QUEST
An overarching control system

QUEST System Design and Architecture Lessons Learned

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Project Partners

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REVIEW

Name	Role	Date
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APPROVAL

Name	Role	Signature & date
Dan Randles	Head of Network Innovation	Daniel Randles Digitally signed by Daniel Randles Date: 2021.12.22 15:08:04 Z
Maurice Lynch	QUEST Programme Manager	Maurice Lynch Digitally signed by Maurice Lynch Date: 2021.12.22 14:47:38 Z

CONTENTS

EXECUTIVE SUMMARY

This report, "QUEST Design and Architecture Options Lessons Learned", is the second of nine key project deliverables for the QUEST NIC (Network Innovation Competition) project.

For the purposes of this report, "the project" refers to the Network Innovation Competition (NIC) funded project, "QUEST" refers to the overarching system, and the "optimisation software" refers to the software used to enable QUEST.

This report follows the first the project deliverables, "QUEST Initial Report – Use Cases", published in July 2021, which introduces the project and explores the range of use cases and scenarios identified, outlining possible challenges and solutions within the overarching control of the Smart Street, ANM and CLASS systems. This report builds upon the first deliverable to ensure that the design and architecture options will help to achieve the project goals.

The second project deliverable comprises two workstreams:

1. Architecture Options, and
2. Modelling Regime.

The Architecture Options workstream was led by Schneider Electric (SE) and the Modelling Regime workstream was led by Smarter Grid Solutions (SGS). Each partner was tasked with producing a detailed report as part of this deliverable. Section 2 of this report provides an overview of SE's two reports on architecture options, "QUEST Architecture Options Detailed Design Subphase 1 Report" and "QUEST Architecture Options Detailed Design Subphase 2 Report" and overview of SGS's report on the modelling regime, "Modelling Regime" – these reports are also published on our website.

The Architecture Options workstream comprised two phases. Phase one focuses on the further clarification of the initial use cases. The use cases are analysed (proved/disproved, updated or replaced etc) to firm up the design specification and to provide the necessary inputs for the second phase. Phase 2 of the Architecture Options workstream focuses on different architecture options for the optimisation software and makes a recommendation on which to use.

The Modelling Regime workstream conducted a desktop exercise to demonstrate the conflicts identified when operating multi voltage control systems and the potential solutions to overcome these conflicts. This modelling regime report encapsulates.

- The existing and potential network control methods applied to ENWL's network
- how these control methods are applied to a simulated ENWL network,
- and how these control methods are controlled and co-ordinated by the optimisation software.

The modelling regime report supports the development of architecture options. It was important to demonstrate through power system modelling that the architecture options were achievable and valid to develop the QUEST voltage optimisation system

Workshops were held virtually from July 2021 to December 2021. The main challenge for this deliverable was carrying out this work virtually whilst also ensuring the architecture options and modelling regime workstreams were aligned, with no contradictions or misalignments between the reports. To ensure both workstreams were aligned and covered the project objectives, another project partner - Fundamentals Ltd - reviewed each workstream report.

The learning output for this deliverable provided an in-depth review of the architecture options based on the use cases, in addition to a specification for the network models and modelling regime that aligns with the architecture options. This deliverable will support selection of a functional architecture and voltage control methodology specification while also outlining the trial design, which is the next project deliverable, due on 30 June 2022.

1 INTRODUCTION

1.1 Purpose of this report

The purpose of this report is to provide a summary of two workstream reports of the second QUEST project deliverable: System Design and Architecture Options Lessons Learned. This deliverable comprises two main streams of work: Architecture Options and Modelling Regime. These were carried out in parallel to fulfil the programme requirements for this deliverable. This report outlines how these were carried out and what learning outcomes were achieved. The report also provides insight into the challenges encountered and how these were overcome to ensure requirements were completed on time and to the required standard. Finally, the report provides overview of the main conclusions/learning outputs within each workstream and how details how this will feed into next project deliverable [name of the deliverable here] due to commence in January 2022 and complete in June 2022.

1.2 Project update

The project is currently on track to meet its aims, objectives, and all deliverables (outlined within the full submission), as per the project plan. One of the main challenges within the early stages of the project were the strict travel restrictions due to the pandemic, which meant all meetings and project discussions were held virtually until October 2021. Despite this challenge, the project was still able to deliver all planned key project milestones.

