QUEST Architecture Options

Detailed Design Subphase 1 Report

Design Specification

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Revision History

Version	Authors	Date	Comments
1.0	Milena Jajčanin	2-Dec-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.	Mandatory Frequency Response	An external link which leads to *www.nationalgrideso.com* page and opens the document "Mandatory Frequency Response".

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 and SE), 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 what existing voltage control service is prioritised, and when and how the voltage optimisation systems already in place will interact with each other. The main goal of defining the Use Cases was to understand the areas of conflict between the existing voltage regulating techniques (CLASS, Smart Street and ANM), in combination with receiving instructions from ESO for emergency response or when providing a contractual service. They also determine possible options to overcome these conflicts (definition of objectives and constraints of the QUEST algorithm and its triggers) and to set a foundation for a detailed design and architecture specification for the QUEST overarching software.

Having that in mind, 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 initial 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 has and is being developed during workshops running from August until the middle of November 2021. The main goal of the detailed design phase is to fill in the gaps within the first version of the Use Cases and to provide architecture options for the QUEST overarching software. This QUEST detailed design phase is divided into two subphases. The first subphase focuses on the clarification of the initial Use Cases, where the Use Cases are analysed (proved/disproved, updated or replaced) in further detail. This is done to help firm up the design specification to provide the inputs for the second subphase which will focus on different architecture options for QUEST’s overarching software.

This document provides a review of the first subphase of QUEST’s detailed design phase. It is important to stress that although the Use Cases were analysed in more detail within this subphase, there are still some open questions outlined within this document, that need to be answered by ENWL. The final sections to this report include key conclusions and observations made during this subphase that provide further direction for detailed design subphase 2.

3. OVERVIEW

This document focuses on the clarification of the first version of the QUEST Use Cases. Each Use Case has been analysed and revised in more detail. Through discussions during the second set of design workshops, additional clarifications and corrections to the Use Cases and QUEST Use Case matrixes have been included within this document.

Key topics for discussion detected during the analysis of the first version of the Use Cases are:

- QUEST network efficiency mode – resources and methodology confirmation.
- QUEST reaction to CLASS functions, enablement vs activation ("CLASS forecast and optimise mode" (CFOM)):
  - Putting Smart Street in "CLASS forecast and optimise mode" and releasing from it.
  - Putting ANM in "CLASS forecast and optimise mode" and releasing from it.
- Smart Street and ANM coordination – discussion regarding suggested options within use case 3.
- ESO instructions for emergency response:
  - Detection of the "LFDD forecast and optimise mode" (LFOM):
    - Putting Smart Street in "LFDD forecast and optimise mode" and releasing from it.
    - Putting ANM in "LFDD forecast and optimise mode" and releasing from it.
  - Detection of the "OC6 mode":
    - Putting Smart Street in "OC6 mode" and releasing from it.
    - Putting ANM in "OC6 mode" and releasing from it.

The remainder of this document considers each topic above detailing the agreed outputs from the second set of workshops. This includes the agreed amendments to each Use Case and the expanded detail and options for conflict resolution identified in each use case, see "Options to avoid or mitigate conflicts" sections for each Use Case.

4. QUEST NETWORK EFFICIENCY MODE

The purpose of this section is to confirm QUEST's methodology for the network efficiency mode and to confirm QUEST's resources to achieve this objective.

4.1. QUEST Use Case Matrix - Network Efficiency Mode

The initial version of the network efficiency use case matrix is provided in Table 4.1.

Table 4.1 – Network efficiency use case matrix

Use Case	Trigger	Systems for QUEST to Co-ordinate				General Comments regarding potential system conflicts/resolution
		ESO	Enhanced AVC Including CLASS	Smart Street	ANM	
QUEST running in network efficiency mode	**N/A**	N/A	DISABLED	ENABLED	ENABLED/ Possible or acceptable conflict	QUEST operating in network efficiency mode may impact ANM if volts are too high. Raising system voltages increases capacity on the 33kV network for generation export.

Yellow	**Systems not considered in use case**
Green	**No Conflict**
Red	**Conflict**
Amber	**Potential or acceptable conflict**

The initial concern regarding the conflict between ANM and QUEST operating in network efficiency mode was that raising voltages on the 33kV part of the network may affect the operation of DERs. The concern was that since raising system voltages could potentially increase demand on the 33kV network this in turn would increase the possible capacity for generation export. In this network efficiency mode, the primary substation 33/11kV or 33/6.6kV transformers continue to maintain their target 11kV and 6.6kV voltage so the demand on the 11kV, 6.6kV and LV networks is largely unaffected. Through discussions, it has been agreed that any impact on 33kV network demand and the potential for increased flexible connection generation export is likely to be small and can be neglected as an issue for QUEST.

Discussions took place regarding the comments made on raised 33kV network voltages, during the activation of network efficiency mode limiting the export capability of generators. Based on the outcome of these discussions, it was agreed that this is unlikely to be the case and this ANM conflict can be removed from the use case matrix. The following points describe the reasons for this decision:

- All DERs connected to the 33kV network agree to operate in a safe manner within +/- 6% voltage range (part of contracted connection agreement).
- While in network efficiency mode, QUEST will raise 33kV voltages towards the upper statutory limit of 106%(usually 105% +/- 0.8%) and continuously monitor the voltage profile to ensure that the upper voltage limit is never violated across the DNO 33kV network.

An additional change has been made regarding the coordination with CLASS and QUEST when operating in network efficiency mode. The previous conclusion was that QUEST network efficiency mode can be enabled only in periods when CLASS functions are disabled (outside commercially contracted periods). This is because raising voltages on 33kV network would negatively affect the capacity for providing CLASS services at the primary substations. Primary substation 33/11kV and 33kV/6.6kV transformers would move towards the lower end of their tap range to reduce their 11kV and 6.6kV network voltage to the normal set target, reducing their ability to provide CLASS demand reduction related services. After analysing each CLASS function, it has been concluded that for the CLASS DB function, network efficiency mode would actually be beneficial since raising the voltages on primary sides of the 33/11kV and 33kV/6.6kV transformers would make additional room for boosting the voltages on the 11kV and 6.6kV part of the network.

Based on the reasoning above, the use case matrix has been updated and is displayed in the revised Table 4.2.

Table 4.2 – Network efficiency use case matrix (revised)

Use Case	Trigger	Systems for QUEST to Co-ordinate				General Comments regarding potential system conflicts/resolution
		ESO	CLASS	Smart Street	ANM	
QUEST running in network efficiency mode	**N/A**	N/A	DISABLED with exception of DB	ENABLED	ENABLED	QUEST operating in network efficiency mode. Raising 33kV voltages through network efficiency mode will not impact ANM operation since QUEST will make sure that there are no over-voltages on that part of the network. Also, all DERs connected to that part of the network will be able to operate in a safe manner within the +/- 6% voltage range. CLASS DB function, network efficiency mode would benefit from raising the voltages on the primary side of the 33/11kV transformer by boosting the voltages on the 11kV part of the network +/- 6% voltage range.

Yellow	**Systems not considered in use case**
Green	**No Conflict**
Red	**Conflict**
Orange	**Potential or acceptable conflict**

4.2. Use Case 1 - Quest Network Efficiency, CLASS, ANM & Smart Street

Based on the changes made to the QUEST use case matrix, the use case for network efficiency has also been changed. The updated version of Use Case 1 is provided in the table below.

Use Case Name					
Use Case Number	UC 1	**Version**	1	**Status**	Final
Use Case Development Owner	ENWL				
Use Case Description	This use case describes the coordination between discrete systems at 33kV voltage levels to provide network efficiency. The QUEST Voltage Optimiser executes in line with its "Operational Objective" to reduce network losses on the 33kV system.				
Primary users	DNO				
Secondary users	DNO				
Trigger	QUEST will automatically switch to network efficiency mode, minimising losses on the 33kV network, when all CLASS functions are in the disabled state (Outside commercial contracted periods). The exception to this is CLASS Demand Boost (DB) function which can be enabled. The status of ANM and Smart Street does not affect network efficiency mode operation (both ANM and Smart Street could be enabled).				
Preconditions	CLASS is disabled as no commercial agreements are in place, the exception being CLASS DB which may be enabled with a commercial agreement in place. Smart Street is enabled. ANM is managing various Distribution Energy Resources (DER) to control power flows at several constraint points on constraint management zones by issuing set points to DER at times to manage the constraint where possible. ANM has the capability to issue MW and MVAr set points. Cloud ANM Flexibility Service dispatch is operating. 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.				
Post Conditions	Network is running in its most efficient mode as per losses calculations in QUEST software.				
Main Success Scenario	**Steps**	**Actions**			
	1	QUEST to minimise system losses to maximise benefits to customers by raising 33kV voltages to the upper statutory limit. Optimal voltage profile across the 33kV network with ANM and Smart Street enabled, and CLASS DB enabled. All remaining CLASS functions are disabled. Operating at a higher 33kV system voltage with CLASS in DB mode will not impact the ability of CLASS to provide demand boost functionality as this requires the primary substation transformers to tap up.			

Conflict/Coordination Issue Path	1a	A CLASS service (with the exception of DB) is enabled compromising network efficiency.
Possible Coordination Resolution Path	2	Network efficiency is switched off by QUEST. This now is effectively a CLASS, Smart Street and ANM Use Case, refer to Use Case 5 - Smart Street, CLASS and ANM for further details. There are no ENWL BSPs without a CLASS primary substation site connected to it. Therefore, when a CLASS function, other than DB, is enabled QUEST network efficiency optimisation mode must be disabled. If there was a BSP that fed all non-CLASS sites, then network efficiency optimisation could remain enabled at that BSP.
Extensions	The initial use case is based on a radial type of system. Network meshing/parallels at 33kV, 11kV and 6.6kV should be evaluated to determine the effects of load flows and what measures need to be considered. Where parallels are required the control engineer will evaluate voltage levels and take appropriate action prior to paralleling two separate sources. Ordinarily, voltages are equalised at both sources by fixing taps (make non-auto) and tapping the appropriate transformers and in some cases switching out a transformer.	
Notes and Outstanding issues (if any)	***NOTE:*** **1.** Voltage optimisation at 11/6.6kV is not considered as previous electrical system studies have shown that the dominant maximum losses benefit is achieved by altering the 33kV system voltage profile. ***NOTE:*** **2.** The Whitegate system (QUEST Trial Network) is a radial system, fed from a single voltage source and as such power flow swings caused by meshing are not considered under normal circumstances. Where system parallels are carried out for planned work (can be at 33kV, 11kV or 6.6kV, but only 33kV parallels have implications for efficiency mode), the control room takes action to prevent high power flows through the system so this again would not be an issue (control room puts paralleled transformers in Non-Auto mode, so these BSP sites will not be considered for QUEST network efficiency mode). **Assumption 1**: There are no faults on the network causing disruption to network efficiency. **Assumption 2**: Achieving network optimum efficiency is the highest priority. **Assumption 3**: QUEST network efficiency can be switched in for individual zone (BSP). **Assumption 4**: QUEST network efficiency will be evaluated based on calculated I^2 R losses associated with cables and transformers measured from real time power flows.	

	Assumption 5: In case of switching off network efficiency, all 132/33kV grid transformers will be returned to the original normal target voltage.

4.3. Options to Avoid or Mitigate Conflicts

When QUEST is operating in network efficiency mode, the 33kV system voltage is likely to be running above nominal voltage by raising the tap position of the 132/33kV grid transformers. This is not a global optimum voltage optimisation. QUEST will determine the optimum 33kV voltage profile to minimise losses on the 33kV system. QUEST network efficiency will be evaluated based on calculated I^2 R losses associated with cables and transformers measured from real time power flows.

The only conflict that has been detected with QUEST operating in network efficiency mode is with CLASS providing commercial services, except for DB. Raising the tap position of the 132/33kV grid transformers will result in the primary transformers (33/11kV) fed from these grid transformers to tap down to regulate the 11kV voltage to the nominal target voltage. By doing so, sufficient tap capability will be provided for DB. For other CLASS functions, this is not the case since voltage reduction to reduce demand is expected. Hence, it has been concluded that in case of enablement of any of CLASS functions, except DB, QUEST will need to switch off network efficiency mode.

4.4. QUEST Voltage Optimiser Additional General Requirements

All the Use cases, including Use case 1 highlights general functional requirements that will benefit the QUEST Voltage Optimiser including:

- QUEST Voltage Optimiser should have visibility of BSP, Primary substation and Smart Street distribution substation tap positions. This would allow QUEST to make decisions that avoid running out of transformer tap positions e.g., Primary substations as a result of changing the 33kV voltage at the BSP transformers. QUEST should also monitor for tap not achievable alarms from the voltage control relays.
- QUEST requires monitoring of voltages across the DNO network at the various voltage levels including the point of connection locations with DER.

5. QUEST’S REACTION TO CLASS FUNCTIONS ENABLEMENT VS ACTIVATION

Within this chapter, the focus is to clarify use cases describing potential conflicts between CLASS functions and Smart Street and ANM operation (Use Case 2 and Use Case 4). Through the definition of these use cases, it has been concluded that Smart Street and ANM should be put in a safe mode upon CLASS functions enablement in order not to counteract one with another. In the rest of the chapter, the following topics are discussed and explained in more detail:

- Definition of “CLASS forecast and optimise mode” (CFOM).
- Putting Smart Street in “CLASS forecast and optimise mode” and releasing from it.
- Putting ANM in “CLASS forecast and optimise mode” and releasing from it.

5.1. CLASS Forecast and Optimise Mode (CFOM)

During the Use Cases definition phase, it was concluded that “CLASS forecast and optimise mode” could be:

1. A rigid rule-based approach – assumes (forecasting) the worst-case condition and prioritises (optimising) certain system objectives ahead of others.
2. A complex forecast of network state to predict when abnormal conditions may occur and implement a multi-objective optimisation that blends discrete system objectives to achieve a global optimum.
3. A hybrid approach with elements of network state forecasting to predict when abnormal conditions may occur and elements allowing multiple objective options and suitable information to guide operators in option selection.

It has been agreed that a hybrid approach will be considered for this phase of the QUEST project. The second option requires complex forecast calculations to determine when the ESO services would be needed and when CLASS services would be activated. These calculations would require additional time to design and implement the solution, which is not in accordance with the current QUEST project milestones. On the other hand, the QUEST rigid rule-based approach is also identified as not an acceptable option since it continually assumes the worst-case scenarios and represents a simple switch-off/ switch-on approach as soon CLASS is enabled/disabled. Having that in mind, a third option has been introduced to provide QUEST with some flexibility in order not to continually assume the worst-case scenarios. For example, disabling Smart Street as soon CLASS services are enabled and thus minimising the customer benefits from Smart Street during that period. These periods can last up to several days, so the effect of using CLASS in a worst-case scenario would reduce Smart Street benefits to unacceptable levels. However, by using a more nuanced approach and minimising the reduction in customer benefits from Smart Street by allowing it to perform Conservation Voltage Reduction (CVR) on some parts of the network or the entire network but with more conservative limits can provide some benefits whilst allowing CLASS to be enabled. The flexibility in the QUEST hybrid approach for coordination of Smart Street and ANM with CLASS functions is explained in more detail in the rest of this chapter (sections “Options to avoid or mitigate conflicts between CLASS and Smart Street/ANM”).

5.2. Putting Smart Street in and releasing it from "CLASS Forecast and Optimise Mode"

Through the use case definition, it has been identified that Smart Street may result in conflict with CLASS services and that QUEST needs to send appropriate signals to Smart Street to prevent that conflict. The purpose of this section is to clarify how QUEST will intervene in Smart Street operation, upon CLASS enablement, to prevent these systems from conflicting with one another.

The commentary following the Use Case 2 table provides details of the proposed options for QUEST intervention to avoid or mitigate the conflict between CLASS and Smart Street. Different architecture options for coordination are also suggested and explained in detail.

5.2.1. Use Case 2 - CLASS & Smart Street

<table>
<tr><td>Use Case Name</td><td colspan="6"></td></tr>
<tr><td>Use Case Number</td><td>UC 2</td><td>Version</td><td>1</td><td>Status</td><td>Draft</td></tr>
<tr><td>Use Case Development Owner</td><td colspan="6">ENWL</td></tr>
<tr><td>Use Case Description</td><td colspan="6">This use case describes the coordination between CLASS and Smart Street functionalities provided by the QUEST algorithm (QUEST Voltage Optimiser). The QUEST Voltage Optimiser executes in line with its "Operational Objective".</td></tr>
<tr><td>Primary users</td><td colspan="6">DNO / ESO</td></tr>
<tr><td>Secondary users</td><td colspan="6">None</td></tr>
<tr><td>Trigger</td><td colspan="6">QUEST is triggered to take action when any of the CLASS functions, that will cause potential conflict between objectives or network issues due to coordination of actions with Smart Street, are enabled.
These functions are either manual or require an external signal to trigger, such as:
• Demand Reduction (DR) function
• Demand Boost (DB) function
• Tap stagger Function (TSF)
Or automatic, primed to act after a certain threshold is met, such as:
• Primary Frequency Response (PFR)
• Secondary Frequency Response (SFR)
• Load Limiting (LL)*[1]</td></tr>
<tr><td>Preconditions</td><td colspan="6">Smart Street is operating on network area of interest in CVR mode.</td></tr>
</table>

[1] CLASS Load Limiting is a DNO service designed to reduce demand at peak times to defer Primary and BSP substation upgrade requirements due to peak demand issues. LL is not a CLASS service that is activated by the ESO and hence is not considered in the use case.

	CLASS is enabled to execute one of several functions upon request from ESO or when providing commercial agreements. Where a commercial agreement is in place, the DNO will enable the contracted services, which will only activate following a trigger from ESO or by an automatic network trigger such as frequency. ANM is not enabled on the considered part of the network. QUEST is not optimising the network for efficiency when CLASS is enabled or active (related to all CLASS functions except DB). 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.	
Post Conditions	Voltages on the HV and LV networks in the QUEST trial area are within the technical limits. CLASS maintains the ability to provide ESO services and DNO requirements on the considered part of the network. Smart Street continuously optimises voltages in the LV part of the network.	
Case 1: ESO Service - DR (DRF/ DRH)		
Trigger	QUEST Voltage Optimiser assumes a potential conflict where CLASS Demand Reduction (DR) activation would cause voltage violations in the LV part of the network since the voltages in the LV part are already close to the lower limit under the operation of Smart Street CVR. Demand Reduction (DR) function is available at two levels. Demand Reduction Full (DRF) which provides a 5% voltage reduction and Demand Reduction Half (DRH) which provides a 3% voltage reduction.	
Main Success Scenario	**Steps**	**Actions**
	1	CLASS receives instruction from either ESO or DNO to execute DR function.
	2	CLASS DR function is activated on all the primaries where it was previously enabled by the CLASS scheduler.
No conflict	3a	CLASS achieves its objective without causing any low voltage violations that cannot be resolved by Smart Street.
Possible conflict	3b	On several primaries where voltage reduction was performed CLASS does not achieve expected demand reduction due to Smart Street's reaction to voltage reduction. Voltage reduction causes low voltage violations in the LV part of the network and Smart Street tries to resolve them by increasing the tap position on a distribution transformer and thus causing the demand to increase.
Possible conflict	3c	CLASS achieves the expected demand reduction by applying the voltage reduction, but this action causes short term low

		voltage violations in the LV part of the network while Smart Street adjusts the distribution transformer tap position to restore LV voltages above the minimum statutory limit. Note that if Smart Street cannot resolve the LV voltage violation by increasing the tap position on the distribution transformers e.g., if the voltage on the primary side of the distribution transformer is too low then the LV voltage violation will be longer.
Conflict Resolution	4	QUEST assumes Smart Street being enabled will cause issues with CLASS either achieving its objective or cause LV voltage violation issues (short term or longer). QUEST determines that Smart Street functionality needs to be put into a "CLASS forecast and optimise mode" (CFOM). Smart Street CFOM mode will be activated when CLASS DR is enabled (at the NMS level) and will optimise the Smart Street set points, securing the network against any issues whilst balancing all system objectives. On completion of the CLASS service (CLASS disabled), QUEST assumes that it is now safe to enable Smart Street functionality again.
Case 2: ESO Service – DB		
Trigger	The QUEST Voltage Optimiser detects that the CLASS DB function will: make additional room for lowering the voltage values in the LV part of the network which will additionally decrease the demand and possibly conflict with the CLASS DB objective.	
Main Success Scenario	**Steps**	**Actions**
Trigger	1	CLASS receives instruction from ESO to execute DB.
No conflict	2a	CLASS alters its EAVC Relay controller set point to increase demand. Voltages on the primary side of the 11kV/LV distribution transformers are increased which in turn raises the distribution transformer LV terminal voltage. Smart Street will look to reduce the LV voltage back to the target CVR voltage by tapping down the distribution transformer, but all the Smart Street transformers are already on the lowest tap position, so Smart Street does not provide any further LV voltage reduction or demand decrease and does not conflict with CLASS DB function.
Conflict	2b	CLASS alters its EAVC Relay controller set point to increase demand. Voltages on the primary side of the 11kV/LV distribution transformers are increased which in turn raises the distribution transformer LV terminal voltage. Smart Street will

		look to reduce the LV voltage back to the target CVR voltage by tapping down the distribution transformer. Smart Street taps down the distribution transformer to decrease the LV voltage because it is aiming for the CVR target voltage. This LV voltage reduction causes an associated demand reduction which results in CLASS not achieving the expected demand boost (DB) objective.
Conflict Resolution	3b	QUEST assumes Smart Street's reaction. This is because the results of the Smart Street action will tend to reduce demand and will thus result in CLASS failing to meet its CLASS DB function objective. Hence QUEST determines that Smart Street functionality needs to be put into a "CLASS forecast and optimise mode (CFOM)". Smart Street CFOM mode will be activated when CLASS DB is enabled (at the NMS level) and will optimise the Smart Street set points, securing the network against any issues whilst balancing all system objectives. On completion of the CLASS service (CLASS disabled), QUEST assumes that it is now safe to enable Smart Street functionality again.
Case 3: ESO Service – TSF		
Triggers	Instruction from ESO	
Main Success Scenario	**Steps**	**Actions**
	1	CLASS receives instruction from ESO to execute TSF.
No conflict	2	CLASS alters its EAVC Relay controller OLTC controllers set points to increase reactive power absorption. Smart Street OLTC tap operations reacting to the new Primary Transformer voltage set points cause no issues as the resultant 11kV voltage change caused by TSF is minimal or zero. The action does not alter voltage on the transformer's secondary network side and hence will not result in any Smart Street voltage issues.
Case 4: ESO Service - PFR/SFR		
Triggers	QUEST Voltage Optimiser assumes a potential conflict where low voltage tap activation would cause voltage violations in the LV part of the network since the voltages in the LV part are already close to the lower limit under the operation of Smart Street CVR.	
Main Success Scenario	**Steps**	**Actions**
PFR	1	When PFR is enabled the tap-stagger is put in place. Once the frequency threshold is exceeded PFR is automatically activated by the on-site CLASS EAVC Relay. The 11/6.6kV Circuit

		Breaker (CB) of the Primary Transformer (33/11kV or 33/6.6kV) which is on the higher tap position out of the two Primary Transformers, is opened. Tapping does not normally take place while PFR is activated.
No Conflict	2a	The CLASS PFR actions cause no issues, as planning margins are adequate.
Conflict/Coordination Issue	2b	CLASS achieves voltage reduction. However, this action causes low voltage violations in the LV part of the network and Smart Street tries to resolve them by increasing the tap position on a distribution transformer, thus causing the demand to increase.
Possible Coordination Resolution Path	3	QUEST determines that Smart Street functionality needs to be put into a "CLASS forecast and optimise mode" (CFOM), securing the network against any issues whilst balancing all system objectives. This Smart Street CFOM mode will be activated when CLASS PFR is enabled (at the NMS level) and will optimise the Smart Street set points securing the network against any issues whilst balancing all system objectives.
SFR	1	The frequency threshold is exceeded causing both transformers to tap down.
No Conflict	2a	The CLASS SFR actions cause no issues as planning margins are adequate.
Conflict/Coordination Issue	2b	CLASS achieves voltage reduction, but this action causes low voltage violations in the LV part of the network and Smart Street tries to resolve them by increasing the tap position on a distribution transformer and thus causing the demand to increase (be restored to pre SFR levels at Smart Street substations).
Possible Coordination Resolution Path	3	QUEST determines that Smart Street functionality needs to be put into a "CLASS forecast and optimise mode". (CFOM). This Smart Street CFOM mode will be activated when CLASS SFR is enabled (at the NMS level). It will optimise the Smart Street set points securing the network against any issues, whilst balancing all system objectives.
Extensions	The CLASS forecast and optimise mode (CFOM) could be: • A rigid rule-based approach assumes (forecasting) the worst-case condition and prioritising (optimising) certain system objectives ahead of others. • A complex forecast of network state to predict when abnormal conditions may occur and implement a multi-objective optimisation that blends discrete system objectives to achieve a global optimum.	

