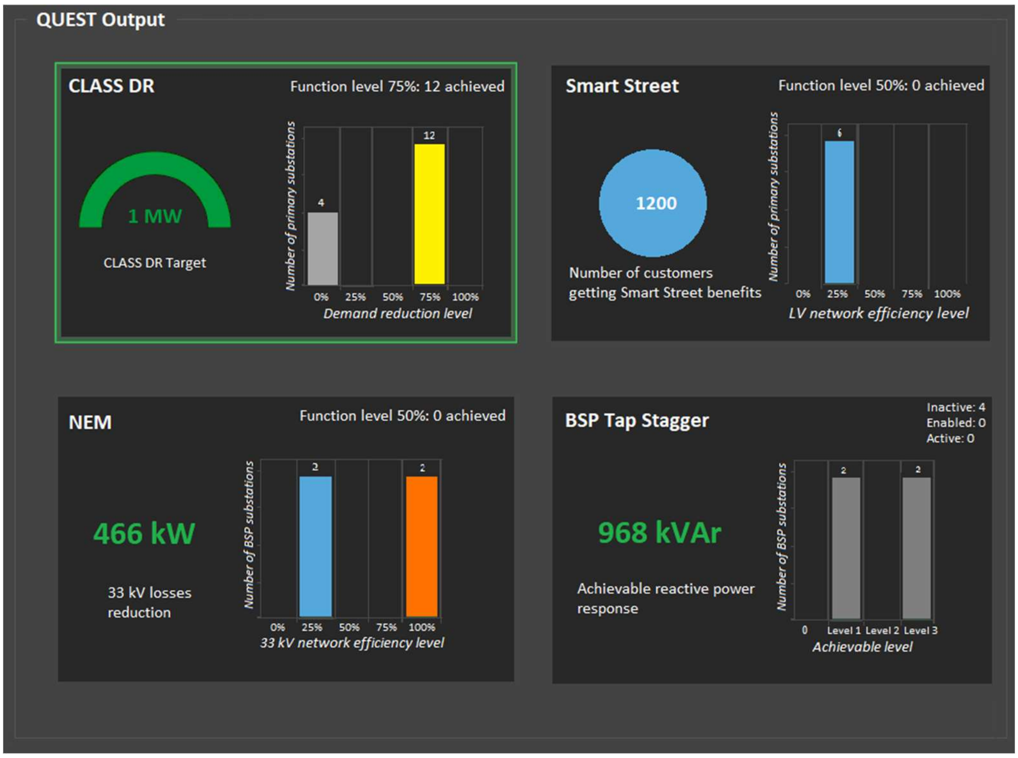


Figure 4-14 – QUEST Dashboard – QUEST Output section

For CLASS, the committed MW target for the current half an hour interval is presented as well as the information whether it is satisfied or not. If the MW target is satisfied, the bar representing CLASS DR/DB target in the CLASS tile is all green. If the MW target is not satisfied, the shortfall in providing the MW services is also displayed. In this situation the bar representing the MW target is coloured green until it reaches the MW value achieved with all CLASS primaries being enabled. The difference between that value and the MW target value represents the shortfall in providing the MW services. The bar charts representing CLASS DR/DB function levels are also presented in the CLASS section. The number of CLASS primaries for each function level is also shown ("Demand reduction level" section in CLASS tile). The tile also provides information regarding the number of CLASS primaries on which the desired CLASS function level is achieved ("Function level %" section in CLASS tile. From the example displayed in Figure 4-14, it can be seen in the top right corner of CLASS tile, that the desired function level of 75% is achieved on 12 CLASS primaries.

For SMST, the number of customers gaining some level of SMST benefits is presented, as well as the bar charts representing the levels of the SMST LV efficiency. Unlike the CLASS tile, the SMST tile does not present the target value, since the SMST target is full CVR mode, meaning that, if not in a safe mode, SMST reduces voltage values as close as possible to the ESQCR limit in order to reduce the demand. In the example shown in Figure 4-14 all SMST transformers are put in a safe mode that suits CLASS DRTQ function level and are displayed within the 25% bar. Also, the pie chart representing the number of customers gaining benefits from SMST is coloured in the same colour as the 25% bar since all SMST transformers are in the same safe mode. If for example some of SMST transformers were in 75% LV efficiency, the pie chart would have additional colour (yellow) representing the number of customers supplied from transformers which have 75% function level applied. The same as in CLASS tile, "Function level %" section is also displayed in the top right corner of SMST tile indicating the number of SMST transformers on which this level is achieved. In the example presented, it can be seen that the number is zero, meaning that the desired level of 50% of LV efficiency is not achieved on any of the SMST transformers due to CLASS adjustment.

Similarly, as for CLASS and SMST, the NEM tile also contains bar charts representing the number of BSP substations under different NEM levels, as well as the “Function level %” section. This tile also indicates the 33kV network losses reduction and does not contain any target value, since NEM target is the maximum 33kV network efficiency.

The section related to BSP TSF is different from the other sections. Since BSP TSF in most of the cases will not be enabled at the moment when QUEST performs coordination actions, its activation status per each BSP substation at the moment is presented (inactive, enabled, active). In the example provided in Figure 4-14, BSP TSF is inactive on 4 BSP substations at the moment. It is not enabled or activated on any of BSP substations so the number for those states is zero. Since QUEST is not aware on which BSP transformers TSF will be enabled when coordination is performed, it can only determine what is the present achievable level of TSF per each pair of BSP transformers. This is determined based on the tap positions of BSP transformers at the moment when coordination is performed. Bearing that in mind, in the bar charts related to BSP TSF, the achievable level for each BSP is presented. Also, in accordance with the achievable levels of BSP TSF, achievable reactive power response is also determined and displayed on the dashboard. Achievable reactive power response value represents the aggregated value for all the BSPs. More details regarding BSP TSF are provided in the “Methodology” section.

As mentioned in the section “QUEST Contention Management Process”, the Output tile from the CMP displays the same data as the QUEST Dashboard. The only difference is that for the CMP’s Output report the Yield Summary data are not displayed. This section is not shown in the Outcome report due to the two following reasons:

- The purpose of Yield summary section is to provide insight into benefits gained after QUEST real time operation is activated.
- Yield summary data are determined based on the real time data populated after QUEST coordination is performed. Since the CMP is the simulation process through which QUEST actions are not actually executed, the Yield summary data cannot be determined.
- The purpose of the CMP is to fine tune the function levels and technique priorities, and to prepare QUEST for real time operation.

5. METHODOLOGY

5.1. Network efficiency

One of the three core operational objectives of the QUEST overarching software is to enhance distribution network operational efficiency. To achieve this objective, QUEST Network Efficiency Mode (NEM) has been introduced within QUEST Overarching Software.

When QUEST is operating in NEM, the 33kV system voltage operates above nominal voltage by raising the tap position of the 132/33kV BSP transformers. QUEST determines the optimum level of the 33kV voltage increase in order to increase the network efficiency as much as possible, but in a way not to conflict other voltage control techniques. The levels of voltage increase applied by QUEST are predefined and are based on the results of the offline analysis. More details regarding the allowed levels of NEM are provided in section 5.3.1 "Coordinating NEM operation".

QUEST does not periodically re-optimise the target voltage of the 132/33kV BSP transformers in order to keep the 33kV network voltages within the statutory limits. The function of the enhanced AVC relay is to readjust the tap position of the 132/33kV BSP transformers to keep the voltages in the regulated point within the statutory limits.

The effect of NEM is evaluated based on the achieved reduction in the 33kV system losses. The reduction in losses is determined by comparing the losses value after NEM is applied and the estimated losses value that would exist without NEM being applied i.e. with BSP transformers maintaining the nominal voltage value.

5.2. CLASS enhancements within QUEST

Enhancements of CLASS functionality provided through the QUEST overarching software are as follows:

- CLASS scheduling functionality enhancements,
- Introduction of the additional levels of demand reduction (¼ - demand reduction (DROQ) and ¾ - demand reduction (DRTQ),
- BSP TSF.

The enhanced CLASS Dashboard within QUEST is displayed in Figure 5-1.

Figure 5-1 – Enhanced CLASS Dashboard within QUEST

5.2.1. CLASS scheduling mechanism enhancements

The main reason for a decision to enhance the CLASS scheduling functionality in QUEST is the fact that QUEST, as an overarching software, has awareness of all the voltage control techniques in the network. Thus, it can enhance CLASS scheduling functionality to enable CLASS primaries in a way that satisfies a CLASS committed target, but by trying to gain as much benefits as possible from the other voltage control systems (e.g. first enabling CLASS primaries that do not have SMST installed and thus providing the customer benefits from not putting SMST in a safe mode due to CLASS enablement where not required to meet the CLASS service target).

Another reason for enhancing the CLASS scheduling functionality through QUEST overarching software is the fact that the development of the CLASS Dashboard is closed. This being the case the functionality cannot be changed, but in order to test all the use cases during the QUEST trials, some enhancements needed to be provided.

The CLASS scheduling mechanism, as it is currently used in ENWL, provides scheduling of primary substations based on the defined half an hour targets, however only for Demand Reduction Full (DRF) services. The objective of QUEST is to coordinate the voltage control techniques by adjusting their function levels to satisfy their goals, but also to prevent them counteracting each other. In order to do so, QUEST needs the possibility of adjusting the levels of CLASS DR i.e. to use CLASS DR function level other than DRF services.

Currently, CLASS functionality is used in ENWL only for the provision of DR services. Thus, the DR targets for half-an-hour periods can be imported into the CLASS dashboard from an external system. For CLASS demand boost (DB) that is not the case. CLASS DB services are currently not considered within the CLASS scheduler and DB targets for half-an-hour periods cannot be imported into the CLASS dashboard from an external system. Hence, in order to test the coordination of other systems with CLASS DB during the QUEST trials, this logic is also introduced through QUEST.

5.2.2. Additional levels of CLASS DR within QUEST

In order to introduce additional flexibility through the QUEST overarching software, additional levels of CLASS DR were considered throughout the QUEST design process. Since the CLASS SuperTAPP Relay can be enhanced to include additional levels of voltage reduction in addition to the existing ones (DRF and DRH), and due to the fact, the scheduling of CLASS primaries is already introduced in QUEST, the project team decided to test and trial these additional levels of voltage reduction through QUEST.

Summary of CLASS Demand Reduction functions (original and proposed):

- DRF – Demand reduction full: Target = 5% of nominal voltage[3] (11kV, 6.6kV), +/-0.7%, provides a 5.7% - 4.3% voltage reduction.
- DRTQ – Demand reduction three quarters: Target = 4%, +/-0.7%, provides a 4.7% - 3.3% voltage reduction.
- DRH – Demand reduction half: Target = 3%, +/-0.7%, provides a 3.7% - 2.3% voltage reduction.

