QUEST Architecture Options

Detailed Design Subphase 2 Report

Design Specification

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Revision History

Version	Authors	Date	Comments
1.0	Milena Jajčanin	30-Nov-21	Initial version

Final review and approval of the latest version:

	Date	Name & Surname	Business Role	Signature
Approver	17-Nov-2021	Izabela Stefani	Product Manager	

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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.

2. INTRODUCTION

The QUEST Use Cases which were researched and studied from April 2021 to July 2021 via workshops organized between ENWL and the QUEST project partners (Fundamentals, SGS, SE & ESO), defined how the QUEST overarching control will be expected to work (see “QUEST an Overarching Control System, QUEST Initial Report - Use Cases” document [1]).

The defined Use Cases considered the prioritisation of existing voltage management services, and when and how the existing voltage optimisation systems will interact with each other. The main goal of defining the Use Cases was to understand the areas of conflict between the existing voltage regulation management techniques (CLASS) and approved in flight voltage regulating projects (Smart Street and ANM) and receiving instructions from ESO for emergency response or when providing a contractual service. Use Cases also determine the possible options to overcome these conflicts and set a foundation for a detailed design and architecture specification for the QUEST overarching software.

The first version of the Use Cases, created during the initial workshops, was focused more on the detection of the potential conflicts rather than conflict resolution. The Use Cases provided only high-level descriptions and options on how the QUEST overarching software could be implemented to cope with the outlined conflicts.

The detailed design for the QUEST overarching software was developed during workshops running from August 2021 to mid-November 2021. The main goal of this detailed design phase was to fill in the gaps within the first version of the Use Cases and to provide architecture options for the QUEST overarching software.

This detailed design phase was divided into two subphases. The first subphase, completed in October 2021, was focused on the clarification of the initial Use Cases. Here the Use Cases were analysed (proved/disproved/updated/replaced) in further detail to help firm up the design specification and provide inputs for the second subphase.

This document provides a review of the second subphase of QUEST’s detailed design which focuses on different architecture options for QUEST’s overarching software. Detailed design subphase 1 considered three QUEST macro level architecture options that could be used to resolve the detected conflicts found in the Use Cases. Option 3, the “hybrid approach”, has been chosen as the one to take forward into the second subphase of the detailed design. Several ‘meso level’ architecture options, which in different ways satisfy the criteria of macro-option 3, were explored within the second subphase of the detailed design.

The key conclusions and observations from the first subphase of the detailed design were also used as the main input for the second subphase. Although the main goal of the second subphase was to provide different architecture options for the QUEST overarching software, during subphase 2, additional points that were transitioned from the first subphase were discussed as follows:

- The terms used for the various safe modes of operation described to manage conflict such as, CLASS Forecast and Optimise Mode (CFOM), are to be reviewed by ENWL to ensure they are not ambiguous or confusing. Where required they should be replaced with more appropriate terms.
- Providing reactive power absorption services to the ESO at BSP level is to be clarified. The question remains whether CLASS tap stagger functionality on a BSP level should be implemented within CLASS, QUEST, or some other system within the NMS.

- Regarding the coordination between ANM and Smart Street, it has been noted that presently the impact of Smart Street on ANM is likely to be small and may not be an issue for many years, if at all. Several options for coordination which were provided during the first subphase should be additionally discussed during subphase 2 of the detailed design to determine whether QUEST's intervention between these systems is expected or not.
- Similar to the approach taken to manage conflicts between CLASS DR or DB and Smart Street where QUEST considers a range of options with possible differing impacts on service delivery of each, other use cases should be investigated further to identify if a similar approach can be taken. Are there alternatives to switching the 33kV network efficiency mode off when a CLASS service other than DB is enabled e.g., if CLASS DRH is enabled? Is there a level of 33kV network efficiency that could be achieved through a limited level of voltage increase rather than setting the BSP target 33kV voltage to the full 106% limit?
- Subphase 2 of the detailed design should consider additional options regarding the Smart Street and CLASS DR coordination. Since Smart Street transformers have a fast tap capability, it should be discussed whether this additional flexibility for the QUEST overarching software would facilitate coordination upon CLASS DR activation rather than CLASS DR enablement. The Smart Street fast tap capability should also be considered to improve QUEST coordination of CLASS DB and Smart Street when CLASS DB is being deactivated.

During the Use Case refinement, additional general functional requirements for the QUEST Voltage Optimiser were identified and carried through to subphase 2 of the detailed design. These include:

- The QUEST Voltage Optimiser should have visibility of BSP, Primary substation and Smart Street distribution substation transformer tap positions. This would allow QUEST to make decisions that avoid the risk of running out of transformer tap positions e.g., in primary substations as a result of changing the 33kV voltage at the BSP transformers.
- QUEST should monitor for 'tap not achievable' alarms from the Automatic Voltage Control (AVC) relays.
- QUEST requires monitoring of voltages across the DNO network (including 132kV) at various voltage levels including the point of connection locations with DER (excludes small LV connected DER).

During the second subphase, all the above stated topics were discussed in further detail. The QUEST architecture options provided within this document have been based on the information gathered during these discussions.

3. OVERVIEW

QUEST is envisioned as a part of the EcoStruxure ADMS functionality (ENWL NMS system) which is specifically designed to integrate discrete voltage management techniques into one overarching, coordinated and optimised system. QUEST is a holistic, centralised optimisation engine intended to demonstrate the use of an overarching optimisation function to coordinate and control the previously mentioned existing systems to provide an optimum whole system voltage profile at all times. QUEST will demonstrate the benefits of running this holistic whole system voltage optimisation program, allowing for the concurrent operation of discrete voltage management techniques across the network.

The objectives of the QUEST project, 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 National Grid Electricity System Operator (ESO) intake to the interface with the domestic customer.
- By viewing and controlling the distribution system as a whole, QUEST software will coordinate the often-competing objectives of the various, discrete voltage control techniques to ensure an optimised operation whilst maximising benefits for customers.
- The QUEST project will 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 (LCTs).
- Under normal operation, 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.
- The QUEST project will also explore how to unlock benefits for 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.
- QUEST software shall maintain statutory voltage limits as per Electricity Safety, Quality and Continuity Regulations (ESQCR) and will ensure no disruption to system commercial contractual agreements, unless under emergency response situations.
- In the event of loss of system communication, the QUEST overarching control system shall ensure it and any associated discrete voltage systems default to a safe mode setting, to maintain network stability and safety.

QUEST has three core operational objectives:

- Coordinate operation of system voltage control and optimisation systems.
- Identify and avoid potential conflicts between multiple systems, always ensuring appropriate configuration of key voltage control and optimisation systems.
- Enhance operational efficiency.

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Bearing the above and the QUEST functionality identified during subphase 1 of the detailed design in mind, different architecture options for the QUEST overarching software have been proposed in remainder of this document.

4. QUEST OVERARCHING SOFTWARE ARCHITECTURE OPTIONS

The main architecture diagram, displaying the QUEST Voltage Optimiser as an overarching software, is shown in Figure 4.1.

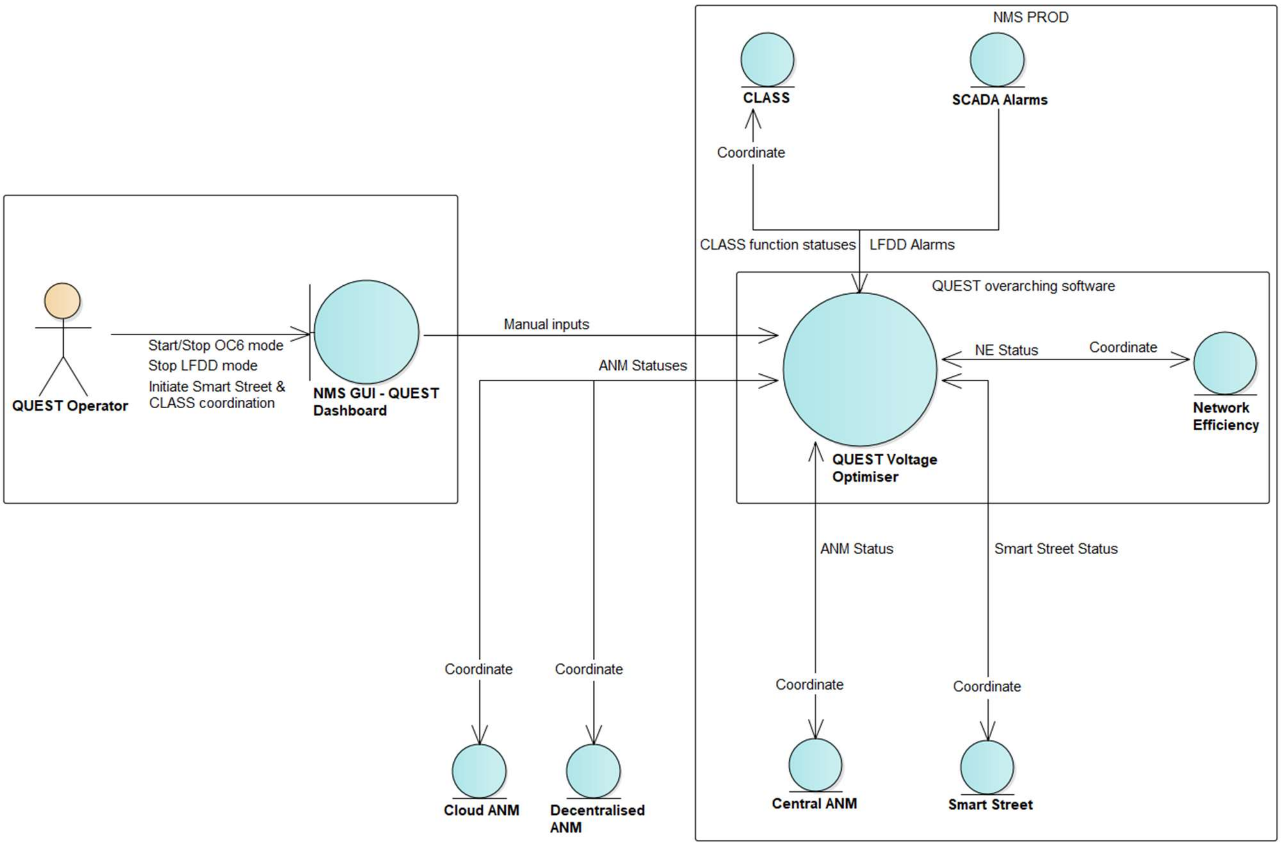

Figure 4.1 – The QUEST Voltage Optimiser – main architecture diagram

On the right side of Figure 4.1Figure 4.1, the ENWL's NMS production system is presented with the QUEST overarching software in the centre. Since it is located within the NMS system, QUEST is aware of the statuses of all the other existing systems in the NMS system (Enhanced AVC including CLASS, Smart Street and Central ANM). QUEST is also aware of all the information coming from DNO's SCADA system, such as SCADA alarms, BSP, Primary substation and Smart Street distribution substation transformer tap positions, as well as monitored and calculated voltage values across the whole DNO network.