	• A hybrid approach allowing multiple objective options and suitable information to guide operators in option selection.
Notes and Outstanding issues (if any)	**Assumption 1**: CLASS commitment should have priority over Smart Street. **Assumption 2**: Since DR and potentially PFR and SFR can be activated multiple times during the day, if Smart Street is enabled and is maintaining the voltages in the LV part of the network, each DR/PFR/SFR activation would cause excessive voltage violations in the LV part of the network, and this should be prevented through CLASS forecast and optimise mode (CFOM) optimising the control.

5.2.2. QUEST Use Case Matrix - CLASS & Smart Street

The initial version of the use case matrix related to Smart Street and CLASS coordination is provided in Table 5.1. After the discussion regarding this Use Case, changes were made to the use case matrix to produce the revised matrix in Table 5.2.

Table 5.1 – CLASS & Smart Street Use Case matrix

Use Case	Trigger	Systems for QUEST to Co-ordinate				General Comments regarding potential system conflicts/resolution
		ESO	CLASS	Smart Street	ANM	
Smart Street and CLASS	**CLASS function ENABLED/ ACTIVE**	N/A	DISABLED	ENABLED	N/A	QUEST operating in network efficiency mode.
Smart Street and CLASS	**CLASS function ENABLED/ ACTIVE**	N/A	ENABLED (DR/SFR/ PFR/DB/TS)	Alternative mode due to CLASS/Smart Street conflict	N/A	Conflict in the event that CLASS functions activated. Potential for CLASS DR to be cancelled out by Smart Street. QUEST will need to send appropriate signal to Smart Street, when any CLASS Function (except TS) is enabled, to mitigate conflict.
Smart Street and CLASS	**CLASS function ENABLED/ ACTIVE**	N/A	ACTIVE (DR/SFR/ PFR/DB/TS)	Alternative mode due to CLASS/Smart Street conflict	N/A	Conflict in the event that CLASS functions activated. Potential for CLASS DR to be cancelled out by Smart Street. QUEST will need to send appropriate signal to Smart Street, when any CLASS Function (except TS) is enabled, to mitigate conflict.

Yellow	**Systems not considered in use case**
Green	**No Conflict**

	Conflict
	Potential or acceptable conflict

Table 5.2 – CLASS & Smart Street Use Case matrix (revised)

Use Case	Trigger	Systems for QUEST to Co-ordinate				General Comments regarding potential system conflicts/resolution
		ESO	CLASS	Smart Street	ANM	
Smart Street and CLASS	**CLASS function DISABLED ENABLED/ ACTIVATED** [2]	N/A	DISABLED	ENABLED	N/A	QUEST operating in network efficiency mode.
Smart Street and CLASS	**CLASS function DISABLED/ ENABLED/ ACTIVATED**	N/A	ENABLED (DR/SFR/ PFR/DB/LL/ TS)	Alternative mode due to CLASS/Smart Street conflict	N/A	Conflict in the event that CLASS functions are activated. Potential for CLASS demand reduction/demand boost to be reduced by Smart Street. QUEST will need to send an appropriate signal to Smart Street, when any CLASS Function (except TS) is enabled, to mitigate the conflict when the CLASS function is activated, either by control room actions (DR, DB) or by frequency relays (PFR/SFR).
Smart Street and CLASS	**CLASS function DISABLED ENABLED/ ACTIVATED**	N/A	ACTIVE (DR/SFR/ PFR/DB/LL/ TS)	Alternative mode due to CLASS/Smart Street conflict	N/A	Conflict in the event that CLASS functions activated. Potential for CLASS demand reduction/demand boost to be reduced by Smart Street. QUEST will need to send an appropriate signal to Smart Street, when any CLASS Function (except TS) is enabled, to mitigate the conflict.

	Systems not considered in use case
	No Conflict
	Conflict
	Potential or acceptable conflict

[2] There is an additional CLASS functions state - deactivated. When it is deactivated, CLASS function can either transit to enabled state or disabled state. Since QUEST's expected intervention upon CLASS functions enablement and disablement is already stated and explained in the Use Case matrix, it has been agreed that there is no need to add deactivate state in the matrix.

5.2.3. Options to Avoid or Mitigate Conflicts between CLASS and Smart Street

When operating in Conservation Voltage Reduction mode (CVR), Smart Street lowers LV voltages towards the lower statutory limit (94% of nominal LV voltage) 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 Smart Street installed. Activation of CLASS functions on parts of the network where Smart Street operates will have a negative impact either on Smart Street operation (i.e., the already reduced LV voltages drop temporarily below statutory limits) or on providing committed CLASS services (Smart Street reacting to reduced LV voltages and thus conflicts with providing CLASS services).

Activation of CLASS voltage reduction functions (DR, PFR, SFR) could cause LV voltages to drop below statutory limits where Smart Street is operating in CVR mode. For CLASS DR function this is not acceptable due to the frequency of service enablement. Also, where Smart Street responds to activation of CLASS voltage reduction functions, to raise LV voltages to the target CVR voltage, the associated LV demand increase will reduce the CLASS target demand reduction. This is not acceptable.

Where Smart Street responds to activation of CLASS voltage demand boost (DB) to reduce LV voltages to the target CVR voltage, the associated LV demand decrease will in turn tend to reduce the CLASS target demand boost. This is not acceptable.

In order to prevent these systems from counteracting one another, QUEST's intervention is expected. Since it is not possible to accurately predict when the ESO will request a CLASS demand reduction (DR) or demand boost (DB) in sufficient time to take actions to avoid conflicts between Smart Street and CLASS, it has been concluded that QUEST needs to take an action when CLASS is enabled.

The assumption for CLASS/Smart Street conflict resolution in UC2 is that CLASS services to the ESO take priority. This means that when services such as DR and DB are enabled on the CLASS dashboard, Smart Street needs to be put into a safe mode where conflict with CLASS is avoided before the CLASS service is activated in response to an ESO command. The difficulty here is that CLASS functions such as DR or DB could be enabled for several days at a time with little or no activation. While the DNO will maintain benefits from CLASS services provided to the ESO, the cost benefits to customers from demand reduction via Smart Street CVR mode are reduced. While customer benefits from the reduction in ancillary service costs to the ESO from CLASS, need to be considered, the assumed priority of CLASS services to the ESO over Smart Street services to customers has been considered further. It has been considered that QUEST could have some flexibility to manage conflicts i.e., should CLASS service provision be sacrificed or partially sacrificed to maintain Smart Street benefits to customers or are there options for operating CLASS to minimise the reduction in benefits from Smart Street to customers that can be trialled?

Moving Smart Street to a safe mode refers to:

- Determining the new safe target voltage (determined by QUEST or using a predefined target voltage value).
- Sending newly determined target voltage to all HV/LV distribution transformers (takes up to 3 minutes to do this) – action performed by QUEST.
- Fixing HV/LV distribution transformer taps – action performed by QUEST.

NOTE: **1**. When Smart Street is disabled, the existing Smart Street configuration and target voltage are maintained. A new target voltage can be manually applied. It is also noted that Smart Street has no functionality to lock the HV/LV distribution transformer taps. While disabling Smart Street will lock the LV meshing in place, this will not lock the transformer taps in position. QUEST will be required to provide the functionality to fix Smart Street transformer taps in position and release taps from being in a fixed position.

NOTE: **2**. Accounting for Note 1, disabling Smart Street does not offer a safe mode of operation. To provide a safe mode, QUEST requires the ability to issue to each Smart Street site a revised target voltage, wait for confirmation that the Smart Street transformer has moved to this voltage, and then send a signal to lock the distribution transformer taps. It may also then possibly need to disable Smart Street to lock the LV CB meshing in place (it has been discussed that locking LV CB meshing is not required since these actions have limited impact on LV voltages).

5.2.3.1. CLASS DR

Consider UC2, Case 1 (CLASS DR), possible conflicts 3b and 3c. Table 5.3 outlines four potential options to mitigate the potential conflicts between CLASS DR and Smart Street. The options offer differing impacts on the benefits to LV customers and the DNO/ESO.

Table 5.3 – Possible Options to address Smart Street Conflict with Enabled CLASS DR

Option	1	2	3	4
Smart Street	QUEST sets Smart Street to a defined safe target voltage[3] where the upstream primary substation has CLASS DR enabled (DRF or DRH). Once Smart Street adjusts to this target voltage, QUEST fixes the associated Smart Street transformer taps such that on activation of CLASS DR, Smart Street will not adjust any transformer taps to adjust the LV voltage which will remain at the reduced LV voltage caused by CLASS DR activation (which will be above the minimum statutory LV voltage limit), but it will be able to adjust LV circuit breakers for meshing.	QUEST does not intervene and lets Smart Street operate in CVR mode with the existing minimum target voltage.	QUEST sets Smart Street to a defined safe target voltage (lower than in Option 1). Once Smart Street adjusts to this target voltage, QUEST fixes the associated Smart Street transformer taps such that on activation of CLASS DRH, Smart Street will not adjust any transformer taps to adjust the LV voltage which will remain at the reduced LV voltage caused by CLASS DRH activation (which will be above the minimum statutory LV voltage limit), but it will be able to adjust LV circuit breakers for meshing.	QUEST sets some Smart Street controllers to a defined safe target voltage where upstream primary substation has CLASS DR enabled (DRF or DRH) e.g., at substations with fewer LV customers than others. Once Smart Street adjusts to the target voltage, QUEST fixes the associated Smart Street transformer taps such that on activation of CLASS DR (DRF or DRH), Smart Street will not adjust any transformer taps to adjust the LV voltage which will remain at the reduced LV voltage caused by CLASS DR activation (which will be above the minimum statutory LV voltage limit), but it will be able to adjust LV circuit breakers for meshing.
CLASS DR	CLASS DR enabled for 3% (DRH) and 5% (DRF) voltage reduction.	CLASS DR at Smart Street associated primary substation is disabled	CLASS DR at Smart Street associated primary substation is only enabled for 3% voltage reduction (DRH).	CLASS DR enabled for 3% (DRH) and 5% (DRF) voltage reduction, but not at all Smart Street associated primary substations (CLASS DRF is disabled on primaries where Smart Street is not put in a safe mode).
LV customer impacts	Customer benefits from Smart Street CVR are reduced while CLASS DR is enabled but not active.	Customer benefits from Smart Street CVR are fully maintained.	Customer benefits from Smart Street CVR are reduced while CLASS DR is enabled but to a lesser extent than in Option 1 i.e., benefits are partially maintained.	Customer benefits from Smart Street CVR are reduced at LV substations where Smart Street is put to safe mode while CLASS DR is enabled but not active. At other LV substations with Smart Street, customer benefits from Smart Street CVR are fully maintained.
DNO/ESO impacts	DNO/ESO CLASS benefits are fully maintained.	DNO/ESO benefits from CLASS DR are potentially reduced depending on the number of primary substations with installed Smart Street.	DNO/ESO benefits from CLASS DR may or may not reduce depending on the overall DNO demand reduction achieved.	DNO/ESO CLASS DR service benefits from the overall DNO network may be fully maintained or there may be some reduction in providing the benefits, but not as great as with Option 2.
Comments	Worst case impact on customer benefits from Smart Street.	Worst case impact on DNO/ESO benefits from CLASS DR.	Reduces impacts on customers compared with Option 1 and on DNO/ESO compared with Option 2. Potentially still some impact on the DNO/ESO where CLASS cannot deliver the full commitment to DR service. This impact should be investigated further to fully assess Option 3.	Reduces impacts on some customers compared with Option 1 while other customers will see the same impact as in Option 1. Reduced or no impact on DNO/ESO compared with Option 2.
Extensions		QUEST provides information about MWs that could be provided by CLASS DR by using other available primaries (where Smart Street is not installed or enabled).		QUEST provides information about MWs that could be provided by CLASS DR by using other available primaries (where Smart Street is not installed or enabled).

[3] In Option 1, 3 and 4, the defined "safe target voltage" for Smart Street relating to CLASS DR service enablement could be a pre-defined voltage programmed into QUEST. QUEST would not have the logic to determine this pre-defined voltage value which could be established through external network simulations. The defined "safe target voltage" would be required for each of the proposed options 1, 3 and 4 (the same safe target voltage for options 1 and 4 and a different one for option 3). An alternative solution to determine pre-defined safe target voltages could possibly be to perform the simulations of the CLASS function activation within the QUEST calculation and to determine what is the minimum allowed target voltage in order not to cause violations of LV voltage limits upon the CLASS functions activation. It has been agreed that safe target voltage determination will be discussed during the second phase of the detailed design.

Option 1 aligns with the present UC2 assumption that CLASS takes priority over Smart Street operations which reduces benefits to LV customers but maintains full benefits to the DNO/ESO. Option 2 maintains the Smart Street benefits to LV customers, but potentially with a reduction to the DNO/ESO benefits (which may translate into some cost increases to customers through Transmission Use of System charges on their electricity bills). Options 3 and 4 demonstrate some of the potential options to mitigate the impacts on customer benefits of Option 1 and on the DNO/ESO benefits from Option 2.

The requirement for QUEST should be to allow some flexibility compared with Option 1 by facilitating other options such as 3 and 4 and possibly Option 2 or a combination of these. It is not planned that QUEST would decide on the CLASS Primary Substations or Smart Street LV substations to be enabled or disabled. What is envisaged is that on a regular basis (e.g. weekly) QUEST could be provided with the schedule of available substations that can provide CLASS DR (there is potential here for QUEST to forecast CLASS substation availability based on the forward outage plan), the DR MW level each substation can deliver (there is potential here for QUEST to use net demand forecasts from the NMS to support this if not already forecast in CLASS), and the demand reduction MW level committed to the ESO if and when CLASS DR is activated. A QUEST algorithm would then consider each option 1, 2, 3 and 4 and determine if the committed CLASS DR MW level can be achieved by each option, the number of customers that would lose all or partial Smart Street CVR benefits delivering CLASS DR and any short fall in the CLASS DR delivery. Note that for Option 2, not all CLASS primary substations have downstream substations with Smart Street installed, therefore there is no requirement for all CLASS primary substations to be disabled. For Option 2 QUEST would therefore check if the available CLASS primary substations with no downstream Smart Street can deliver the required DR service or not and would provide this information as a result, as well. The same functionality can be applied to Option 4 if disabling CLASS on a number of primaries where Smart Street is not put into a safe mode, is reducing DNO/ESO benefits from CLASS DR.

Having determined the ability of each Option to deliver the amount of CLASS demand reduction which has been committed to the ESO, the number of Smart Street customers impacted negatively and any short fall in the CLASS DR service commitment, QUEST would provide this information to the QUEST operator who would select the preferred option in QUEST. Having selected the preferred option, the CLASS operator would set up the CLASS DR Dashboard based on a list of CLASS full (DRF) and half (DRH) DR enabled substations provided by QUEST for the selected option. The QUEST operator would check that the CLASS Dashboard aligns with the selected option CLASS details and instruct QUEST to move the associated Smart Street substations to the safe operating mode ("CLASS forecast and optimise mode" (CFOM)).

Note that although the above process would be on a regular basis e.g., weekly, where the available CLASS enabled substations or available Smart Street active substations change during the period (this includes forecast updates of availability), the process would need to be repeated intra period.

The QUEST algorithm could be further developed to consider combinations of Options e.g., 2 and 3, 2 and 4 and 2, 3 and 4 displaying the results to the QUEST operator who would then select the preferred option and the CLASS operator would update the CLASS DR dashboard accordingly. A future stage could consider automating the process where QUEST selects the best option and updates the CLASS DR dashboard automatically. However, this would require amendments to CLASS and is deemed to be outside of the present QUEST scope, program, and budget.

It is also noted that CLASS can only have one service enabled at any one time so there is no need to determine a suitable Smart Street safe target voltage to simultaneously enable both CLASS DR and DB services. However, time (3 to 4 minutes estimated) to allow the Smart Street safe target voltage to be amended, moved to by Smart Street and fixed in place by QUEST when transitioning from one CLASS enabled service to another before the service can be activated is required. This is also true when moving from no CLASS service enabled to either CLASS DR or Demand Boost (DB) being enabled to allow Smart Street to move from the normal Smart Street CVR voltage to the safe Smart Street target voltage and be fixed in place by QUEST.

5.2.3.2. CLASS DB

Consider UC2, Case 2 (CLASS DB), possible conflict 2b. Table 5.4 outlines five potential options to mitigate the potential conflicts between CLASS DB and Smart Street. The options offer differing impacts on the benefits to LV customers and the DNO/ESO.

Table 5.4 – Possible Options to address Smart Street Conflict with Enabled CLASS DB

Option	1	2	3	4	5
Smart Street	QUEST sets Smart Street to a defined safe target voltage[4] where upstream primary substation has CLASS DB enabled. Once Smart Street adjusts to this target voltage, QUEST fixes the associated Smart Street transformer taps such that on activation of CLASS DB, Smart Street will not adjust any transformer taps to adjust the LV voltage which will remain at the raised LV voltage caused by CLASS DB activation (which is below the maximum statutory LV voltage limit), but it will be able to adjust LV switchgear for meshing.	QUEST does not intervene and lets Smart Street operate in CVR mode with the existing minimum target voltage.	QUEST sets Smart Street to a defined safe target voltage (same as in Option 1). Once Smart Street adjusts to this target voltage QUEST fixes the associated Smart Street transformer taps such that on activation of CLASS DB, Smart Street will not adjust any transformer taps to adjust the LV voltage which will remain at the raised LV voltage caused by CLASS DB activation (which is below the maximum statutory LV voltage limit)), but it will be able to adjust LV switchgear for meshing.	QUEST sets some Smart Street controllers to a defined safe target voltage where upstream primary substation has CLASS DB enabled, e.g., at substations with fewer LV customers than others. Once Smart Street adjusts to this target voltage, QUEST fixes the associated Smart Street transformer taps such that on activation of CLASS DB, Smart Street will not adjust any transformer taps to adjust the LV voltage which will remain at the raised LV voltage caused by CLASS DB activation (which is below the maximum statutory LV voltage limit), but it will be able to adjust LV switchgear for meshing.	QUEST does not intervene and lets Smart Street operate in CVR mode with the existing minimum target voltage.
CLASS DB Function	CLASS DB enabled for 3% (DBH) and 5% (DBF) voltage increase.	CLASS DB at Smart Street associated primary substation is disabled	CLASS DB at Smart Street associated primary substation is only enabled for a 3% voltage increase (DBH).	CLASS DB enabled for 3% (DBH) and 5% (DBF) voltage increase but not at all Smart Street associated primary substations (CLASS DB is disabled on primaries where Smart Street is not put in a safe mode).	CLASS DB is enabled at additional substations to over deliver the committed to DB service volume by a sufficient margin to compensate for Smart Street CVR reducing the overall CLASS DB service to the ESO.
LV customer impacts	Customer benefits from Smart Street CVR are maintained, but not at a full value as in Smart Street CVR mode, while CLASS DB is enabled but reduced when active.	Customer benefits from Smart Street CVR are fully maintained.	Customer benefits from Smart Street CVR are largely maintained while CLASS DB is enabled but reduced when active. When CLASS DB is active the reduction in Smart Street benefits to LV customers is less than in Option 1.	Customer benefits from Smart Street CVR are reduced at LV substations where Smart Street is disabled while CLASS DB is active but likely to be largely retained when enabled as safe Smart Street voltage will be closer to the minimum CVR voltage than the safe voltage for DR. At other LV substations with Smart Street, customer benefits from Smart Street CVR are fully maintained (where CVR can maintain a minimum voltage limit).	Very small impact on Smart Street CVR benefits to LV customers as Smart Street adjusts voltage back down to CVR target voltage.
DNO/ESO impacts	DNO/ESO CLASS benefits are fully maintained.	DNO/ESO benefits from CLASS DB are potentially reduced.	DNO/ESO benefits from CLASS DB may or may not reduce depending on the overall DNO demand boost achieved.	DNO/ESO CLASS DB service benefits from the overall DNO network may be fully maintained or there may be some reduction in providing the benefits, but not as great as with Option 2.	If additional CLASS DB enabled substations compensate for the Smart Street CVR voltage response, then no negative impact on CLASS DB services to the ESO.
Comments	Worst case impact on customer benefits from Smart Street.	Worst case impact on DNO/ESO benefits from CLASS DB.	Reduces impacts on customers compared with Option 1 and on DNO/ESO compared with Option 2. Potentially still some impact on the DNO/ESO where CLASS cannot deliver the full DB service.	Reduces impacts on some customers compared with option 1 while other customers will see the same impact as Option 1. Reduced or no impact on DNO/ESO compared with Option 2.	While the level of Smart Street CVR demand reduction deployment is relatively low, it is anticipated that this can be compensated for by over enabling the number of CLASS substations for DB services. In the future when Smart Street CVR deployment is higher this may not be the case, however, studies are required to investigate this solution for future scenarios of Smart Street deployment.
Extensions		QUEST provides information about MWs that could be provided by CLASS DB by using other available		QUEST provides information about MWs that could be provided by CLASS DB by using other available primaries (where Smart Street is not installed or enabled).	