The first project deliverable, "QUEST Initial report - Use Cases", was successfully submitted to Ofgem on 31 July 2021 and published on Electricity North West's (ENWL's) QUEST project website. The project subsequently moved on to focus on the second deliverable, "QUEST System Design and Architecture Lessons Learned", the objective of which is to review the architecture options and provide a specification for the network models and modelling regime. This deliverable is on track and due for submission to Ofgem on 31 December 2021, in line with the project plan. In addition to this work, two Industry Steering Group (ISG) events have been held, in July and November 2021, to provide dissemination of the project learning to date to key industry stakeholders. The first annual Project Process Report was submitted to Ofgem in December 2021 and publishes on the project website.

In addition, site surveys within the BSPs (Bulk Supply Points), primaries and distribution substations for the installations of the AVCs (Automatic Voltage Control) and upgraded OLTCs (On-Load Tap Changers) have been completed for the QUEST trials and tests. Procurement of the OLTCs and AVCs is underway, and this kit is due for delivery in February 2022.

1.3 Purpose of the System Design and Architecture Lessons Learned deliverable

The purpose of the System Design and Architecture Lessons Learned deliverable is to expand and provide any additional technical clarifications for the development of the architecture options and voltage control mythologies

The use cases identified within the first deliverable, outlined below:

1. QUEST Network Efficiency
2. Smart Street and Enhanced AVC including CLASS
3. Smart Street and ANM (Flexible service and connections)
4. Enhanced AVC including CLASS and ANM (Flexible service and connections).
5. Smart Street, Enhanced AVC including CLASS and ANM (Flexible service and connections).

NG ESO responses

6. Smart Street, Enhanced AVC including CLASS, ANM and LFDD
7. Smart Street, Enhanced AVC including CLASS, ANM and OC6
8. Smart Street, Enhanced AVC including CLASS, ANM and Deliver Reactive Response

The above use cases are the scenarios and challenges identified within the first project deliverable. They outline possible clashes between the existing voltage management systems operating under the QUEST system (Smart Street, ANM and Enhanced AVC including CLASS), and also detail possible solutions to overcome these scenarios on a purely theoretical basis. As part of the second deliverable, these use cases were further analysed and the Enterprise Architect software was used to design and create different architecture options that could cater for the outlined use cases. This software creates a framework for each type of architecture that allows software programmers to write code for the associated architecture options. It also allows for any modified changes within the architecture to filter down through the architecture application as whole and ensures that the same functionality is achieved.

In conjunction with the Enterprise Architect software analysis, the use cases were also investigated and modelled using IPSA (Interactive Power System Analysis), to identify the benefits, such as resolution of conflicts between the network control methods, and limitations, such as compromises to the benefits on network control methods as a result of co-ordination, of the optimisation software.

The research and analysis outlined in the above is critical to be able to move on to the next project deliverable, “QUEST Trials, Design and Specification”, where the project team will pick a functional architecture and control methodology to move forward with for the overarching control development application.

1.4 System Design and Architecture Lessons Learned development process

In order to achieve the required outputs of this deliverable to feed into the next stage of the project, a development process was created to allow for the individual workstreams to achieve their individual goal within this deliverable but also to ensure that they stayed in line with the project objectives and governance.

As stated in the Executive Summary of this report, there are two individual workstreams within this deliverable:

1. QUEST Architecture Options
2. QUEST Modelling Regime

For the Architecture Options workstream, the architecture options working group was structured as seen in Figure 1.4.1.