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 is able to provide the distribution network full coordination to manage voltage profiles with an appropriate balance between centralised and decentralised control hierarchy. In addition to coordinating operations of the existing systems in the network, the QUEST Voltage Optimiser tries to increase the network efficiency whenever possible, by increasing the voltages on the 33kV parts of the distribution network.

Based on the inputs provided to QUEST, QUEST determines and automatically performs appropriate coordination actions. All the inputs provided to QUEST are displayed in Figure 4.1 as arrows directed towards the QUEST Voltage Optimiser. All the coordination actions performed by QUEST, based on different inputs, are also displayed as arrows, but with the direction from the QUEST Voltage Optimiser.

Inputs for QUEST are divided into automatically detected inputs and inputs manually provided by the QUEST operator.

Automatically detected inputs are statuses of the existing systems in the network including SCADA alarms (based on which automatic Low Frequency Demand Disconnection (LFDD) activation is detected), voltage values on the whole network, and visibility of BSP, Primary substation and Smart Street distribution substation transformer tap positions.

During the discussion of the Use Cases in subphase 1 of the detailed design, it was agreed that it will be a business procedure to manually activate and deactivate OC6 modes, deactivate LFDD mode and initiate Smart Street and CLASS coordination. These actions are considered as inputs manually provided for QUEST and are displayed as such on the main architecture diagram.

In the remainder of section 4, options for each individual coordination action performed by QUEST are presented and explained in detail.

One of the key conclusions and observations from subphase 1 of the detailed design was that the terms used for the various safe modes of operation described to manage conflicts, such as CLASS Forecast and Optimise Mode (CFOM), may be misleading or confusing. These were reviewed within subphase 2 of the detailed design and replaced with new proposed terms as shown in Table 4.1 – QUEST safe modes terminology.

NOTE: Proposed terminology for CFOM may change in the future as we continue to explore QUEST architecture options.

Table 4.1 – QUEST safe modes terminology

No	Old term	Description	Proposed term
1.	CFOM	In order to properly coordinate other systems with CLASS, it was concluded that QUEST should differentiate which CLASS function has been enabled/disabled/activated/deactivated. Hence, several new safe mode terms have been proposed. It was agreed that in the case of coordinating CLASS and ANM, the term “mitigation mode” should be used. For Smart Street, where CLASS dashboard is also adjusted, the term “safe mode” is used. Additionally, mitigation mode for coordination of CLASS DRF and Smart	CLASS DR Safe Mode (CLASS-DR-SM) – used for Smart Street coordination
			CLASS DB Safe Mode (CLASS-DB-SM) – used for Smart Street coordination
			CLASS DR Mitigation Mode (CLASS-DR-MM) – used for ANM coordination
			CLASS DB Mitigation Mode (CLASS-DB-MM) – used for ANM coordination
			CLASS DRF Fast Tap Mitigation Mode (CLASS-DRF-FastTap-MM)

		Street with fast tap capability is introduced[1].	
2.	LFDD mode	The only change is that the word “mitigation” has been added.	LFDD mitigation mode (LFDD-MM)
3.	OC6 mode	This mode has been divided into two modes, one related to performing voltage reduction (OC6.5) and the other one related to demand disconnection (OC6.7). The word “mitigation” has been added in both newly determined terms.	OC6 Voltage Reduction Mitigation Mode (OC6-VR-MM)
			OC6 Demand Disconnection Mitigation Mode (OC6-DD-MM)

NOTE: The proposed terminology has only been applied to the subphase 2 report of the detailed design. All architecture diagrams have been created considering the new terminology. The terminology used within the first subphase report has not been changed. The decision not to change the subphase 1 report terminology has been made so that the chronology of QUEST’s detailed design development would be clearly visible.

4.1. Network Efficiency

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

When QUEST is operating in NEM, the 33kV system voltage will operate above nominal voltage by raising the tap position of the 132/33kV BSP transformers. QUEST will determine the optimum 33kV voltage profile to minimise losses on the 33kV distribution system and NEM will be evaluated based on the calculated I^2 R losses associated with cables and transformers measured from real time power flows.

During subphase 2 of the detailed design, it has been agreed that QUEST will 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 will be to readjust the tap position of the 132/33kV BSP transformers to keep the voltages in the regulated point within the statutory limits. However, it has been discussed that different voltage profiles due to load changes during the day should be addressed somehow, for example during very low load periods cable capacitance could dominate, and therefore, re-optimisation may be required due to high levels of reactive power. The conclusion is that there are several options associated with this approach. The first option is to perform offline studies to determine which are the critical periods during the day when over-voltages may occur and to determine the reduced levels of network efficiency based on voltage values in these periods. The decision could be either to run the network efficiency with the reduced levels of voltage increase or to run it with the maximum levels of voltage increase, except in these critical periods of the day when network efficiency would be switched off. The inputs regarding the maximum and reduced levels of voltage increase should be provided within the

[1] “Mitigation mode“ terminology is used for coordination of other systems performed by QUEST upon CLASS activation, while “safe mode” terminology is used for coordination actions performed prior CLASS activation, i.e., upon CLASS enablement.

Workstream 2: Network modelling regime of the QUEST detailed design based on the simulation models will be carried out within this modelling workstream. The second option, which is more advanced and would be a further step in QUEST development, is that QUEST should monitor voltage measurements across the 33kV network and if it detects that voltages are above the high voltage limits, it re-adjusts the allowed level of voltage increase.

The QUEST operator will also be able to manually control NEM (switch off, switch on) as per independent BSPs and also for higher levels of network hierarchy.

The only conflict that has been detected with QUEST operating in NEM during the first subphase of the detailed design is with CLASS providing commercial services except for DB. Raising the tap position of the 132/33kV BSP transformers will result in the primary transformers (33/11kV or 33/6.6kV) being 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 will be provided for DB. However, for other CLASS functions, involving voltage reduction services (DR, PFR, SFR), this may not be the case. Hence, it has been concluded that for any CLASS function enablement, except DB, QUEST will need to switch off NEM.

Based on the inputs provided during subphase 1 of the detailed design, QUEST's architecture option for the Network Efficiency Use Case has been determined. This option has been illustrated in

Figure 4.2.

Figure 4.2 – QUEST coordinating the network efficiency – Option 1

Since QUEST is aware of the CLASS functions' status, it determines when the NEM should be switched on or off. During the detailed discussions of each Use Case, it has been determined that it is safe to operate in NEM when CLASS is outside of the commercial agreements, i.e. in times when CLASS functions are disabled. When any of CLASS DR functions becomes enabled (input 1: DRF/DRH Enable displayed in

Figure 4.2), NEM is automatically switched off by QUEST and all the transformers on the BSP level are returned to their safe target voltages maintaining the 33 kV voltage (coordination action 1.1: Switch Off in

Figure 4.2). After CLASS DR functions are disabled (input 2: DRF/DRH Disable), QUEST switches the NEM on again (coordination action 2.1 Switch On).

During the final discussions relating to the first subphase report, a question was raised regarding the alternatives to switching NEM off when a CLASS service other than DB is enabled e.g., if CLASS DRH is enabled. The question was: Is there a level of 33kV network efficiency that could be achieved through a limited level of voltage increase rather than setting the BSP target 33kV voltage to the full 106% limit?

During this subphase, this question was considered in more detail and another architecture option which provided the additional level of flexibility regarding the coordination of NEM was introduced as displayed in

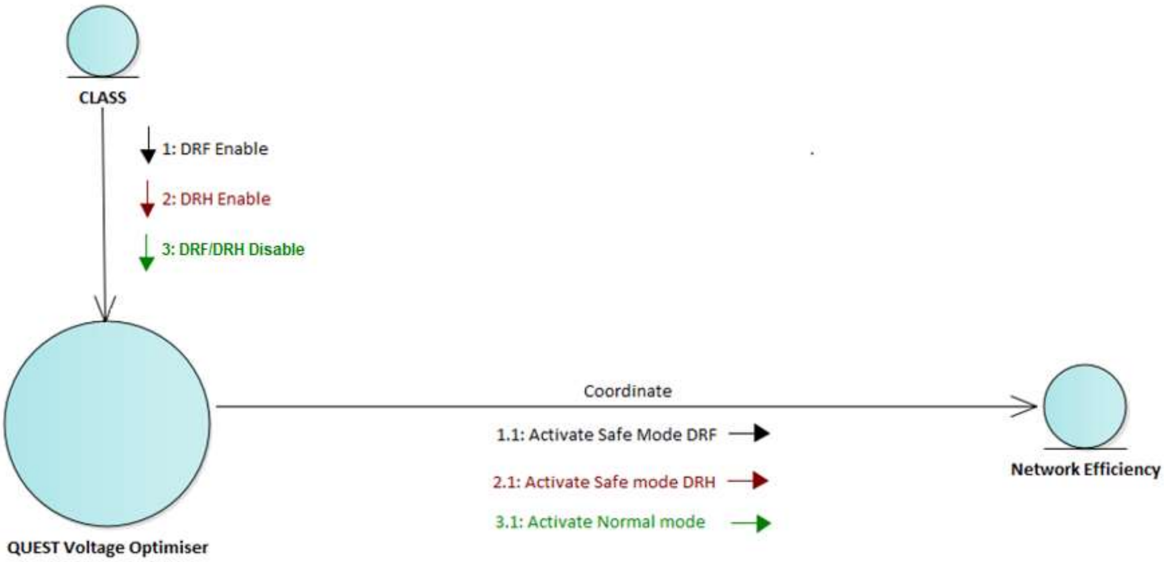

Figure 4.3.