[3] SuperTAPP's target voltage setting is a percentage of nominal and is set by ENWL. The voltage target adjustments for demand boost/reduction are also a percentage of nominal and are added to the target voltage when applied.

- DROQ – Demand reduction one quarter: Target = 2%, +/-0.7%, provides a 2.7% - 1.3% voltage reduction.

For this version of the QUEST project, additional levels of voltage change are introduced only for demand reduction. Additional levels for demand boost are left for any possible future phases.

NOTE: Since these additional levels of demand reduction are introduced through QUEST, the QUEST architecture is extended to consider the effect of each CLASS DR level on other voltage control techniques (NEM and SMST) and to determine the allowed levels of other techniques in accordance with CLASS DR levels. For each CLASS DR level, a safe mode (CLASS-DR-SM) is introduced for NEM and SMST. A safe mode for NEM and SMST for each CLASS DR level represent the level of NEM voltage increase and the level of SMST voltage reduction that can be applied in order not to conflict with each level of CLASS DR. More details regarding NEM and SMST coordination with CLASS are provided in the section 0“QUEST coordination under normal operating conditions”.

5.2.3. TSF on a BSP level

Tap Stagger Functionality (TSF) on a primary substation level is currently supported through the CLASS Dashboard. Similarly, as for the additional levels of CLASS DR, since the SuperTAPP Relay on BSP transformers can be enhanced to support TSF, it is agreed to introduce and test this functionality through QUEST. Three stages of TSF are provided for BSP transformers, which are effectively 2 taps apart (TS1), 4 taps apart (TS2) and 6 taps apart (TS3) from one another.

The effect of each TSF stage on a BSP level (in terms of additional MVAr absorption) is determined in a QUEST calculation and presented through the enhanced CLASS Dashboard in QUEST. Based on the presented TSF MVAr response from each BSP, the CE is able to determine on which BSPs, TSF should be enabled and activated. The enablement and activation of each stage of BSP TSF is performed manually by the QUEST CE.

5.3. QUEST coordination under normal operating conditions

One of QUEST’s core objectives is to coordinate voltage control techniques to try to gain, as much benefit as possible, from each technique and to prevent them from conflicting with one another. Also, by preventing the voltage control techniques from conflicting with one another, QUEST makes sure that the voltage profile across the whole DNO network is maintained within the required limits.

Conflicts between voltage management techniques, that use tap changers, can result in tap changers ‘running out’ of taps i.e. tapping to top (tap No 14/17/19) or bottom (tap No 1). Once the tap changer has ‘run out’ of further tap positions (taps) in one direction then no further voltage regulation can be achieved in that direction by the tap changer. If a tap changer is at tap 1, it cannot tap down any further therefore it cannot reduce the system voltage any further. If the voltage is above statutory limits the tap changer on tap 1 can do nothing to restore the voltage down inside those limits.

The first step in performing coordination among voltage control techniques is to determine the conflicts between them. In the remainder of this section, conflicts for each of the voltage control techniques are described, as well as QUEST’s expected behaviour for each of the detected conflicts.

All conflicts described are related to CLASS functions activation. In order to resolve detected conflicts or to prevent them from occurring, two types of coordination are introduced in QUEST:

- Proactive coordination,
- Responsive coordination.

Proactive coordination refers to QUEST's intervention where coordination is performed ahead of need in order to prevent conflicts from happening. In this situation QUEST reacts upon a CLASS functions enablement. Within this coordination type, voltage control techniques that are coordinated by QUEST, are put into a CLASS safe mode (CLASS-SM) in order not to cause conflicts upon a CLASS functions activation.

Responsive coordination refers to QUEST's intervention upon CLASS functions activation. In this situation, voltage control techniques are put in CLASS mitigation modes (CLASS-MM). Within this coordination type the conflicts are not prevented but resolved.

The list of all CLASS-SM and CLASS-MM is provided in Appendix, section 6.2 "QUEST terminology for normal operation".

5.3.1. Coordinating NEM operation

One of the conflicts that has been postulated with QUEST operating in NEM is with CLASS providing commercial services (except for DB). Raising the tap position of the 132/33kV BSP transformers results in the primary transformers (33/11kV or 33/6.6kV) fed from these BSP transformers to tap down to regulate the 11kV or 6.6kV voltage to the nominal target voltage. By doing so, sufficient tap capability is provided for DB. However, for CLASS DR functions, this is not the case. Hence, QUEST needs to coordinate the levels of NEM and CLASS DR in order for them not to counteract each other. Depending on the level of voltage reduction required by CLASS, QUEST determines allowed levels of 33kV network voltage increase. This increase will also allow the associated primary transformers to deliver the required voltage reduction i.e., the primary transformers retain a sufficient number of available tap positions to deliver the required DR. Since NEM potentially conflicts with the provision of the CLASS DR, the coordination between these two techniques is done proactively which means that NEM is put in a CLASS SM.

Based on the CLASS DR levels supported though SuperTAPP Relay, the NEM allowed levels (safe modes) are defined as follows:

- **0% of max 33 kV network efficiency - CLASS-DRF-SM** – this percentage of 33 kV efficiency means that NEM is put in a safe mode that corresponds to CLASS DRF enablement. Since the highest level of CLASS DR is applied to associated CLASS primaries, the lowest level of voltage increase on BSP transformers is allowed in order not to have a conflict between them. In this situation it is assumed that NEM will not be applied in order to provide enough room for DRF to be applied on primary transformers.
- **25% of max 33 kV network efficiency - CLASS-DRTQ-SM** – this percentage of 33 kV efficiency means that NEM is put in a safe mode that corresponds to CLASS DRTQ enablement.
- **50% of max 33 kV network efficiency - CLASS-DRH-SM** – this percentage of 33 kV efficiency means that NEM is put in a safe mode that corresponds to CLASS DRH enablement.
- **75% of max 33 kV network efficiency - CLASS-DROQ-SM** –this percentage of max 33kV efficiency means that NEM is put in a safe mode that corresponds to CLASS DROQ enablement - the highest safe mode level of voltage increase on BSP transformers, since the lowest level of voltage reduction (one quarter) is applied to associated CLASS primaries.

- **100% of max 33 kV network efficiency - NEM Full** – this means that no safe mode is applied to NEM since all associated CLASS primaries do not have CLASS DR enabled. E.g. 105% voltage target for 100% achievable 33kV efficiency in terms of network losses.

The target voltage for each NEM safe mode is predefined and determined based on the offline analysis.

The determination of allowed level of NEM in accordance with the level of CLASS DR and vice versa is done based on the QUEST configuration which defines voltage control technique priorities and desired function levels (see section 4.2.1 “QUEST ”).

Another conflict detected for NEM is with BSP TSF. This conflict is explained in section 5.3.4 “Coordinating BSP TSF”.

5.3.2. Coordinating Smart Street Operation

When operating in CVR mode, SMST lowers LV voltages towards the lower statutory limit (94% of nominal LV voltage (230V)) and performs actions to keep LV voltages as low as possible to continuously reduce the demand. It is expected that CVR is continually performed on all the distribution substations that have SMST installed. Activation of CLASS functions on parts of the network where SMST operates has a negative impact either on SMST operation or on providing committed CLASS services.

Activation of CLASS DR will cause LV voltages to drop below statutory limits where SMST is operating in CVR mode. For CLASS DR function this is not acceptable due to the frequency of service enablement. Also, where SMST responds to activation of CLASS DR functions, to raise LV voltages to the target CVR voltage, the associated LV demand increase will reduce the CLASS targeted demand reduction which is also not acceptable.

Where SMST responds to activation of CLASS DB to reduce LV voltages to the target CVR voltage, the associated LV demand decrease (caused by SMST actions) will in turn tend to reduce the CLASS targeted demand boost which is not acceptable.

In order to prevent these systems from counteracting one another, QUEST’s intervention is expected. This means that QUEST needs to coordinate the levels of SMST CVR and levels of CLASS DR/DB in order to prevent them counteracting each other.

Depending on the level of CLASS DR/DB, the allowed levels of SMST LV efficiency are determined. These allowed levels of SMST LV efficiency are defined as safe modes for SMST since in this situation proactive coordination is performed. Proactive coordination is performed in the case of SMST and CLASS coordination since QUEST is not able to determine when CLASS services will be needed and when CLASS will be activated by ESO. Due to this fact, QUEST is not able to perform the coordination actions prior to CLASS being activated. On the other hand, if coordination would be performed after CLASS being activated, SMST transformers, under normal operation, would not have enough time to react to a new target voltage and LV violations would be caused, which is not acceptable.

NOTE: SMST transformers have additional capability of fast tapping. This capability is agreed to be used to test responsive type of coordination between CLASS and SMST during the QUEST trial. This coordination is described in more details in section 5.3.6 “Responsive coordination type”.

Based on the CLASS DR levels supported though SuperTAPP Relay, the SMST allowed levels (safe modes) are defined as follows:

- **75%, 50%, 25%, 0%** of LV efficiency means that SMST is put in a safe mode due to CLASS functions enablement, but with a certain level of voltage reduction:
    - **75% - CLASS-DROQ-SM** - this percentage of LV efficiency means that SMST is put in a safe mode that corresponds to CLASS-DROQ enablement - the highest level of voltage reduction on SMST transformers, since the lowest level of voltage reduction (one quarter) is applied to associated CLASS primaries.
    - **50% - CLASS-DRH-SM** - this percentage of LV efficiency means that SMST is put in a safe mode that corresponds to CLASS-DRH enablement.
    - **25% - CLASS-DRTQ-SM** - this percentage of LV efficiency means that SMST is put in a safe mode that corresponds to CLASS-DRTQ enablement.
    - **0% - CLASS-DRF-SM** - this percentage of LV efficiency means that SMST is put in a safe mode that corresponds to CLASS-DRF enablement.
- **100% of LV efficiency –** this percentage means that SMST is performing in CVR mode and that no safe modes are applied by QUEST. SMST is allowed to operate in CVR mode on all distribution transformers supplied from primary substations that do not have CLASS functions enabled.