Figure 1.4.1: QUEST Architecture Options workstream structure

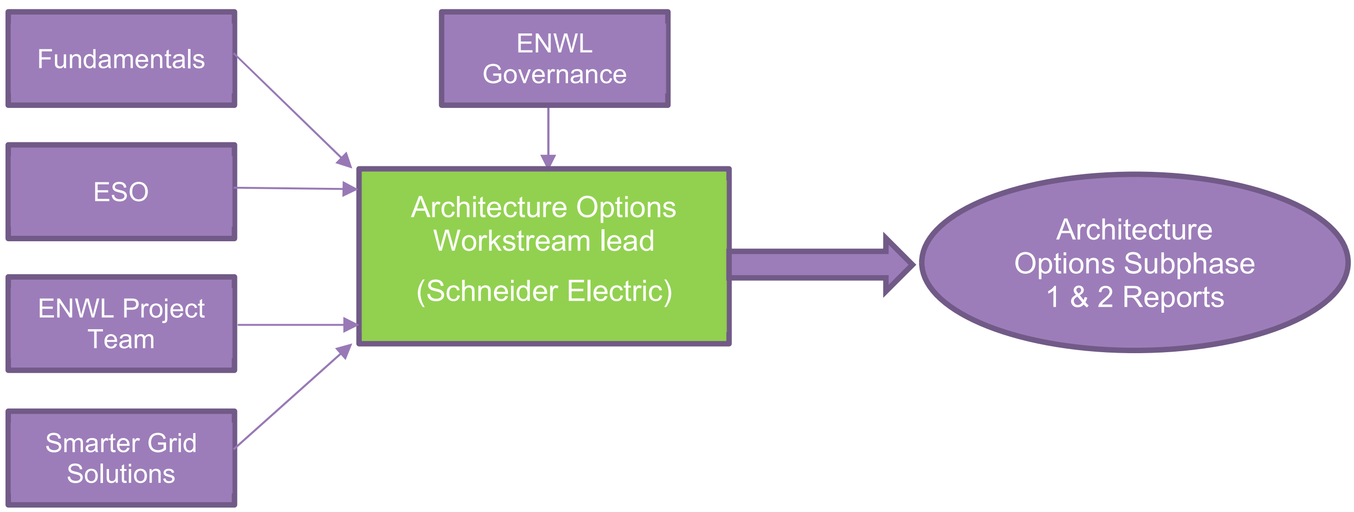
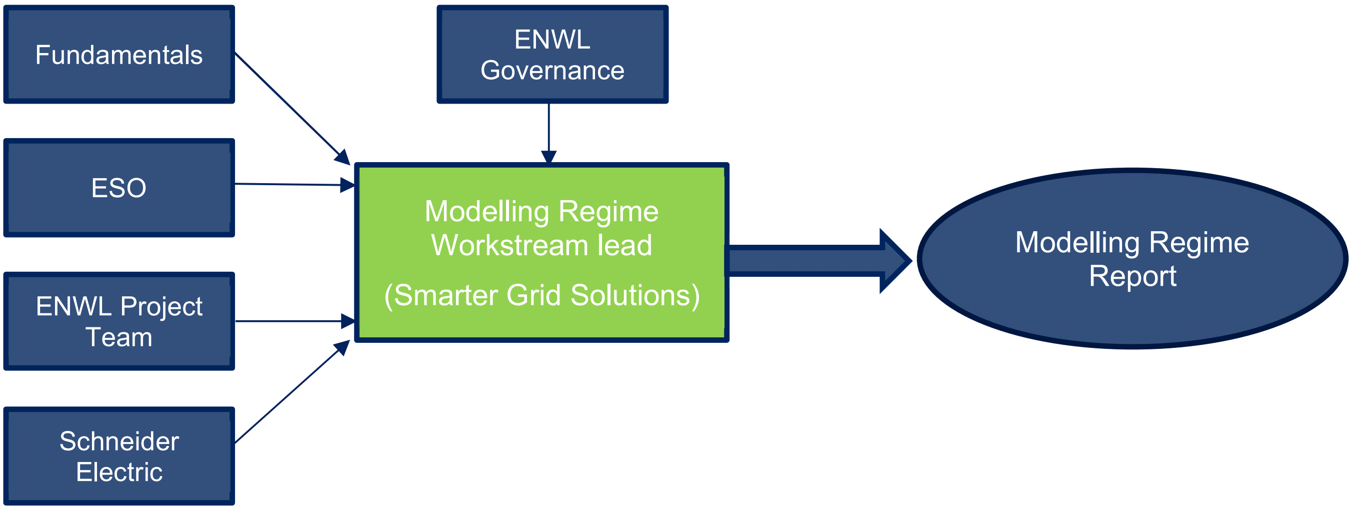


Figure 1.4.1 shows the structure of the architecture options workstream. Schneider Electric led in the development of these reports as they are responsible for software development hence were best placed to lead on this work. Other partners were heavily involved in the input to these reports, with the ENWL team providing governance to ensure the output of the research and drafted reports meets the objectives of the project. The meeting schedule of this workstream commenced in early August 2021, with two weekly meetings held each week until early November 2021, at which point Schneider Electric began drafting of the Subphase 1 & 2 reports. Both reports were reviewed by ENWL and Fundamentals Ltd and approved at the end of November 2021.