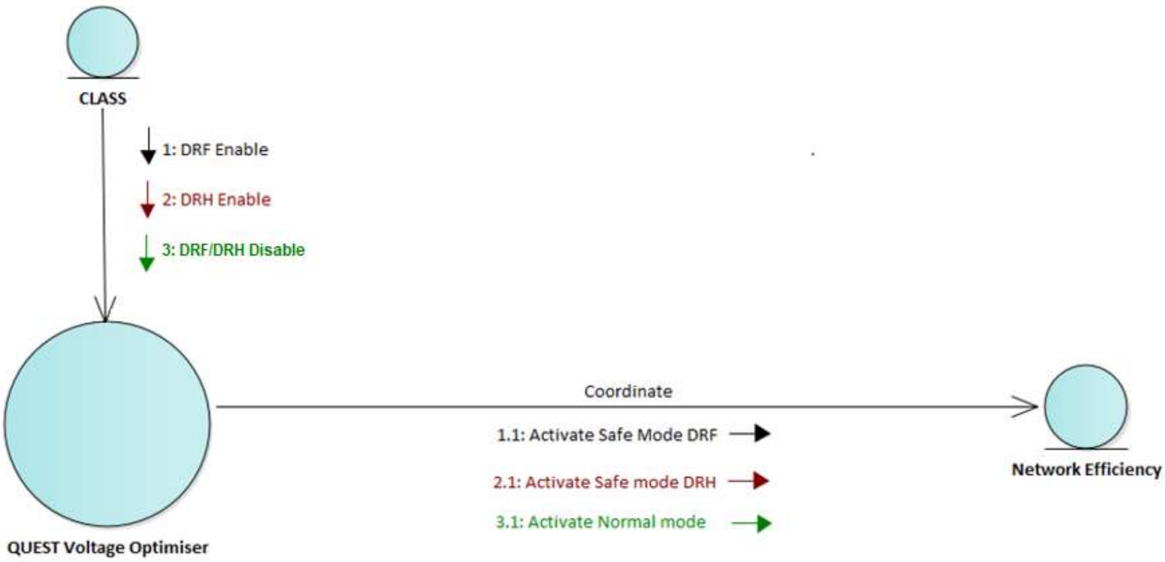

Figure 4.3 – QUEST coordinating the network efficiency – Option 2

In comparison to Option 1 displayed in

Figure 4.2, additional safe modes for NEM have been introduced within Option 2. With this approach, QUEST differentiates whether CLASS DRF or CLASS DRH function is enabled. Depending on the level of voltage reduction required by CLASS, QUEST determines allowed levels of 33kV network voltage increase that 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. These allowed levels of voltage increase are defined as safe modes for network efficiency.

For example, if CLASS DRH becomes enabled (input 2: DRH Enable in

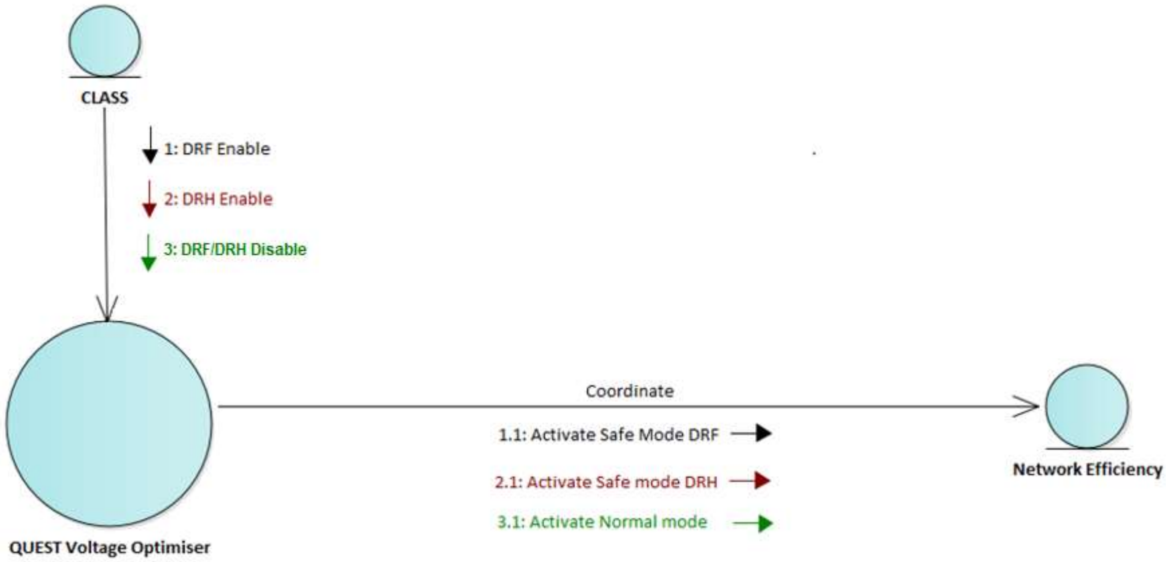

Figure 4.3), QUEST will not switch NEM off as shown in Option 1. Instead, it will activate safe mode DRH (coordination action 2.1 Activate Safe mode DRH). In this safe mode the voltage increase at the 33kV network will still be performed, but with a more conservative level of increase (safe target voltage DRH, e.g., 103% target voltage). This is to provide enough room for the primary substation transformers to tap down and perform the required voltage reduction, while still delivering a level of losses reduction with the increased 33kV network voltage. The same logic is applied in the case of DRF enablement: Instead of switching NEM off, QUEST will determine the maximum allowed limit for a voltage increase at the 33 kV network to provide losses reduction, but it will not prevent CLASS from providing its committed MWs by performing the full voltage reduction (DRF). By putting network efficiency in a DRF safe mode with limited voltage increase (safe target voltage DRF), sufficient tap capability for each primary substation will be provided even though NEM is not switched off.

Additionally, since QUEST has visibility of all the transformers tap positions, it will be able to detect if any primary substation transformers have reached their lowest tap position and to perform appropriate coordination actions in order to provide additional tap capability for such transformers. An example is readjusting the level of voltage increase at the BSP transformer that is supplying a primary substation from a maximum 33kV voltage increase to the next available lower voltage increase level.

Upon a CLASS DR function disablement, QUEST returns network efficiency into a normal mode of operation, where it is allowed to increase the 33kV voltages towards the full 106% limit (usually 105% +/- 0.8%).

With this architecture option, additional flexibility is introduced within the “hybrid approach” macro level architecture option of the QUEST overarching software. With this newly introduced “meso level” architecture option, QUEST does not only prioritise one system during the coordination but provides a

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range of options with possible differing impacts on service delivery of each system that is being coordinated.

Allowed levels of voltage increase (safe target voltage for DRF and DRH and target voltage for the Normal mode of operation) for network efficiency could be predefined levels determined by performing offline analysis or running simulations within the QUEST algorithm each time coordination is performed. During subphase 2, it has been agreed that these levels should be predefined with the inputs being provided within QUEST project Workstream 2: Network modelling regime of the QUEST detailed design. Based on the simulation modelling carried out within this workstream, the total impact of the different levels of network efficiency on a tap capability of each primary substation to perform DRF or DRH could be determined and tested during the QUEST trials.

4.2. CLASS and ANM Coordination

While discussing Use Case 4 - CLASS and ANM coordination, within subphase 1 of the detailed design, it was concluded that 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 would conflict with CLASS's benefits, which is not acceptable and should be prevented. Additionally, since CLASS DR and DB are network-wide service provisions, constrained DER release prevention is also network-wide service provision requirement. More details regarding this conclusion are provided in the "QUEST Architecture Options - Subphase 1 Report" document [2] in the section "Options to Mitigate or Avoid Conflicts between CLASS and ANM".

Based on the above statements, two ANM mitigation modes have been introduced: CLASS-DB-MM and CLASS-DR-MM. 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 safe modes performed by QUEST is applied for all ANM systems in the QUEST trial area: Central ANM, Decentralised ANM and Cloud ANM.

The architecture diagram displaying the coordination between CLASS and ANM performed by QUEST is displayed in Figure 4.4.

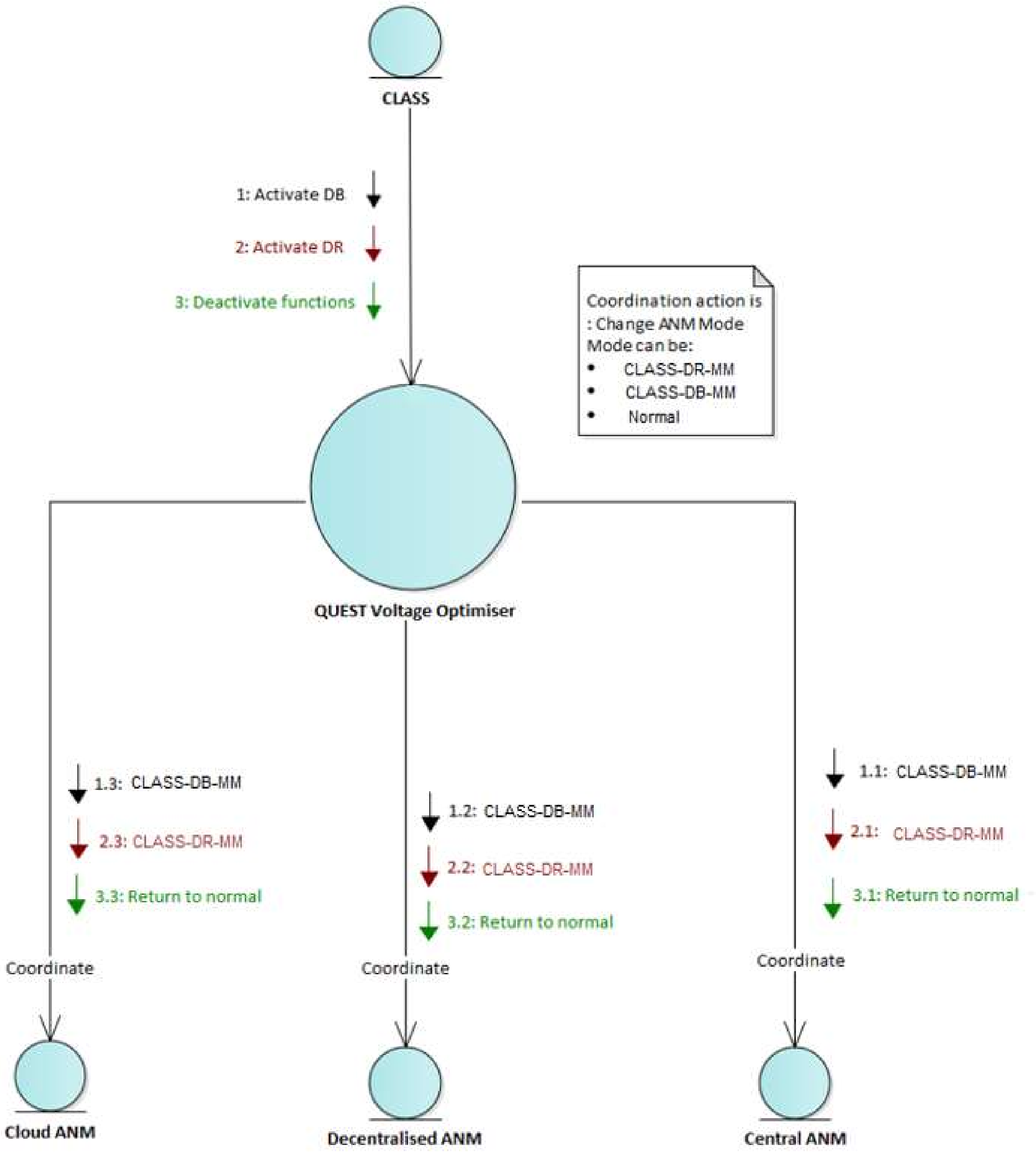

Figure 4.4 – CLASS and ANM coordination

As shown in Figure 4.4, QUEST differentiates three CLASS functions statuses: DR/DB deactivated, DR activated, and DB activated. Based on the input provided, QUEST performs appropriate coordination actions. For example, if it detects that DR is activated (input 2: Activate DR), it will put each of the ANM systems in a CLASS-DR-MM (coordination actions 2.1, 2.2 and 2.3 CLASS-DR-MM applied for each ANM system) network-wide. Once it detects the deactivation[2] of CLASS functions (input 3: Deactivate functions), it will return each of the ANM systems to a normal mode of operation.