Based on the CLASS DB levels supported though the SuperTAPP Relay, the SMST allowed levels (safe modes) are defined as follows:

- **0% – CLASS-DBF-SM –** this percentage of LV efficiency means that SMST is put in a safe mode that corresponds to CLASS DBF enablement. The target voltage is determined in a way not to have LV voltage violations upon CLASS DBF deactivation.
- **50% – CLASS-DBH-SM –** this percentage of LV efficiency means that SMST is put in a safe mode that corresponds to CLASS DBH enablement. The target voltage is determined in a way not to have LV voltage violations upon CLASS DBF deactivation.
- **100% of LV efficiency –** this percentage means that SMST is performing in CVR mode and that no safe modes are applied by QUEST. SMST is allowed to operate in CVR mode on all distribution transformers supplied from primary substations that do not have CLASS functions enabled.

NOTE: 25%, 75% levels of LV efficiency are not supported in case of SMST coordination with CLASS DB since additional levels of DB are not introduced in this version of QUEST project.

Target voltage for each SMST safe mode is predefined and determined based on the offline analysis.

The determination of allowed level of SMST in accordance with the level of CLASS DR/DB and vice versa is done based on the QUEST PROFILE which defines voltage control technique priorities and desired function levels.

Moving SMST to a safe mode refers to:

- Sending the safe mode target voltage to all HV/LV SMST distribution transformers (takes up to 3 minutes to do this and achieve the new target voltage through SMST actions),
- Fixing HV/LV SMST distribution transformer taps after SMST has moved to the new target voltage.

5.3.3. Coordinating ANM operation

The only conflict postulated for ANM operation is with CLASS operation.

ANM, as a constraint management system whose primary goal is thermal protection of the network assets, takes priority over any CLASS actions. ANM should not be prevented from keeping the assets safe upon thermal violation occurrences regardless of the CLASS functions statuses. QUEST's intervention is expected only in a situation where ANM tries to release previously curtailed demand or generation once it detects additionally released capacity in the network due to CLASS DR or DB function activation, respectively. By releasing the constrained DER, ANM conflicts with CLASS's benefits, which is not acceptable and needs to be prevented. Additionally, since CLASS DR and DB are network-wide service provisions, constrained DER release prevention is also network-wide service provision requirement.

Based on the above statements, two ANM mitigation modes have been introduced: CLASS-DB-MM and CLASS-DR-MM. ANM is put in a mitigation mode, not a safe mode. This is because in case of coordinating ANM operation, QUEST reacts responsively upon CLASS's activation since ANM only needs to be coordinated in situations when it reacts to additionally created network capacity due to CLASS DR or DB activation.

CLASS-DB-MM prevents the release of constrained DER power export across the full area of the ANM controlled network and is activated and deactivated by QUEST when CLASS DB activation is changed.

A second ANM mode, CLASS-DR-MM, is provided to prevent the release of constrained DER power demand across the full area of the ANM controlled network and is activated and deactivated by QUEST when CLASS DR activation is changed.

The activation of ANM mitigation modes performed by QUEST is applied for all ANM systems in the QUEST trial area: Central ANM, Decentralised ANM and Cloud ANM.

5.3.4. Coordinating BSP TSF

After analysing the BSP TSF use case, it is concluded that QUEST's intervention is related only to NEM operation. NEM is performed on the same transformers as BSP TSF (BSP transformers). In the case of enabling BSP TSF, QUEST needs to make sure that there is enough 'tapping room'[4] on parallel transformers to perform the tap stagger. For example, if NEM (highest level of voltage increase - e.g., 105%) is active and then BSP TSF is enabled, there is a risk that one of the pair of BSP transformers will reach its maximum tap position before achieving the desired level of tap stagger i.e. a lack of 'head room'.

QUEST checks if BSP transformers have enough head room to tap up in the case of a TSF activation. If there is enough head room to perform TSF, QUEST does not intervene. Otherwise, QUEST's intervention is expected.

QUEST intervention depends on the technique's priorities defined through QUEST's configuration. If BSP TFS has priority over NEM, in case of conflict detection, QUEST automatically transits NEM into the next lower level of voltage increase to provide the possibility of performing reactive power response via BSP TSF (e.g., from 105% to 104% of 33kV). If this level of voltage increase also conflicts with BSP TSF, then QUEST moves NEM to the next lower level of voltage increase and so on (e.g., from 104% to 103% of 33kV).

4 The term 'tapping room' is shorthand for the concept of having enough available tap positions to fully perform a voltage management techniques function. When a function tends to make the AVC scheme tap down towards bottom tap (number 1 tap position) then the number of available taps is colloquially referred to as 'leg room'. When a function tends to make the AVC scheme tap up towards top tap (number 19 tap position at most BSPs) then the number of available taps is colloquially referred to as 'head room'.

In case that NEM has priority over BSP TSF, that means that the level of NEM cannot be automatically readjusted upon BSP TSF enablement. In that situation, QUEST reports an appropriate message to the user informing them that the chosen stage of BSP TSF is not feasible due to the applied NEM level. Examples of coordinating NEM and BSP TSP are provided in Appendix, section 6.3.2 “Workflow 2 – Coordination of BSP TSF, NEM, CLASS and SMST”.

Performing BSP TSF in a situation when NEM is not in use and the 132kV system is on a high voltage[5] has also been discussed. If the 132kV system is at its upper statutory voltage limit of +10% (145.2kV) then the BSP transformers need to tap down 6 taps to correct the 33kV side voltage to its normal (33 kV) value. BSP transformers normally have a nominal tap position of tap 7. This means it is likely that during a high 132kV voltage event the BSP tap changer will tap down 6 taps from 7 to 1, and that TSF will not be possible. In situations like these, since 275/132kV transformer tap changers (National Grid) are not under ENWL’s jurisdiction and cannot be operated by QUEST, then upon BSP TSF enablement, QUEST notifies the CE that TSF is not possible by reporting an appropriate alarm message.

5.3.5. Proactive coordination type

As explained in previous sections, in case of proactive coordination, QUEST performs coordination actions upon a CLASS functions enablement. Since it has been decided to enhance the CLASS scheduling mechanism within the QUEST overarching software, in case of proactive coordination type, QUEST is the system in charge of CLASS primaries enablement.

When this coordination type is configured, QUEST automatically disables the CLASS scheduling mechanism within the CLASS Dashboard in order not to have it overriding QUEST’s decisions.

Since QUEST is the system that automatically enables CLASS primaries, within this coordination type, it is the QUEST CE who has the ability to define the priorities on which the voltage control techniques are coordinated, as well as to define the desired function levels for each of them. For more details regarding QUEST configuration in case of proactive coordination, see section 4.2.1 “QUEST ”.

The ability to define different priorities among coordinated techniques is introduced within QUEST since these priorities may vary in time within the same utility and may differ between different DNOs.

Based on the configured technique priorities (TPL) and desired function levels (BLENDS), QUEST determines what is the optimal adjustment of each coordinated voltage control technique.

The TPL determines the starting point for QUEST’s algorithm. Based on the configured priorities, QUEST runs a simulation to determine whether the configured function level for each voltage control technique is achievable.

Desired CLASS DR function levels that could be configured through QUEST PROFILEs are as follows:

- **100% - demand reduction full (DRF)** – if this percentage is configured, QUEST will try to satisfy CLASS committed targets by applying the DRF on all the primaries needed.

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[5] A low 132kV system voltage is unlikely to be cause conflicts. If the 132kV system is on a low voltage (-10% or 118.8kV) then the BSP transformer will have to tap up 6 taps from 7 to 13 to maintain a secondary 33kV voltage. This would then leave 6 taps (19-13=6) for NEM and TSF. NEM maximum level is 5% voltage increase or 3 taps (1.67%/tap). Max Tap stagger would require three more taps in addition to the 3 for NEM. This is a total of 6 taps for NEM & TSF which a 19 tap BSP tap changer can still provide given a 118.8kV starting tap of 13.

- **75% - demand reduction three quarters (DRTQ)** - if this percentage is configured, QUEST will try to satisfy CLASS committed targets by applying the DRTQ on all the primaries needed.
- **50% - demand reduction half (DRH)** - if this percentage is configured, QUEST will try to satisfy CLASS committed targets by applying the DRH on all the primaries needed.
- **25% - demand reduction one quarter (DROQ)** - if this percentage is configured, QUEST will try to satisfy CLASS committed targets by applying the DROQ on all the primaries needed.
- 0% - no voltage reduction performed.

Also note that choosing a CLASS DR BLEND to be for example 50% (DRH) does not mean that QUEST should try to satisfy only 50% of the CLASS committed target, but to try to satisfy the whole amount by applying the DRH voltage reduction. Also, note that there is potential business process feedback required here to those setting the contracted CLASS targets if it is known that these will conflict with the desire to deliver a certain level of benefits from other services such as SMST. QUEST does not deal with this business process area, which is for the DNO to deliver, QUEST only presents the potential flexibility to deliver differing service levels through the QUEST setting of priorities and BLENDS.

The allowed levels of NEM and SMST are described in the previous sections ("Coordinating NEM operation" and "Coordinating Smart Street Operation"). These depend on the CLASS function level adjustment. The level of CLASS function that will be enabled is determined during the QUEST simulation based on the configured priorities. If CLASS is set as the highest priority technique, its function level is set in accordance with the CLASS configured function level (e.g. DRTQ). SMST and NEM are adjusted in accordance with CLASS adjustments in this case (both set to safe modes referring to CLASS-DRTQ). On the other hand, if SMST or NEM have priority over CLASS, their level is set in accordance with the QUEST PROFILE, and CLASS level is adjusted in a way not to cause conflicts with SMST or NEM. That means that in some situations, although CLASS function level is configured to perform higher voltage reduction (e.g. DRTQ), CLASS is adjusted to a lower function level (e.g. DRH) because higher levels of voltage reduction would conflict adjusted levels of SMST and NEM.

The examples of coordinating BSP TSF, NEM, CLASS and SMST in case of proactive coordination type are provided in Appendix, section 6.3 "Examples of QUEST's proactive coordination type".

5.3.6. Responsive coordination type

Responsive coordination is mainly focused on the coordination of CLASS and SMST operations.

As previously explained, in case of responsive coordination, QUEST reacts upon a CLASS functions activation. This process of coordination is always applied within QUEST when it coordinates the operation of ANM. For SMST coordination, it is configurable through QUEST PROFILE, whether proactive or responsive coordination will be used.

Responsive coordination type is related to the SMST transformers fast tap capability. When this capability is activated, SMST transformers do not wait the predefined initial time delay (default 180s) to readjust the tap positions when the voltage value is outside of the defined bounds, but they react instantaneously.

With the fast tap capability, SMST transformers are able to quickly react and increase the LV voltage prior to CLASS DR changing the primary substation transformer taps when activated. Hence, this approach enables QUEST to react responsively upon CLASS's activation instead of proactively. With this approach

SMST benefits for the customers are provided all the time, as SMST is put in a mitigation mode only for a short period until demand responds to a voltage reduction performed by CLASS.