[4] In Option 1, 3 and 4, the defined "safe target voltage" could be a pre-defined voltage programmed into QUEST. This may be the same predefined voltage for option 1, 3 and 4 as it will be dictated by the normal substation demand variation rather than the CLASS action. An option to improve on using pre-defined safe target voltages would be to perform the simulations of the CLASS function activation within the QUEST calculation and to determine what is the minimum allowed target voltage in order not to cause violations of LV voltage limits upon the CLASS functions activation. It has been agreed that safe target voltage determination will be discussed during the second phase of the detailed design.

		primaries (where Smart Street is not installed or enabled).			

Option 1 aligns with the present UC2 assumption that CLASS takes priority over Smart Street operations which reduces benefits to LV customers but maintains full benefits to the DNO/ESO. Option 2 maintains the Smart Street benefits to LV customers, but potentially with a reduction to the DNO/ESO benefits (which may translate into some cost increases to customers through Transmission Use of System charges on their electricity bills). Options 3, 4 and 5 demonstrate some of the potential options to mitigate the impacts on customer benefits of Option 1 and on the DNO/ESO benefits from Option 2.

Additionally, for some of the above suggested options QUEST's intervention upon CLASS DB disablement should also be considered. When CLASS DBF or DBH are disabled, and the 11kV primary voltage drops, it could lead to the LV voltage dropping below statutory limits if Smart Street safe target voltage is not appropriately adjusted.

For options 1, 3 and 4 there are two possibilities. The first one is to determine the voltage drop upon CLASS DB disablement and to consider it right away within the "safe target voltage" to which Smart Street transformers are put into upon DB enablement. With this approach, the safe target voltage would be slightly higher than the CVR mode target voltage during the whole period when CLASS DB is enabled. This allows for the fact that the Smart Street transformer taps are fixed and cannot adjust the LV voltage as the LV demand changes. When CLASS DB is activated, the LV voltage rises and remains high until CLASS DB is deactivated or disabled. At this point the LV voltage will reduce back down to the original safe level and when CLASS DB is disabled, the Smart Street tap fixing will be removed and CVR mode operation restored. This is the approach for options 1, 3 and 4 described in the Table 5.4. A second variation on the above solution is that when CLASS DB is activated the tap fixing is removed and the Smart Street transformer taps the voltage back down to the "safe target voltage" to which Smart Street transformers are put into upon DB enablement. This will largely maintain customer benefits while CLASS DB is activated as well as enabled. Prior to CLASS DB being deactivated or disabled, the "safe target voltage" would require to be readjusted to a voltage higher than the previous one to prevent causing the LV voltage dropping below statutory limits. Since there is limited improvement in Smart Street customer benefits adopting this second more complex option, the approach outlined in Table 5.4 will be adopted for options 1, 3 and 4.

For option 5, where Smart Street is allowed to operate in CVR mode upon CLASS DB enablement, it will be necessary to put the Smart Street transformers into a safe mode prior to CLASS DB disablement. Safe target voltage in this situation would be determined only based on the voltage drop expected upon CLASS DB disablement.

For option 2, intervention is not expected since CLASS DB will be disabled on all the Smart Street associated primary substations.

Note that if the Smart Street defined safe target voltage for CLASS DB enabled services is set to the Smart Street CVR lower voltage limit and the Smart Street transformer tap is fixed, there is a danger that demand variations would push the LV voltage below the statutory LV voltage limit. Therefore, the safe Smart Street target voltage for CLASS DB would be above the Smart Street minimum CVR target voltage.

Note that Option 5 would not be applicable to CLASS demand reduction services to the ESO, such as CLASS DR, PFR and SFR. This is because Smart Street would always require that it be placed at a safe higher target voltage (new target voltage sent by QUEST when CLASS DR service is enabled) to avoid LV voltage drops below the statutory minimum limit when DR is activated. Following this the Smart Street transformer taps would need to be fixed when DR is activated. This allows the LV voltage to drop when CLASS DR is activated, but still suitably above the minimum statutory LV voltage limit thus maximizing the Smart Street benefits to customers while DR is active but not when enabled. If the Smart Street transformer taps were unlocked when DR is active, then Smart Street would try and adjust to maintain the safe target voltage which would reduce the Smart Street benefits to LV customers and therefore reduce the CLASS DR services to the ESO. While Smart Street could be issued with a new lower CVR target voltage after CLASS DR is activated and the transformer taps unlocked, this adds further complexity. Hence, an option similar to Option 5 is not considered for CLASS DR at present.

The requirement for QUEST should be to allow some flexibility compared with Option 1 by facilitating other options such as 3, 4 and 5 and possibly Option 2 or a combination of these. It is not planned that QUEST would decide on the CLASS Primary Substations or Smart Street LV substations to be enabled or disabled. What is envisaged is that on a regular basis (e.g. weekly) QUEST could be provided with the schedule of available substations that can provide CLASS DB (there is potential here for QUEST to forecast CLASS substation availability based on the forward outage plan), the DB MW level each substation can deliver (there is potential here for QUEST to use net demand forecasts from the NMS to support this if not already forecasted in CLASS), and the total network DB MW level committed to the ESO if and when CLASS DB is activated. A QUEST algorithm would then consider each option 2, 3, 4 and 5 and determine if the CLASS committed to DB MW level can be achieved by each option, the number of customers that would lose all or partial Smart Street CVR benefits delivering CLASS DB and any short fall in the CLASS DB delivery. Note for Option 2, not all CLASS primary substations have downstream substations with Smart Street installed, hence, not all CLASS primary substations need to be disabled. For Option 2 QUEST would therefore check if the available CLASS primary substations with no downstream Smart Street can deliver the required DB service or not. The same functionality can be applied to Option 4 if disabling CLASS on a number of primaries where Smart Street is not put into a safe mode, reducing DNO/ESO benefits from CLASS DB.

Having determined the ability of each Option to deliver the amount of CLASS demand boost which has been committed to the ESO, the number of Smart Street customers impacted negatively and any short fall in the CLASS DB service commitment, QUEST would provide this information to the QUEST operator who would select the preferred option in QUEST. Having selected the preferred option, the CLASS operator would set up the CLASS DB Dashboard based on a list of CLASS full and half DB enabled substations provided by QUEST for the selected option. The QUEST operator would check that the CLASS Dashboard aligns with the selected option CLASS details and would instruct QUEST to move the associated Smart Street substations to the safe operating mode ("CLASS forecast and optimise mode" (CFOM)).

Note that although the above process would be on a regular basis e.g., weekly, where the available CLASS enabled substations or available Smart Street active substations change during the period (this includes forecast updates of availability) then the process would need to be repeated intra period.

The QUEST algorithm could be further developed to consider combinations of Options e.g., 2 and 3, 2 and 4 and 2, 3 and 4 displaying the results to the QUEST operator who would then select the preferred option and the CLASS operator would update the CLASS DB dashboard accordingly. A future stage could consider automating the process where QUEST selects the best option and updates the CLASS DB dashboard automatically. However, this would require amendments to CLASS and is deemed to be outside of the present QUEST scope, program, and budget.

It is also noted that CLASS can only have one service enabled at any one time so there is no need to determine a suitable Smart Street safe target voltage to simultaneously enable both CLASS DR and DB services. However, time (3 to 4 minutes estimated) to allow the Smart Street safe target voltage to be amended, moved to by Smart Street and locked in place by QUEST when transitioning from one CLASS enabled service to another before the service can be activated is required. This is also true when moving from no CLASS service enabled to either CLASS DR or DB being enabled to allow Smart Street to move from the normal Smart Street CVR voltage to the safe Smart Street target voltage and be locked in place by QUEST.

5.2.3.3. CLASS PFR/SFR

It is noted that CLASS SFR and PFR are not used and are not part of the CLASS dashboard. Also, ENWL has no plans at present to utilise SFR and PFR for regulatory or market-based services.

However, although ENWL has decided that CLASS PFR and SFR are not to be considered further in the QUEST functional design development, explanations of potential conflicts and expected QUEST reactions in case of using PFR/SFR for market based or regulatory services in the future are captured below.

5.2.3.3.1. Market Based Services

If CLASS SFR and PFR were to be set and used for future commercial based frequency control markets, activation would be more common and allowing Smart Street CVR to operate and the resulting LV voltage drops below the statutory LV voltage limits would not be acceptable. In this scenario actions would be required to place Smart Street in a safe operating mode when CLASS SFR or PFR are enabled. The requirements to address conflicts between CLASS and Smart Street would be similar to CLASS DR discussed above. However, option 3 for a half demand reduction service would not be applicable to CLASS SFR or PFR.

5.2.3.3.2. Regulated Services

CLASS PFR and SFR could provide the ESO with mandatory frequency response services (see National Grid document "Mandatory Frequency Response" [2])), or OC6. In this case, it is likely that PFR and SFR CLASS functions would be enabled on an almost permanent basis, therefore, moving Smart Street to a safe mode when PFR or SFR are enabled would not make sense. PFR services require to be delivered within 10 seconds after an event and can be sustained for a further 20 seconds. SFR services require to be delivered within 30 seconds after an event and can be sustained for a further 30 minutes.

The active provision of PFR and SFR services while enabled is expected to be a rare event, hence, a drop in the LV voltage below the statutory minimum limit (216.2v) during Smart Street operations would be acceptable for a brief period. However, for SFR where demand reduction could last for up to 30 minutes, during Smart Street operations any drop in the LV voltage below the statutory minimum limit may possibly require Smart Street to correct this. While this would impact the level of demand reduction achieved, Smart Street could possibly be allowed to operate to bring LV voltages back above the statutory minimum limit. Hence, for regulated mandatory services with rare event occurrence when CLASS SFR is enabled and activated, Smart Street could possibly be allowed to continue normal operations and the reduction in SFR service accepted. This does not apply to CLASS PFR. For PFR, where service provision lasts only up to 30 seconds, during this short period it would also be acceptable to allow Smart Street to continue operating as no transformer tap actions would be completed within this short timescale. Hence, Smart Street would need to remain in normal CVR operations while both PFR and SFR are enabled and activated.

5.3. Putting ANM in and releasing it from "CLASS Forecast and Optimise Mode"

Through the use case definition, it has been identified that ANM may conflict with CLASS services and that QUEST needs to send appropriate signals to ANM to prevent that conflict.

The purpose of this section is to clarify how QUEST will intervene in ANM operation upon CLASS enablement/activation in order to prevent these systems from conflicting with one another.

This section provides the CLASS & ANM Use Case explaining the identified conflicts, as well as the Use Case matrix summarising which situations QUEST will intervene in to resolve conflicts. Options to avoid or mitigate the conflict between CLASS and ANM, and different architecture options for coordination are also suggested and explained in detail.

5.3.1. Use Case 4 - CLASS & ANM

<table>
<tr><td>Use Case Name</td><td colspan="5">CLASS & ANM</td></tr>
<tr><td>Use Case Number</td><td>UC 4</td><td>Version</td><td>1</td><td>Status</td><td>Draft</td></tr>
<tr><td>Use Case Development Owner</td><td colspan="5">ENWL</td></tr>
<tr><td>Use Case Description</td><td colspan="5">This use case describes the coordination between Customer Load Active System Services (CLASS) 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”.</td></tr>
<tr><td>Primary users</td><td colspan="5">ESO</td></tr>
<tr><td>Secondary users</td><td colspan="5">DNO</td></tr>
<tr><td>Trigger</td><td colspan="5">QUEST is triggered when any of the CLASS functions, that will cause potential conflict between objectives or network issues due to coordination of actions with the ANM, are executed.
These functions are either manual or require an external signal to trigger, such as:
• Demand Reduction (DR) function
• Demand Boost (DB) function
• Tap stagger Function (TSF)
Or automatic, primed to act after a certain threshold is met, such as:
• Primary Frequency Response (PFR)
• Secondary Frequency Response (SFR)
• Load Limiting (LL)[5]</td></tr>
<tr><td>Preconditions</td><td colspan="5">CLASS is enabled to execute several functions upon request from 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 ESO or by an automatic network trigger such as frequency.
The ANM system is managing various Distribution Energy Resources (DER) to control power flows at a number of constraint points on constraint management zones by issuing set points to DER at times to manage the constraint where possible. ANM has the capability to issue MW and MVAr set points.
Smart Street is not operating in CVR mode on considered part of the network.
QUEST is not optimising the network for efficiency when CLASS is enabled or active (related to all CLASS functions except DB).</td></tr>
</table>

[5] CLASS Load Limiting is a DNO service designed to reduce demand at peak times to defer Primary and BSP substation upgrade requirements due to peak demand issues. LL is not a CLASS service that is activated by the ESO and hence is not considered in the use case.

	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.	
Post Conditions	Voltages on the HV and LV networks in the QUEST trial area are within the 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.	
Main Success Scenario	**Steps**	**Actions**
Trigger-DR	1	CLASS receives instruction from either ESO or DNO to execute DR.
No Conflict	2a	CLASS alters its EAVC Relay controller set point to reduce demand.
Conflict/Coordination Issue Path	2b	CLASS alters its EAVC Relay controller set point to reduce demand. The action causes a reduction in local demand, increasing export at a thermal constraint, leading to a violation in the constraint management zone. ANM alters DER set points to solve thermal constraint issues, this can cause a flexible connection to exceed its Curtailment Index (CiD). A Distributed Energy Resource (DER) providing a flexible service, associated with the constraint is forced to reduce dispatch, resulting in partial service provision.
Possible Coordination Resolution Path	2c	QUEST presumes CLASS actions may cause a temporary constraint violation as the system transitions from one steady state to the next if uncoordinated. QUEST instructs ANM to move into "CLASS forecast and optimise mode (CFOM)", securing the network against any issues whilst balancing all system objectives and constraints e.g., not exceeding curtailment index (CiD). CLASS alters its EAVC Relay controller set point to reduce demand. QUEST records pertinent parameters to audit the conflict/coordination resolution action on its impact to other systems/services as a post analysis. On completion of the CLASS service, QUEST instructs ANM to return to its original operational mode.
Trigger-DB	1	CLASS receives instruction from ESO to execute DB.

No Conflict	2a	CLASS alters its EAVC Relay controller set point to increase demand. The action does not cause capacity at a constraint location to be released. The ANM achieves full-service provision.
Conflict/Coordination Issue Path	2b	CLASS alters its EAVC Relay controller set point to increase demand. The action causes capacity at a constraint location to be released. ANM alters DER set points to release any constrained DER up to the released capacity, possibly reducing the impact of CLASS actions.
Possible Coordination Resolution Path	2c	QUEST presumes CLASS actions may cause a temporary constraint violation as the system transitions from one steady state to the next if uncoordinated. QUEST instructs ANM to move into "CLASS forecast and optimise mode (CFOM)", securing the network against any issues whilst balancing all system objectives and constraints e.g., not exceeding curtailment index. CLASS alters its EAVC Relay controller set point to increase demand. QUEST records pertinent parameters to audit the conflict/coordination resolution action on its impact on other systems/services as a post analysis. On completion of the CLASS service, QUEST instructs ANM to return to its original operational mode.
Trigger-TSF	1	CLASS receives instruction from ESO to execute TSF.
No Conflict	2a	CLASS alters its EAVC Relay controller set point to increase reactive power absorption. The action does not cause constraint violation in the constraint management zone. ANM achieves full-service provision.
PFR	1	When PFR is enabled tap-stagger is put in place. Once the frequency threshold is exceeded PFR is automatically activated by the on-site CLASS EAVC relay. The 11/6.6kV CB of the Primary Transformer (33/11 or 33/6.6kV) which is on the higher tap position, out of the Primary Transformers is opened. Tapping does not take place while PFR is activated.
No Conflict	2a	This action does not cause a thermal constraint violation in the constraint management zone.
Conflict/Coordination Issue Path	2b	The action does cause a thermal constraint violation in the constraint management zone.

		ANM alters generation set points to solve the thermal constraint issue.
Possible Coordination Resolution Path	2c	QUEST assumes CLASS actions will cause a temporary constraint violation if uncoordinated. QUEST instructs ANM to move into "CLASS forecast and optimise mode (CFOM)", securing the network against any issues whilst balancing all system objectives and constraints e.g., not exceeding curtailment index. CLASS PFR is activated. On completion of the CLASS service, CLASS reinstates the CB moving to post event state. QUEST sets the ANM objective back to normal.
SFR	1	The frequency threshold, monitored by CLASS, is exceeded.
No Conflict	2a	CLASS instructs a primary transformer pair to tap down. The action does not cause a thermal constraint violation in the constraint management zone.
Conflict/Coordination Issue Path	2b	CLASS instructs a primary transformer pair to tap down. The action does cause a thermal constraint violation in the constraint management zone. ANM alters generation set points to solve the thermal constraint issue.
Possible Coordination Resolution Path	2c	QUEST presumes CLASS actions will cause a temporary constraint violation if uncoordinated. QUEST instructs ANM to move into "CLASS forecast and optimise mode (CFOM)", securing the network against any issues whilst balancing all system objectives and constraints e.g., not exceeding curtailment index. CLASS instructs both primary transformer pairs to tap down. On completion of the CLASS service QUEST sets the ANM objective back to normal.
Extensions	The forecast and optimise mode could be: • A rigid rule-based approach assumes (forecasting) the worst-case condition and prioritising (optimising) certain system objectives ahead of others. • A complex forecast of network state to predict when abnormal conditions may occur and implement a multi-objective optimisation that blends discrete system objectives to achieve a global optimum. • A hybrid approach allowing multiple objective options and suitable information to guide operators in option selection.	
Notes and Outstanding issues (if any)	**Assumption 1**: CLASS will not induce a voltage constraint due to its actions. **Assumption 2**: Achieving CLASS objectives has the highest priority and QUEST will forecast and optimise systems in line with this.	

	Assumption 3: Tap Stagger is implemented on transformers that are loaded appropriately to allow an increase in total MVA not to exceed equipment rating.

5.3.2. QUEST Use Case Matrix - CLASS & ANM

The initial version of the use case matrix related to ANM and CLASS coordination is provided in Table 5.5.

Table 5.5 – CLASS & ANM use case matrix

Use Case	Trigger	Systems for QUEST to Co-ordinate				General Comments regarding potential system conflicts/resolution
		ESO	CLASS	Smart Street	ANM	
CLASS and ANM	**CLASS function ENABLED/ ACTIVE**	N/A	DISABLED	N/A	ENABLED/ Possible or acceptable conflict	QUEST operating in network efficiency mode may impact ANM if volts are too high. Raising system voltages increases network generation capacity.
CLASS and ANM	**CLASS function ENABLED/ ACTIVE**	N/A	ENABLED (DR/SFR/PFR/ DB/TS)	N/A	Alternative mode due to CLASS/ ANM conflict	Conflict in the event that CLASS functions activated. Potential for ANM to signal DER for certain CLASS functions. QUEST will need to send an appropriate signal to ANM, when any CLASS Function (except TS) is enabled, to mitigate the conflict.
CLASS and ANM	**CLASS function ENABLED/ ACTIVE**	N/A	ACTIVE (DR/SFR/PFR/ DB/TS)	N/A	Alternative mode due to CLASS/ ANM conflict	Conflict in the event that CLASS functions activated. Potential for ANM to signal DER for certain CLASS functions. QUEST will need to send an appropriate signal to ANM, when any CLASS Function (except TS) is activated, to mitigate the conflict.

(yellow)	**Systems not considered in use case**
(green)	**No Conflict**
(red)	**Conflict**
(orange)	**Potential or acceptable conflict**

During the detailed design phase, additional changes to the use case matrix were made. The first change is related to QUEST impacting ANM operation while operating in network efficiency mode. It was concluded that ANM should not be put in a safe mode if QUEST is operating in network efficiency mode. A detailed explanation regarding this change is provided in the section explaining network efficiency mode, see section 4.1.

Another question that was discussed regarding this topic is when to put ANM in a safe mode to prevent it from conflicting with CLASS benefits. Should ANM be put in a safe mode upon CLASS function enablement, the same way as Smart Street, or upon CLASS function activation? Since ANM is a constraint management system whose main role is thermal protection of the network assets, it was concluded that ANM should not be prevented from operating to keep the assets safe by reacting to the appearance of the thermal violations at the monitored constraint points, regardless of the CLASS functions status. Potential conflict occurs if after CLASS function activation, ANM assumes that it is safe to release previously constrained generation or demand, where it detects additional capacity created as a consequence of CLASS actions. By releasing previously constrained generation or demand, depending on whether a CLASS demand boost or demand reduction function is activated, ANM conflicts with CLASS benefits and this would not be acceptable. Hence, the conclusion is that ANM should be put in a safe mode only upon CLASS function activation and not when enabled. More details regarding putting ANM in a safe mode are provided in the section 5.3.3.

In accordance with the reasoning above, the use case matrix has been updated and is displayed in the revised Table 5.6.

Table 5.6 – CLASS & ANM use case matrix (revised)

Use Case	Trigger	Systems for QUEST to Co-ordinate				General Comments regarding potential system conflicts/resolution
		ESO	CLASS	Smart Street	ANM	
CLASS and ANM	**CLASS function DISABLED/ ENABLED/ ACTIVE**	N/A	DISABLED	N/A	ENABLED	QUEST operating in network efficiency mode. Raising 33kV voltages through network efficiency mode will not impact ANM operation since QUEST will make sure that there are no over-voltages on that part of the network. Also, all DERs connected to that part of the network will be able to operate in a safe manner within the +/- 6% voltage range.
CLASS and ANM	**CLASS function DISABLED/ ENABLED/ ACTIVE**	N/A	ENABLED (DR/SFR/ PFR/DB/LL/ TS)	N/A	ENABLED	Alternative mode due to CLASS/ANM conflict is not required until CLASS service is activated. No conflict.
CLASS and ANM	**CLASS function DISABLED/ ENABLED/ ACTIVE**	N/A	ACTIVE (DR/SFR/ PFR/DB/LL/ TS)	N/A	Alternative mode due to CLASS/ANM conflict	Conflict in the event that CLASS functions activated. Potential for ANM to signal DER for certain CLASS functions. QUEST will need to send an appropriate signal to ANM, when any CLASS Function (except TS) is activated, to mitigate the conflict.

	Systems not considered in use case
	No Conflict
	Conflict
	Potential or acceptable conflict

5.3.3. Options to Avoid or Mitigate Conflicts between CLASS and ANM

ANM (Central ANM, Decentralised ANM, Cloud ANM) has a primary function to ensure that the operation of DER managed by the ANM system does not result in the exceedance of defined DNO network thermal limits. ANM will respond to changing situations such as demand reduction or circuit outages to control DER import/export set points based on a priority stack ensuring network thermal limits are adhered to in real time. Thermal protection of the network takes priority over any CLASS actions.

To help illustrate the following descriptions regarding the interactions of CLASS DB and DR with ANM, each case has a set of illustrative diagrams provided in APPENDIX A - Interactions between CLASS DR and ANM and APPENDIX B - Interactions between CLASS DB and ANM respectively.