4.3. CLASS and Smart Street Coordination

As discussed within the first subphase of the detailed design, coordination between Smart Street and CLASS DR/DB functions[3] should be performed by QUEST for the following reasons:

- Activation of CLASS DR functions on parts of the network where Smart Street operates will have a negative impact on Smart Street operation - the already reduced LV voltages due to Smart Street CVR will drop temporarily below statutory LV voltage limits upon CLASS DR activation.
- Smart Street actions will have a negative impact on providing committed CLASS services as it will react to reduced LV voltages in the case of DR activation, or increased LV voltages in the case of DB activation while trying to maintain its target voltage value.
- Since it is not possible to accurately predict when the ESO will request a CLASS DR or DB service action in sufficient time to take mitigating actions to avoid conflicts between Smart Street and CLASS, it has been concluded that QUEST needs to act upon enablement of CLASS functions. At this point it will put Smart Street in a safe mode in which it will not conflict with CLASS operation and that voltage issues will be prevented in time.

Moving Smart Street to a safe mode refers to:

- Determining the new safe target LV voltage.
- Sending newly determined target voltages to all HV/LV distribution transformers (it takes up to 3 minutes to do this and achieve the new target voltage through Smart Street actions) – action performed by QUEST.
- Fixing HV/LV distribution transformer taps – action performed by QUEST.

NOTE: Safe target voltage could be a pre-defined voltage programmed into QUEST, or it could be determined by performing simulations of CLASS function activations within the QUEST calculation. This could then be used to determine the minimum/maximum allowed target voltage in order not to cause violations of the low/high voltage limits upon CLASS DR/DB function activation. During subphase 2 of the detailed design, it has been agreed that safe target voltages will be predefined. Input for these values should be provided within the Workstream 2: Network modelling regime of the QUEST detailed design based on the simulation models carried out within this modelling workstream.

In order to introduce flexibility in managing conflicts between Smart Street and CLASS, several options for coordinating CLASS DR and DB with Smart Street were suggested during the first subphase of the detailed design. For more details regarding each option, please refer to the “QUEST Architecture Options -

[2] When CLASS functions are deactivated, they are transited either in enabled or disabled state. In both cases, QUEST’s expected intervention is the same, so the term deactivated is used in the architecture diagram.

[3] During the subphase 1 detailed design, it was concluded that CLASS TSF does not require QUEST coordination with other systems. Also, PFR and SFR are not included in the trial as these CLASS services are not presently used, which is also the case for CLASS LL.

Subphase 1 Report" document [2]. QUEST architectures for these options are presented in the rest of this chapter.

During subphase 1 of the detailed design, it was concluded that QUEST will not change the status of CLASS functions since the automatic adjustment of the CLASS dashboard is not acceptable for the first phase (trial) of the QUEST project. Scheduling of primary substations for providing CLASS services will stay within the CLASS scheduling mechanism, and QUEST will only be allowed to suggest the list of additional primary substations to be enabled (to achieve CLASS committed targets, if needed after performing coordination with Smart Street), which would then be manually adjusted by the CLASS operator through the CLASS dashboard. It is important to note that during subphase 2, this approach was discussed, and it was concluded that it should be changed for several reasons:

- Adjustment of the CLASS dashboard would require substantial manual intervention, which is not acceptable bearing in mind that CLASS committed targets vary during the day. This would require QUEST to perform the coordination each time the target is changed, and it would then need to manually apply them to the CLASS dashboard. Exporting the QUEST results into a .CSV file and importing it into a CLASS dashboard was also considered, in order to decrease the number of manually performed actions but excluded since it is impossible to import the list of primary substations to a CLASS dashboard and this functionality currently cannot be changed.
- At the moment, scheduling of primary substations based on the defined half-an-hour targets is only performed for DRF services by the CLASS scheduling mechanism. The DRF targets for half-an-hour periods can be imported into the CLASS dashboard from an external system. DBF 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, it was concluded that the logic for scheduling primary substations for DBF has to be implemented within QUEST since the development of the CLASS Dashboard is closed and this functionality cannot be changed.

Considering all the obstacles, the decision has been made to implement and enhance the CLASS scheduling mechanism logic within the QUEST overarching software and to allow QUEST to perform the automatic adjustment of the CLASS dashboard. During the QUEST trials, the (BAU) CLASS scheduling mechanism will be disabled so as not to override QUEST's actions.

4.3.1. CLASS DR and Smart Street Coordination

Four potential options to mitigate conflicts between CLASS DR and Smart Street were suggested during the first subphase of the detailed design. During subphase 2 of the detailed design, these options have been named as follows:

1. Prioritise CLASS
2. Prioritise Smart Street
3. Equalise CLASS and Smart Street priority
4. Hybrid approach

Explanations regarding each of these options are provided in the "QUEST Architecture Options - Subphase 1 Report" document [2], in the section "Options to Avoid or Mitigate Conflicts between CLASS DR and Smart Street".

A diagram displaying the QUEST architecture for CLASS DR and Smart Street coordination action is shown in Figure 4.5.

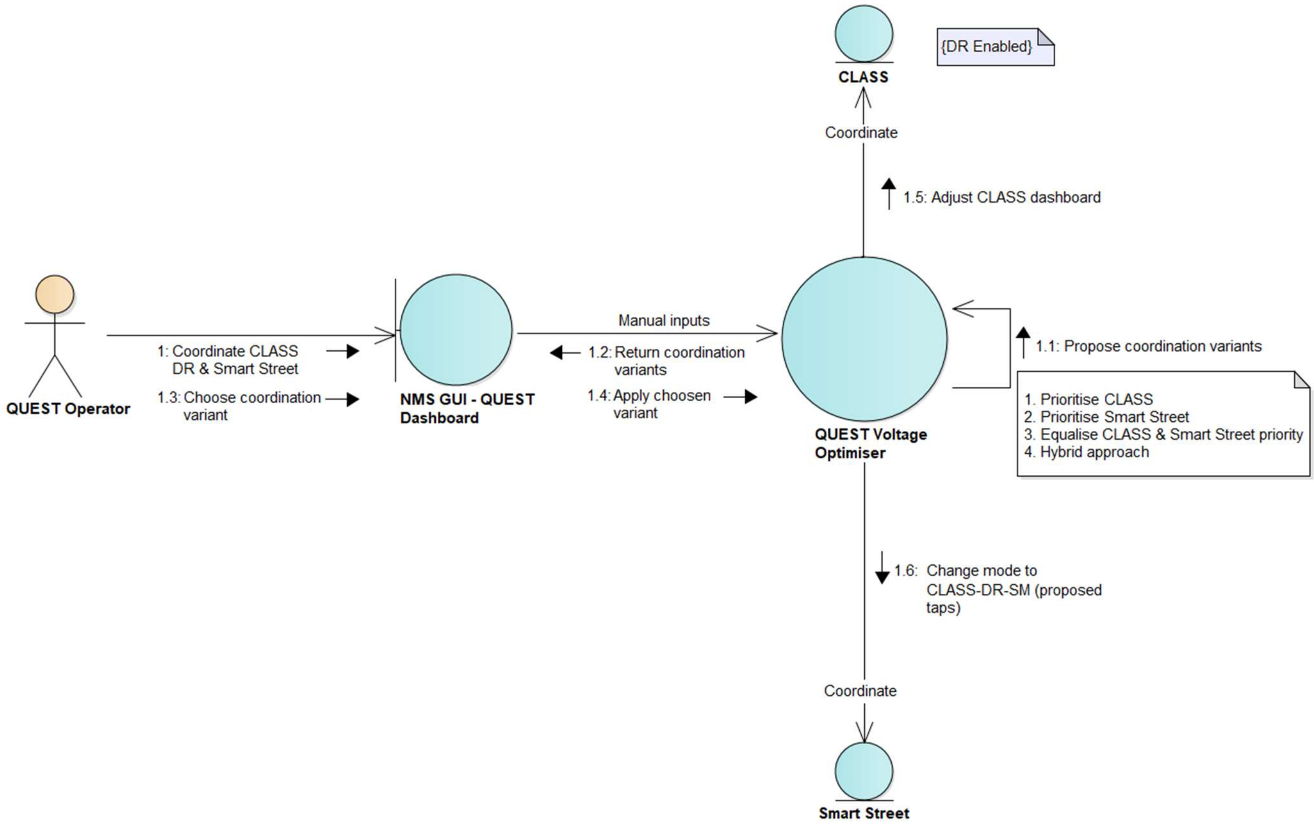

Figure 4.5 – CLASS DR and Smart Street coordination – Option 1

As agreed during the first subphase of the detailed design, the QUEST operator manually starts the CLASS DR and Smart Street coordination, e.g., on a weekly basis (input 1: Coordinate CLASS DR & Smart Street displayed in Figure 4.5). Prior to starting the coordination process, CLASS DR half-an-hour targets are imported in the CLASS dashboard and made available to QUEST. The QUEST Voltage Optimiser then performs a calculation to consider each option 1, 2, 3 and 4 and determines if the committed CLASS DR MW level can be achieved by each option and the number of customers that would lose all or partial Smart Street CVR benefits delivering CLASS DR and any shortfall in the CLASS DR delivery (action 1.1: Propose coordination variants shown on the architecture diagram). QUEST subsequently provides this information to the QUEST operator who selects and applies the preferred option after analysing the displayed results. Having applied the preferred coordination option, the QUEST operator instructs QUEST to automatically adjust the CLASS dashboard (coordination action 1.5: Adjust CLASS dashboard) and to move the associated Smart Street substations to a safe operating mode (CLASS-DR-MM).