The only risk with this approach is that the fast tap capability of SMST transformers is analysed only in theory and has not been proven in the field. Bearing this in mind, it was agreed that as a first step, only fast tap functionality will be trailed in the field in order to confirm whether it is feasible to incorporate it in the QUEST functionality in some future QUEST version. Nevertheless, the responsive coordination type is explained in detail in this document to present the concept and the conclusions made during the QUEST design. Based on the same reasons, the responsive coordination type option is presented on QUEST's UI, as can be seen on Figure 4-5, but no additional logic behind this option is implemented within the current QUEST version.

If the fast tap capability is confirmed to be suitable for QUEST responsive coordination type approach, it will be then considered and trialled within some future QUEST version. In the rest of this section, a proposal of how it would be included in QUEST in the future is explained.

As a first step, this type of coordination would be tested only when CLASS DR is performed and in a way that is currently used in the ENWL distribution network (only CLASS DRF is enabled and activated automatically by CLASS scheduler).

Bearing that in mind, for this type of coordination, the CLASS scheduling mechanism would be used for enabling CLASS primaries using DRF. The enhanced logic of scheduling CLASS primaries introduced for QUEST proactive coordination type would not be considered within this approach. This is the reason why the voltage control technique's priorities and function levels cannot be configured in the case of Responsive coordination type being chosen in the QUEST PROFILE (see section 4.2.1 "QUEST ").

In addition, QUEST would only determine which SMST substations are connected to CLASS primary substations selected for DRF. When CLASS is activated by the ESO via the Web Link, QUEST would be made aware of that signal, and at the same time as DRF is activated on all the selected primary substations, QUEST would send commands to all the affected SMST transformers to put them in a mitigation mode using the SMST fast tap capability (CLASS-DRF-FastTap-MM).

Putting the SMST in CLASS-DRF-FastTap-MM would refer to following actions:

- Enable fast tap option for all the affected SMST transformers,
- Tap up two taps to offset the primary transformer voltage reduction required by DRF,
- Fix the tap positions on the newly proposed positions for a period long enough to allow the CLASS DRF primary substation transformer voltage reduction (this prevents SMST adjusting transformer taps to attain the CVR target voltage before CLASS DRF has reached the target primary substation voltage reduction),
- Once CLASS DRF has activated and achieved the primary substation voltage reduction, release the associated SMST tap fixing and allow SMST to maintain the original pre-set target voltage.

By tapping up by two positions prior to the CLASS DRF voltage reduction performed on the primary substation transformers, SMST transformers would make sure that LV voltages do not drop below the statutory LV voltage limits at any time. Tapping up two taps at a SMST substation provides approximately a 5% voltage increase on the LV busbars.

After CLASS is deactivated and the primary substation and associated SMST voltages rise, all the SMST transformers would tap down to maintain their CVR target voltages.

NOTE: This option is valid until the penetration of Smart Street becomes too great to meet CLASS targets.

NOTE: A short time delay may need to be applied to CLASS DRF activation to ensure voltage drops below low statutory limit are prevented. The duration of this delay can be established during the QUEST trials.

If the fast tap functionality is confirmed to be suitable for QUEST responsive coordination type during the trials, it will be incorporated in some future QUEST versions and used as a coordination approach for many years ahead, until the penetration of SMST areas becomes too great to meet CLASS targets.

5.4. QUEST operation in case of emergency condition

In case of emergency condition activation, QUEST's objective is to enable provision of the emergency response to the ESO. That means that voltage control techniques will be put in appropriate mitigation modes (MM) by QUEST to prevent them conflicting the emergency response provision. The system conditions that refer to emergency states are SYSCONs 1-5. QUEST's behaviour in case of each of these condition activations is described in the remainder of this section. More details regarding each emergency SYSCON are also provided.

5.4.1. OC6 (SYSCON-4 & SYSCON-5)

OC6 mode is an emergency action manually performed by the DNO upon receiving the instruction from the ESO (this excludes OC6.6 – automatic low frequency demand disconnection). The DNO first gets a warning to prepare for the OC6. In the case of activating OC6, all primary substation transformers get the instruction to perform voltage reduction (3% or 6% voltage reduction) to reduce the demand (OC6.5 or OC6-VR are represented as SYSCON-5). These actions are performed regardless of the CLASS status on these primary substations (CLASS could even be providing DB commercial services at that moment). If the DR requirements are not satisfied upon performing the voltage reduction, manual demand disconnection (DD) is performed by opening HV CBs to disconnect demand in a controlled manner (OC6.7 or OC6-DD are represented as SYSCON-4).

It will be a business procedure to manually select these conditions in QUEST (selecting SYSCON-4 or SYSCON-5) prior to issuing the actual OC6 commands. This is to allow QUEST to prepare the voltage regulating techniques for the OC6 mode.

It will, also, be a business procedure to manually start the SYSCON-6 (normal operating mode), after the OC6 mode is deactivated in order to deactivate SYSCONs 4 & 5 from the perspective of QUEST.

5.4.1.1. OC6 and NEM

When SYSCON-5 is activated, NEM is switched off by QUEST. The reason for switching off NEM prior to activating the OC6-VR is to enable the primary substations to perform the expected voltage reduction to reduce the demand. Leaving the NEM on would cause 33kV voltages to be higher than nominal. This would in turn mean that downstream primary transformers must tap down to maintain their secondary voltage at 11kV or 6.6kV. The primary transformers would then be closer to their bottom tap (tap 1) than they would be if the NEM was off. Being on a lower tap position may affect the primary transformer capability to deliver voltage reduction to reduce the demand, which is not acceptable in the case of OC6-VR activation.

In the case of SYSCON-4 activation, NEM being switched on does not affect the process of demand disconnection and, hence, it is not switched off by QUEST. When SYSCON-4 activates, NEM is locked in whatever voltage target setting the BSP transformer was in before this condition was activated. Therefore, NEM either stays at its prior voltage level or stays off (at its normal voltage target level). This is because if OC6-DD is enacted after OC6-VR has already occurred (and is still in place), then QUEST needs to ensure that the process of demand reduction via OC6-DD is not altered or interfered with by increasing or reducing the level of NEM at the BSPs. If OC6-DD is activated without OC6-VR having been activated (before or at the same time as OC6-DD) then the same action is still appropriate i.e., lock NEM at the prior voltage target level.[6] In the case of locking NEM, QUEST will not be allowed to change the target voltage of the BSP transformers for any reason, until the OC6-DD-MM (SYSCON-4) is deactivated.

5.4.1.2. OC6 and Smart Street

Since this is an emergency, it is permitted to allow voltages to be below the outside statutory limits[7]. In the case of activating the voltage reduction, SMST, if enabled, would react to low voltage violations, and would try to fix them by increasing the target voltage value of distribution transformers which would conflict with the OC6 VR. Having that in mind, in the case of a SYSCON-5 selection in QUEST, global action for fixing all the SMST transformers on their current tap positions is performed prior to manually carrying out OC6 actions.

In the case of SYSCON-4 selection, SMST is locked in whatever voltage target setting it was in before SYSCON-4 was selected. The reason for that is the same as for NEM coordination, to ensure that the process of demand reduction via OC6-DD is not altered or interfered with by increasing or reducing the level of SMST CVR.

5.4.1.3. OC6 and ANM

Similar to coordination with CLASS DR and with LFDD, ANM needs to be prevented from releasing any curtailed demand in case of an OC6 mode activation. In the case of selecting either SYSCON-4 or SYSCON-5, a global action for putting ANM into OC6-MM will be sent network wide.

5.4.1.4. OC6 Mode Coordination

SYSCON-4 and SYSCON-5 are manually activated through the SYSCON Selector. It will be a business procedure to activate these states in QUEST prior to manually issuing the actual OC6 commands. Upon selecting one of these states, QUEST is automatically triggered to perform appropriate OC6 mitigation mode

[6] Activating OC6-VR after OC6-DD has already been activated is unlikely to happen and has not been analysed from QUESTs perspective. The expected sequence of operation is starting OC6-VR and then OC6-DD, if needed, or starting OC6-DD right away.

[7] The justification for this assertion is in the de-facto operation of OC6.5 via voltage reduction for many decades in GB. When a 6% voltage reduction is applied under OC6.5 this changes the AVC relays target voltage to 0.94 p.u. Legacy AVC relays (AVE 3) had electromechanically set dead bands. These were up to +/-2% in magnitude (ENWL SuperTAPP SG relays are set to 1.4% normally). This means that applying a 6% voltage reduction under OC6.5 on a legacy AVC scheme could result in a voltage reduction at 11kV of up to 8% or 0.92 p.u. This is 2% below the statutory 11kV voltage limits, hence these limits must not apply during OC6.

(OC6-MM) actions on the whole trial area. Since there is a difference in QUEST's behavior upon activating these two states, OC6-VR-MM and OC6-DD-MM are introduced.

The list of voltage control techniques affected by OC6 and QUEST's intervention regarding each technique is presented in the table below.

Table 1 – QUEST's behaviour in case of OC6 modes activation/deactivation

Emergency condition/Affected techniques	ANM	NEM	Smart Street
OC6 VR Activated	**OC6-VR-MM**: Putting ANM in OC6-MM network-wide (preventing the release of the previously curtailed demand).	**OC6-VR-MM**: Switching off NEM at all the BSPs.	**OC6-VR-MM:** Fixing all the SMST transformers on their current tap positions.
OC6 DD Activated	**OC6-DD-MM:** Putting ANM in OC6-MM network-wide (preventing the release of the previously curtailed demand).	**OC6-DD-MM:** Locking NEM at all the BSPs in whatever voltage target setting the BSP transformers were in before SYSCON-4 was activated.	**OC6-DD-MM:** 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).

5.4.2. LFDD (SYSCON-2 & SYSCON-3)

In case of LFDD activation, circuit breakers on BSP level (33kV circuit breakers) are tripped (depending on the frequency threshold set), creating disconnected sections of the network that are no longer energised, until the system frequency returns within predefined limits and the ESO instructs that disconnected demand can be restored.

Once all the BSP circuits are disconnected via LFDD, it does not matter what NEM, CLASS, SMST and ANM are doing since these parts of the network are disconnected from the grid. The conflicts that need to be resolved are related to the BSP circuits not disconnected via LFDD.

QUEST's behaviour is the same in the case of automatic LFDD activation (SYSCON-2) and manual LFDD activation (SYSCON-3).