Where CLASS DB is activated increasing the level of demand, flexible connection generation which is not under an existing active ANM constraint set point can increase export until ANM is required to issue a constraint set point to maintain adherence to the network thermal limits. Where generation is already under an active ANM constraint setpoint, ANM must prevent the generator under constraint from releasing any constrained generation export. The scenario here is that CLASS DB creates additional demand which removes the generation constraint that could allow the constrained generation to be released which would in turn reduce the CLASS DB service provided to the ESO. Since it is a CLASS action that creates the capacity that would allow an ANM constrained generator to have its constrained export released, it seems fair to keep the generator at the ANM constrained export level when CLASS DB is activated. Note if the DB activation creates a thermal limit violation due to demand import, ANM would be able to constrain flexible demand connections (e.g., battery charging) to maintain the network within thermal limits. However, this is not thought to be a likely event.

Where CLASS DR is activated to reduce the level of demand, flexible connection demand (e.g., battery charging) which is not under an existing active ANM constraint set point can increase import until ANM is required to issue a constraint set point to maintain adherence to the network thermal limits. Where flexible connection demand is already under an active ANM constraint setpoint ANM must prevent the flexible connection demand under constraint from releasing any constrained flexible connection demand. The scenario here is that CLASS DR creates additional capacity to increase demand which removes the flexible connection demand constraint that could allow the constrained flexible demand to be released which would in turn reduce the CLASS DR service provided to the ESO. Since it is a CLASS action that creates the capacity that would allow an ANM constrained flexible demand to have its constrained import released, it seems fair to keep the flexible demand at the ANM constrained import level when CLASS DR is activated. Note if DR creates a thermal limit violation due to generation export ANM would be able to constrain flexible connection generation to maintain the network within thermal limits.

5.3.3.1. CLASS DR and DB

CLASS DR and DB provide demand reduction and demand boost services respectively to the ESO. Where CLASS DR or DB services are activated either by the ESO or DNO, the ANM will continue to manage DER 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 reducing CLASS DR or DB service provision to the ESO. This is an acceptable conflict. However, ANM actions taken in response to CLASS DR or DB activation that are not to maintain the network within thermal limits, would constitute a conflict where CLASS service provision should take priority and the ANM system would require to be prevented from taking such control actions. Such actions would include releasing already constrained DER import (demand) when CLASS DR is activated or releasing already constrained DER export when CLASS DB is activated. Both these scenarios would result in reduced CLASS service provision. In both cases, ANM would be required to prevent releasing already constrained DER import (CLASS DR activation) or already constrained DER export (CLASS DB activation) 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).

While it is noted that Flexible Services DER could potentially be managed to support CLASS DR or DB services (reduce demand import or increase generation export for CLASS DR, increase demand import or reduce generation export for CLASS DB) this is not the function of the ANM or QUEST systems and is not considered in the development of the QUEST functionality.

A further point to consider in CLASS/ANM conflict resolution is the Flexible Connection generator contracted limit on DER constraining, CiD[6]. CiD should be a consideration in the ANM priority stack and is not a function of CLASS or QUEST. The ANM system will record when individual DER constraining events start and stop to determine the DER position against the CiD and amend the DER position in the priority stack where required. QUEST could record the start and end times for each CLASS DR or DB service activation along with any associated changes in DER curtailment that appear to be due to CLASS service provision. This would allow the DNO to analyse the amount of DER CiD exceedance penalty payments against the provision of CLASS services. However, this is not viewed as a QUEST function and the DNO should use CLASS and ANM data sources for this performance analysis if required.

The primary function of the ANM system is managing DER to adhere to defined network thermal limits, it is not a system aimed at voltage control, other network components and systems control network voltages in real time e.g., transformers with online tap changers, CLASS and Smart Street[7] . While in theory QUEST could be developed to calculate individual DER P and Q import/export set points and issue these to individual DER to assist with voltage control, this is not the intention of the QUEST system at present. The QUEST system is being designed to coordinate the actions of existing voltage control systems (CLASS, Smart Street) or systems that have an impact on these systems (ANM). In the future other voltage control systems may have to be considered for management under QUEST such as ADMS VVC (Advance Distribution Management System Volt Var Control) or ADMS VVO (Volt Var Optimisation) systems.

[6] Curtailment Index. CiD- Refers to the permissible amount of curtailment applied to a DER before the DNO incurs a penalty, the exact amount of which is laid out in the individual DER connection agreement.

[7] It is noted that the Central ANM system has the logic to manage voltage constraints. However, it was discussed, during the detailed design, that for the QUEST trial purposes the Central ANM will not be configured to consider voltage constraints. With this configuration, the behaviour of the Central ANM will be aligned with the Decentralised ANM which does not provide DER voltage control to ensure voltage limits are not violated.

Since CLASS DR and DB are network wide service provisions, constrained DER release prevention will also be network wide. Hence the ANM system could have a mode that prevents the release of constrained DER export across the full area of ANM controlled network, activated and deactivated by QUEST when CLASS DB is activated. A second ANM mode could be provided to prevent the release of constrained DER demand across the full area of ANM controlled network, activated and deactivated by QUEST when CLASS DR is activated. The decentralised and Cloud ANM systems still have to be deployed making inclusion of these ANM operational modes feasible. However, establishing these modes for the existing Central ANM system needs to be defined. With the present Central ANM implementation, there is no possibility for the Central ANM to be prevented from releasing constrained demand/generation. To support this functionality, the ANM algorithm should be enhanced. Since the Central ANM functionality is to be rolled out in production, within the NMS project, this QUEST enhancement, intended for research purposes, would affect the rest of the NMS project. The proposition is to enhance the Central ANM version that will be used for the QUEST trial purposes through the implementation of the QUEST algorithm. The Central ANM version that will be rolled out in the production within the NMS project will not be changed. If during the QUEST trial, it is concluded that this functionality is required for the Central ANM operating in the production, it will be implemented during the second phase of the NMS ANM project.

It is noted that while CLASS DR and DB are network wide service provisions to the UK ESO at present, this could possibly change resulting in a more granular approach to preventing DER constrained import or export being released during CLASS active service provision. The next level of granularity may be to consider the DER in each GSP supplied network area i.e., QUEST could instruct ANM to prevent the release of constrained power import or export on a GSP network area basis. While it is not planned to implement this in the QUEST trial, this point is recorded for future reference.

5.3.3.2. Cloud ANM

It should be noted that while the Central ANM and Decentralised ANM operate in real time to respond to network thermal constraints by issuing P and Q set points to controllable DER impacting the constraint point based on a flexible connection priority stack, the Cloud ANM is different. The Cloud ANM uses network constraint forecasts and flexible services bid by Flexibility Service Providers (FSP) for available DER, to establish a DER dispatch schedule. The forecast constraints, DER availability/bid rates/ bid capacity are typically established a day ahead, and a day ahead optimised dispatch schedule covering each 15 minutes or half hour of the following day is calculated and issued to the corresponding FSPs prior to the dispatch day commencing (the dispatch schedule can be automatically issued to the FSP DER management system via a suitable API link. If DER becomes unavailable during the dispatch schedule day, then a revised dispatch schedule is calculated and issued for the remainder of the day (uses a receding dispatch horizon)).

5.3.3.2.1. CLASS DB, Cloud ANM

If CLASS DB is activated, QUEST would need to instruct the Cloud ANM not to allow the dispatching of DER export above the level being dispatched when DB was activated. This instruction would be running until DB is deactivated. How this feature is deployed would need to be developed for the deployment of the Cloud ANM and the associated flexibility service specification that FSPs are required to comply with, including the specification of the FSP API (ENWL may have some guidance for SGS on these specifications developed for other FSPs). For example, the FSPs could be issued with an instruction (via the API) to cap the active dispatch schedule at the present MW or kW level until CLASS DB is deactivated at which point the FSP would receive (via the API) an instruction to remove the schedule cap and continue with the remainder of the original active day dispatch schedule. If the scheduled level of export drops this does not negatively impact the level of demand boost being provided by CLASS DB. If the scheduled level of export rises it is capped at the scheduled export when CLASS DB was activated to prevent any negative impact on the CLASS DB service.

5.3.3.2.2. CLASS DR, Cloud ANM

If CLASS DR is activated, QUEST would need to instruct the Cloud ANM not to allow the dispatching of flexible DER demand import above the level being dispatched when DR was activated, this instruction running until DR is deactivated. How this feature is deployed would need to be developed for the deployment of the Cloud ANM and the associated flexibility service specification that FSPs are required to comply with, including the specification of the FSP API (ENWL may have some guidance for SGS on these specifications developed for other FSPs). For example, the FSPs could be issued with an instruction (via the API) to cap the active demand dispatch schedule at the present MW or kW level until CLASS DR is deactivated at which point the FSP would receive (via the API) an instruction to remove the demand schedule cap and continue with the remainder of the original active day dispatch schedule. If the scheduled level of demand import drops this does not negatively impact the level of demand reduction being provided by CLASS DR. If the scheduled level of demand import rises it is capped at the scheduled export when CLASS DR was activated to prevent any negative impact on the CLASS DR service.

5.3.3.3. CLASS PFR/SFR

It is noted that CLASS SFR and PFR are not used and are not part of the CLASS dashboard. ENWL has no plans at present to utilise SFR and PFR for regulatory or market-based services.

However, although ENWL has decided that CLASS PFR and SFR are not required to be considered further in the QUEST functional design development, explanations of potential conflicts and expected QUEST reactions in the cases of using PFR/SFR for market based or regulatory services are explained below.

CLASS SFR and PFR both provide demand reduction services to the ESO to assist with frequency control, hence the conflict with ANM is similar to CLASS DR, the difference being that SFR and PFR are activated by the EAVC relays at each substation where CLASS is installed and not by the ESO or DNO control room. Hence, SFR and PFR could in theory be activated at some CLASS SFR and PFR enabled substations and not others. The conflict resolution is to prevent the ANM system from releasing constrained flexible demand when PFR or SFR is activated which would increase the demand at each associated GSP. It is assumed here that at GSPs where no downstream CLASS SFR or PFR is activated there is no conflict with ANM to resolve i.e., PFR and SFR are treated as GSP related services to the ESO rather than DNO network wide services to the ESO such as CLASS DR. This needs to be confirmed by ENWL as blocking ANM constrained demand release at specific GSPs where SFR or PFR is activated is more complex than simply blocking ANM demand release across the full DNO network.

5.3.3.3.1. Market Based Services

Where future market-based services would require CLASS SFR or PFR to be enabled for short periods, the requirements to address conflicts between CLASS and ANM would be similar to those discussed above for CLASS DR and ANM. The ANM mode to manage potential conflict with CLASS SFR and PFR would only be required on activation of these CLASS services with ANM being switched from this mode when CLASS SFR and PFR services are deactivated. QUEST would identify when CLASS SFR or PFR are activated/deactivated and switch the ANM mode accordingly.

5.3.3.3.2. Regulatory Services

Where future regulatory services would require CLASS SFR or PFR to be enabled permanently to provide CLASS SFR and or PFR services, the requirements to address conflicts between CLASS and ANM would be similar to CLASS DR and ANM discussed above. The ANM mode to manage potential conflict with CLASS SFR and PFR would only be required on activation of these CLASS services with the ANM being switched from this mode when CLASS SFR and PFR services are deactivated. QUEST would identify when CLASS SFR or PFR are activated/deactivated and switch the ANM mode accordingly.

6. SMART STREET AND ANM COORDINATION

This chapter focuses on ANM and Smart Street coordination. During the initial UC definition, it was concluded that these two systems, both running periodically in real time, should not affect each other and should be allowed to operate without QUEST's intervention. This argument is confirmed within the use case matrix provided in Table 6.1.

Table 6.1 – Smart Street & ANM use case matrix

Use Case	Trigger	Systems for QUEST to Co-ordinate				General Comments regarding potential system conflicts/resolution
		ESO	CLASS	Smart Street	ANM	
Smart Street and ANM	**ANM or Smart Street active**	N/A	N/A	ENABLED	ENABLED	ANM load/generation planned using P2/6 and therefore ANM should not cause issues with Smart Street or vice versa.

Yellow	**Systems not considered in use case**
Green	**No Conflict**
Red	**Conflict**
Orange	**Potential or acceptable conflict**

However, within the UC there is still one potential conflict left to consider and discuss in more detail. The potential conflict considers cases where a drop in the LV demand results in ANM Flexible Connection generation being constrained beyond their contracted limit of constraining, CiD. The drop in the LV demand, as explained within the UC, may result either due to Smart Street CVR actions in isolation or in combination with Cloud ANM dispatching of Flexibility Services, either a scheduled decrease in Flexible Services demand or an increase in Flexible Services generation. It is 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, it has been agreed that the QUEST functionality to mitigate this potential conflict should be designed and implemented now to future proof the QUEST system.

This potential conflict between Smart Street's CVR operation and the exceedance of flexible generation CiDs where QUEST's intervention is expected is open to interpretation since it can be assumed that CiD should be a consideration in the ANM priority stack, and it is questionable whether QUEST should be aware of that. On the other hand, there is also a question of how much Smart Street operation will really impact the flexible connection generation connected to the 11kV and 33kV networks. Inputs from the Workstream 2: Network modelling regime based on the Use Case scenarios is expected to help with this question. Based on the simulation models carried out within this modelling workstream, the total impact of the Smart Street operation on the ANM operation will be determined.

Based on the reasoning above, the initial UC remains unchanged. The potential conflict is stated within the UC, as well as the possible coordination options. In the Options to Avoid or Mitigate Conflicts between Smart Street and ANM, see section 6.2, more details regarding each coordination option are provided.

6.1. Use Case 3 - Smart Street & ANM

Use Case Name	Smart Street & ANM				
Use Case Number	UC 3	**Version**	1	**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 A	3a.	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.
Potential Resolution: Option B	3b	QUEST Voltage Optimiser forecasts and optimises (based on its priority matrix) that it is less expensive to amend Smart Street behaviour to reduce the LV demand reduction effects on some distribution transformers.
	4b	The QUEST Voltage Optimiser reduces the level of Smart Street CVR allowing demand to increase (may need to amend Smart Street CVR target voltage or amend meshing at one or more locations) affecting the ANM managed thermal constraint locations to avoid constraining one or more Flexible Connection generator exports beyond their connection agreement curtailment index. The QUEST Voltage Optimiser monitors the duration of the Smart Street CVR amended service and records the start and end time for each substation where Smart Street demand reduction behaviour is amended.
	5b	The QUEST Voltage Optimiser forecasts and optimises when the Smart Street full CVR level can be restored without constraining any Flexible Connection generators past their connection agreement curtailment index and restores the full Smart Street CVR level, recording the start and end times of the intervention on each Smart Street location affected.
Potential Resolution Option C	2c	QUEST Voltage Optimiser forecasts and optimises (based on its priority matrix) that it is less expensive to modify ANM Flexible Service dispatching than to amend Smart Street CVR behaviour

		to reduce the LV demand reduction effects on some distribution transformers to prevent the curtailment index from being exceeded at one or more Flexible Connection generators. QUEST Voltage Optimiser intervenes in Flexible Service dispatch via ANM.
	3c	The QUEST Voltage Optimiser continues to modify ANM Flexible Service dispatch until no longer required or amending Smart Street CVR behaviour becomes less expensive than modifying ANM Flexible Service dispatching. The QUEST Voltage Optimiser records the start and end times of each intervention to each Smart Street location and similarly for each ANM Flexible Service intervention.
Potential Resolution Option D	2d	This is an extension of Option B where the prevention of Flexible Connection curtailment more than the connection agreement curtailment index would be better economically addressed through a combination of Smart Street CVR amended behaviour and amended ANM Flexible Service dispatching.
	3d	The QUEST Voltage Optimiser continues to modify ANM Flexible Service dispatching and Smart Street CVR behaviour according to QUEST economic decisions until no longer required. The QUEST Voltage Optimiser releases Smart Street CVR and Flexible Service amended behaviour intervention when no longer required. The QUEST Voltage Optimiser records the start and end times of each intervention to each Smart Street location and similarly for each ANM Flexible Service intervention.
Extensions	To enable options B-D an optimisation would need to be implemented to allow QUEST to understand the cost of when connection agreements (curtailment index) are breached and forecast when this may occur to alter its decision.	
Notes and Outstanding issues (if any)	**Assumption 1**: Smart Street actions are a higher priority than Flexible Connections (free to alter within Curtailment Index). **Option A**: 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. **Option B-D**: Assumes QUEST intervention once contractual obligations result in ENWL penalties, implements interventions by varying priority list driven by exceedance of a curtailment index. **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 MWhr 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.). 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.

6.2. Options to Avoid or Mitigate Conflicts between Smart Street and ANM

There is one conflict described in UC3 between Smart Street and ANM and four options for conflict resolution. The conflict considers cases where a drop in the LV demand results in ANM Flexible Connection generation being constrained beyond their contracted limit of constraining, CiD. The drop in demand that results in this is either due to Smart Street CVR actions in isolation or in combination with Cloud ANM dispatching of Flexibility Services, either a scheduled decrease in Flexible Services demand or an increase in Flexible Services generation.

However, the concept of a conflict between Smart Street's CVR operation and the exceedance of flexible generation CiDs is open to interpretation particularly if Smart Street CVR operates on a continual basis or is operational prior to the connection of the flexible connection generators. It could be interpreted that no such conflict exists or will exist that requires to be resolved by QUEST (noting that QUEST is an overarching voltage management system and not a thermal constraint management system) and hence, only option A in Use Case 3 has any merit. At present, with the limited rollout of Smart Street at distribution substations, there will be no or very little identifiable impact on flexible connection generation which are typically connected to the 11kV and 33kV networks. Depending on the level of Smart Street rollout, the impact could change in the future.

Ignoring the argument of whether a conflict between ANM Flexible Generation, Smart Street and ANM Flexible Services is a valid conflict for QUEST to address, the resolution options considered include the following. The decision to proceed with options B, C and D further in the QUEST design needs to be considered by ENWL.

1. (Option A in UC3) – do nothing and accept that the aggregated duration of Flexible Connection generation constraining may be increased by Smart Street CVR actions at some Flexible Connection generation. This may result in increased compensation penalties paid by the DNO where the level of Flexible Connection export constraining exceeds the contracted connection agreement levels, CiD, for specific generator connections.
2. (Option B in UC3) – QUEST forecasts the level of constraining for each Flexible Connection generator and considers the best economic solution to apply concluding that Smart Street CVR behaviour should be amended to reduce the level of demand reduction (increase CVR target voltage, amend meshing) at some substations.

3. (Option C in UC3) – QUEST forecasts the level of constraining for each Flexible Connection generator and considers the best economic solution to apply concluding that the dispatching of Flexibility Services should be modified.
4. (Option D in UC3) – QUEST forecasts the level of constraining for each Flexible Connection generation and considers the best economic solution to apply concluding that a combination of Smart Street CVR behaviour amendment at some substations in combination with modifications to the dispatching of Flexibility Services provides the optimum economic solution.

Option 1 is a very simple do-nothing option where the DNO accepts the consequences of increased CiD penalty payments and requires no QUEST functionality. This option may be unacceptable as it does not provide QUEST with the new innovative solutions expected by ENWL or the Regulator. On the other hand, this option is a valid solution if it is confirmed by ENWL that the concept of a conflict between Smart Street's CVR operation and the exceedance of Flexible Connection generation CiDs is not actually a conflict that requires QUEST's intervention.

Options 2, 3 and 4 require:

- Forecasting the level of network constraining at all ANM managed constraints.
- Determining the best (optimised) economic solution to address the forecast constraining including:
    - Allow ANM to address each network constraint in real time using DER with Flexible Connections (Central and Decentralised ANM).
    - Optimally modify Smart Street CVR behaviour to reduce the level of demand reduction (e.g., amend the Smart Street CVR target voltage, modify meshing) at some substations to address each network constraint.
    - Optimally modify planned dispatching of Flexibility Services.
    - Optimised combination of these solutions for each network constraint location.
- Recording all decisions with start and stop times and quantities of each intervention action at each network constraint location.

Forecasting demand and generation and translating this into a forecast constraint is already a function of the Central ANM. It is also a planned function of the Cloud ANM to forecast demand and generation and provided these forecasts to the NMS which will then use the NMS network model to forecast constraints and send these to the Cloud ANM which will then schedule the dispatch of Flexibility Services to address these forecast constraints. What QUEST requires is to use the forecast constraints and determine an economically optimised schedule for the deployment of Smart Street, Flexible Connection generation and Flexibility Services (Cloud ANM and Central ANM Flexibility Services). The optimised solution schedule should utilise an optimiser that can include not just economic data, but boundaries that relate to regulatory and operational rules as well as allow the optimiser to be modified or developed as economic data, regulatory and operational rules change over time. However, since this functionality requires complex advanced analytics, an economic optimisation to allow QUEST to understand the cost of when connection agreements (curtailment index) are breached and forecast when this may occur to alter its decision, it is still an open question whether this functionality should be left for a future QUEST implementation phase.

7. CLASS, SMART STREET AND ANM COORDINATION

In managing CLASS, Smart Street and ANM potential operational conflicts simultaneously, the “CLASS forecast and optimise mode” proposed for Smart Street and ANM for UC2, 3 and UC4 above are applicable to UC5. No additional conflicts in this case were detected.

7.1. Use Case 5 - Smart Street, CLASS and ANM

Use Case Name	Smart Street, Enhanced AVC Including CLASS and ANM				
Use Case Number	UC 5	**Version**	1.0	**Status**	Final
Use Case Development Owner	ENWL				
Use Case Description	This use case identifies the conflict and coordination issues between Enhanced AVC including CLASS, Smart Street, and ANM functionalities (which enables Flexible Connections and Flexible Services). It also suggests possible resolutions provided by the QUEST Voltage Optimiser. The QUEST Voltage Optimiser executes in line with its “Operational Objective”.				
Primary users	ESO, DNO				
Secondary users	DNO				
Trigger	QUEST is triggered when any of the CLASS functions, that will cause potential conflict between objectives or network issues due to coordination of actions with Smart Street and ANM, are executed. These functions are either manual or require an external signal to trigger, such as: • Demand Reduction (DR) function • Demand Boost (DB) function • Tap stagger Function (TSF) Or automatic, primed to act after a certain threshold is met, such as: • Primary Frequency Response (PFR) • Secondary Frequency Response (SFR) • Load limiting (LL)[8]				
Preconditions	CLASS is enabled to execute a number of functions upon request from ESO or commercial agreements. Where a commercial agreement is in place the DNO will enable the contracted services, which will only activate				

[8] CLASS Load Limiting is a DNO service designed to reduce demand at peak times to defer Primary and BSP substation upgrade requirements due to peak demand issues. LL is not a CLASS service that is activated by the ESO and hence is not considered in the use case.

	following a trigger from ESO or by an automatic network trigger such as frequency. 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 statutory limit. ANM is managing various Distribution Energy Resources (DER) to control power flows at a number of constraint points on constraint management zones by issuing set points to DER at times to manage the constraint where possible. ANM has the capability to issue MW and MVAr set points. Cloud ANM Flexible Services dispatching is operating according to a day ahead dispatch schedule. QUEST is not optimising the network for efficiency when CLASS is enabled or active (related to all CLASS functions except DB). 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 at all key locations on the distribution network.	
Post Conditions	Voltages on the HV and LV networks in the QUEST trial area are within the technical limits. CLASS continues to enable ESO services and Smart Street enables CVR and ANM continues to control power flows at constraint points by managing the set points of DER when required. Cloud ANM Flexibility Service dispatch continues with a revised schedule where required.	
Main Success Scenario	**Steps**	**Actions**
DR	1	CLASS receives instruction from either ESO or DNO to execute DR.
No Conflict	2a	CLASS activates the EAVC Relay to reduce demand. The result causes no thermal violation in the constraint management zone. ANM achieves full-service provision. Smart Street tap operations reacting to the new voltage set point cause no issues.
Conflict/Coordination Issue Path	2b	CLASS alters its EAVC Relay controller set point to reduce demand. The action causes a reduction in local demand, increasing export at a thermal constraint, leading to a violation in the constraint management zone. ANM alters DER set points to solve the thermal constraint issue. DER providing a flexible service, associated with the constraint is forced to reduce dispatch, resulting in partial service provision.