Each time either the DR target value changes or some of the CLASS primary substations become unavailable (e.g., automatically, or manually inhibited), QUEST triggers in order to readjust the CLASS dashboard and, consequently, Smart Street affected transformers. Since it is not acceptable that the QUEST operator applies a coordination variant each time QUEST is triggered to adjust the CLASS dashboard, it has been agreed that the QUEST operator will choose the most suitable variant only after manually starting the initial coordination for that week. On each next trigger, QUEST will readjust the CLASS dashboard and Smart Street according to the variant previously chosen by the QUEST operator. If the QUEST operator, at some point, determines that it would be better to coordinate CLASS & Smart Street according to some other variant, the operator will re-execute CLASS & Smart Street coordination on demand and choose a coordination variant that is the most suitable at that moment. QUEST will then continue performing coordination according to that variant.

4.3.2. CLASS DB and Smart Street Coordination

Five potential options to mitigate conflicts between CLASS DB and Smart Street were suggested during the first subphase of the detailed design. During subphase 2 of the detailed design, these options have been named as follows:

1. Prioritise CLASS
2. Prioritise Smart Street
3. Equalise CLASS and Smart Street priority
4. Hybrid approach
5. Over-enable CLASS

Explanations regarding each of these options are provided in the “QUEST Architecture Options - Subphase 1 Report” document [2], in the section “Options to Avoid or Mitigate Conflicts between CLASS DB and Smart Street”.

A diagram displaying the QUEST architecture for CLASS DB and Smart Street coordination action is shown in Figure 4.6.

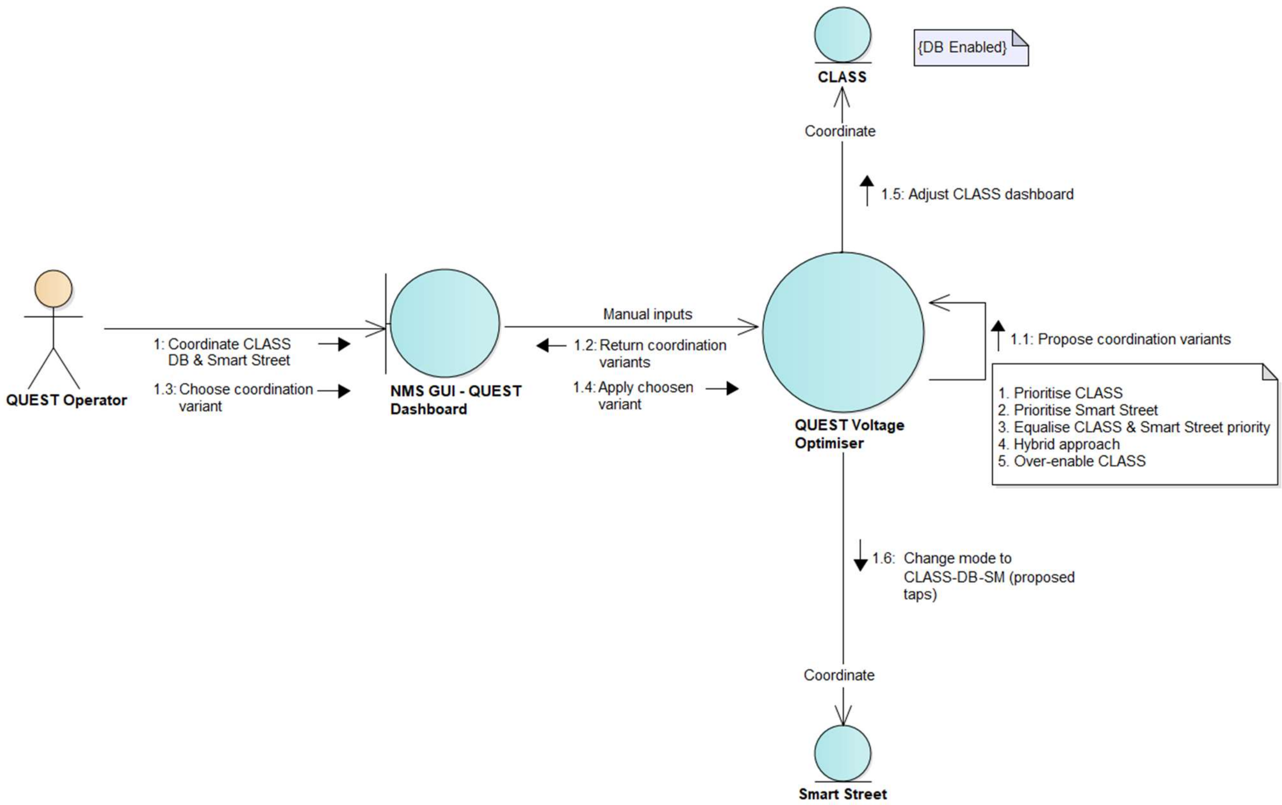

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Figure 4.6 – CLASS DB and Smart Street coordination – Option 1

The coordination process shown in Figure 4.6 is the same as the CLASS DR and Smart Street coordination. The only difference between these two processes is that DB half-an-hour targets will be imported through the QUEST Voltage Optimiser directly since this function does not exist in the CLASS dashboard.

Additionally, during subphase 1 of the detailed design it was concluded that CLASS DB and Smart Street coordination option 5 QUEST’s intervention is required on CLASS DB deactivation. For option 5, where the Smart Street is allowed to operate in CVR mode upon CLASS DB enablement, prior to deactivation of CLASS DB, QUEST will put all the affected Smart Street transformers in a safe mode. Newly determined Smart Street safe mode is active only for a short period until primary substation transformers tap to their normal target voltages (11kV or 6.6 kV) and then it is deactivated by QUEST in order to release the associated Smart Street tap fixing and allow Smart Street to maintain the original pre-set target voltage. The proposal for this coordination option is provided in the next section where Smart Street fast tap capability is explained.

4.3.3. Coordination of CLASS and Smart Street with Fast Tap Capability

During the final discussion of the subphase 1 report, fast tap capability of Smart Street transformers was raised. Based on this information, it was concluded that this capability could be used to leverage the coordination of Smart Street and CLASS with Smart Street being put into a safe mode upon CLASS functions activation (DR), rather than CLASS functions enablement. This approach introduces additional flexibility to the QUEST overarching software since it provides the possibility to fully maintain customer benefits from Smart Street CVR during the whole period of CLASS functions enablement.

Based on the discussions held during the subphase 2 design, it was concluded that this approach, as a first step, should be considered for coordination of Smart Street with CLASS DRF, as it is currently used in the ENWL distribution network. With this approach, the CLASS scheduling mechanism will remain the same, the CLASS scheduler will be the one in charge of DRF enablement on all the required primary substations and QUEST will not intervene in this process. Upon CLASS DRF enablement, QUEST determines which Smart Street substations are connected to CLASS primary substations selected for DRF, but it does not put them into a safe mode. When CLASS is activated by the ESO via the Web Link, QUEST is aware of that signal, and at the same time as DRF is activated on all the selected primary substations, QUEST sends commands to all the affected Smart Street transformers to put them in a safe mode (CLASS-DRF-FastTap-MM). CLASS-DRF-FastTap-MM refers to the following actions:

- Enable fast tap option for all the affected Smart Street 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 Smart Street 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 Smart Street tap fixing and allow Smart Street 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, Smart Street transformers will make sure that LV voltages will not drop below the statutory LV voltage limits at any time. Tapping up two taps at a Smart Street substation provides an approximately 5% voltage increase on the LV busbars.

After CLASS is deactivated and the primary substation and associated Smart Street voltages rise, all the Smart Street transformers will 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.

The QUEST architecture option for this newly introduced approach is presented in Figure 4.7.

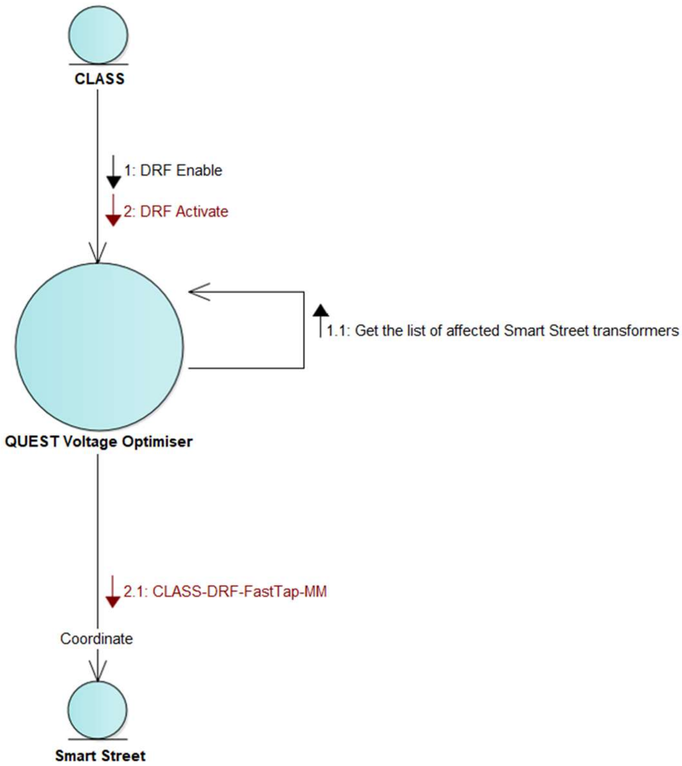

Figure 4.7 – CLASS DRF and Smart Street coordination – Option 2

The fast tap capability of Smart Street transformers could also be considered and trialled for readjusting the Smart Street safe modes upon CLASS DB deactivation, as described in section 4.3.2 CLASS DB and Smart Street Coordination. When CLASS DB is deactivated, the primary substation voltage reduces to the pre-CLASS DB level causing the Smart Street CVR controlled LV voltage to drop below LV statutory limits for a short period while Smart Street responds to raise the voltage back up the CVR target voltage. The solution is to apply the Smart Street fast tap option (perform CLASS-DRF-FastTap-MM actions explained above). This will rapidly tap the LV voltage up to compensate for the primary substation voltage reduction when the upstream CLASS DB function is deactivated. The Smart Street LV voltage only requires to be raised and fixed for a period long enough for the primary substation voltage to reduce during CLASS DB deactivation, the Smart Street taps can then be released, and Smart Street is allowed to return to the pre-set CVR voltage control level.