5.4.2.1. LFDD and NEM

In the case of LFDD activation, QUEST switches off NEM. There are several reasons for switching off NEM. The first one is that in the case of an under-frequency emergency situation, the issue of network efficiency becomes a low level of priority compared with the system stability. Energy saved by network efficiency is only significant in the long term and is negligible in the context of trying to balance the electricity system. The second is that of demand restoration becomes a higher level of priority for the DNO control room than network efficiency during emergency conditions. The third reason is that after an LFDD event has occurred at a BSP, parts of the network below the 33kV circuit breaker are disconnected from the grid. At these network areas, NEM being on or off is irrelevant. However, if the NEM is turned off, then the BSP transformer automatic voltage control relay will reduce the tap position until the normal 33kV target voltage is restored. This means that once the ESO instructs the DNO that it is now safe to restore the demand, any 33kV connected demand will be restored at a lower voltage leading to a reduced demand (assuming no manual CE intervention). For Primary connected loads, this will also be the case as their tap position will have been constant from the time of the LFDD event to the time of 33kV restoration. These will therefore be on a reduced tap position (to cope with the network efficiency mode higher voltage prior to the LFDD) and this will mean their 11kV system restoration voltage will be lower. This will usually lead to a reduced demand. This slight demand reduction, compared to the one with network efficiency mode on, will help keep the system frequency from reducing once again (noted that on supply restoration demand can be higher than the pre-supply disconnection condition).

5.4.2.2. LFDD and CLASS

In case of LFDD activation, CLASS remains in its current state. Since CLASS is manually activated by the ESO, it is assumed that in this emergency condition, CLASS DB will never be activated. CLASS DR activation, on the other hand, can only provide additional response in this situation and thus, there is no need for QUEST's intervention in this situation.

5.4.2.3. LFDD and Smart Street

In the case of LFDD activation, the demand is disconnected to ensure that the electricity network remains stable when there is a shortage of active power generation to meet GB demand. The assumption is that in this situation, there will be no voltage issues on the BSP circuits not disconnected via LFDD and that SMST will not need to increase the distribution transformers taps to return the voltages within the statutory limits. Having that in mind it can be concluded that SMST will not perform actions which would conflict with LFDD, and thus, there is no need to put SMST into LFDD mitigation mode (LFDD-MM). This assumption assumes that the ESO controlled transmission network voltage remains relatively stable during LFDD operations. However, it is recognized that how the transmission grid voltage at the 132kV side of the BSPs behaves during a low frequency event that activates an automatic LFDD action has a degree of uncertainty.

NOTE: If CLASS is enabled on any primary connected to a BSP circuit not disconnected via LFDD, SMST will already be in a CLASS-SM.

5.4.2.4. LFDD and ANM

ANM will continue to manage DERs in real time to ensure network thermal limits are not exceeded. ANM adherence to network thermal limits is a priority even at the expense of conflicting with the LFDD actions. This is an acceptable conflict.

What is not an acceptable conflict is ANM releasing previously curtailed demand once it detects additional released demand capacity in case of LFDD being active. Hence, in the case of LFDD activation, ANM is put in LFDD-MM, preventing it from releasing curtailed demand (it is allowed to release curtailed generation if it detects that is safe to do so) as long as the network thermal limits are not exceeded (ANM must always be allowed to control DER to keep the network within the defined thermal limits in real time).

5.4.2.5. LFDD Mode Coordination

LFDD can be activated automatically (SYSCON-2) or manually by the QUEST CE (SYSCON-3).

In case of automatic LFDD activation, the QUEST system will detect “LFDD alarms” coming in from the DNO’s SCADA system. Multiple SCADA alarms will be reported, one per each relay, that has reacted to an under-frequency situation. QUEST will automatically trigger, upon a configurable number of SCADA alarm appearances within the configurable time period and perform LFDD-MM actions on the whole network. The default value of number of LFDD alarms is three, unique, alarms within period of 10 seconds[8]. The three LFDD alarms must be unique i.e. from three different BSP transformers. SYSCON-2 cannot be activated by sending three LFDD alarms from the same BSP transformer, such as during protection testing.

The list of voltage control techniques affected by LFDD and QUEST’s intervention regarding each technique is presented in the Table 2.

QUEST’s intervention in the case of automatic and manual LFDD activation is the same.

QUEST does not intervene in CLASS’s and SMST’s operation.

LFDD deactivation is a manual operation. The DNO receives instructions from the ESO to restore previously LFDD shed load. It will be a business procedure to return QUEST from the LFDD-MM upon LFDD deactivation by selecting the SYSCON-6 (normal operating condition) in order to deactivate SYSCONs 2 and 3.

Table 2 – QUEST’s behaviour in case of LFDD mode activation/deactivation

[8] This time period has two constraints. Choosing the lowest possible time period reduces QUEST’s reaction time to the LFDD event. This quick reaction time is desirable because it will reduce the risk of QUEST performing actions that are counter to the needs of the national electricity system during an LFDD event. In addition, a low time period reduces the risk of on-site protection testing of LFDD relays from causing a mal activation of the QUEST SYSCON 2 (Auto LFDD) state. On the other hand, if the time period is set too low then there is a risk that the LFDD alarms may not occur on-site at exactly the same time (due to transient system frequency deviations) or due to SCADA delays. 10 seconds should be enough time to overcome any transient system effects and SCADA delays whilst making the likelihood of protection testing causing a mal-activation and QUEST adverse actions to be low.

Emergency condition/Affected techniques	ANM	NEM
LFDD Activated	**LFDD-MM:** Putting ANM systems in LFDD-MM network-wide (preventing the release of the previously curtailed demand).	**LFDD-MM:** 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 techniques' priorities and function levels (BLENDs).

5.4.3. System recovery (SYSCON-1)

A System Recovery or Black Start event (SYSCON-1 State) has yet to occur after more than 80 years of National Grid operation in GB. Since this SYSCON has never happened so far, QUEST's behaviour in this situation is not determined for this QUEST research and trial project.

For SYSCON-1 (Black Start), it was agreed to provide an additional button on QUEST's User Interface (UI) that refers to this system state, but no additional logic behind this button will be implemented within QUEST.

5.5. Event of loss of system communication

When it comes to a loss of communications, there are two situations:

- Loss of communication with the devices in the field,
- Loss of communication between QUEST and the Decentralised ANM and Cloud ANM.

NOTE: Since other techniques that QUEST is coordinating are located within the NMS environment, QUEST will always be aware of their statuses. This communication cannot be lost.

In the case of loss of communication with devices in the field, each of the systems that QUEST is coordinating should have its own logic for the event of loss of communication. This logic is in accordance with the local controllers of the devices that each system considers in its voltage optimisation (e.g. CLASS SuperTAPP AVC relays will reset to their default settings after a pre-determined reset timer setting, SMST AVC relays will stay in the mode they were last commanded to perform, etc.). QUEST as a central, overarching software should not intervene in this situation. QUEST should only be aware that the communication with devices in the field has been lost and should not send commands to those devices (e.g. do not send commands to SMST transformers to transit to a particular safe mode).

NOTE: The behaviour of NEM in the case of loss of communication with the controller in the field will be adjusted by adding a new SuperTAPP relay setting to determine the timeout for resetting commands/setpoints after a loss of comms is detected.

A special situation of loss of communication with the devices in the field is when the communication with CLASS primaries is of good quality, but the communication with SMST transformers has been lost. In this situation, QUEST will not be able to put SMST transformers in appropriate safe modes upon CLASS enablement/activation. In this situation, automatic QUEST intervention is performed. Since it is aware of all the CLASS primaries supplying SMST transformers with the lost SCADA communication, QUEST disables/inhibits CLASS on all those primaries and tries to compensate the provision of services by enabling CLASS on other primaries that do not supply SMST transformers, if such exist. Additionally, the QUEST CE is notified that QUEST automatically intervened due to a loss of communication with the SMST transformers by reporting an appropriate alarm message.

Loss of communication is an unusual situation where the principal objective is to keep the system operating safely within its boundaries. The degradation of the actual SMST services to customers or CLASS services in this situation is the secondary issue which can be tolerated.

In case of a loss of communications between QUEST and the Decentralised ANM or Cloud ANM, ANM systems continue operating based on the operating state in which they were prior to the communication being lost. E.g. if the decentralised ANM is running in the normal mode of operation and at some point, communication with QUEST is lost, it will continue operating in that mode of operation. If for example CLASS is activated while QUEST and the external ANM systems do not have good communication, QUEST is not able to send appropriate commands to these systems. In this situation, it is acceptable to have ANM counteracting the CLASS benefits, since the ANM systems are constraint management systems and their main role is protection of the network assets. Additionally, in this situation, an appropriate alarm message is reported to the QUEST CE to make the CE aware of the potential degradation of CLASS benefits since ANM systems will continue working in the normal mode of operation.

6. APPENDIX

6.1. QUEST messages

A list of QUEST messages is given in the Table 3. For each message, a default type of message (alarm or event) and description are also given.

Table 3 – QUEST event and alarm messages

Message	Type	Description
QUEST is started on GSP {ID}.	Event	The message appears when the CE starts QUEST for one GSP (Whitegate GSP area for QUEST trials).
QUEST is turned off on GSP {ID}.	Event	The message appears when the CE stops QUEST for one GSP (Whitegate GSP area for QUEST trials).
QUEST is triggered on CLASS target change.	Event	Upon CLASS target change, QUEST will be triggered, and this message will appear.
QUEST is triggered due to CLASS primary {ID} unavailability.	Event	When CLASS primary becomes unavailable (inhibited, test, contribution is zero), QUEST will be triggered, and this message will appear.
QUEST is triggered on CLASS {Name of the CLASS function} activation.	Event	This message will appear when QUEST is triggered on CLASS activation. QUEST will be triggered on CLASS activation in the following situations: • In a case of responsive coordination (fast tap), to create actions for SMST transformers. • To send an appropriate MM for ANM.
QUEST is triggered on {emergency condition name} activation.	Event	The message appears when the CE sets emergency system condition within the QUEST Control & Monitoring window (OC6 VR (5)/