		Smart Street tap operations, reacting to the new voltage, may not resolve the LV violation.
Possible Coordination Resolution Path	3	QUEST presumes CLASS actions may cause a temporary constraint violation if uncoordinated with ANM and continuous if uncoordinated with Smart Street. QUEST instructs ANM to move into “CLASS forecast and optimise mode”, securing the network against any issues whilst balancing all system objectives and constraints e.g., not exceeding curtailment index. QUEST determines that Smart Street functionality needs to be put into a “CLASS forecast and optimise mode”, securing the network against any issues whilst balancing all system objectives. CLASS activates the EAVC Relay to reduce demand. QUEST records pertinent parameters to audit the conflict/coordination resolution action on its impact on other systems/services as a post analysis. On completion of CLASS service, QUEST informs ANM and Smart Street to move back into normal operation modes.
DB	1	CLASS receives instruction from ESO to execute DB.
No Conflict	2a	CLASS activates the EAVC Relay to increase demand. The action does not cause capacity at a constraint location to be released. Smart Street tap operations reacting to the new voltage set point cause no issues. ANM achieves full-service provision.
Conflict/Coordination Issue Path	2b	CLASS activates the EAVC Relay to increase demand. The action causes capacity at a constraint location to be released. ANM alters DER set points to release generation up to the released capacity, reducing the impact of CLASS actions. Smart Street tap operations, reacting to the new voltage set points, decreasing demand within their area and the wider area, reducing the impact of CLASS actions. ANM arranges a service associated with the release of capacity e.g. (battery export).
Possible Coordination Resolution Path	2c	QUEST presumes ANM, Smart Street actions will interfere with the CLASS objective if uncoordinated. QUEST instructs ANM to move into “CLASS forecast and optimise mode”, securing the network against any issues whilst balancing all system objectives and constraints e.g., not exceeding curtailment index.

		QUEST determines that Smart Street functionality needs to be put into a "CLASS forecast and optimise mode", securing the network against any issues whilst balancing all system objectives. CLASS activates the EAVC Relay to increase demand. QUEST records pertinent parameters to audit the conflict/coordination resolution action on its impact on other systems/services as a post analysis. On completion of the CLASS service, QUEST informs ANM and Smart Street to resume their normal operation mode.
TSF	1	CLASS receives instruction from ESO to execute TSF.
	2a	CLASS activates the EAVC Relay to increase reactive power absorption. The action does not cause constraint violation in the constraint management zone. ANM achieves full-service provision. Smart Street tap operations, reacting to the new voltage set point, cause no issues.
PFR	1	When PFR is enabled the EAVC Relay puts tap-stagger in place. Once the frequency threshold is exceeded PFR is automatically activated by the on-site EAVC relay. The 11/6.6kV CB of the Primary Transformer (33/11 or 33/6.6kV) which is on the higher tap position, out of the Primary Transformers is opened. Tapping does not take place while PFR is activated.
No Conflict	2a	The action does not cause a thermal constraint violation in the constraint management zone.
Conflict/Coordination Issue Path	2b	PFR activation causes a thermal constraint violation in the constraint management zone. ANM alters generation set points to solve the thermal constraint issue. Smart Street tap operations, reacting to the new voltage, causes a low voltage issue it cannot resolve.
Possible Coordination Resolution Path	2c	QUEST presumes CLASS actions will cause a temporary constraint violation if uncoordinated. QUEST instructs ANM to move into "CLASS forecast and optimise mode", securing the network against any issues whilst balancing all system objectives. CLASS instructs a primary transformer pair with tap stagger applied to open one CB. QUEST determines that Smart Street functionality needs to be put into a "CLASS forecast and optimise mode", securing the network against any issues whilst balancing all system objectives.

		On completion of the CLASS service, the EAVC Relay reinstates the CB moving to a post event state. QUEST sets the Smart Street and ANM objective back to normal.
SFR	1	The frequency threshold, monitored by CLASS, is exceeded.
No Conflict	2a	The EAVC Relays instruct a primary transformer pair to tap down. The action does not cause a thermal constraint violation in the constraint management zone.
Conflict/Coordination Issue Path	2b	The EAVC Relays instruct a primary transformer pair to tap down. The action does cause a thermal constraint violation in the constraint management zone. ANM alters generation set points to solve the thermal constraint issue. Smart Street tap operations, reacting to the new voltage, cause a low voltage issue it cannot resolve.
Possible Coordination Resolution Path	2c	QUEST presumes CLASS actions will cause a temporary constraint violation if uncoordinated. QUEST instructs ANM to move into “CLASS forecast and optimise mode”, securing the network against any issues whilst balancing all system objectives. QUEST determines that Smart Street functionality needs to be put into a “CLASS forecast and optimise mode”, securing the network against any issues whilst balancing all system objectives. The EAVC Relays instruct both primary transformers to tap down. CLASS SRF expires, transformers tap back up. QUEST sets the Smart Street and ANM objective back to normal.
Extensions	The forecast and optimise mode could be: • A rigid rule-based approach, presuming (forecasting) the worst-case condition and prioritising (optimising) certain system objectives ahead of others. • A complex forecast of network state to predict when abnormal conditions may occur and implement a multi-objective optimisation that blends discrete system objectives to achieve a global optimum. • A hybrid approach allowing multiple objective options and suitable information to guide operators in option selection.	

Notes and Outstanding issues (if any)	**Assumption 1**: CLASS will not induce a voltage constraint due to its actions. **Assumption 2**: Achieving CLASS objectives has the highest priority and QUEST will forecast and optimise systems in line with this. **Assumption 3**: ENWL wants QUEST to minimise or mitigate constraint exceedance during network state transition. **Assumption 4**: Tap Stagger is implemented on transformers that are loaded appropriately to allow an increase in total MVA not to exceed equipment rating.

8. ESO INSTRUCTIONS FOR EMERGENCY RESPONSE

Within this chapter, the focus is to clarify the effects of ESO instructions for the emergency response on the Smart Street and ANM operation and CLASS functions. (Use Case 6, Use Case 7 and Use Case 8). Through the definition of these Use Cases, it has been concluded that Smart Street and ANM should be put in a safe mode ("LFDD forecast and optimise mode" and "OC6 mode") while the DNO is providing emergency regulatory services to the ESO. The main topics within this chapter are:

- Detection of the "LFDD forecast and optimise mode" detection of this mode.
  - Putting Smart Street in "LFDD forecast and optimise mode" and releasing from it.
  - Putting ANM in "LFDD forecast and optimise mode" and releasing from it.
- Detection of the "OC6 mode".
  - Putting Smart Street in "OC6 mode" and releasing from it.
  - Putting ANM in "OC6 mode" and releasing from it.

8.1. "LFDD Forecast and Optimise Mode"

Low frequency demand disconnection and its effect on the other systems (CLASS, ANM and Smart Street) are explained in detail within this section. Through the discussions regarding the provision of LFDD response to the ESO, it was clarified how QUEST needs to intervene to maintain system stability for National Grid.

8.1.1. QUEST Use Case Matrix - LFDD Response to the ESO

The initial version of the use case matrix explaining conflicts between LFDD, CLASS, ANM and Smart Street is provided in the Table 8.1.

Table 8.1 – LFDD, CLASS & ANM use case matrix

Use Case	Trigger	Systems for QUEST to Co-ordinate				General Comments regarding potential system conflicts/resolution
		ESO	CLASS	Smart Street	ANM	
LFDD, CLASS, Smart Street and ANM	**LFDD**	LFDD	ENABLED (DR/SFR/PFR/ DB/LL/TS)	ENABLED but operating in alternative mode due to LFDD/Smart Street conflict	ENABLED but operating in alternative mode due to LFDD/ANM conflict	LFDD conflict with Smart Street and ANM. Both Smart Street and ANM to operate in alternative mode to maintain system stability for the ESO. Following LFDD operation DNO to maintain system demand so as not to cause any change in system state (balance) that may have a negative impact on the transmission system.
LFDD, CLASS, Smart Street	**LFDD**	LFDD	ACTIVE (DR/SFR/PFR/ DB/LL/TS)	ENABLED but operating in alternative mode due to	ENABLED but operating in alternative mode due to	LFDD conflict with Smart Street and ANM. Both Smart Street and ANM to operate in alternative mode to maintain system stability

and ANM				LFDD/Smart Street conflict	LFDD/ANM conflict	for the ESO. Following LFDD operation DNO to maintain system demand so as not to cause any change in system state (balance) that may have a negative impact on the transmission system.

	Systems not considered in use case
	No Conflict
	Conflict
	Potential or acceptable conflict

The QUEST partners have agreed that there is no conflict between LFDD and Smart Street. Smart Street will continue performing CVR on all the distribution substations connected via BSP's not disconnected by LFDD. However, on primary substations where CLASS is enabled or active, Smart Street will already have been put in CFOM mode to prevent conflict with CLASS functionality. Hence, the Smart Street column within the use case matrix remains red coloured, but the conflict pointed out relates to the Smart Street and CLASS coordination, not to coordination with LFDD.

Regarding ANM operation, no changes to the use case matrix were made. It is confirmed that ANM may conflict with the LFDD and hence, it needs to be put in a safe mode by QUEST upon detection of the LFDD activation.

An updated version of the use case matrix is provided in Table 8.2.

Table 8.2 – LFDD, CLASS & ANM use case matrix (revised)

Use Case	**Trigger**	**Systems for QUEST to Co-ordinate**				**General Comments regarding potential system conflicts/resolution**
		ESO	**CLASS**	**Smart Street**	**ANM**	
LFDD, CLASS, Smart Street and ANM	**LFDD**	LFDD	ENABLED (DR/SFR/PFR/DB/LL/TS)	ENABLED but operating in alternative mode due to CLASS/Smart Street conflict	ENABLED but operating in alternative mode due to LFDD/ANM conflict	LFDD conflict with ANM. ANM to operate in alternative mode to maintain system stability for the ESO. Following LFDD operation DNO to maintain system demand reduction so as not to cause any change in system state (balance) that may have a negative impact on NG.
LFDD, CLASS, Smart Street and ANM	**LFDD**	LFDD	ACTIVE (DR/SFR/PFR/DB/LL/TS)	ENABLED but operating in alternative mode due to CLASS/Smart Street conflict	ENABLED but operating in alternative mode due to LFDD/ANM conflict	LFDD conflict with ANM. ANM to operate in alternative mode to maintain system stability for the ESO. Following LFDD operation DNO to maintain system demand reduction so not to cause any change in system state (balance)

						that may have a negative impact on NG.
						Systems not considered in use case
						No Conflict
						Conflict
						Potential or acceptable conflict

8.1.2. Use Case 6 - Smart Street, CLASS, ANM & LFDD

Use Case 6 has been updated to provide additional information regarding the National Grid Code Operating Condition 6 (OC6) and automatic Low Frequency Demand Disconnection (LFDD) detailed in OC6.6.

Also, parts of the Use Case stating that Smart Street will conflict with LFDD and options to mitigate that conflict are removed since it has been concluded that no such conflict will exist.

Use Case Name	Smart Street, Enhanced AVC Including CLASS, ANM & LFDD				
Use Case Number	UC 6	**Version**	1	**Status**	Final
Use Case Development Owner	ENWL				
Use Case Description	This use case describes the coordination between Low Frequency Demand Disconnection (LFDD) activation from ESO and 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”. The National Grid Operating Code No. 6 (OC6) defines various methods for Distribution Network Operators to reduce demand to ensure that the electricity network remains stable when there is a shortage of active power generation to meet GB demand. Demand reduction can be automatic such as by operation of protection relays to trip demand when the frequency falls below a set value (Low Frequency Demand Disconnection) and manual demand reduction by voltage reduction or demand disconnection. In the case of manual disconnection, NG will issue a warning/instruction to the DNO to reduce demand to a required level (MW) within a specified time period. This use case is specific to automatic Low Frequency Demand Disconnection detailed in OC6.6				
Primary users	ESO				
Secondary users	DNO				

Trigger	QUEST is triggered when it sees three LFDD alarms come in from the DNO SCADA system.	
Preconditions	Smart Street, CLASS, ANM enabled, all systems running in normal operating conditions. CLASS is enabled to execute one of a number of functions upon request from ESO or commercial agreements. Where a commercial agreement is in place the DNO will enable the contracted CLASS service, which will only activate following a trigger from ESO or by an automatic network trigger such as frequency. QUEST is not in “efficiency mode” if a CLASS service is enabled other than DB. 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.	
Post Conditions	LFDD has acted as expected (demand disconnected and not yet restored), CLASS remains enabled, ANM goes into LFDD mode and “efficiency mode” is switched off by QUEST for CLASS services other than DB. When efficiency mode is disabled, having been in operation, the 132kV/33kV grid transformers will regulate to their normal voltage set point. Smart Street remains enabled or in the CFOM mode (if it was previously put in this mode due to coordination with CLASS) On all the primaries remaining connected to the BSPs (not disconnected via LFDD) 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 while in LFDD mode (it is only prevented from releasing any curtailed demand). Cloud ANM Flexibility Service dispatch operates within LFDD mode. QUEST to maintain system voltages within statutory limits where possible.	
Main Success Scenario	**Steps**	**Actions**
LFDD	1	LFDD relays respond to system frequency change, and begin to open CBs at BSPs
	2	QUEST removes its voltage optimisation at BSPs associated with efficiency mode allowing the BSP transformers to regulate automatically.
No conflict	3	Smart Street continues to perform CVR on all the distribution sites connected to BSPs not disconnected via LFDD. Where Smart Street was operating in CFOM prior to an LFDD action due to CLASS service enablement at upstream primary

		substations this will continue to be the case while the CLASS service remains enabled.
Conflict	4	QUEST puts ANM into LFDD mode. (Manages thermal constraints as normal but does not release constrained demand capacity.) Cloud ANM Flexibility Service dispatch put into LFDD mode e.g., may halt dispatching of flexible demand services.
No conflict	5	QUEST makes no change to CLASS status.
Conflict	6	If QUEST is operating in network efficiency mode, QUEST switches this mode off. When efficiency mode is disabled the 132kV/33kV grid transformers will regulate to their normal voltage set point.
	7	Instruction from ESO to return systems to precondition state.
Extensions	None	
Notes and Outstanding issues (if any)	**Assumption 1**: LFDD instruction has priority over all system operating constraints. **Assumption 2**: ENWL is looking to modify (via a separate project) the way LFDD is implemented via the CLASS EAVC relays. This may affect the current LFDD CLASS interaction. **Assumption 3**: Agreed that there is no requirement to modify Smart Street operating regime. Distribution sites connected to BSPs disconnected via LFDD will be non-operational and therefore no point in altering voltage settings or fixing taps. Those distribution sites not triggered by LFDD should continue to operate as per pre-LFDD activation (Smart Street substations operating in CFOM due to CLASS service enablement will continue to do so). If the system suffers from voltage reduction, then BSP Transformers and Primary Transformers will attempt to restore voltages to nominal far quicker than Smart Street OLTCs.	

8.1.3. Options to Mitigate Conflict between LFDD and Smart Street and ANM

In case of automatic LFDD activation, circuit breakers on BSP level (33kV circuit breakers) are tripped (depending on the frequency threshold set), creating disconnected sections of the network that are no longer energised, until frequency returns within the predefined limits and the ESO instructs that disconnected demand can be restored. LFDD activation is detected through the DNO's SCADA system. Multiple SCADA alarms are reported, per each relay that has reacted to an under-frequency situation.

Once all the BSP circuits are disconnected via LFDD, it does not matter what CLASS, Smart Street 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 being disconnected via LFDD.

8.1.3.1. LFDD and Smart Street

In the case of automatic 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 Smart Street 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 Smart Street will not perform actions which would conflict with LFDD, and thus, there is no need to put Smart Street into LFDD safe mode. 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, Smart Street will already be in CFOM mode.

8.1.3.2. 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 needs to be put in LFDD mode, 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).

8.1.3.3. LFDD and QUEST Operating in the Network Efficiency Mode

In the case of automatic LFDD activation, QUEST will switch off network efficiency mode. There are several reasons for switching off network efficiency mode. 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 demand restoration becoming 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, network efficiency mode being on or off is irrelevant. However, if the network efficiency mode 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. 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).

8.2. OC6 Mode (Manually Initiated Disconnection)

Through the definition of Use Case 7 related to the OC6 activation, it has been concluded that Smart Street and ANM should be put in a safe mode called "OC6 mode". In the rest of this chapter, more information regarding OC6 activation is provided. It is also discussed how QUEST will be aware of the OC6 activation and what are the required QUEST actions in this ~~emergency~~ situation.

8.2.1. QUEST Use Case Matrix - OC6 Response to the ESO

The initial version of the use case matrix related to OC6 (manually initiated demand disconnection) coordination with Smart Street, ANM and CLASS is provided in Table 8.3. After discussion regarding this Use Case, no changes were made to the original use case matrix.

Table 8.3 – OC6, CLASS & ANM use case matrix

Use Case	Trigger	Systems for Quest to Co-ordinate				General Comments regarding potential system conflicts/resolution
		ESO	CLASS	Smart Street	ANM	
OC6, CLASS, Smart Street and ANM	**OC6**	OC 6	ENABLED (DR/SFR/ PFR/DB/LL/ TS)	Alternative mode due to OC6/Smart Street conflict	Alternative mode due to OC6/ANM conflict	OC 6 conflicts with Smart Street and ANM. Both Smart Street and ANM to operate in alternative mode to maintain system stability for the ESO. Following OC6 operation DNO to maintain system demand reduction so not to cause any change in system state (balance) that may have a negative impact on NG.
OC6, CLASS, Smart Street and ANM	**OC6**	OC 6	ACTIVE (DR/SFR/ PFR/DB/LL/ TS)	Alternative mode due to OC6/Smart Street conflict	Alternative mode due to OC6/ANM conflict	OC 6 conflicts with Smart Street and ANM. Both Smart Street and ANM to operate in alternative mode to maintain system stability for the ESO. Following OC6 operation DNO to maintain system demand reduction so not to cause any change in system state (balance) that may have a negative impact on NG.

(yellow)	**Systems not considered in use case**
(green)	**No Conflict**
(red)	**Conflict**
(orange)	**Potential or acceptable conflict**

8.2.2. Use Case 7 - Smart Street, Enhanced AVC Including CLASS, ANM & OC6

Use Case 7 has been updated to provide additional information regarding the National Grid Code Operating Condition 6 (OC6).

Use Case Name	Smart Street, Enhanced AVC Including CLASS, ANM & OC6 (OC6.5 Procedure for the Implementation of Demand Control on the Instructions of ESO - demand control disconnection as per grid code)				
Use Case Number	UC 7	**Version**	1	**Status**	Final
Use Case Development Owner	ENWL				
Use Case Description	This use case describes the coordination between OC6 activation from ESO and 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". National Grid Code Operating Condition 6 (OC6) defines various methods for Distribution Network Operators to reduce demand to ensure that the electricity network remains stable when there is a shortage of active power generation to meet GB demand. Demand reduction can be automatic such as by operation of protection relays to trip demand when the frequency falls below a set value (Low Frequency Demand Disconnection) and manual demand reduction by voltage reduction or demand disconnection. In the case of manual disconnection, NG will issue a warning/instruction to the DNO to reduce demand to a required level (MW) within a specified time period. This use case is specific to manual disconnection on instruction from the ESO as detailed in OC6.5 or OC6.7 for emergency manual disconnection.				
Primary users	ESO				
Secondary users	DNO				
Trigger	Upon instruction from ESO to reduce demand in the event of insufficient Active Power generation being available to meet Demand.				
Preconditions	Smart Street, CLASS, ANM enabled, all systems running in normal operating conditions. CLASS is enabled to execute one of a number of functions upon request from ESO or commercial				

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	agreements. Where a commercial agreement is in place the DNO will enable the contracted CLASS services which will only activate following a trigger from ESO. QUEST is not in "efficiency mode" if a CLASS service is enabled other than DB. 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	
Post Conditions	OC6 has been implemented as requested (demand reduction / disconnected and not yet restored), CLASS remains enabled, Smart Street and ANM go into OC6 mode, and "efficiency mode" is switched off by QUEST. 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 while in OC6 mode. Cloud ANM Flexibility Service dispatch operates within OC6 mode. QUEST to maintain system voltages within statutory limits where possible.	
Main Success Scenario	**Steps**	**Actions**
OC6 Instruction	1	DNO Control Room follows the due process according to OC6.5 / 6.7 requirements.
	2	DNO Control Room applies voltage reduction & demand disconnection and causes the following conflicts.
Conflict/Coordination Issue Path	1a	The result causes thermal constraint violation in the constraint management zone.
	1b	Smart Street will potentially counteract demand reduction where voltage reduction is applied to reduce demand under OC6.5.
	1c	QUEST attempts to optimise network impacting demand reduction capability.
Possible Coordination Resolution Path	2	DNO Control Room puts QUEST into OC6 mode. Which will automatically follow steps 2a to 2c below.
	2a	QUEST Voltage Optimiser removes its voltage optimisation at BSPs associated with efficiency mode allowing the BSP transformers to regulate

		automatically to the restored normal target voltage set point.
	2b	QUEST Voltage Optimiser sends global lock taps signal to Smart Street transformers.
	2c	QUEST Voltage Optimiser puts ANM into OC6 mode. (Manages thermal constraints as normal but does not release constrained demand capacity. Cloud ANM Flexibility Service dispatch put into OC6 mode e.g., may halt dispatching of flexible services in particular scheduled demand increases.)
	3	DNO Control Room follows the due process according to OC6.5 / 6.7 requirements.
	4	QUEST Voltage Optimiser makes no change to CLASS status.
	5	If in QUEST "efficiency mode", QUEST switches this off.
	6	Confirmation from ESO to restore load as instructed.
	7	DNO Control Room restores the system to normal operation as per preconditions stated above. (Normal operating condition).
	8	DNO Control Room to take QUEST out of OC6 mode.
Extensions	None	
Notes and Outstanding issues (if any)	**Assumption 1**: OC6 instruction has priority over all system operating constraints. **Assumption 2**: It will be a business procedure to put the QUEST into the OC6 mode prior to activating the OC6 mode.	