The Modelling Regime workstream was structured similarly, where Smarter Grid Solutions led on this phase of work due to their experience and knowledge around technical research modelling with other organizations' ANM systems. Figure 1.4.2 shows how the Modelling Regime workstream was structured.

Figure 1.4.2: QUEST Modelling Regime workstream structure



The meeting schedule of the Modelling Regime workstream was similar to the Architecture Options workstream, but less frequent. This work commenced in early August 2021 where one weekly meeting was held each week until late October 2021, when the SGS team then begin drafting the Modelling Regime report. This report was reviewed and approved by other project partners in early November 2021.

2 DELIVERABLE WORKSTREAM REPORTS

This section of the report provides insight into each of the workstream report output, as the Architecture Options and Modelling Regimes reports are very detailed. The aim of this section of the report is to provide high a level overview of each report without the reader needing to read each report in full.

2.1 QUEST Architecture Options Subphase 1 Report Overview

The Architecture Options Subphase 1 report focuses on the first deliverable QUEST Initial Report "Use Case" which have been analysed and revised in more detail. Through discussions and design workshops at the beginning of this deliverable, 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.

2.2 QUEST Architecture Options Subphase 1 Report Main Outputs

During this detailed design subphase 1 work, 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 subphase 1 report. The subphase 1 document contains the latest updated version of the Use Cases and Use Case Matrixes that were 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. This analysis has shown that although for most scenarios QUEST's expected behaviour has been determined, there were still some questions left open that needed additional internal discussion within the project team. These questions were further analysed within subphase 2 with the adequate response provided.

In section 5.1 (CLASS Forecast and Optimise Mode (CFOM)) of the Architecture Options Subphase 1 report. During the use cases definition phase, it was concluded that "CLASS forecast and optimise mode" should be categorised as one of the following macro options;

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 states 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.

After careful review of the above options with the project team it has agreed that a hybrid macro approach (No. 3 above) was the approach to take 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.

2.3 QUEST Architecture Options Subphase 2 Report Overview

The QUEST architecture options subphase 2 report provides a review of QUEST's detailed design which focuses on different architecture options for QUEST's overarching software. QUEST architecture options subphase 1 report considered three QUEST macro level architecture options that could be used to resolve the detected conflicts found in the Use Cases. As already stated, option 3, the "hybrid approach", was chosen as the one to take forward into the subphase 2 of the detailed design. Several architecture options, which in different ways satisfy the criteria of macro-option 3, were explored within this subphase 2 detailed design report.

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

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

During this second subphase, all the above stated topics were discussed in further detail. The QUEST architecture options provided within subphase 2 document have been based on the information gathered during these discussions.

2.4 QUEST Overarching Software Architecture Options

The main architecture diagram, displaying all the components of the QUEST Overarching control system, is shown in Figure 2.4.1