		OC6 DD (4)/ LFDD (3&2)/ BLACK START (1)), while QUEST Real Time Control is activated.
QUEST is triggered on {emergency condition name} deactivation.	Event	The message appears when user sets NORMAL system condition within the QUEST Control & Monitoring window, while QUEST Real Time Control is activated.
QUEST is triggered on BSP TSF enablement.	Event	This message appears when BSP TSF has priority over NEM and current level of NEM conflicts with required level for BSP TSF. QUEST will be triggered, to readjust the level of NEM.
System condition has been changed to {SYSCON Name}.	Event	The message appears when the user changes SYSCON within the QUEST Control & Monitoring window (NORMAL (6)/ OC6 VR (5)/ OC6 DD (4)/ LFDD (3&2)/ BLACK START (1)).
Network Efficiency is blocked on BSP {ID}.	Event	Upon manually blocking NEM for one BSP, this message will appear.
Network Efficiency is unblocked on BSP {ID}.	Event	Upon manually unblocking NEM for one BSP, this message will appear.
Central ANM will be prevented from releasing previously curtailed demand.	Event	This message appears when QUEST changes Central ANM mode (due to CLASS DR/LFDD/OC6 VR/OC6 DD activation).
Decentralised ANM will be prevented from releasing previously curtailed demand.	Event	This message appears when QUEST changes Decentralised ANM mode (due to CLASS DR/LFDD/OC6 VR/OC6 DD activation).
Cloud ANM will be prevented from releasing previously curtailed demand.	Event	This message appears when QUEST changes Cloud ANM mode (due to CLASS DR/LFDD/OC6 VR/OC6 DD activation).
Central ANM will be prevented from releasing previously curtailed generation.	Event	This message appears when QUEST changes Central ANM

		mode (due to CLASS DB activation).
Decentralised ANM will be prevented from releasing previously curtailed generation.	Event	This message appears when QUEST changes Decentralised ANM mode (due to CLASS DB activation).
Cloud ANM will be prevented from releasing previously curtailed generation.	Event	This message appears when QUEST changes Cloud ANM mode (due to CLASS DB activation).
Central ANM is returned to normal mode of operation.	Event	This message appears when QUEST returns Central ANM to normal mode upon CLASS DB/CLASS DR/LFDD/OC6 VR/OC6 DD deactivation.
Decentralised ANM is returned to normal mode of operation.	Event	This message appears when QUEST returns Decentralised ANM to normal mode upon CLASS DB/CLASS DR/LFDD/OC6 VR/OC6 DD deactivation.
Cloud ANM is returned to normal mode of operation.	Event	This message appears when QUEST returns Cloud ANM to normal mode upon CLASS DB/CLASS DR/LFDD/OC6 VR/OC6 DD deactivation.
Command is sent to device {ID}.	Event	This message appears when command is issued to device (BSP transformers, CLASS primaries, SMST transformers), but command execution is still not verified.
Command to device {ID} is successfully executed.	Event	This message appears when command is successfully executed (device responded to the command).
QUEST PROFILE {name} has been created.	Event	The CE created the QUEST PROFILE.
QUEST PROFILE {name} has been updated.	Event	The CE updated the QUEST PROFILE.
QUEST PROFILE {name} has been removed.	Event	The CE removed the QUEST PROFILE.

QUEST PROFILE {name} has been applied to GSP {ID} for QUEST Real Time Control.	Event	A QUEST PROFILE is assigned to the GSP, for QUEST Real Time Calculation.
QUEST time schedule {name} has been created.	Event	The CE created QUEST time schedule.
QUEST time schedule {name} has been updated.	Event	The CE updated QUEST time schedule.
QUEST time schedule {name} has been applied to GSP [ID] for QUEST Real Time Control.	Event	A QUEST time schedule is assigned to the GSP, for QUEST Real Time Calculation.
Communication with Decentralised/Cloud ANM is lost.	Alarm	An alarm will be reported to notify the CE that communication with the external ANM systems has been lost.
Chosen level of BSP TSF for BSP {ID} is not feasible. NEM has priority over BSP TSF.	Alarm	Upon BSP TSF enablement, when NEM is set as a higher priority technique than BSP TSF, QUEST notifies the CE if the chosen level of BSP TSF is not feasible.
Chosen level of BSP TSF for BSP {ID} is not feasible. NEM could not be readjusted since CLASS has priority over BSP TSF.	Alarm	Upon BSP TSF enablement, when BSP TSF is set as a higher priority technique than NEM, QUEST tries to readjust the level of NEM. If QUEST determines that adjusting the level of NEM would conflict with CLASS, NEM would not be readjusted since CLASS has priority over BSP TSF and this alarm will be displayed to the CE.
Chosen level of BSP TSF for BSP {ID} is not feasible. BSP tap changer is on its lowest tap position.	Alarm	This message appears upon BSP TSF enablement in a situation when NEM is not in use, but there are not enough tap positions to perform BSP TSF due to high voltage value set on a GSP transformer.
CLASS DR inhibited for primary substations {ID} due to loss of SCADA communication with associated SMST transformers.	Alarm	This message appears in situation when SCADA communication with SMST transformers is lost, and it is of good quality for CLASS primaries. Since SMST transformers cannot be put in CLASS-SM, all

		associated CLASS primaries are inhibited by QUEST.

6.2. QUEST terminology for normal operation

The list of QUEST terminology related to operation under normal system conditions is provided in the table below.

Table 4 - QUEST terminology for normal operation

No	Voltage control technique	Safe mode	Description
1.	NEM	CLASS-DRF-SM	Safe mode[9] that is applied to NEM upon CLASS DRF enablement.
		CLASS-DRTQ-SM	Safe mode that is applied to NEM upon CLASS DRTQ enablement.
		CLASS-DRH-SM	Safe mode that is applied to NEM upon CLASS DRH enablement.
		CLASS-DROQ-SM	Safe mode that is applied to NEM upon CLASS DROQ enablement.
2	SMST	CLASS-DRF-SM	Safe mode that is applied to SMST upon CLASS DRF enablement.
		CLASS-DRTQ-SM	Safe mode that is applied to SMST upon CLASS DRTQ enablement.
		CLASS-DRH-SM	Safe mode that is applied to SMST upon CLASS DRH enablement.
		CLASS-DROQ-SM	Safe mode that is applied to SMST upon CLASS DROQ enablement.
		CLASS-DBF-SM	Safe mode that is applied to SMST upon CLASS DBF enablement.
		CLASS-DBH-SM	Safe mode that is applied to SMST upon CLASS DBH enablement.
		CLASS-DRF-FastTap-MM	Mitigation mode in which SMST is put when responsive fast tap coordination is performed.
3	ANM	CLASS-DR-MM	Mitigation mode in which ANM is put upon CLASS DR activation.

[9] "Safe mode" terminology is used for coordination actions performed by QUEST prior to CLASS activation, i.e., upon CLASS enablement, while "mitigation mode "terminology is used for coordination actions performed upon CLASS activation.

		CLASS-DB-MM	Mitigation mode in which ANM is put upon CLASS DB activation.

6.3. Examples of QUEST’s proactive coordination type

In the remainder of this section, through the two workflows examples, proactive coordination between different voltage control techniques performed by QUEST is explained in detail. These examples are focused to better explain how NEM and BSP TSF are considered within QUEST’s prioritisation process in addition to prioritising CLASS and SMST.

Within the first workflow, to simplify the examples, only NEM, CLASS and SMST are considered within the prioritisation process. Within the workflow 2, additional complexity is introduced by including the BSP TSF in the priority list, as well.

6.3.1. Workflow 1 – Coordination of NEM, CLASS and SMST

Within this workflow, examples of coordinating NEM, CLASS and SMST are provided. BSP TFS is not considered. Since three different voltage control techniques are prioritised within this workflow, TPL provides 6 possible priority combinations. Not all of them are analysed in the examples below. Three combinations are chosen at random with the approach that in each example a different voltage control technique is chosen as the highest priority technique.

6.3.1.1. Example 1 – SMST as a highest priority technique

In this example SMST is chosen as the primary technique (highest priority). The secondary technique is CLASS and NEM tertiary.

The TPL and the configured function levels (BLENDs) are presented on the figures below.

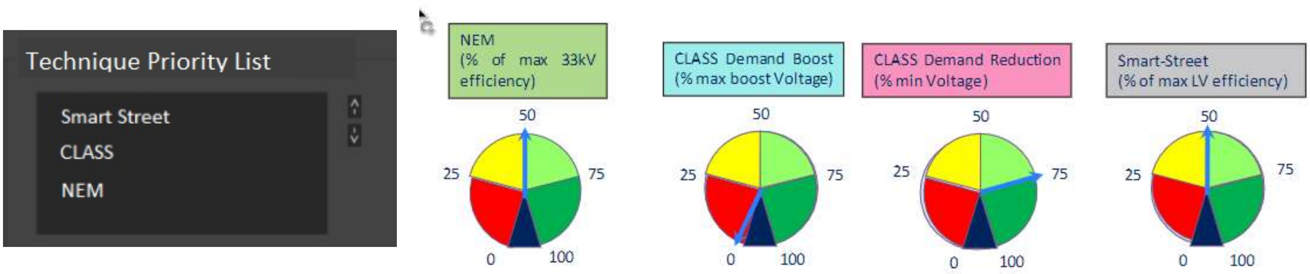

Figure 6-1 – TPL and BLENDs adjustment – SMST as a highest priority technique

Based on the predefined configuration, QUEST knows that SMST is the highest priority and that the desired % of LV efficiency is 50%. This is the requirement that QUEST should satisfy. 50% of LV efficiency means that some level of voltage reduction will be performed on SMST transformers, but they will be put in a safe mode that suits CLASS DRH voltage reduction (safe target voltage is the one that is predicted to allow CLASS DRH to be activated and not to cause LV violations). Since the desired level of voltage reduction for SMST is known in advance, QUEST then adjusts CLASS in a way that should not conflict with the SMST benefits but will still try to satisfy the CLASS commitments. CLASS DR BLEND is adjusted to 75%, that equates to three quarters of a maximum voltage reduction. QUEST knows in advance that this % of CLASS voltage reduction will conflict with SMST transformers and tries to find a suitable solution. First, it applies 50% CLASS DR blend on all the primaries needed (the ones supplying SMST transformers and additional ones, if needed). Then it checks if the committed CLASS MW are satisfied. If the answer to this is yes, then that is the final solution. If not, QUEST tries to compensate for the shortfall in providing CLASS benefits by applying the higher level of voltage reduction on other CLASS primaries (named Y CLASS Primaries in this example) that do not have SMST installed (if such a situation exists). On these primaries (named X CLASS Primaries in this example), QUEST simulates the next in line higher level of voltage reduction (75% BLEND that is actually set as desired) and checks whether the CLASS commitments can be satisfied. If yes, that is the final solution (DRH applied to all primaries that have SMST installed and 75% or DRTQ on the number of primaries needed to compensate for the shortfall in provided MWs). If this solution still does not provide expected CLASS MWs reduction, QUEST performs another iteration of the process. It tries with the next in line higher level of voltage reduction (100% BLEND that refers to applying DRF) and then checks the CLASS DR targets, again. After the CLASS functional level is set, QUEST choses the next technique in priority list which is NEM. Since NEM has a lower priority in comparison to CLASS it is adjusted in a way not to conflict with providing CLASS benefits (NEM is put in a safe mode that suits CLASS DR level). Since CLASS DRH is enabled on all the X primaries that supply SMST, on all BSP transformers that supply these primaries, NEM is put in a safe mode that suits CLASS adjustment, which is 50% (CLASS-DRH-SM). Since NEM is set to 50% 33kV efficiency, the BLEND on these BSP transformers that supply X CLASS primaries is satisfied. On the BSP transformers that supply Y CLASS primaries, that have higher level of voltage reduction, NEM is put in a lower level of 33kV efficiency (25% - CLASS-DRTQ-SM or 0% - CLASS-DRF-SM). With this adjustment QUEST provides the final solution:

- 50% of SMST LV network efficiency – **SMST BLEND satisfied.**
- CLASS DRH enabled on all the X primaries that supply distribution transformers with SMST installed. – **CLASS BLEND not satisfied but CLASS targets satisfied.**
- CLASS DRTQ or CLASS DRF enabled on the Y of the remaining CLASS primaries in order to satisfy CLASS committed targets.
- 50% of 33kV efficiency on all the BSP transformers supplying X CLASS primaries.
- 25% or 0% of 33kV efficiency on all the BSP transformers supplying Y CLASS primaries. – **NEM BLEND partially satisfied.**
- Additionally, if the CLASS target is not satisfied with applying DRF on all the remaining CLASS primaries, the shortfall is presented as a result, as well.
- Also, since NEM BLEND is not satisfied on all the BSP transformers, the percentage of BSP transformers with satisfied or not satisfied BLEND is presented as a result.

Based on the provided results, QUEST CE analyses the achieved benefits of each of the voltage management techniques compared to the predefined adjustment of BLENDS and TPL. The QUEST CE then concludes whether the final solution is acceptable, or if some fine tuning of the BLENDs should be performed. If the solution is acceptable, the QUEST CE applies the coordination results (or schedules the coordination for specific period) and QUEST continues to coordinate NEM, CLASS and SMST based on this configuration (on CLASS target value change or on availability of CLASS primaries change, QUEST automatically reruns the coordination process). If the solution is not acceptable, the QUEST CE changes the configuration of BLENDS and/or TPL and reruns the coordination.

The rest of the examples provided will not be explained in as much detail as the first one, since there is an analogy with this example.

6.3.1.2. Example 2 – CLASS as a highest priority technique

In this example CLASS is chosen as a highest priority technique. Since CLASS is the highest priority, both NEM and SMST need to be adjusted according to CLASS adjustment (NEM not counteracting the provision of CLASS DR and SMST not to cause LV voltage violations). Since both depend on the CLASS adjustment and do not counteract one another, it is irrelevant which of them takes priority afterwards. In this example, NEM is listed as a second priority technique and SMST as the least important one.

The BLEND configuration is changed in this example in comparison to the previous one, in order to cover as many different scenarios as possible. The configuration of BLENDs and TPL are provided in Figure 6-2.

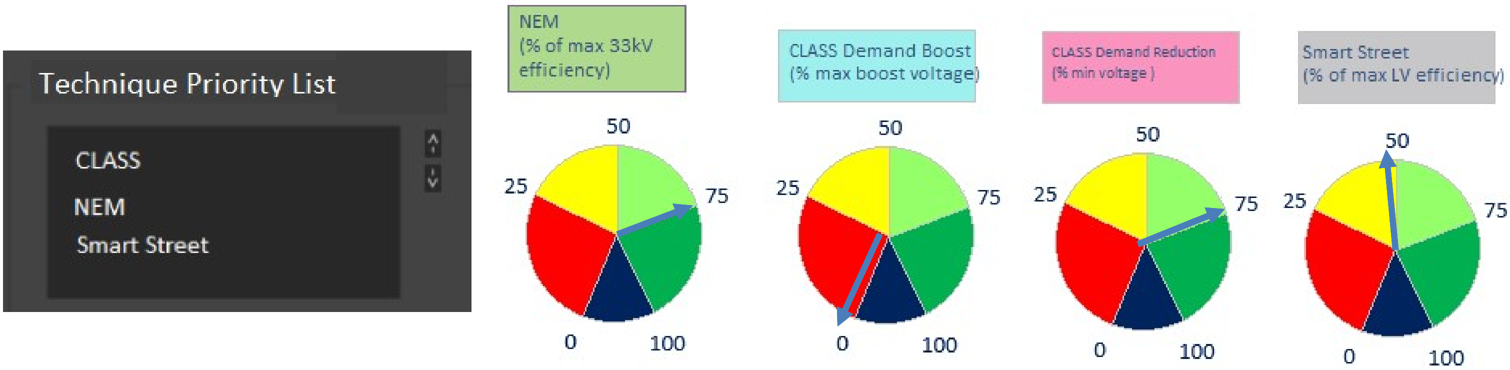

Figure 6-2 - TPL and BLENDs adjustment – CLASS as a highest priority technique

Since CLASS is the highest priority technique, QUEST first adjusts all the CLASS primaries to DRTQ (as per the blue arrow above pointing to 75% on the CLASS DR dial) to achieve committed targets. After CLASS is set, QUEST readjusts the other voltage control techniques.

NEM is adjusted in accordance with CLASS functional setting (DRTQ = 75%) to provide enough room for CLASS primaries to perform the desired demand reduction. All BSP transformers that supply CLASS primaries that have CLASS DRTQ enabled, are put in 25% - CLASS-DRTQ-SM. If there are BSP transformers that supply primaries without CLASS DRTQ enabled, on these primaries, NEM is put in 100% of 33kV efficiency mode. A situation where some of the CLASS primaries are not enabled for DR within the CLASS commercial periods is not a real-life scenario since CLASS targets are set according to the forecasted capacity (MW response) for the whole Whitegate area. In order to have a situation where CLASS committed targets can be satisfied by enabling CLASS DR only on a number of CLASS primaries, not all of them, during the QUEST trials the CLASS target can be set to a value lower than the value that would be set normally.

SMST is adjusted in order not to have LV voltage violations upon CLASS activation. On all SMST transformers supplied from CLASS primaries that have CLASS DRTQ enabled, SMST is put in a safe mode 25% - CLASS-DRTQ-SM. If there are SMST transformers supplied from primaries that do not have CLASS enabled, SMST continues to operate in full CVR mode.

With this adjustment, QUEST displays results to the CE:

- CLASS DRTQ enabled on X primaries – **CLASS BLEND satisfied.**
- SMST transformers supplied from X CLASS primaries put to 25% LV efficiency mode – **SMST BLEND not satisfied.**

- If there are SMST transformers supplied from primaries that do not have CLASS enabled, SMST continues to operate in full CVR mode. – **SMST BLEND partially satisfied.**
- NEM put to 25% 33kV efficiency on all BSP transformers supplying CLASS primaries with DRTQ enabled – **NEM BLEND not satisfied.**
- If there are BSP transformers that supply primaries without CLASS DRTQ enabled, on these primaries, NEM is put in 100% of 33kV efficiency mode. – **NEM BLEND partially satisfied.**

NOTE: An enhancement of QUEST functionality in this scenario is that, when adjusting CLASS, QUEST first applies the desired CLASS DR blend (75%) on the primaries that do not have SMST installed. If this satisfies the CLASS target that means that SMST does not need to be put in a safe mode and can continue operating in the full CVR mode. On the other hand, if the target is not satisfied, QUEST then applies the 75% DR on the number of needed remaining CLASS primaries where SMST benefits would be sacrificed. With this approach QUEST tries to gain as much benefits as possible from SMST by decreasing the number of SMST transformers that should be put in a safe mode.

6.3.1.3. Example 3 – NEM as a highest priority technique

In this example NEM is chosen as a highest priority technique. To make the example more interesting, the next in priority list is SMST and then CLASS.

Also, the BLEND configuration is changed in this example in comparison to the previous one, in order to cover as many different scenarios as possible.

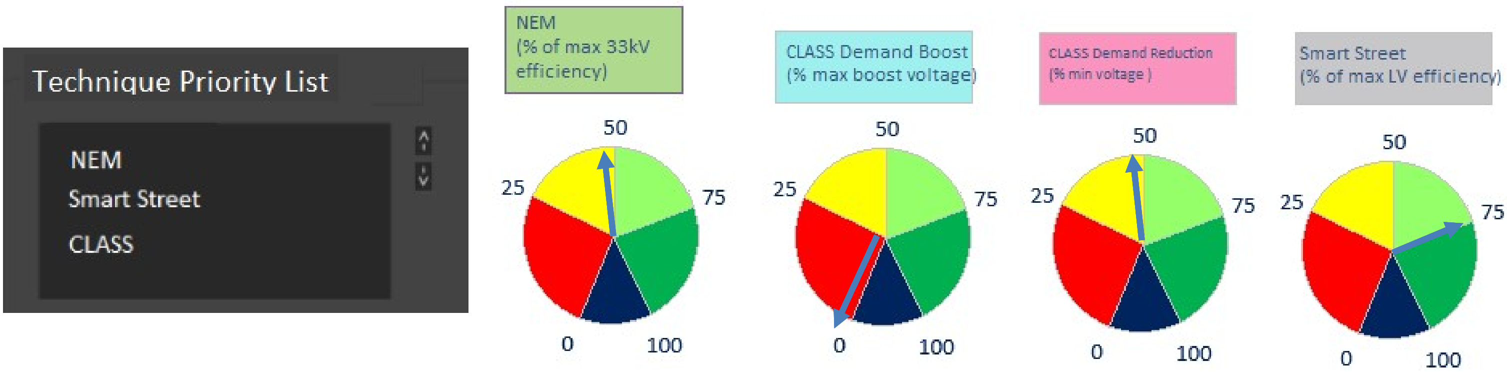

Figure 6-3 - TPL and BLENDs adjustment – NEM as a highest priority technique

Since NEM is chosen as the highest priority technique, QUEST first adjusts NEM on all the BSP transformers. 50% of 33kV efficiency is applied on all the BSP transformers according to NEM BLEND. After NEM is set, QUEST proceeds with the coordination. The next technique in the priority list is SMST. Since NEM does not affect the SMST operation, SMST blend can also be satisfied. SMST is put to a level of 75% of LV efficiency according to the configured BLEND. Now that SMST is set, QUEST continues to proceed with the coordination process. The last technique in the priority list is CLASS DR. Since CLASS adjustment can counteract the adjustment of both NEM and SMST, it has to be adjusted in the most restrictive way. NEM that is of highest priority is set to 50% network efficiency. That allows CLASS DR to also be put in a 50% DR. On the other hand, SMST is adjusted to be in a 75% LV efficiency mode that suits CLASS-DROQ-SM, only one quarter demand reduction could be applied to CLASS primaries in order not to cause LV violations upon CLASS activation. Bearing that in mind, CLASS DROQ is applied to all the CLASS primaries and

CLASS benefits are compared with the CLASS committed target. Since there is no possibility to applying a higher level of demand reduction, QUEST cannot perform any additional actions to try to satisfy CLASS targets.