8.2.3. Options to Mitigate Conflict between OC6 and Other Systems (CLASS, Smart Street and ANM)

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). 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 demand reduction requirements are not satisfied upon performing the voltage reduction, manual demand disconnection is performed by opening HV CBs to disconnect demand in a controlled manner (OC6.7).

8.2.3.1. OC6 and Smart Street

Since this is an emergency, it is allowed for voltages to be below the statutory minimum limits. In the case of activating the voltage reduction, Smart Street, 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 demand reduction. Having that in mind, in the case of OC6 activation, global action for fixing all the Smart Street transformers on their current tap positions will be performed prior to manually carrying out OC6 actions.

NOTE: It should be considered that some Smart Street transformers will already be in a safe target position due to Smart Street's coordination with CLASS (CFOM). When releasing the distribution transformer taps from fixed positions once OC6 mode is deactivated, this should only be performed for those transformers that were not previously fixed due to CFOM. The ones fixed due to CFOM should remain fixed even after OC6 mode is deactivated until QUEST confirms the associated CLASS service is disabled at which point the Smart Street locations operating in CFOM will be released and the distribution transformers free to tap to their revised voltage target set point.

8.2.3.2. OC6 and ANM

Similar to coordination with CLASS DR and with LFDD, ANM should be prevented from releasing any curtailed demand in case of OC6 mode activation. In the case of activating the OC6 mode, a global action for putting ANM in OC6 mode will be sent prior to manually carrying out OC6.6 actions.

8.2.3.3. OC6 and QUEST Operating in the Network Efficiency Mode

Similar to coordination with LFDD (OC6.6), in the case of manual activation of OC6, QUEST will switch off the network efficiency mode, network wide, prior to manually activating OC6 actions. The reason for switching off the network efficiency mode prior to activating the OC6 response is to enable the primary substations to perform the expected voltage reduction to reduce the demand. Leaving the network efficiency mode 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. The primary transformers would then be closer to their bottom tap than they would be if the network efficiency mode 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 activation.

8.3. Reactive Power Response

This section describes the coordination between reactive power response to ESO (absorbing reactive power to reduce the voltage on National Grid Network), Enhanced AVC including CLASS, Smart Street and ANM. While discussing this UC, no changes to the UC matrix were made. It is 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. The initial version of the use case matrix, provided in Table 8.4, confirms this statement.

Table 8.4 – Reactive Power Response, CLASS, Smart Street & ANM use case matrix

	Use Case	Trigger	Systems for QUEST to Co-ordinate				General Comments regarding potential system conflicts/resolution
			ESO	Enhanced AVC Including CLASS	Smart Street	ANM	
8	**Reactive Power Response, CLASS, Smart Street and ANM**	**Reactive Power Response**	Reactive Power Response	ENABLED (DR/SFR/ PFR/DB/LL/ TS)	ENABLED	ENABLED	No conflict identified
8	**Reactive Power Response, CLASS, Smart Street and ANM**	**Reactive Power Response**	Reactive Power Response	ACTIVE (DR/SFR/ PFR/DB/LL/ TS)	ENABLED	ENABLED	No conflict identified

Yellow	**Systems not considered in use case**
Green	**No Conflict**
Red	**Conflict**
Orange	**Potential or acceptable conflict**

However, additional topics were raised during the discussions. ENWL plans to use tap staggering functionality (TS) at the BSP transformers 132/33kV in order to provide reactive power response to the ESO. This functionality is considered as a CLASS function, and it is expected that enabling TS on a BSP level should be performed from the CLASS Dashboard. However, since the development of the CLASS dashboard is closed, and this functionality currently cannot be integrated within the CLASS dashboard, the question remains whether this functionality should be added as a QUEST function. During the first phase of the QUEST project, while initial Use Cases were being defined, it was concluded that QUEST, as an overarching system, should not enhance the functionalities of the other systems, but only coordinate them in order to prevent them from conflicting with each other. On the other hand, if enabling TS on a BSP level is not included within the QUEST functionality, and there is no possibility of including it in the CLASS Dashboard, then it has been concluded that this operation should be performed manually (manual TS would still require some form of software system control either via the CLASS dashboard, QUEST or a new function on the NMS which is activated by the DNO control room). This topic remains an open question. It is for ENWL to align internally and to provide inputs for further discussions.

Until then, the UC8 remains in the same state.

8.3.1. Use Case 8 - Smart Street, Enhanced AVC Including CLASS, ANM & Reactive Power Response

Use Case Name	Smart Street, Enhanced AVC Including CLASS, ANM & Reactive Power Response				
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 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 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 a number of functions upon request from 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 ESO or by an automatic network trigger such as frequency. 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. QUEST is not in “efficiency mode” if a CLASS service is enabled other than DB. QUEST enables BSP TS mode, which reduces 33kV setpoint to maximise tap stagger capability at CLASS sites is enabled.				
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	CLASS Dashboard receives instruction from ESO to execute TS.
	2	CLASS Dashboard activates EAVC Relay to increase reactive power absorption. The result causes no thermal violation in the constraint management zone.
	3	QUEST does not affect Smart Street or ANM operability.
	4	Once the reactive power response has been deactivated, the system returns to the normal precondition state.
Conflict/Coordination Issue Path		None
Extensions	1. QUEST cannot find enough capacity available to absorb reactive power. This would occur if all available sites have already activated tap stagger. Adding Tap Stagger at 132/33kV substations will add a greater reactive power response. 2. If a primary transformer reaches the bottom tap, its supplying 132/33kV grid transformers could have their target voltage adjusted downwards to create more “tap room” (and vice versa).	
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.	

9. CONCLUSION

The purpose of the first subphase of the QUEST detailed design was to fill in the gaps left in the first version of the QUEST Use Cases document [1]. While the focus of the Use Cases definition phase was to identify all the possible conflicts between the different systems operating on the same part of the network (CLASS, Smart Street, ANM and 33kV Network Efficiency Mode), the focus of this subphase was to analyse all the possible QUEST macro level architecture options to resolve the detected conflicts.

During this detailed design subphase, all the Use Cases were discussed and analysed in detail and all the necessary explanations were provided by ENWL and partners. Through the discussion on how to resolve previously identified conflicts, the conclusion in some cases was that conflicts for which QUEST's intervention is expected actually do not exist. These conflicts were removed from the Use Cases.

Additional explanations have been added to the Use Cases as more details were provided within this subphase. This document contains the latest updated version of the Use Cases and Use Case Matrixes that will be carried forward into subphase 2 of the detailed design development.

For most of the conflict scenarios, it has now been clarified how QUEST is expected to react in order to prevent different systems counteracting each other. Different options to avoid or mitigate the conflicts between different systems are provided for each of the defined Use Cases.

Although for most scenarios QUEST's expected behaviour has been determined, there are still some questions left open that need additional internal discussion within the ENWL team. These questions are to be considered by ENWL as the design transitions into subphase 2 of the detailed design and include:

- 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 will be replaced with more appropriate terms.
- How the inclusion of CLASS tap stagger for reactive power absorption services to the ESO at BSPs is to be implemented, is to be clarified. Will this be an operator activated software function within CLASS, QUEST, the NMS or some other system?
- 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. However, it has been agreed that the QUEST functionality to mitigate this potential conflict should be designed and implemented now to future proof the QUEST system. Several options for coordination are provided within this document and should be additionally discussed during the subphase 2 of the detailed design.

During the refinement of the use cases additional general functional requirements for the QUEST Voltage Optimiser have been identified. These will be carried through to detailed design subphase 2. They include:

- 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 running out of transformer tap positions e.g. Primary substations as a result of changing the 33kV voltage at the BSP transformers. QUEST should also monitor for tap not achievable alarms from the voltage control relays.

- QUEST requires to monitor voltages across the DNO network (including 132kV) at the various voltage levels including the point of connection locations with DER (excludes small LV connected DER).

In the final discussions relating to this subphase 1 report a number of important points relating to QUEST functionality and overall objectives were identified that also require to be addressed in detailed design subphase 2. These include:

- Similar to the approach taken to manage conflicts between CLASS DR or DB with 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. In particular, are there alternatives to switching 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? Studies using the Whitegate trail network model should be used to identify potential 33kV network target voltages for network efficiency mode that would work with CLASS services such as DRF and DRH.
- Presently the ENWL network has areas of no, or low levels of, Smart Street or ANM and areas of low CLASS. While QUEST will be trialled on one GSP fed network area, the need for a network zonal approach to QUEST conflict management requires it to be investigated in detailed design subphase 2. This will assist in addressing how QUEST would operate in a full UK DNO network.
- Detailed design subphase 2 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 in detailed design subphase 2, to improve QUEST coordination of CLASS DB and Smart Street when CLASS DB is being disabled which would potentially avoid the need to put Smart Street into a safe mode on CLASS DB enablement or activation but only for disablement.
- Detailed design subphase 2 should commence with a review of the QUEST functionality from detailed design subphase 1 against the QUEST objectives to ensure these are being met. Where deemed necessary, the QUEST team should reach agreement on any design changes that are required to be covered in detailed design subphase 2. This is to ensure that the QUEST objectives are being met or to justify where these require change. Commentary around the detailed design alignment with the QUEST objectives should be included in the final detailed design report.

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. This subphase (1) chose option 3, the “hybrid approach” to be the one to take forward into subphase 2. A number of ‘meso level’ architecture options, which in different ways satisfy the criteria of macro-option 3, will be explored in subphase 2.

10. APPENDICES

10.1. APPENDIX A - Interactions between CLASS DR and ANM

The following diagrams are intended to help illustrate the descriptions regarding interactions between CLASS DR and ANM provided in the Options to Avoid or Mitigate Conflicts between CLASS and ANM.

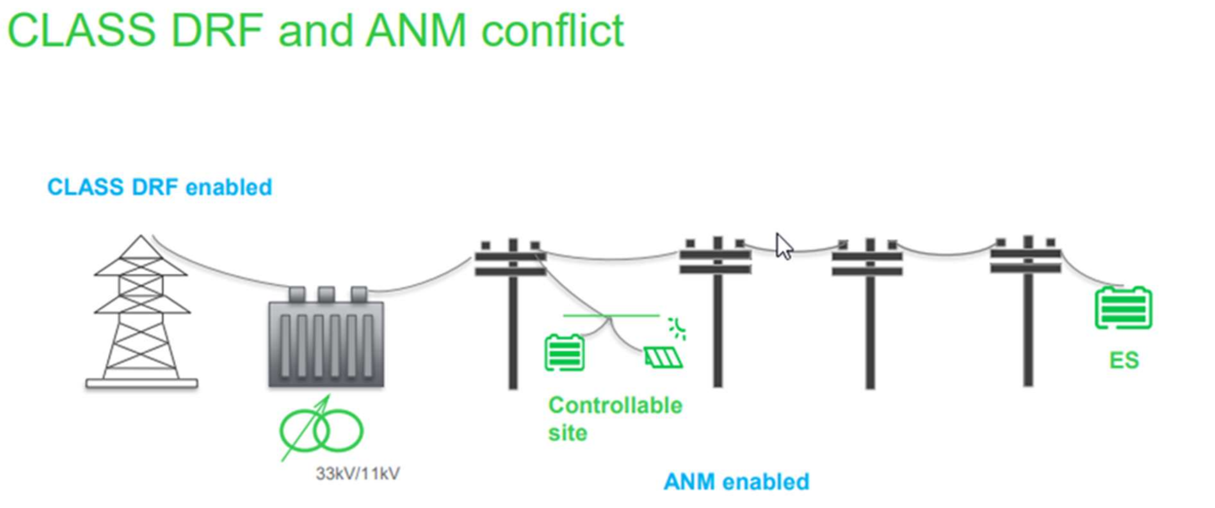

Figure 10.1 – CLASS DRF and ANM conflict: CLASS DRF and ANM are enabled on the same primary substation

In the example above, one primary substation is considered. Initially, CLASS DR is enabled on this primary substation. ANM is enabled on this part of the network, as well, and is monitoring the thermal constraint points. There are two DERs considered on this part of the network, one energy storage (ES) and one controllable site containing a rooftop solar and energy storage.

At one point on the 11kV circuit, a thermal capacity issue appears due to excessive demand.

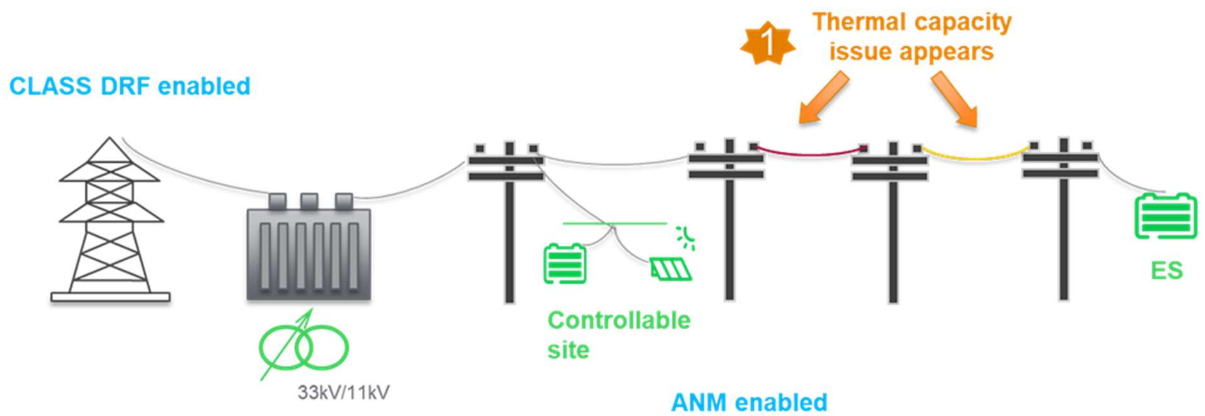

Figure 10.2 – CLASS DRF and ANM conflict: A thermal capacity issue appears

ANM dispatches the ES to increase the power export and reduce the circuit demand to mitigate the thermal capacity issue.

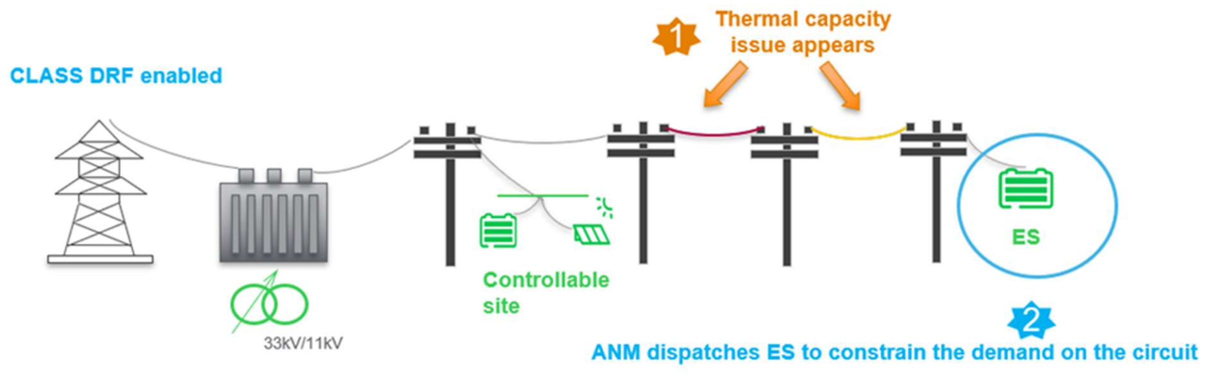

Figure 10.3 - CLASS DRF and ANM conflict: ANM dispatches ES

As a result of dispatching ES power export onto the circuit, the total demand on the 11kV circuit and primary substation is decreased.

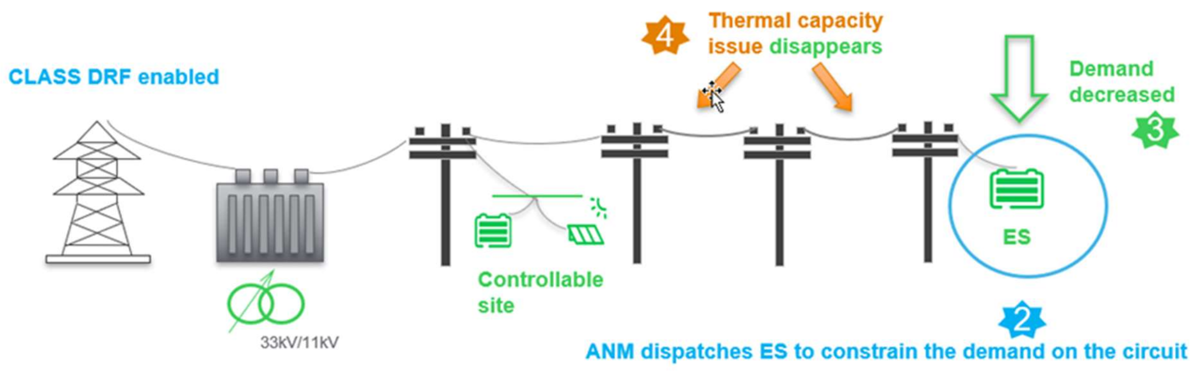

Figure 10.4 - CLASS DRF and ANM conflict: Thermal capacity issue disappears

ANM keeps the ES exporting additional power to reduce the power demand flow on the 11kV circuit until no longer required or the ES runs out of charge. Demand on the 11kV circuit is constrained by the ANM action.

During the 11kV demand constraining, CLASS DR gets activated. As a result of performing DR voltage reduction at the primary substation, the total demand on the 11kV circuit is additionally decreased.

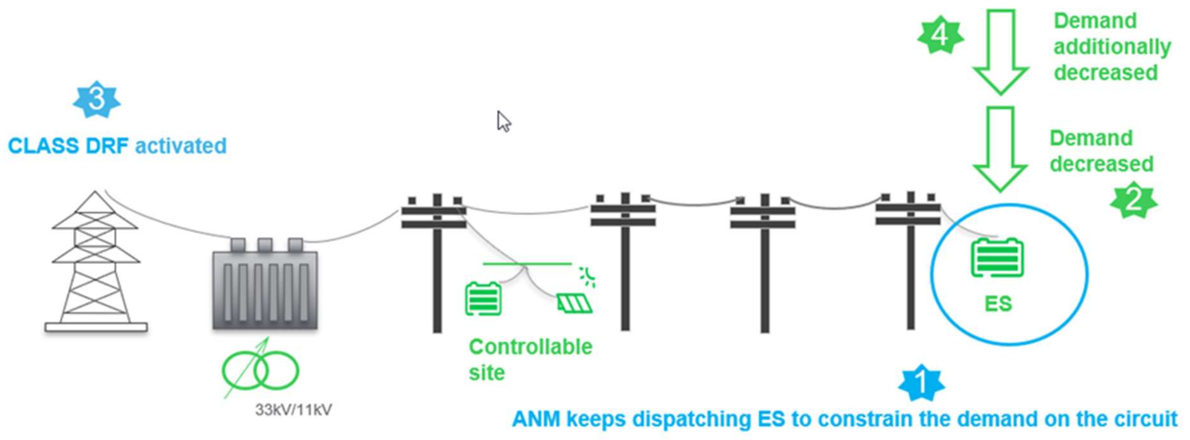

Figure 10.5 - CLASS DRF and ANM conflict: CLASS DRF gets activated

ANM detects that it is now safe to release ES from the discharging state since additional circuit demand capacity has been released as a consequence of the CLASS DR action.

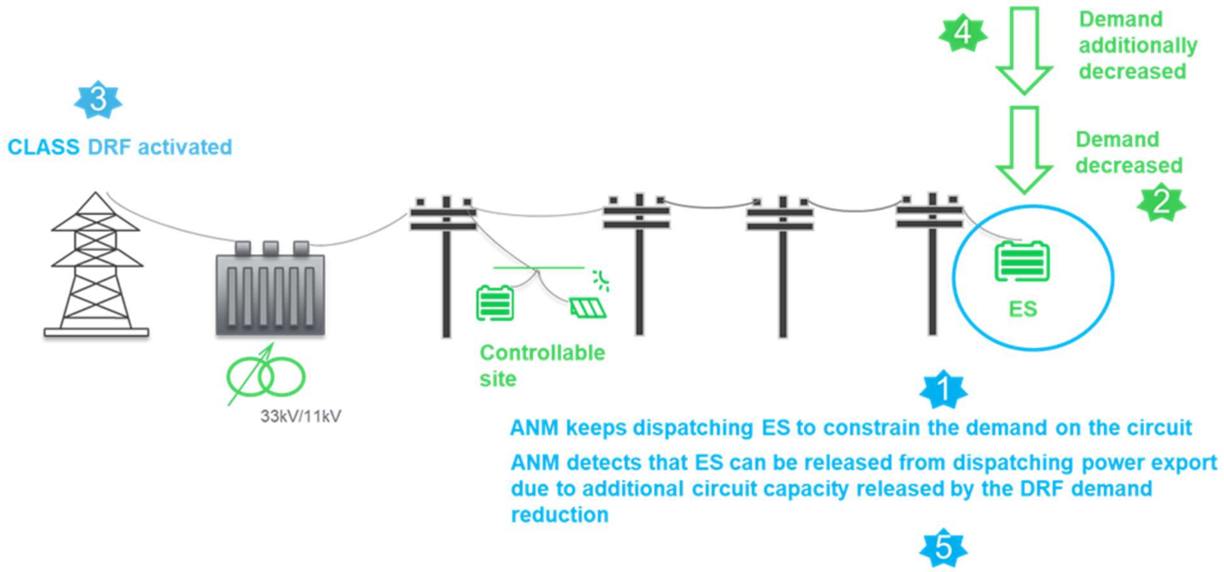

Figure 10.6 - CLASS DRF and ANM conflict: ES can be released from dispatching power export

ANM releases ES from being constrained, as is shown in the Figure 10.7.

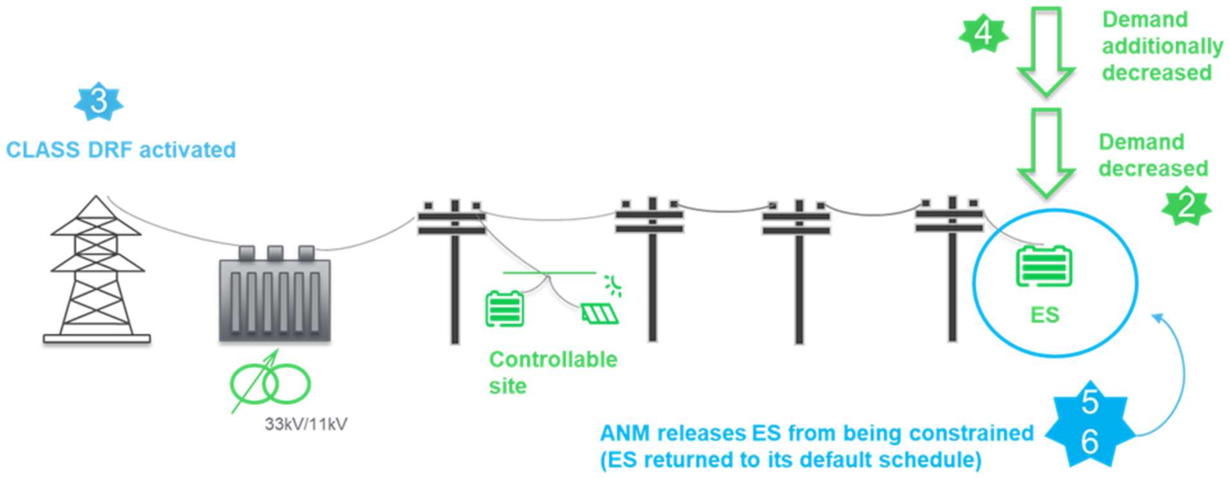

Figure 10.7 - CLASS DRF and ANM conflict: ANM releases ES from dispatching power export

Since ES is not exporting power to the network anymore, the total demand on the 11kV feeder increases.