QUEST architecture option for this approach is presented in Figure 4.8.

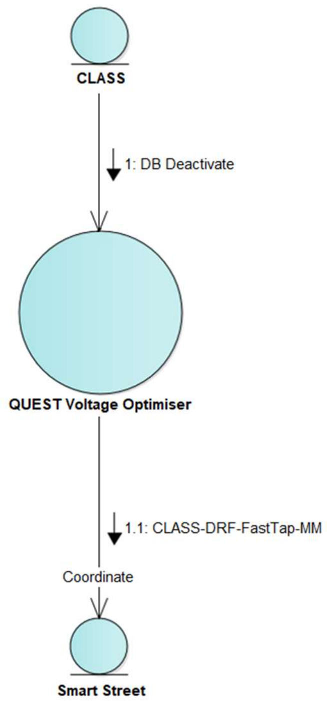

Figure 4.8 – CLASS DB disablement and Smart Street coordination

4.4. ANM and Smart Street Coordination

The conclusion from the subphase 1 report of the detailed design was that the ANM and Smart Street coordination discussion should be transitioned to subphase 2 of the detailed design since it was not decided whether QUEST's intervention between these systems is expected or not.

During subphase 1 of the detailed design it was noted that presently the impact of Smart Street on ANM is likely to be small and may not be an issue for many years, if at all. However, the question remains whether QUEST functionality that can mitigate this potential conflict should be designed and implemented now to future proof the QUEST system.

During subphase 2 of the detailed design, a conclusion has been made that Option 1, where QUEST does not intervene between ANM and Smart Street operation, is the one to consider within this phase of the QUEST project. With this option, the QUEST Voltage Optimiser will only monitor the duration of the start and end time for each Flexible Connection generator that is pushed into a curtailment condition, including the periods when Smart Street operates in CVR mode. This is so that the appropriate post-analysis can be performed to identify if any exceeding of agreed curtailment indexes is influenced by Smart Street operations.

It was also noted that if in the future Smart Street causes HV reverse power violations which result in Flexible Connection generation being constrained beyond their contracted limit (of constraining), Smart Street could be enhanced in a way to prevent this from happening. Smart Street could simulate whether its actions would cause reverse power violations on the HV parts of the network and if it detects such conditions, it could readjust distribution transformers target voltages in a way not to cause violations. However, any such modified Smart Street behaviour would require considering the economic impacts on both LV Smart Street customers and DER customers being managed under an ANM flexible connection agreement.

Based on this decision, Use Case 3 - Smart Street and ANM, is adjusted such that only option 1 is left in the Use Case as an acceptable solution for the defined conflict. An updated version of Use Case 3 is provided in Table 4.2.

Table 4.2 – Use Case 3 - Smart Street and ANM

Use Case Name	Smart Street & ANM				
Use Case Number	UC 3	**Version**	2	**Status**	Draft
Use Case Development Owner	ENWL				
Use Case Description	This use case describes the coordination between Smart Street and the systems providing Flexible Connection ANM functionalities (Central ANM NMS and Decentralised ANM) and Flexible Services ANM (Central ANM NMS and Cloud ANM) provided by the QUEST Voltage Optimiser. The QUEST Voltage Optimiser executes in line with its “Operational Objective”.				
Primary users	DNO				
Secondary users	ANM				
Trigger	The QUEST Voltage Optimiser assumes that Smart Street CVR on the LV network, in isolation or combined with ANM (Flexibility Service) dispatching, will result in flexible connection DER being constrained beyond their connection agreement curtailment index (CiD) due to demand/generation imbalance at ANM managed constraint points on the HV distribution network.				
Preconditions	Smart Street is enabled and is running in Conservation Voltage Reduction mode (CVR). Smart Street performs voltage reduction to the defined limits to provide demand reduction in the LV parts of the network. LV voltages are close to the lower technical limit. ANM is managing DER with flexible connection agreements to control power flows at thermal constraint points within its constraint management zone, issuing set points to DER when required. ANM has the capability to issue MW and MVAr set points. ANM is also providing Flexible Services when required. CLASS is disabled on the considered part of the network. QUEST network efficiency mode is switched on since CLASS is disabled.				

	The QUEST Voltage Optimiser is aware of all the applications that are enabled on the observed part of the network. The QUEST Voltage Optimiser has visibility of voltages at the GSP, BSP and primary substations, and monitors actions taken by the systems. Voltages in the network are within the statutory limits.	
Post Conditions	Voltages on the HV and LV networks in the QUEST trial area are within the technical limits. Smart Street continues to optimise voltages in the LV part of the network. ANM continues to control power flows at thermal constraint points by managing the set points of DER with flexible connection agreements when required. The Flexible Services via ANM continues to be dispatched when needed without causing circuit limit violations on the network or curtailment of DER with flexible connection agreements.	
Main Success Scenario	**Steps**	**Actions**
	1	The QUEST Voltage Optimiser assumes that the level of Smart Street CVR demand reduction in isolation, or combined with ANM Flexible Service dispatching, may reduce available network capacity.
Conflict/Coordination Issue	2	The QUEST Voltage Optimiser does not intervene and both Smart Street and ANM Flexible Services continue to operate independently of each other. This results in ENWL being penalised for exceeding the curtailment index at one or more Flexible Connection generators.
Potential Resolution Option	3.	The QUEST Voltage Optimiser monitors the duration of the detected conflict and records the start and end time for each Flexible Connection generator pushed past their connection agreement curtailment index due to Smart Street CVR actions and or ANM Flexible Service actions.
Notes and Outstanding issues (if any)	**Assumption 1**: Smart Street actions are a higher priority than Flexible Connections (free to alter within Curtailment Index). **Resolution option**: Assumes no QUEST intervention, sticks to baseline priority list. Any contractual exceedances are dealt with post analysis. QUEST extracts pertinent information to settle issues post event. **Assumption 2**: The curtailment index measures the periods where the ANM DER set point instruction is not equal to full DER export capability. This would indicate the period where ANM intervention has occurred, not what MWh volume has been curtailed (decentralised ANM and central ANM, set points are only issued to DG when the ANM decides they need to be constrained. These starting and stopping of issued setpoints are time stamped and recorded. Hence just need to aggregate the constraint times.).	

	Using post analytics of Smart Street actions and Cloud ANM flexibility service dispatching, it may be possible to identify these system influences on the level of ANM curtailment applied. When the CiD exceeds a certain (Contractual) period threshold, the cost of further curtailment would be applied, thus triggering an economic optimisation of each systems' actions. This is a complex process that would require advanced online analytics and, therefore, considered an extension.

4.5. ESO Instructions for Emergency Response

4.5.1. LFDD Mode Coordination

In the 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 underfrequency situation. QUEST will automatically trigger, upon the first three SCADA alarm appearances, and perform LFDD-MM actions on the whole network. The choice of three alarms is to achieve consistency with similar requirements by other NMS power applications and to reduce the risk of protection testing activity causing a maloperation of this trigger. LFDD-MM actions refer to:

- Switching off NEM on all the BSPs.
- Putting ANM in LFDD-MM network-wide.

QUEST does not intervene in CLASS's and Smart Street's operation.

QUEST remains in LFDD-MM until LFDD is deactivated. 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. Once QUEST is returned from LFDD-MM, the following actions are performed:

- NEM is started on all the BSPs supplying the primary substations that do not have CLASS functions enabled (except DB).
- Releasing ANM from LFDD-MM.

The architecture diagram presenting coordination performed by QUEST in the case of LFDD activation is displayed in Figure 4.9.

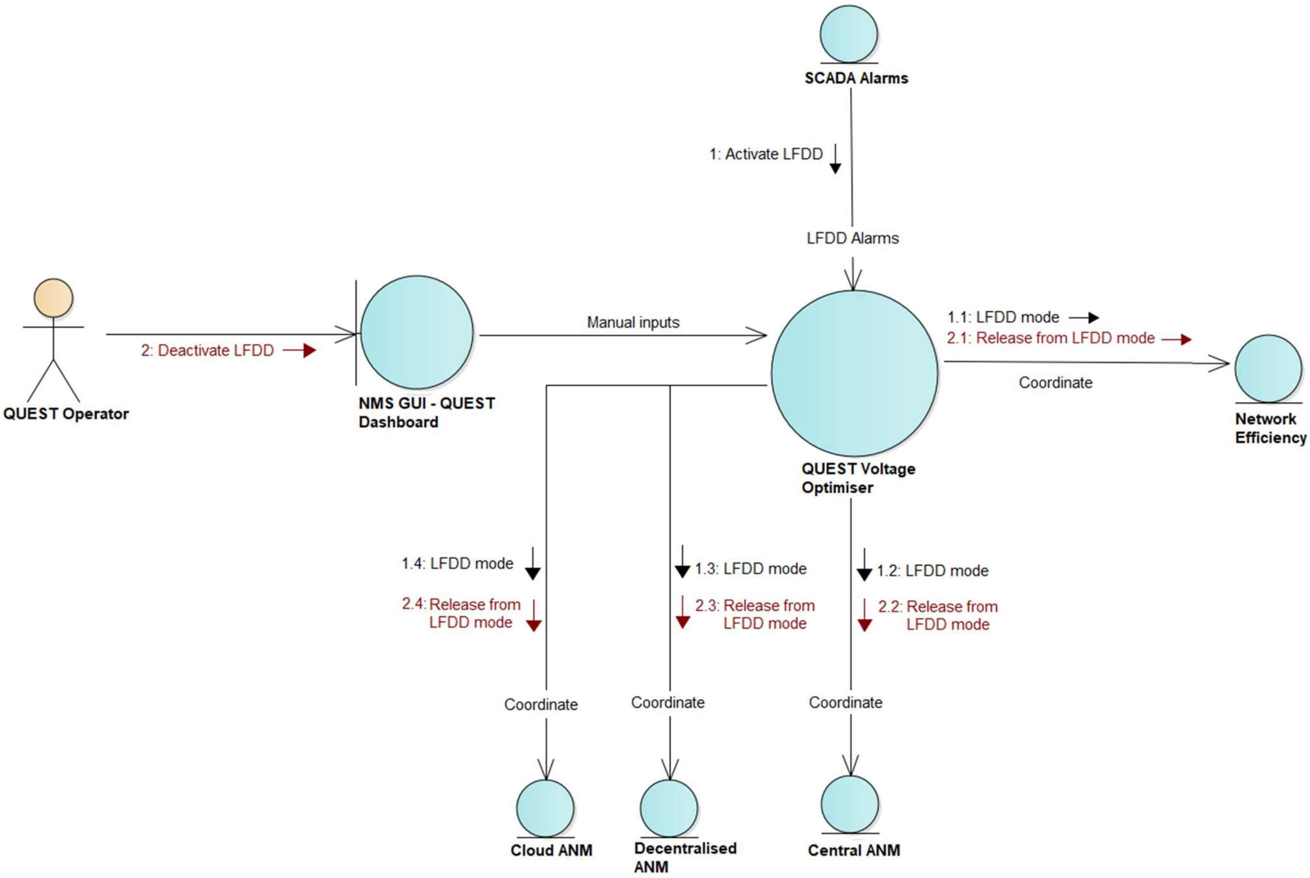

Figure 4.9 – LFDD coordination performed by QUEST

4.5.2. OC6 mode Coordination

During subphase 1 of the detailed design, it has been agreed that in the case of OC6 activation, the QUEST system will be manually put in the OC6 mitigation mode (OC6-MM). It was also noted that this could become an automated process in the future. It will be a business procedure to put QUEST in the OC6-MM prior to manually activating the OC6 commands. QUEST will automatically trigger and perform the OC6-MM actions on the whole network. QUEST OC6-MM actions refer to the followings:

- Switching off NEM at all the BSPs.
- Putting ANM in OC6-MM network-wide.
- Putting Smart Street in OC6-MM network-wide.

