QUEST

Functional Specification

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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 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.

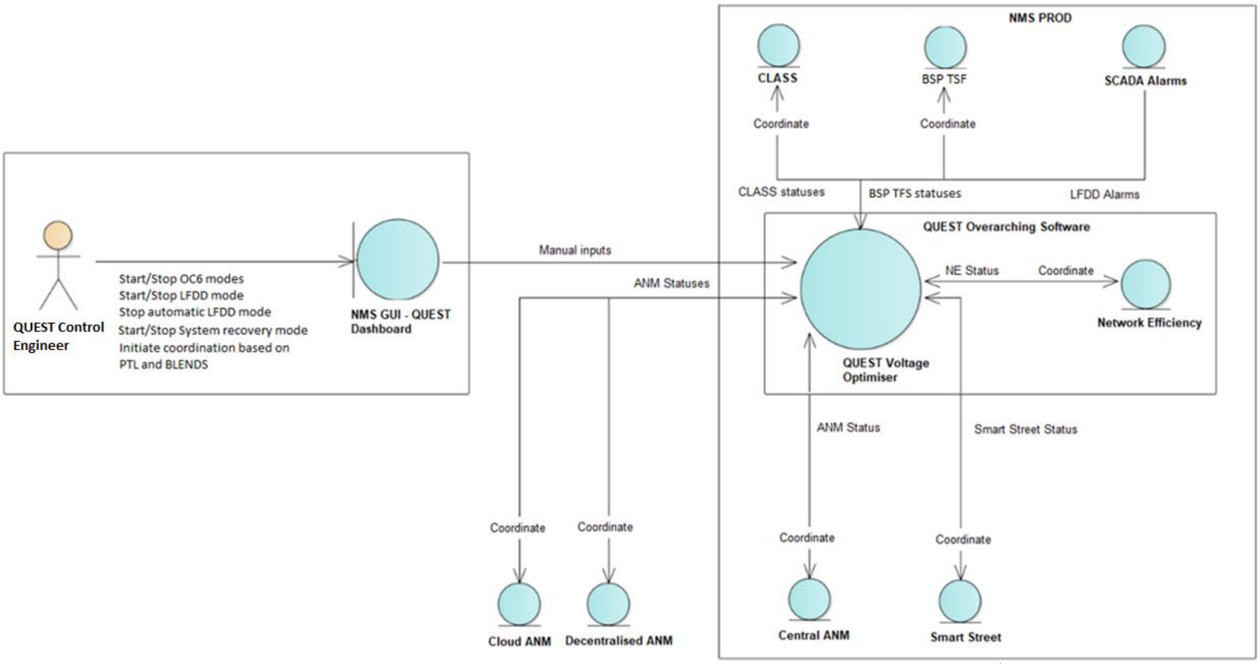

Figure 3-1 – QUEST – Main architecture diagram

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 loads, 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 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.

3.1.2. 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.

For more details regarding QUEST triggering, consult the vendor.

Each of the triggering situations can affect the previous adjustment of voltage control techniques performed by QUEST or a voltage control techniques' target, 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.

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 4-1.

Figure 4-1 – 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.

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 are provided in sections "QUEST coordination under normal operating conditions" and "QUEST operation in case of emergency condition".

4.2. QUEST Contention Management Process

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 CMP section provides possibility to configure QUEST operation, perform simulation of QUEST operation and to observe the Outcome.

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. 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 can be observed. The Outcome Results report has a similar look to the 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.

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. The CE can order the voltage control techniques by desired priority.

[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.

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.

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. This is because responsive coordination type option is only presented on QUEST's UI and no additional logic behind this option is implemented within the current QUEST version. During QUEST design, it has been confirmed that fast tap capability of SMST transformers does not presently satisfy requirements defined for the QUEST responsive coordination type. Bearing that in mind, it has been agreed that the responsive coordination type will only be shown within the QUEST configuration to present the concept and conclusions made during the QUEST design, as well as a reminder for the future QUEST development.

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 in real time operation.

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 or scheduled QUEST's operation.

After it is activated, QUEST continues to automatically perform the coordination based on the configured BLENDs and TPL.

It is important to note that although the QUEST operation is activated, the QUEST CE can apply a different configuration without having to deactivate it. If a new configuration is applied to QUEST running in real time, QUEST is automatically triggered in order to readjust the voltage control techniques according to the newly assigned configuration.

Scheduled QUEST coordination can be set by configuring the QUEST Schedule.

For more details regarding QUEST Scheduling please contact the vendor.

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. The only task for QUEST is to leave the system in a safe operating condition. It is important to note that NEM, as a new module introduced through QUEST, will be switched off upon deactivating QUEST. Switching NEM off means returning it to a target voltage defined as a NEM 0% function level.

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.

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.

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.

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.

4.5. QUEST Dashboard

The QUEST Dashboard can be opened either from QUEST Control & Monitoring window.

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

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.

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.

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.

For more details regarding QUEST dashboard data, please contact the vendor.

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 using comparing methodology.

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.

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.

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[2] (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.
- 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

[2] 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.

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 6.1 "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.

For additional details, contact the vendor.

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.

For additional details, please contact the vendor.

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),
- Waiting the predefined time for tap changer to react on the newly applied target voltage,
- Fixing HV/LV SMST distribution transformer taps after SMST has moved to the new target voltage.

Predefined timer for fixing the tap position is, also, globally configurable through QUEST options, as shown in **Error! Reference source not found.** (Timeout command for fixing the tap position option).

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 globally 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'[3] 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.

For more details, please, contact the vendor.

3 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'.

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.

For more details, please contact the vendor.

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, 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.[4] 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[5]. 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 (OC6-MM) actions on the whole trial area. Since there is a difference in QUEST's behaviour upon activating these two states, OC6-VR-MM and OC6-DD-MM are introduced.

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,

[4] 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.

[5] 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.

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[6], as shown in Figure 5-1. 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.

Figure 5-1 – Global QUEST Options – Automatic LFDD activation

The list of voltage control techniques affected by LFDD and QUEST’s intervention regarding each technique is presented in the **Error! Reference source not found.**.

[6] 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.

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.

In case of automatic LFDD activation, QUEST coordination is the same. The only difference is on GUI where in case of auto LFDD activation, there is a visual indication for it, as shown in Figure 5-2

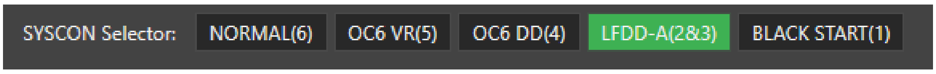

Figure 5-2 - QUEST Control & Monitoring – Automatic LFDD activated

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

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 terminology for normal operation

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

Table 1 - QUEST terminology for normal operation

No	Voltage control technique	Safe mode	Description
1.	NEM	CLASS-DRF-SM	Safe mode[7] 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.

[7] "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.