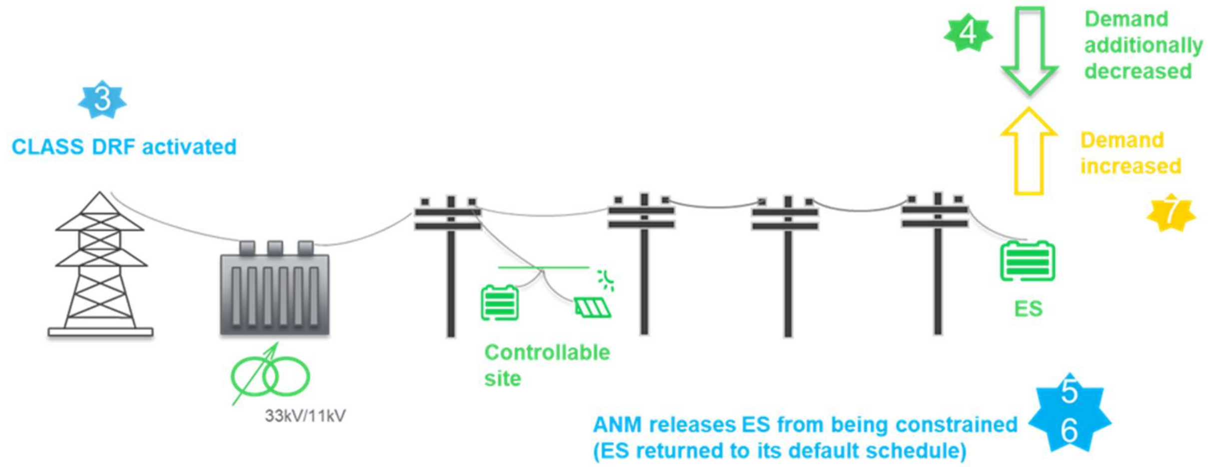

Figure 10.8 - CLASS DRF and ANM conflict: The total demand increases due to releasing ES

By increasing the total demand, ANM counteracts the CLASS demand reduction benefits, and this is not acceptable.

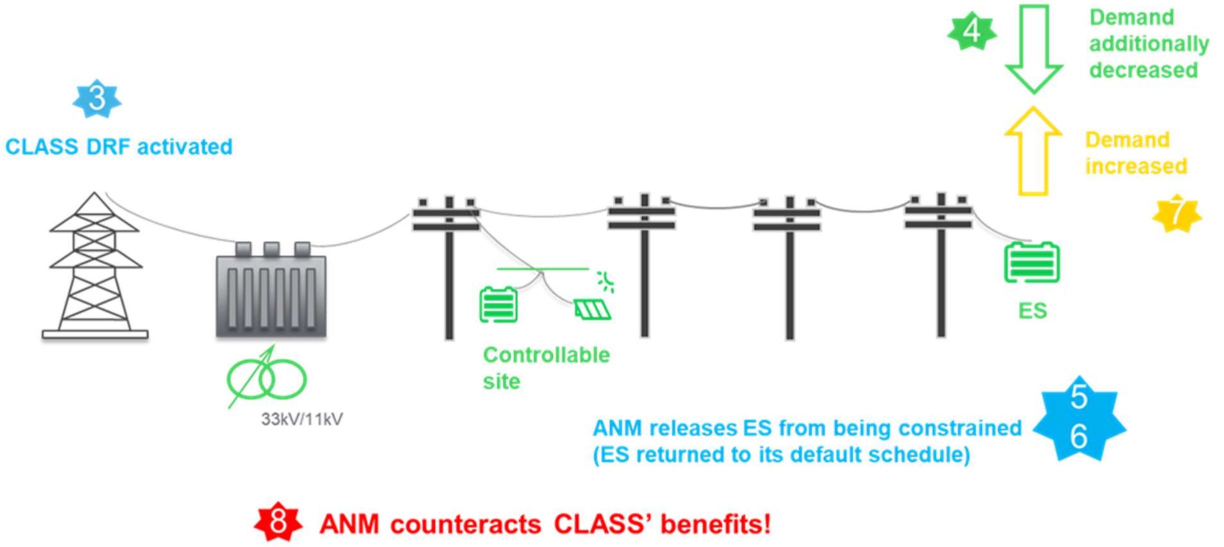

Figure 10.9 - CLASS DRF and ANM conflict: ANM counteracts CLASS' benefits

In order to prevent ANM and CLASS from counteracting each other, a QUEST intervention is expected.

Consider the moment prior to CLASS DR activation (Figure 10.4). ANM has dispatched ES power export in order to resolve the thermal capacity violation. As a result of dispatching ES power export onto the circuit, the total demand on the 11kV circuit and primary substation is decreased.

ANM keeps the ES exporting additional power to constrain the power demand flow on the 11kV circuit until no longer required or the ES runs out of charge. Demand on the 11kV circuit is constrained by the ANM action. During the 11kV demand constraining, CLASS DR is activated. As a result of performing DR voltage reduction at the primary substation, the total demand on the 11kV circuit is additionally decreased, as shown in the Figure 10.5.

Upon DR activation, QUEST prevents ANM from reducing the ES power export to prevent a reduction (due to demand increase if ES export is reduced) in the CLASS DR benefits.

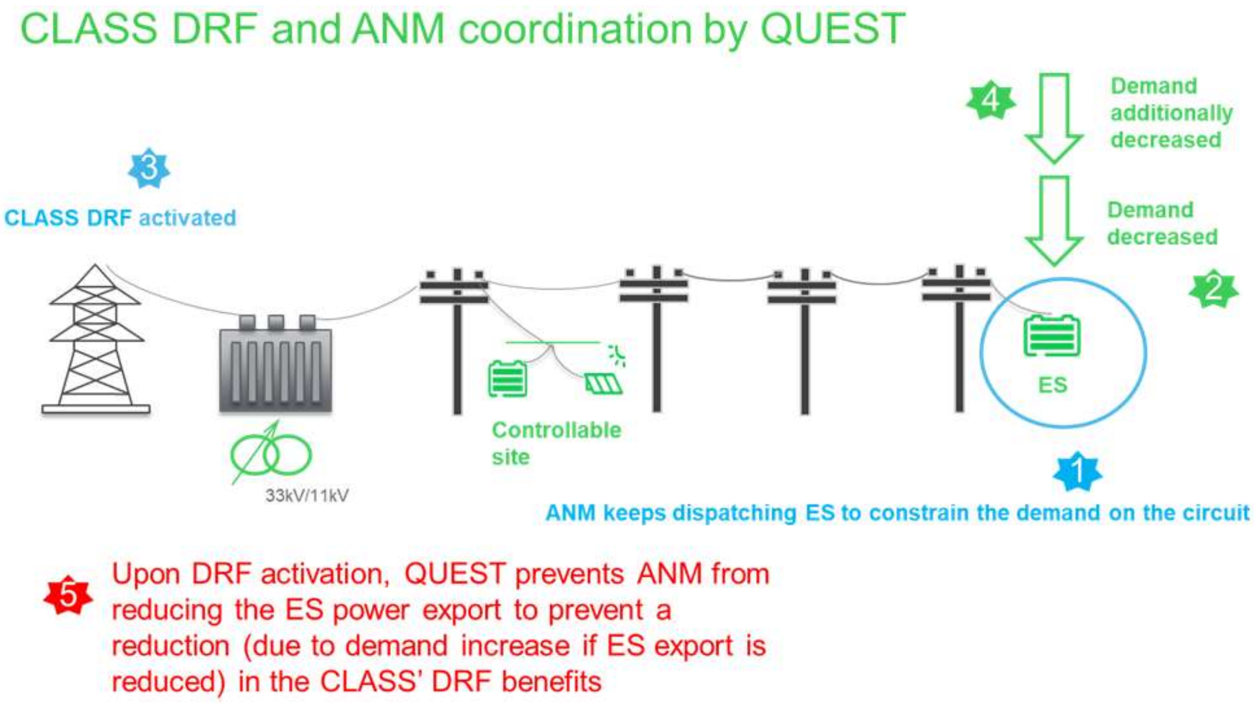

Figure 10.10 – CLASS DRF and ANM coordination by QUEST: QUEST prevents ANM from reducing the ES export

At some point, a reverse power flow violation appears due to additionally released capacity.

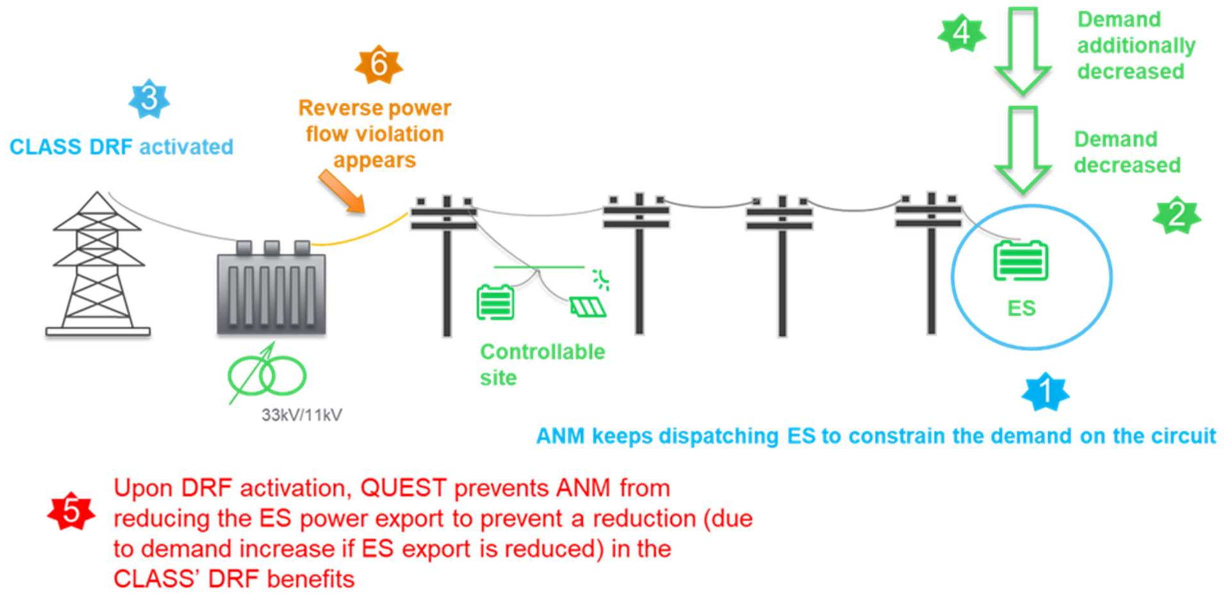

Figure 10.11 – CLASS DRF and ANM coordination by QUEST: A reverse power flow violation appears

QUEST allows ANM to react to the new violation in order to protect the network assets although the action will decrease the CLASS DR benefits. ANM dispatches Controllable Site (reduces ES power export) in order to curtail excessive generation due to decreased demand.

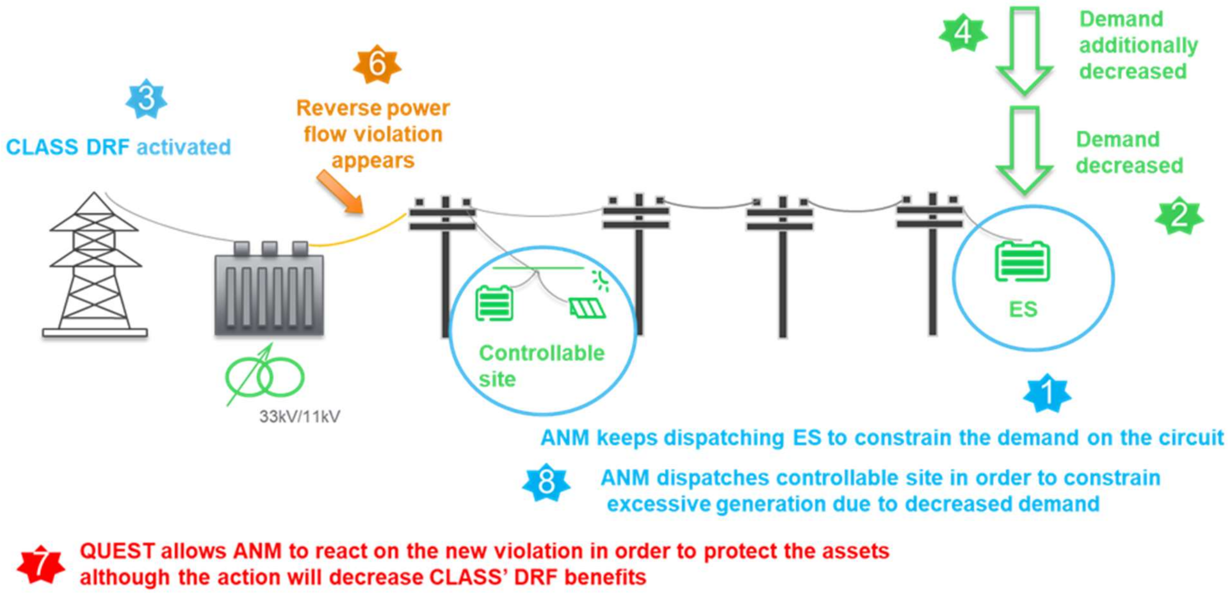

Figure 10.12 - CLASS DRF and ANM coordination by QUEST: ANM reacts to the reverse power flow violation

As a result of reducing the Controllable Site export, the reverse power flow disappears. The network asset is protected, but the total demand is increased which decreases CLASS DR benefits which is, in this situation, an acceptable conflict.

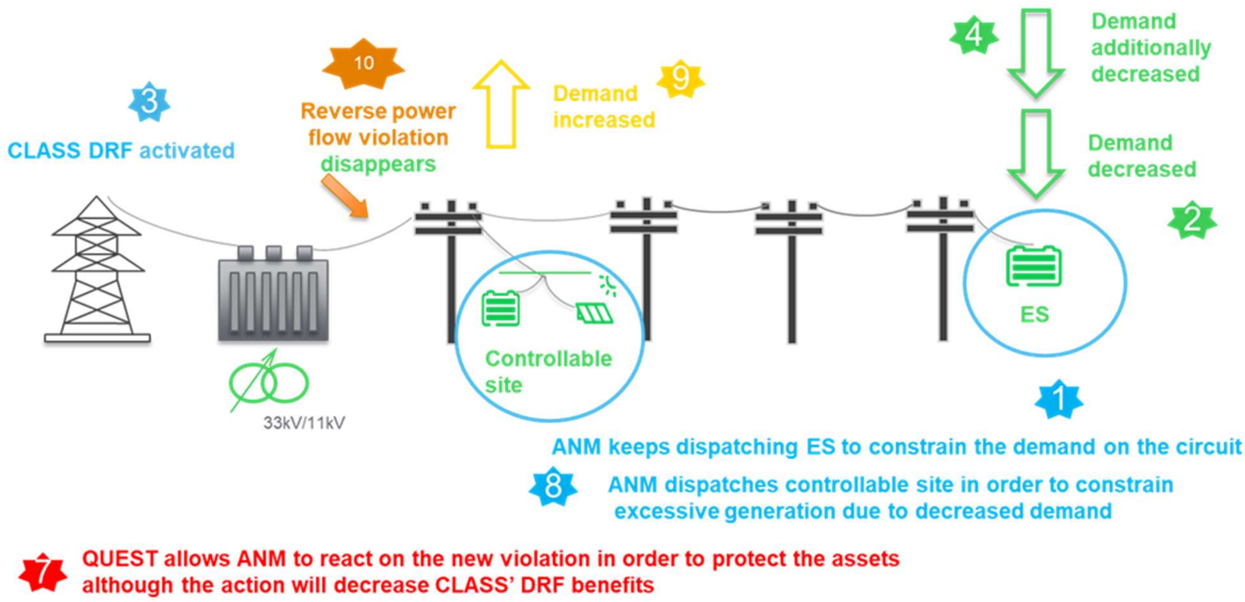

Figure 10.13 – CLASS DRF and ANM coordination by QUEST: The reverse power flow disappears

10.2. APPENDIX B - Interactions between CLASS DB and ANM

The following diagrams are intended to help illustrate the descriptions regarding interactions between CLASS DB and ANM provided in the Options to avoid or mitigate conflicts between CLASS and ANM.

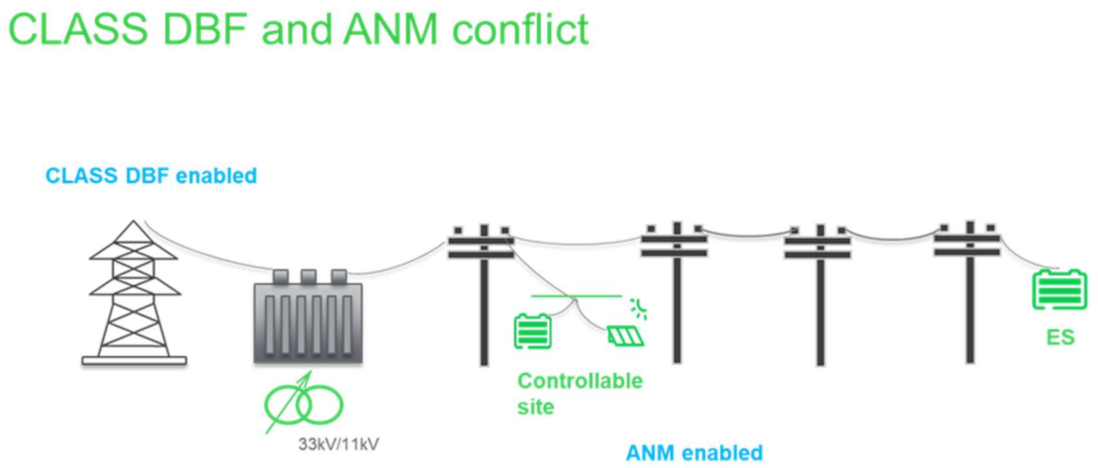

Figure 10.14 - CLASS DBF and ANM conflict: CLASS DBF and ANM are enabled on the same primary substation

In the example above, one primary substation is considered. Initially, CLASS DB is enabled on this primary substation. ANM is enabled on this part of the network and is monitoring the thermal constraint points. There are two DERs considered on this part of the network, one energy storage (ES) and one controllable site containing a rooftop solar and energy storage.

At one point on the 11kV circuit, a reverse power flow violation appears.

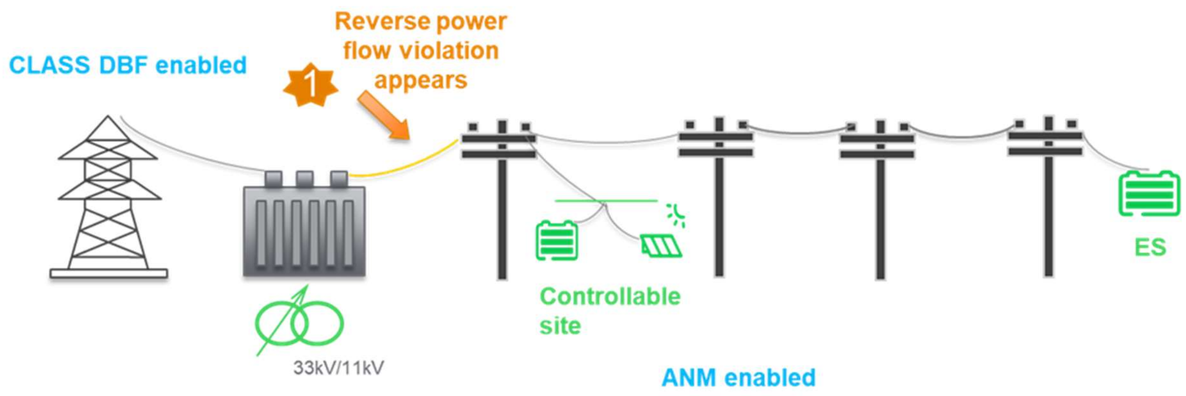

Figure 10.15 – CLASS DBF and ANM conflict: A reverse power flow violation appears

ANM dispatches the Controllable Site to constrain the excessive generation.

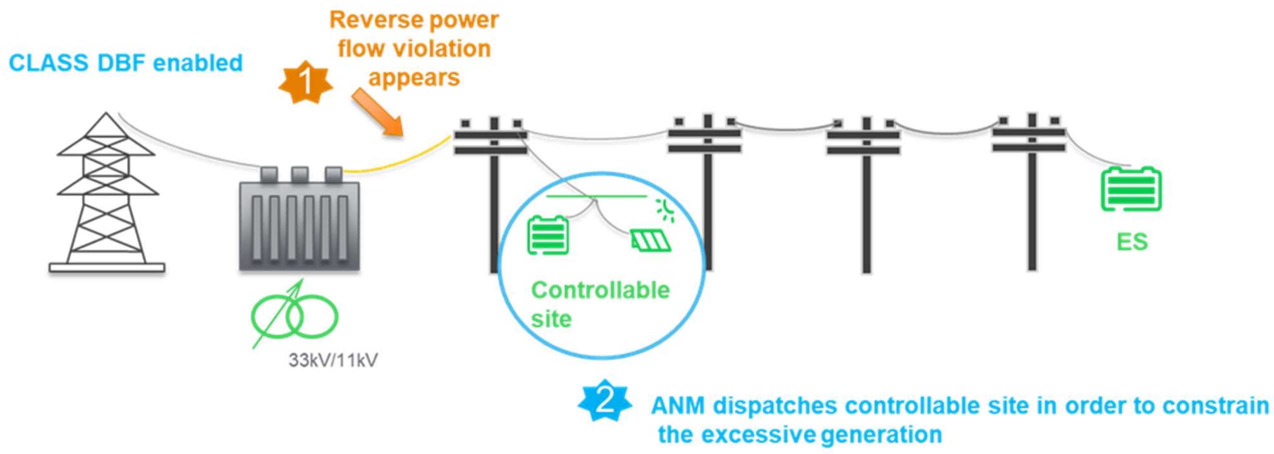

Figure 10.16 – CLASS DBF and ANM conflict: ANM dispatches Controllable Site

As a result of constraining the generation, the reverse power flow on the 11kV circuit and primary substation is reduced. The reverse power flow violation is removed, and the asset is protected.