As described in the subphase 1 report, OC6-MM for ANM refers to preventing the release of the previously curtailed demand and for Smart Street to fixing all the distribution transformers on their current tap positions.

QUEST remains in OC6-MM until it is manually deactivated. Once QUEST's OC6-MM is deactivated, the following actions are performed:

- NEM is switched on for all the BSPs supplying the primary substations that do not have scheduled CLASS functions enabled, with the exception being DB.
- Releasing ANM from the OC6-MM.

- Releasing Smart Street from OC6-MM (release taps of all the distribution transformers that had not been fixed prior to OC6 activation).

It is important to note that during subphase 2 of the detailed design, while terminology of the QUEST safe modes was discussed, it was concluded that OC6-MM should be divided into two separate safe modes:

- OC6 Voltage Reduction Mitigation Mode (OC6-VR-MM)
- OC6 Demand Disconnection Mitigation Mode (OC6-DD-MM)

The reason for the OC6-MM split into two modes is because it has been concluded that for these two modes, QUEST's intervention regarding the NEM and Smart Street should be different.

When OC6-VR-MM occurs, NEM should be switched off by QUEST. The reason for switching off the NEM prior to activating the OC6-VR is to enable the primary substations to perform the expected voltage reduction to reduce the demand (OC6.5). 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 OC6-DD activation, demand disconnection is performed by opening HV CBs at Primary substations to disconnect demand in a controlled manner (OC6.7). In this situation, NEM being switched on does not affect the process of demand disconnection and, hence, it should not be switched off. When OC6-DD-MM occurs NEM should be locked in whatever voltage target setting the BSP transformer was in before OC6-DD-MM was activated. Therefore, NEM would either stay on at its prior voltage boost level or stay 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 putting NEM in OC6-DD-MM, QUEST will not be allowed to change the target voltage of the BSP transformers for any reason, until the OC6-DD-MM is deactivated.

Similar approach is considered for coordination of Smart Street. In case of OC6-VR-MM activation, Smart Street should be put in a safe mode network-wide which means fixing all the Smart Street distribution transformers on their current tap positions in order not to have Smart Street counteracting the performed voltage reduction. In case of OC6-DD-MM activation, Smart Street should be locked in whatever voltage target setting it was in before OC6-DD-MM was activated. 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 Smart Street CVR.

The coordination of ANM in both modes remains the same. ANM is prevented from releasing the previously curtailed demand.

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

During the subphase 1 of the detailed design, it was concluded that QUEST will not intervene in CLASS operation in case of OC6 activation, since CLASS DR could be used to help with the demand reduction. During the subphase 2 of the detailed design, the transitional state from CLASS DR with Smart Street fast tapping coordination option to OC6-VR was also discussed. It was discussed whether tapping up Smart Street distribution transformers, in case of CLASS DR deactivation, would conflict OC6 voltage reduction. It was concluded that no negative effect would occur since on starting OC6-VR-MM, Smart Street will be put in a safe mode with fixed tap positions and therefore tapping up will not be performed in this situation.

The architecture diagram presenting coordination performed by QUEST in the case of OC6-mitigation modes activation and deactivation is displayed in Figure 4.10.

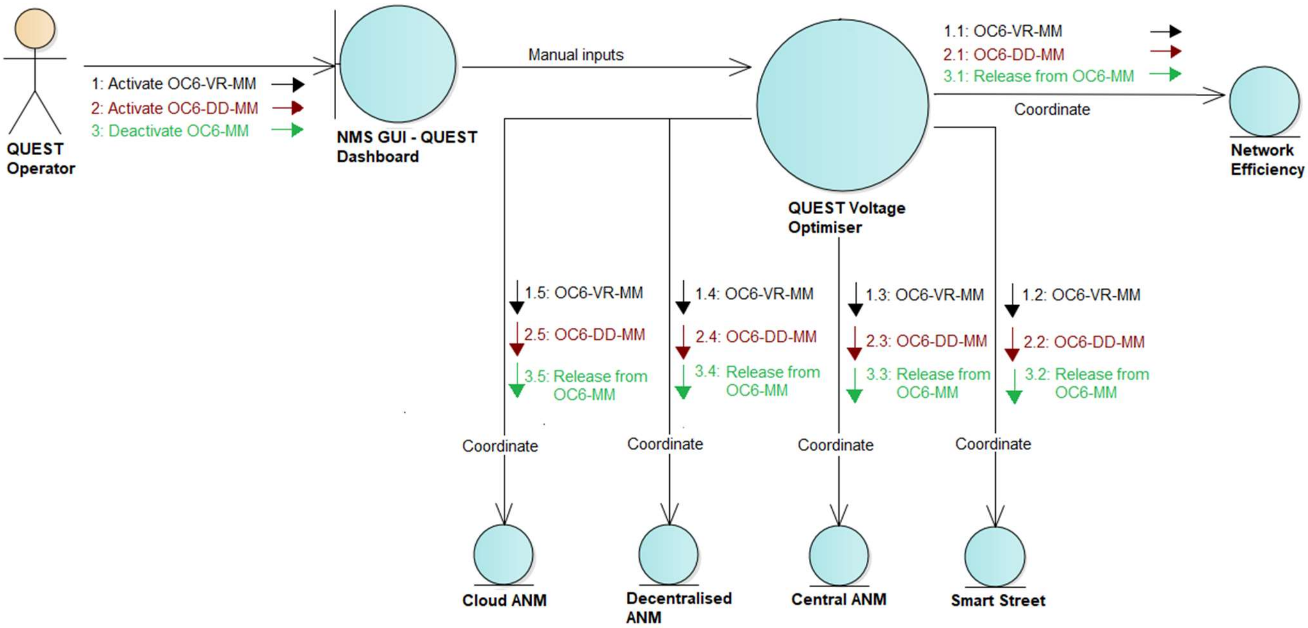

Figure 4.10 – OC6 modes coordination performed by QUEST

4.6. Providing Reactive Power Response to ESO

During the discussions of Use Case 8 - Smart Street, Enhanced AVC Including CLASS, ANM & Reactive Power Response, it was confirmed that providing reactive power response to the ESO will not affect the operation of the other systems. Hence, QUEST's intervention is not expected regarding the coordination of the different systems.

However, additional topics were raised during the discussions within subphase 1 of the detailed design. Since ENWL plans to use tap stagger (TS) function at the BSP 132/33kV transformers to provide reactive power response to the ESO, the question remains as to how the inclusion of CLASS tap stagger at BSPs is to be implemented.

Although this function is considered as a CLASS function and it is expected that enabling TS on a BSP level should be performed from the CLASS Dashboard, this option was excluded during subphase 2 of the detailed design. The reason is that the development of the CLASS dashboard is closed, and this function currently cannot be integrated within the CLASS dashboard.

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Based on subphase 2 of the detailed design discussions, it has been agreed that this CLASS dashboard function, for TS on a BSP level, will be implemented within the QUEST Voltage Optimiser.

The QUEST monitoring and control dashboard will be enhanced to support manual enablement/deactivation of the TS at a BSP level. The QUEST operator will be the one who decides which of the BSP transformers should have TS enabled.

If a signal for activating the reactive power response is sent from the ESO, QUEST will automatically activate the TS on all BSP transformers with enabled TS function. During the QUEST trials, activation will be a manual operation since currently there is no possibility to activate reactive power response via the Web link from the ESO.

Based on the agreement, Use Case 8 is updated and shown in Table 4.3.

Table 4.3 – Use Case 8 - Smart Street, Enhanced AVC Including CLASS, ANM & Reactive Power Response

Use Case Name					
Use Case Number	UC 8	**Version**	1	**Status**	Final
Use Case Development Owner	ENWL				
Use Case Description	This use case describes the coordination between reactive power response to the ESO (absorb reactive power to reduce the voltage on National Grid Network), Enhanced AVC including CLASS, Smart Street and ANM (which enables Flexible Connections and Services) provided by the QUEST Voltage Optimiser. The QUEST Voltage Optimiser executes in line with its “Operational Objective”. Reactive power response is a contractual agreement to provide the ESO with reactive power management.				
Primary users	ESO				
Secondary users	DNO				
Trigger	Activation of Reactive Power Response from ESO.				
Preconditions	Smart Street, CLASS (all functions except PFR), ANM enabled systems are all running in normal operating conditions. CLASS is enabled to execute one of the functions upon request from the ESO or commercial agreements. Where a commercial agreement is in place the DNO will enable the contracted services, which will only activate following a trigger from the ESO. QUEST Voltage Optimiser is aware of all the applications that are enabled on the observed part of the network. QUEST Voltage Optimiser has visibility of voltages at the GSP, BSP and Primary substations and monitors actions taken by the systems.				