With this adjustment, QUEST displays results to the user:

- 50% of 33kV efficiency applied to all BSP transformers - **NEM BLEND satisfied**
- SMST transformers put to 75% LV efficiency mode – **SMST BLEND satisfied**
- CLASS DROQ enabled on all the CLASS primaries – **CLASS BLEND not satisfied** (information about the shortfall in satisfying the CLASS targets provided)

Whilst this is not a likely scenario, it does demonstrate a flexibility of the QUEST overarching software.

6.3.2. Workflow 2 – Coordination of BSP TSF, NEM, CLASS and SMST

BSP TSF brings additional complexity in priority analysis since this functionality is manually started and the CE is the one who decides which level of BSP TSF is to be enabled. That means that in the moment when the QUEST coordination is manually started, BSP TSF should not necessarily be enabled.

Since BSP TSF is enabled manually, BLENDs that include BSP TSF are not introduced in QUEST.

Also, based on the previous analysis, it is known that BSP TSF could only be in conflict with the NEM (e.g., if NEM (highest level of voltage increase - e.g., 105%) is active. Then if BSP TSF is enabled there is a risk that one of the pair of BSP transformers will reach its maximum tap position before achieving the desired level of tap stagger.

Based on that assumption, two situations are analysed:

- NEM has priority over BSP TSF.
- BSP TSF has priority over NEM.

Since now the fourth technique is introduced within the TPL, there are 24 different priority combinations. Within this workflow, only two different examples are provided. In the first one, NEM has priority over BSP TSF and in the other one BSP TSF has priority over NEM. The order of the other techniques within the list is randomly chosen.

6.3.2.1. Example 1 - NEM has priority over BSP TSF

In this example NEM is chosen as the highest priority technique. The next technique in the priority list is BSP TSF and afterwards SMST and CLASS. The configuration of the TPL and BLEND is provided in Figure 6-4.

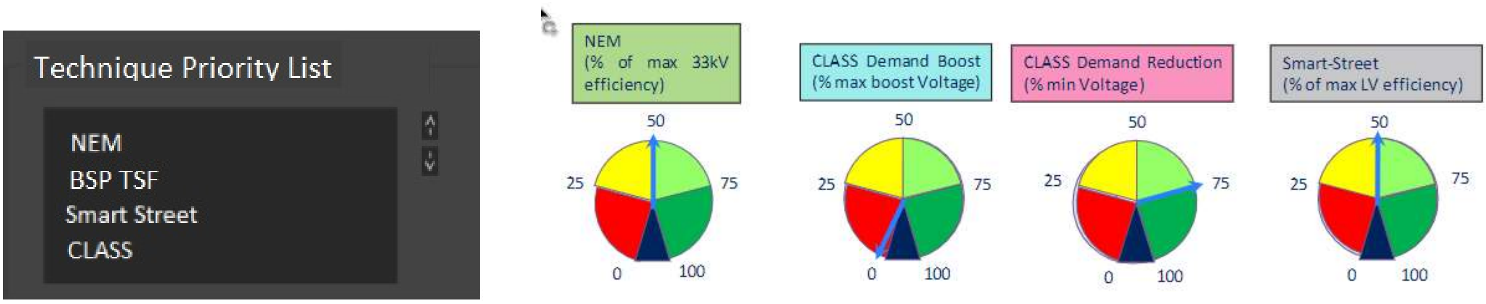

Figure 6-4 - TPL and BLENDs adjustment – NEM has priority over BSP TSF

In the moment of performing the coordination BSP TSF is not enabled. Since NEM is first in the priority list, QUEST adjusts all BSP transformers to 50% of 33kV network efficiency. Since BSP TSF is not enabled at that moment when coordination is performed, QUEST cannot consider it due to an unknown level of BSP TSF. The next technique in the priority list is SMST. As in Example 3 – NEM as a highest priority technique, SMST is adjusted according to the configured BLEND since NEM is not in conflict with the SMST adjustment. 50% LV efficiency is set on all the SMST transformers. CLASS, as the lowest priority (least important) technique, has its BLEND desired setting of 75% DR assessed last. QUEST knows that the desired CLASS BLEND cannot be satisfied since it would conflict both NEM and SMST. QUEST applies CLASS DRH on all CLASS primaries since this level of voltage reduction is not in conflict with either NEM or SMST.

After some period, the CE is required by the ESO to enable TSF level 3 on a BSP transformer that has 50% of 33kV efficiency applied. Upon BSP TSF enablement, QUEST checks whether the NEM level could conflict with TSFs ability to provide its reactive power response. Since QUEST knows that the level of NEM (50%) is not high enough to cause such a conflict, QUEST determines that there should not be any conflicts, and does not intervene.

After that, the CE enables BSP TSF level 3 on another BSP transformer that also has 50% NEM level applied. QUEST checks the potential for conflicts again and determines that in this situation the conflict does exist. QUESTs CMP calculates that there is a possibility that the BSP transformer will reach its maximum tap position before achieving the desired level of tap stagger. This situation is realistic if the GSP transformer supplying that BSP transformer is on a lower tap position and hence, the BSP transformer needs to tap up to maintain the target voltage. Since NEM is set as a higher priority technique, QUEST notifies the CE that the chosen level of BSP TSF is not feasible, by reporting an appropriate alarm/message.

After the alarm/message is reported, the CE readjusts the TSF level on that BSP or chooses another BSP on which TSF could be enabled.

6.3.2.2. Example 2 – BSP TSF has priority over NEM

In this example, BSP TSF has priority over NEM, but is not chosen as the highest priority technique. CLASS is chosen as a highest priority technique, then SMST and afterwards BSP TSF and NEM.

Similarly, as in the previous example, QUEST performs its coordination after it is manually started. In that moment, BSP TSF is not enabled and is not considered in the coordination process. QUEST adjusts NEM, CLASS and SMST in accordance with the BLEND and TPL provided in the figure below.

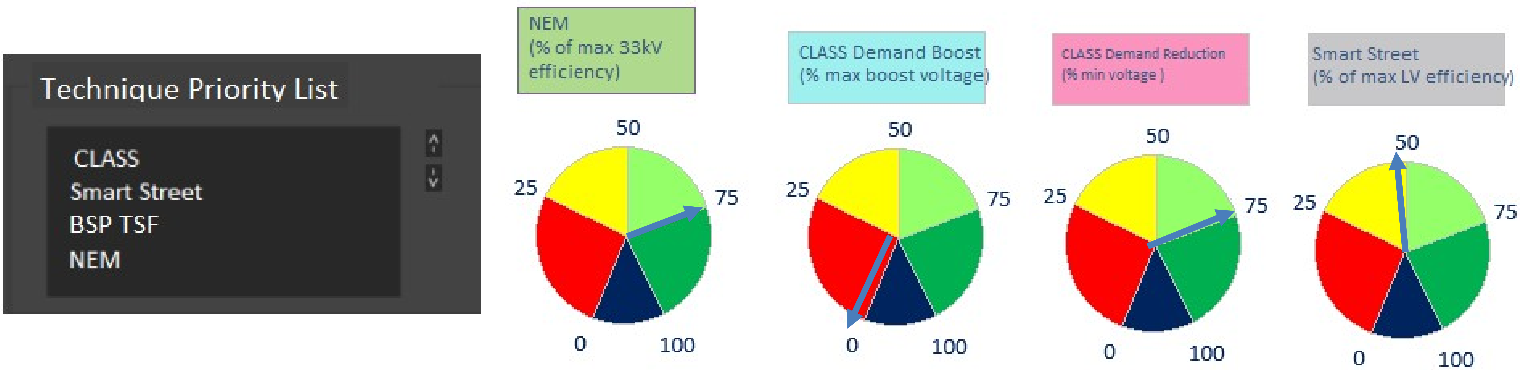

Figure 6-5 – TPL and BLENDs adjustment – BSP TSF has priority over NEM

QUEST first adjusts CLASS DR as it is the highest priority technique. All CLASS primaries are set to 75% DR that suits DRTQ voltage reduction. Afterward SMST is put in a safe mode that suits CLASS DRTQ – 25% of LV efficiency. Since BSP TSF is not enabled, it is skipped in the coordination process. The last in priority line is NEM. According to CLASS adjustment, NEM is put to 25% of 33kV efficiency, although the NEM BLEND is set to 75%.

After some period, the CE enables TSF level 3 on an arbitrary BSP transformer (BSP X). NEM 25% level of 33kV efficiency is applied to all BSP transformers initially. Upon TSF enablement, QUEST checks whether NEM on BSP X conflicts TSF on that same BSP and if it determines that there is no conflict, QUEST does not intervene. On the other hand, if a conflict is detected, since BSP TSF takes priority over NEM in the TPL, QUEST tries to readjust the level of NEM. QUEST determines that lowering the level of NEM from 25% to 0% of 33kV network efficiency does not conflict with CLASS, that is of highest priority, and readjusts the level of NEM.

Note: if QUEST would determine that adjusting the level of NEM would conflict with CLASS, NEM would not be readjusted since CLASS has priority over BSP TSF. Appropriate alarm/message would be displayed to the CE.

With this configuration, QUEST readjusts the voltage regulating techniques in a following way:

- CLASS DRTQ enabled on all the CLASS primaries – **CLASS BLEND satisfied.**
- SMST put in a CLASS-DRTQ-SM (25% of LV efficiency) – **SMST BLEND not satisfied.**
- Possibility to enable and activate TSF on BSP X provided.
- 0% of 33kv network efficiency – **NEM BLEND not satisfied.**

NOTE: As explained above, in the case that BSP TSF is set as a highest priority technique, there is a possibility that QUEST will need to intervene to provide for the possibility of activating BSP TSF. That means that QUEST will also readjust all the affected voltage regulating techniques (NEM, CLASS and SMST) without displaying the results to user, but with reporting the appropriate event message. This readjustment may or may not be in accordance with the results displayed to the user when the coordination was initiated.