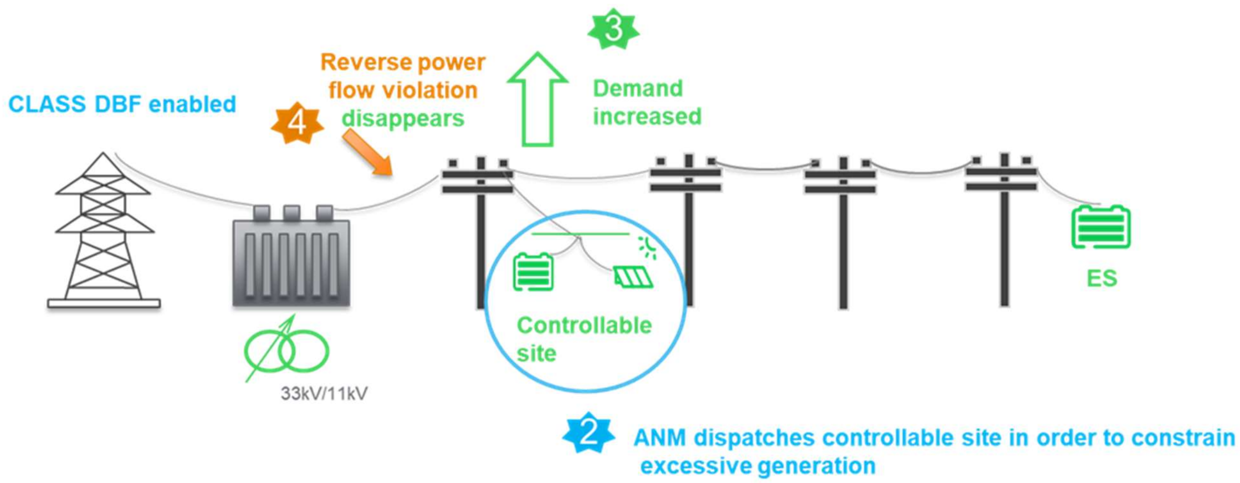

Figure 10.17 – CLASS DBF and ANM conflict: The reverse power flow violation disappears

ANM keeps the generation constrained, as it detects that it is not safe yet to release it from being constrained. Since generation is still constrained, the total demand on the 11kV circuit and primary substation is still increased. At one point CLASS DB gets activated. As a result of performing CLASS voltage boost at the primary substation, the total 11kV circuit demand is additionally increased.

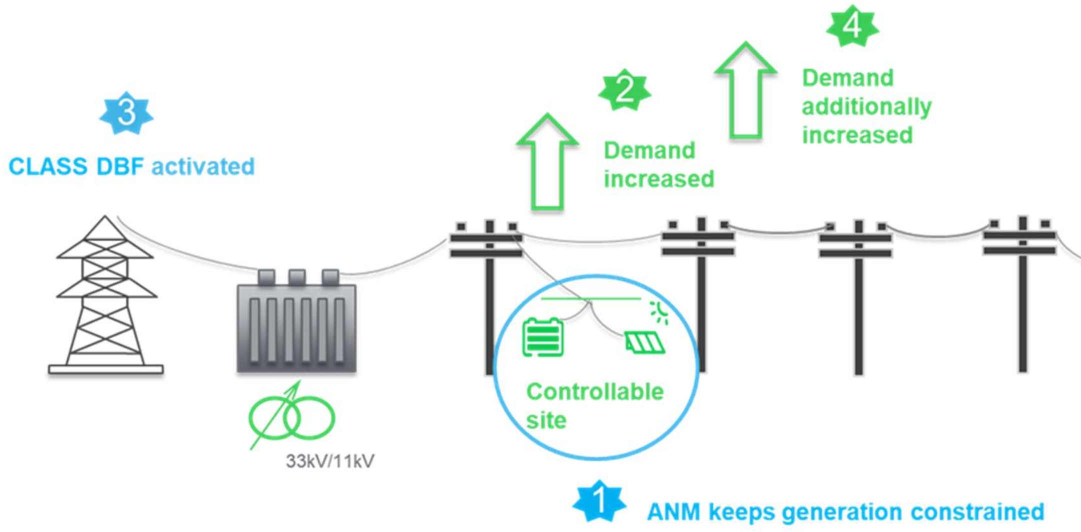

Figure 10.18 - CLASS DBF and ANM conflict: CLASS DBF gets activated

ANM detects that the curtailed generation can be released due to the additional DB demand boost.

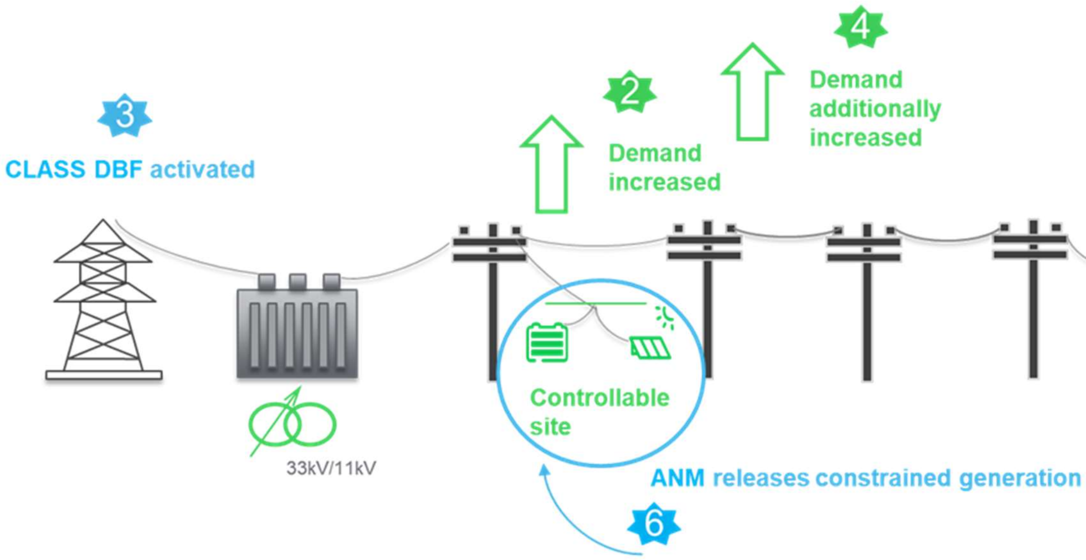

Figure 10.19 - CLASS DBF and ANM conflict: ANM releases the constrained generation

Since exporting power is increased when the Controlled Site power export is released, the total demand on the 11kV circuit and primary substation is decreased. By decreasing the total demand, ANM counteracts the CLASS demand boost benefits, and this is not acceptable.

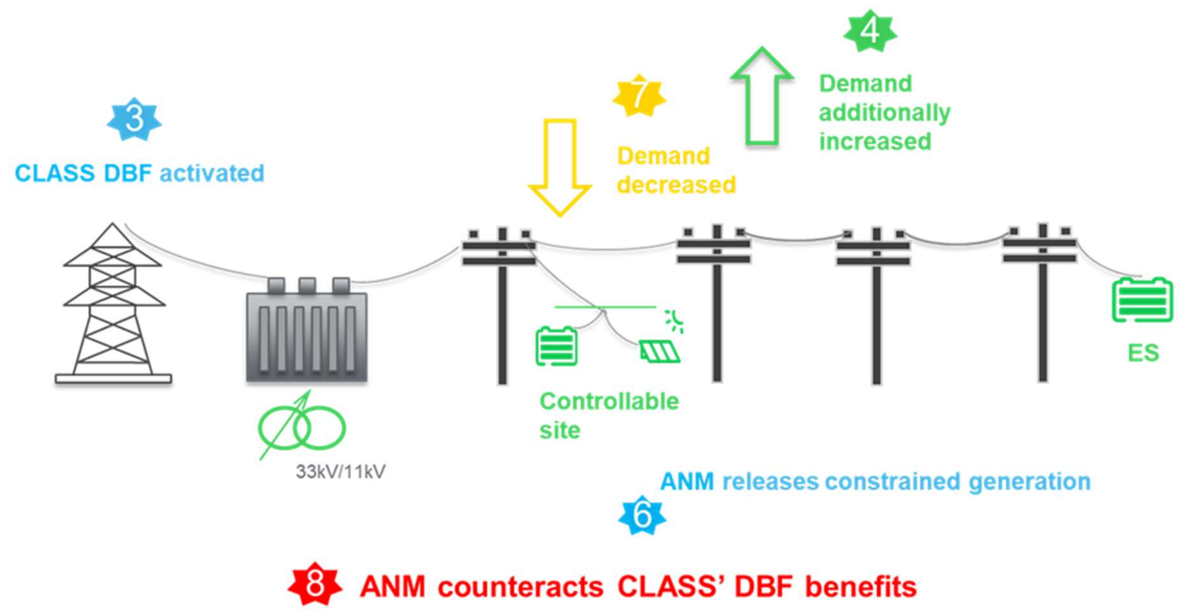

Figure 10.20 - CLASS DBF and ANM conflict: ANM counteracts CLASS' benefits

To prevent ANM and CLASS from counteracting each other, a QUEST intervention is expected.

Consider the moment prior to CLASS DB activation (Figure 10.17). ANM has curtailed the Controlled Site generation export to resolve the reverse power violation. As a result of constraining the generation, the total demand on the 11kV circuit and primary substation is increased. The Reverse power flow violation disappears, and the asset is protected.

ANM keeps the Control Site generation curtailed as it detects that it is not safe yet to release it from being curtailed. Since generation is still curtailed, the total demand on the 11kV circuit and primary substation is still increased. At one point CLASS DB is activated (Figure 10.18). As a result of performing CLASS voltage boost at the primary substation, the total 11kV circuit demand is additionally increased.

Upon CLASS DB activation, QUEST prevents ANM from releasing the curtailed generation in order not to counteract the CLASS DB benefit.

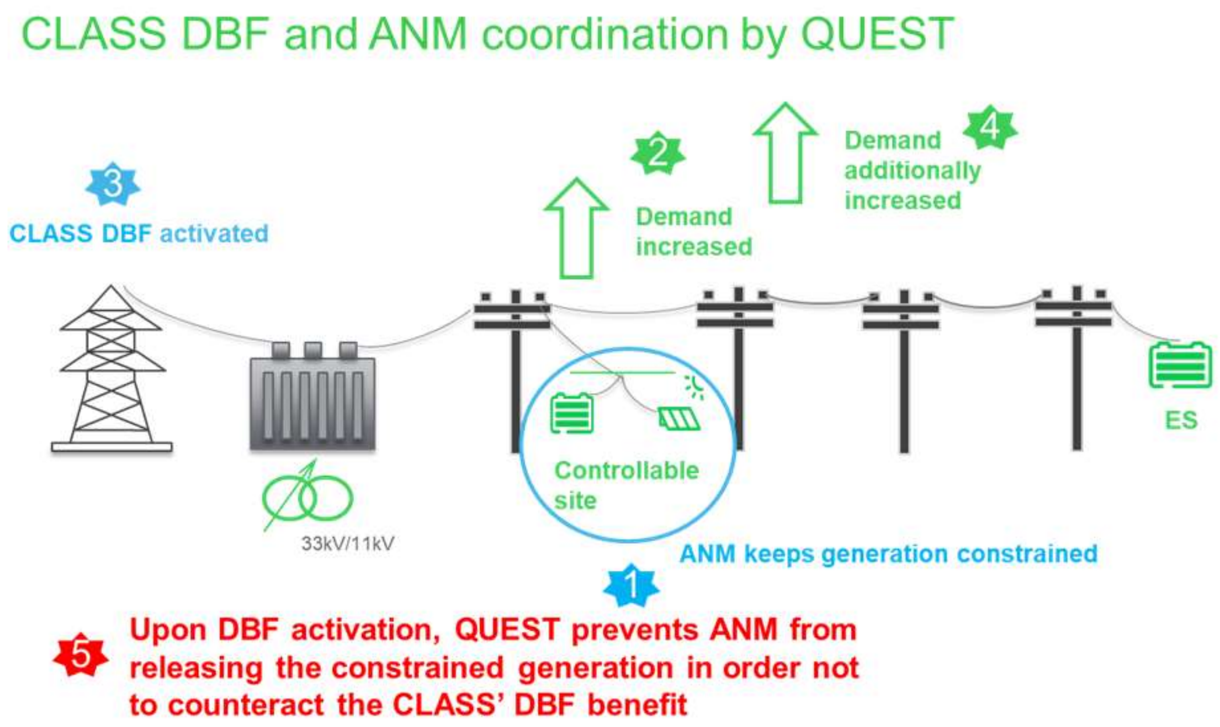

Figure 10.21 - CLASS DBF and ANM coordination by QUEST: QUEST prevents ANM from releasing the constrained generation

At some point a thermal capacity issue appears.

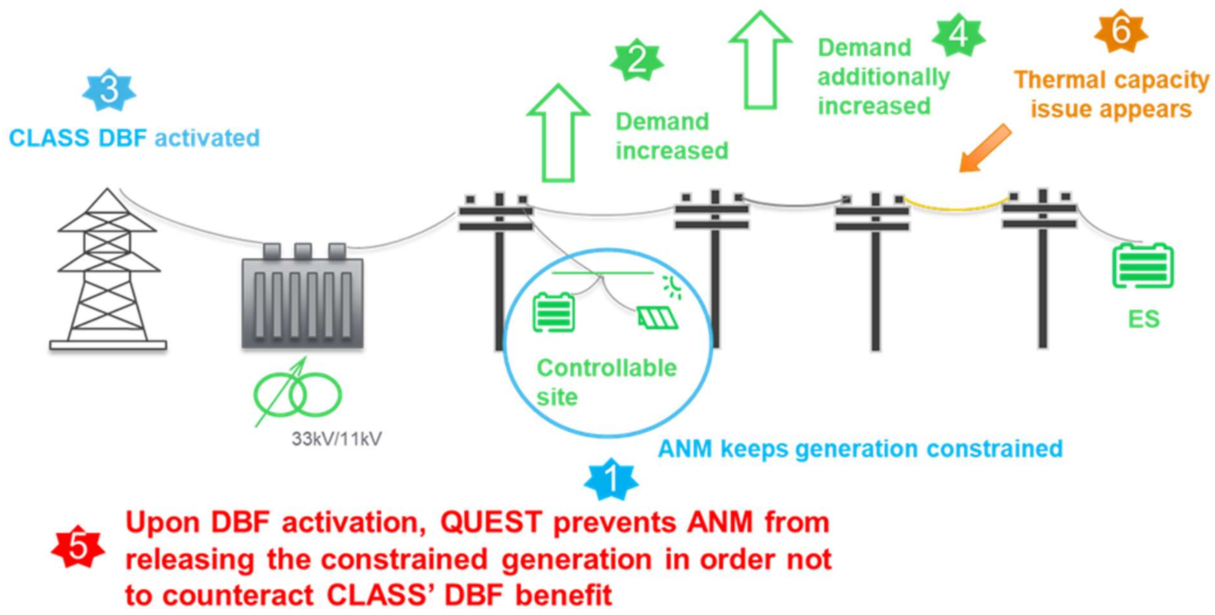

Figure 10.22 – CLASS DBF and ANM coordination by QUEST: A thermal capacity issue appears

QUEST allows ANM to react to the new violation to protect the assets although the action will decrease the CLASS DB benefits. ANM dispatches the ES to increase generation to support the increased demand that is causing the thermal capacity violation.

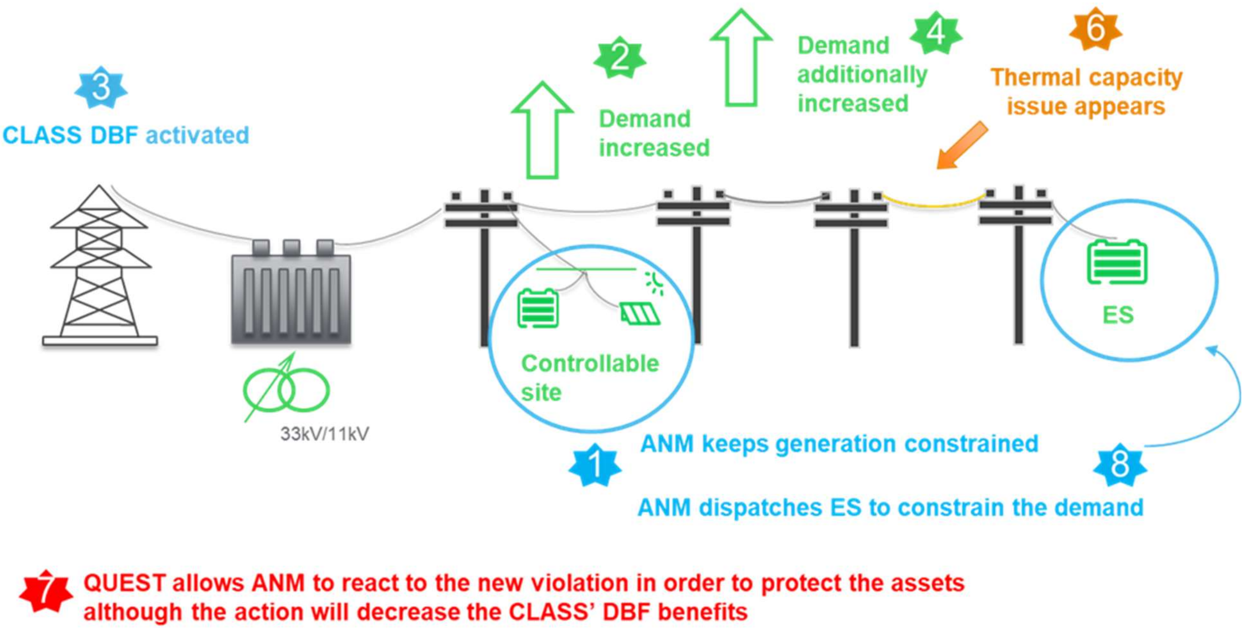

Figure 10.23 - CLASS DBF and ANM coordination by QUEST: ANM reacts to the thermal capacity issue

As a result of dispatching the ES power export, the thermal capacity issue disappears. The asset is protected, but total demand is decreased which decreases the CLASS DB benefits which is, in this situation, an acceptable conflict.

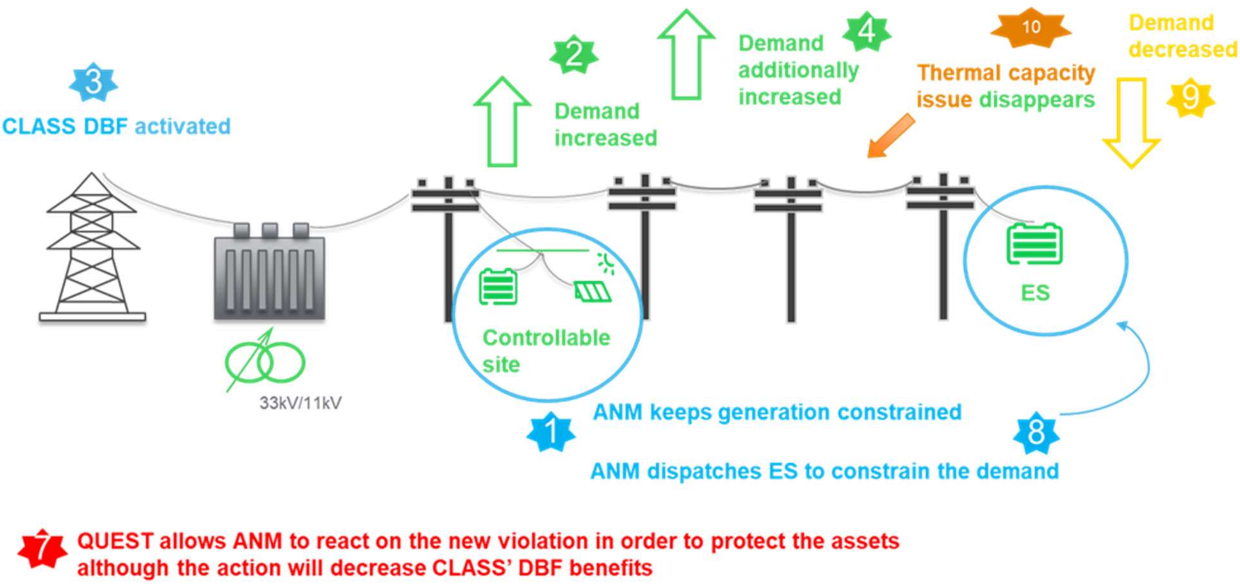

Figure 10.24 - CLASS DBF and ANM coordination by QUEST: The thermal capacity issue disappears

11. DEFINITIONS AND ABBREVIATIONS

Term	Definition
ADMS	Advanced Distribution Management System
ANM	Active Network Management
AVC	Automatic Voltage Control
BaU	Business as Usual – refers to business as usual deployment of QUEST following successful trials
BSP	Bulk Supply Point
CB	Circuit Breaker
CFOM	CLASS Forecast and Optimise Mode
CI	Customer Interruptions
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.
CLASS	Customer Load Active System Services
CML	Customer Minutes Lost
CT	Current Transformer
CVR	Conservation Voltage Reduction
DB	Demand Boost (CLASS Function)
DBF	Demand Boost Full (CLASS Function)
DBH	Demand Boost Half (CLASS Function)
DER	Distributed Energy Resource
DERMS	Distributed Energy Resources Management System
DG	Distributed Generation
DNO	Distribution Network Operator
DNP3	Digital Network Protocol 3
DR	Demand Reduction (CLASS Function)
DRF	Demand Reduction Full (CLASS Function)
DRH	Demand Reduction Half (CLASS Function)
EAVC	Enhanced Automatic Voltage Control
EMS	Energy Management System
ENWL	Electricity North West Ltd.
ESO	National Grid Electricity System Operator

FSP	Flexibility Service Providers
HV	High Voltage (refers to ENWL 6.6kV and 11kV operating voltages)
kV	Kilovolt
ICCP	Inter-Control Centre Communications Protocol
IEC	International Electrotechnical Commission standards
IED	Intelligent Electronic Device
IIS	Interruption Incentive Scheme – regulatory performance incentive scheme based on CI and CML
ISMS	Information Security Management System
LCT	Low Carbon Technologies
LL	Load limiting (CLASS Function)
LOM	Loss of Mains
MOL	Merit Order List
MOMS	Merit Order Management System
MW	Megawatt
NIST	National Institute of Standards and Technology
NMS	Network Management System
OC6	Operating Code NO.6 DEMAND CONTROL
OT	Operational Technology
PFR	Primary Frequency Response (CLASS Function)
RBAC	Role Based Access Control
RTS	Real Time Systems
RTU	Remote Terminal Unit
SCADA	Supervisory Control and Data Acquisition
SE	Schneider Electric
SFR	Secondary Frequency Response (CLASS Function)
SGS	Smarter Grid Solutions
SIEM	Security and Information Event Management
SWBD	Switch Board
TS	Tap Stagger (CLASS Function)
UI	User Interface
VT	Voltage Transformer