	QUEST is not in "efficiency mode" if a CLASS service is enabled other than DB.	
Post Conditions	Reactive power response has been provided and CLASS remains enabled, Smart Street and ANM are in the operating mode applied prior to activating the reactive power response. Voltages on the HV and LV networks in the QUEST trial area are within technical limits. CLASS continues to enable ESO services and ANM continues to control power flows at constraint points by managing the set points of DER when required. QUEST to maintain system voltages within statutory limits where possible. Cloud ANM Flexibility Service dispatch continues with a revised schedule where required. QUEST is not in the network efficiency mode.	
Main Success Scenario	**Steps**	**Actions**
Reactive Power Response	1	Control operator manually enables TS functionality on selectedBSP transformers, via the QUEST Dashboard, in order to prepare for reactive power response.
	2	The QUEST Dashboard receives instruction from the ESO to provide reactive power response.
	3	The QUEST Dashboard activates Enhanced Automatic Voltage Control(EAVC) Relays to increase reactive power absorption on a BSP level. The result causes no thermal violation in the constraint management zone.
	4	QUEST does not affect Smart Street or ANM operability.
	5	Once the reactive power response has been deactivated, the system returns to the normal precondition state.
Conflict/Coordination Issue Path		None
Extensions	If the Control operator cannot find enough capacity available to absorb reactive power by enabling TS on a BSP level, the Control Operator will try to compensate for that by enabling TS on selected primary substation transformers through the CLASS Dashboard.	
Notes and Outstanding issues (if any)	**Assumption 1**: Reactive power absorption can be implemented at 132/33 kV substations without conflicting with CLASS, Smart Street, or flexible connections or services. It may be limited by reaching the end of the tap range, by restrictions on the amount of circulating current or by the potential voltage step change if one of the transformers trips. **Assumption 2**: There will be no noticeable effect on customer voltage levels during reactive power response activation.	

	Assumption 3: Fail safe mode to be considered during a loss of comms within EAVC (SuperTAPP SG) relays already installed in primary substations during tap stagger mode.

5. CONCLUSION

This document provided a review of the second subphase of the QUEST detailed design. The purpose of this subphase was to provide different architecture options for the QUEST overarching software that should be further explored during the next phases of the QUEST project.

Macro-level architecture option “hybrid approach” (macro-option 3) had been chosen as the preferred solution during the first subphase of the detailed design. It was further explored during this phase of the detailed design. Several ‘meso level’ architecture options, which in different ways satisfy the criteria of macro-option 3 were suggested (e.g., for NEM, instead of going with the worst-case scenarios, where NEM would be simply switched on or off upon CLASS DR enablement or deactivation, several levels of the NEM were introduced in order to bring additional flexibility to the QUEST “hybrid approach” architecture option). Architecture diagrams for all considered meso-level architecture options were provided within this document.

Additionally, all the questions that remain open at the end of the first subphase of the detailed design, were discussed further and clarified during this subphase. Some of the changes in respect to the first subphase conclusions have been made based on the clarifications provided:

- QUEST safe mode terminology, such as CFOM, was additionally discussed and the new safe mode terms were proposed. These newly proposed terms were deemed suitable and are in accordance with the ‘meso-level’ architecture options suggested during subphase 2 of the detailed design. However, it should be noted that these may be further refined and changed as we continue to explore QUEST architecture options during the next phases of the project.
- Use Cases that describe conflicts for which QUEST’s intervention was not totally clarified within subphase 1, were readjusted in accordance with clarifications provided within subphase 2.
  - For Smart Street and ANM coordination, it was concluded that QUEST intervention is not expected for this version of the QUEST overarching software, and the use case (Use Case 3) has been adjusted so that only option 1 is left as an acceptable solution for the defined conflict.
  - For the use case related to providing reactive power response, it has been agreed that TS function will be implemented within the QUEST overarching software. Use Case 8 has been adjusted in accordance with the agreements reached and the updated version was provided within this document.
  - Although the coordination between CLASS and Smart Street was clarified during subphase 1, several changes were introduced within subphase 2. The agreement has been made that for QUEST trial purposes, CLASS scheduling functionality will be implemented and enhanced within QUEST. Since QUEST has awareness of all the systems running in the trial area, it is able to enhance the CLASS scheduling mechanism such that it considers the optimal balance between the CLASS commitments and objectives of other systems, such as Smart Street and network efficiency. Also, the process of readjusting the CLASS dashboard each time it is needed will be automated within QUEST and only minimal manual intervention will be expected.
  - Additional coordination option for CLASS DRF and Smart Street was proposed within subphase 2. Based on the information regarding fast tap capability of Smart Street transformers, an option to coordinate Smart Street upon CLASS DRF activation, instead of

enablement, has been introduced. This option is expected to be trialled and if it is confirmed as successful, it will be treated as the preferred option until the penetration of Smart Street becomes too great to meet CLASS targets. This is because preferred option provides the most benefits to Smart Street customers in addition to achieving CLASS committed services.

- OC6 mitigation mode was split into two separate modes since it was concluded that QUEST's intervention regarding NEM should be different for different OC6 actions. For OC6-DD-MM, it was concluded that NEM should not be switched off since it does not affect the demand disconnection whereas for OC6-VR-MM NEM should be switched off. If in future or during the trials, it is concluded that this approach (performing network efficiency in emergency situations) is not suitable, the logic will be changed.

During the definition of the QUEST architecture options, review of the QUEST functionality against the QUEST objectives was performed to make sure that QUEST's objectives are being met with the proposed architecture options. This review has confirmed that the QUEST objectives are being met.

It is important to note that all the conclusions and changes made within subphase 2 could be applied to the subphase 1 report. However, they were intentionally left from the subphase 1 report in order to show how the QUEST detailed design process is evolving and to present the chronology of the decisions made during this process.

In the final discussions relating to this subphase 2 report, additional important points relating to QUEST functionality and overall objectives were mentioned that need to be addressed in the further phases of the QUEST project. These include:

- In the event of loss of system communication, it is expected that the QUEST overarching control system ensures that any associated discrete voltage systems default to a safe mode setting to maintain network stability and safety. It has been concluded that this topic should further be discussed since it is needed to explore how the different voltage management systems respond to a loss of communications in order to determine what is expected QUEST's behaviour in this situation.
- Subphase 1 and 2 of the detailed design have identified that the network modelling studies are required to identify parameters that will be required when setting up the QUEST software for operational trials. These parameters are explained in detail within the Recommendations
- Subphase 1 and 2 of the detailed design only considered CLASS full and half levels of the demand change. It was mentioned that ¼ and ¾ modes could be introduced within the CLASS Supper Tap AVC Relay and that these modes could also be included in QUEST's trials. In the further phases of the QUEST design, it will be explored how can the ¼ and ¾ levels be demonstrated, what would be QUEST's architecture in this case and whether the inclusion of these new modes will be trialled in this version of the QUEST overarching software or left for some future QUEST's development.
- The transitional state from CLASS DR with Smart Street fast tapping coordination option to OC6-VR was discussed to determine whether tapping up Smart Street distribution transformers would conflict OC6 voltage reduction. It was concluded that no negative effect on OC6-VR will occur. This situation will be further explored during the next phases of the QUEST project and the architecture diagram will be provided.

6. RECOMMENDATIONS

Subphase 1 and 2 of the detailed design have identified that the following network modelling studies are required to identify parameters that will be required when setting up the QUEST software for operational trials:

1. For setting up the 33kV NEM, the permitted levels of the voltage increase (safe target voltage for DRF and DRH and target voltage for the normal mode of operation) are to be determined by performing before the loop offline analysis. Inputs for these values are to be provided within the QUEST project Workstream 2: Network modelling regime of the QUEST detailed design. Based on the simulation models carried out within this modelling workstream, the total impact of the different levels of network efficiency on a tap capability of each primary substation to perform DRF or DRH are to be determined and tested during the QUEST trials. ENWL is to discuss with SGS how the permitted levels of the voltage increase can be determined within QUEST project Workstream 2. Important note for determining target voltage for the normal mode of operation: simulation studies should cover different scenarios to determine critical periods of the day when over-voltages may occur if maximum level of voltage increase is applied (e.g., during very low load periods). These studies should provide inputs regarding either maximum allowed levels of voltage increase in normal mode of operation that will never cause over-voltages or periods of the day when network efficiency should not be run.
2. For CLASS and Smart Street coordination the Smart Street safe target voltages are to be pre-defined voltages programmed into QUEST. Determination of these safe target voltages are to be provided within the Workstream 2: Network modelling regime of the QUEST detailed design, based on the trial network simulation models developed within this modelling workstream. ENWL is to discuss with SGS how this work can be achieved within QUEST project Workstream 2.

NOTE: It was agreed that the above stated inputs are not required to be provided for this phase of the QUEST project. These are required for setting up the QUEST software for operational trials.

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7. DEFINITIONS AND ABBREVIATIONS

Term	Definition
ADMS	Advanced Distribution Management System
ANM	Active Network Management
AVC	Automatic Voltage Control
BSP	Bulk Supply Point
CB	Circuit Breaker
CFOM	CLASS Forecast and Optimise Mode
CLASS-DR-MM	CLASS Demand Reduction Mitigation Mode
CLASS-DB-MM	CLASS Demand Boost Mitigation Mode
CLASS-DR-SM	CLASS Demand Reduction Safe Mode
CLASS-DB-SM	CLASS Demand Boost Safe Mode
CLASS-DRF-FastTap-MM	CLASS Demand Reduction Full Fast Tap Mitigation Mode
CID	Curtailment Index – refers to the permissible amount of curtailment applied to a DER before DNO incurs penalty, the exact amount of which is laid out in the connection agreement.
DER	Distributed Energy Resource
DERMS	Distributed Energy Resources Management System
DG	Distributed Generation
DB	Demand Boost (CLASS Function)
DBF	Demand Boost Full (CLASS Function)
DBH	Demand Boost Half (CLASS Function)
DR	Demand Reduction (CLASS Function)
DRF	Demand Reduction Full (CLASS Function)
DRH	Demand Reduction Half (CLASS Function)
DNO	Distribution Network Operator
EAVC	Enhanced Automatic Voltage Control
ENWL	Electricity North West Ltd.
ESO	National Grid Electricity System Operator
GUI	Graphical User Interface
HV	High Voltage (refers to ENW 6.6kV and 11kV operating voltages)
kV	Kilovolt
kVA	Kilovolt-Ampere

LCT	Low Carbon Technologies
LFDD	Low Frequency Demand Disconnection
LFDD-MM	Low Frequency Demand Disconnection Mitigation Mode
LL	Load limiting (CLASS Function)
MW	Megawatt
NMS	Network Management System
NEM	QUEST's network efficiency mode
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
PFR	Primary Frequency Response (CLASS Function)
SCADA	Supervisory Control and Data Acquisition
SE	Schneider Electric
SFR	Secondary Frequency Response (CLASS Function)
SGS	Smarter Grid Solutions
TS	Tap Stagger (CLASS Function)
UI	User Interface