Figure 2.4.1: QUEST Main Architecture Diagram

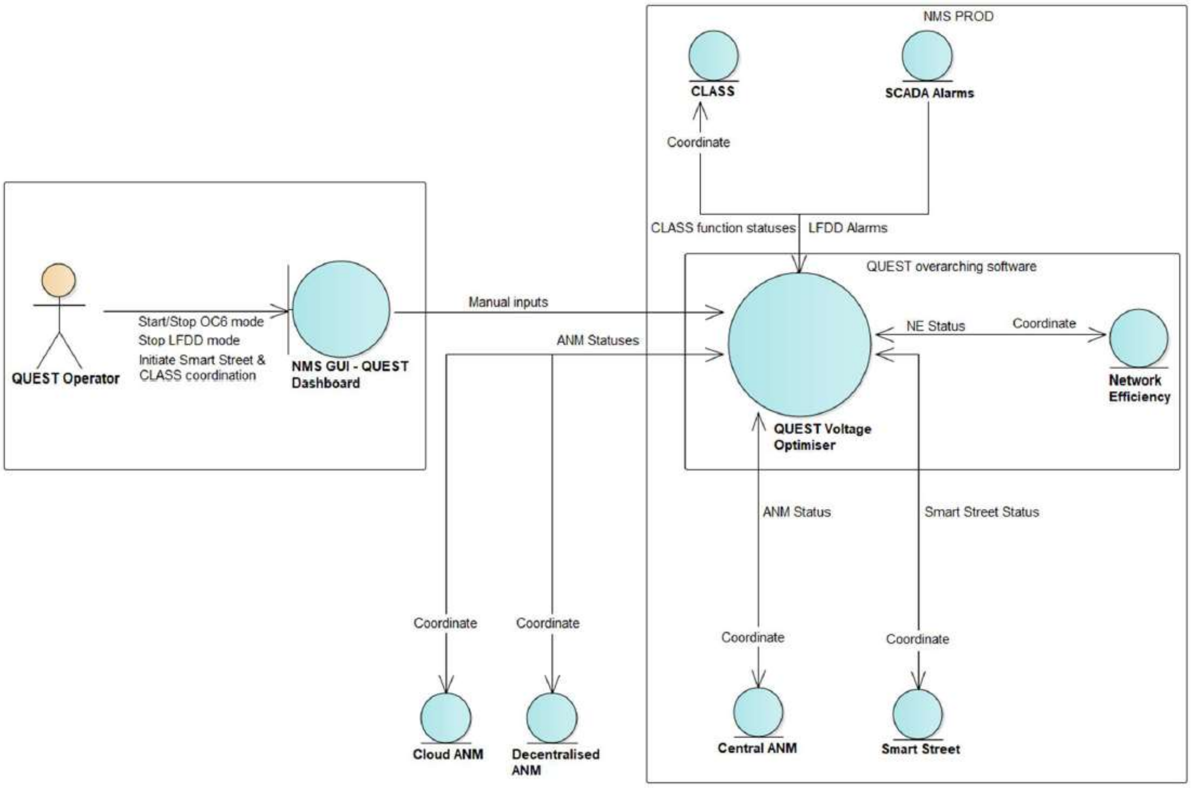


Figure 2.4.1, showcases the ENWL's NMS production system on the righthand side with the QUEST overarching software in the centre. Since it is located within the NMS system, QUEST is aware of the statuses of all the other existing systems in the NMS system (Enhanced AVC including CLASS, Smart Street and Central ANM). QUEST is also aware of all the information coming from DNO's SCADA system, such as SCADA alarms, BSP, Primary substation and Smart Street distribution substation transformer tap positions, as well as monitored and calculated voltage values across the whole DNO network.

QUEST is also integrated with the external ANM systems: Decentralised ANM and Cloud ANM, and is aware of their statuses. Having visibility of all the existing systems in the QUEST trial area, as well as the voltages across the whole DNO network, QUEST is able to provide the distribution network full coordination to manage voltage profiles with an appropriate balance between centralised and decentralised control hierarchy. In addition to coordinating operations of the existing systems in the network, the QUEST Voltage Optimiser tries to increase the network efficiency whenever possible, by increasing the voltages on the 33kV parts of the distribution network.

2.5 QUEST Architecture Options Subphase 2 Report Main Outputs

As already iterated the purpose of this subphase 2 report was to provide different architecture options for the QUEST overarching software that should be further explored during the next phases of the QUEST project. Macro-level architecture option “hybrid approach” (macro-option 3) had been chosen as the preferred solution during the first subphase of the detailed design. It was further explored during this phase of the detailed design. Several architecture options, which in different ways satisfy the criteria of macro-option 3 were suggested (e.g., for NEM (Network Efficiency Mode), instead of going with the worst-case scenarios, where NEM would be simply switched on or off upon CLASS DR enablement or deactivation, several levels of the NEM were introduced in order to bring additional flexibility to the QUEST “hybrid approach” architecture option).
During the definition of the QUEST architecture options, review of the QUEST functionality against the QUEST objectives was performed to make sure that QUEST’s objectives are being met with the proposed architecture options. This review has confirmed that the QUEST objectives are being met.

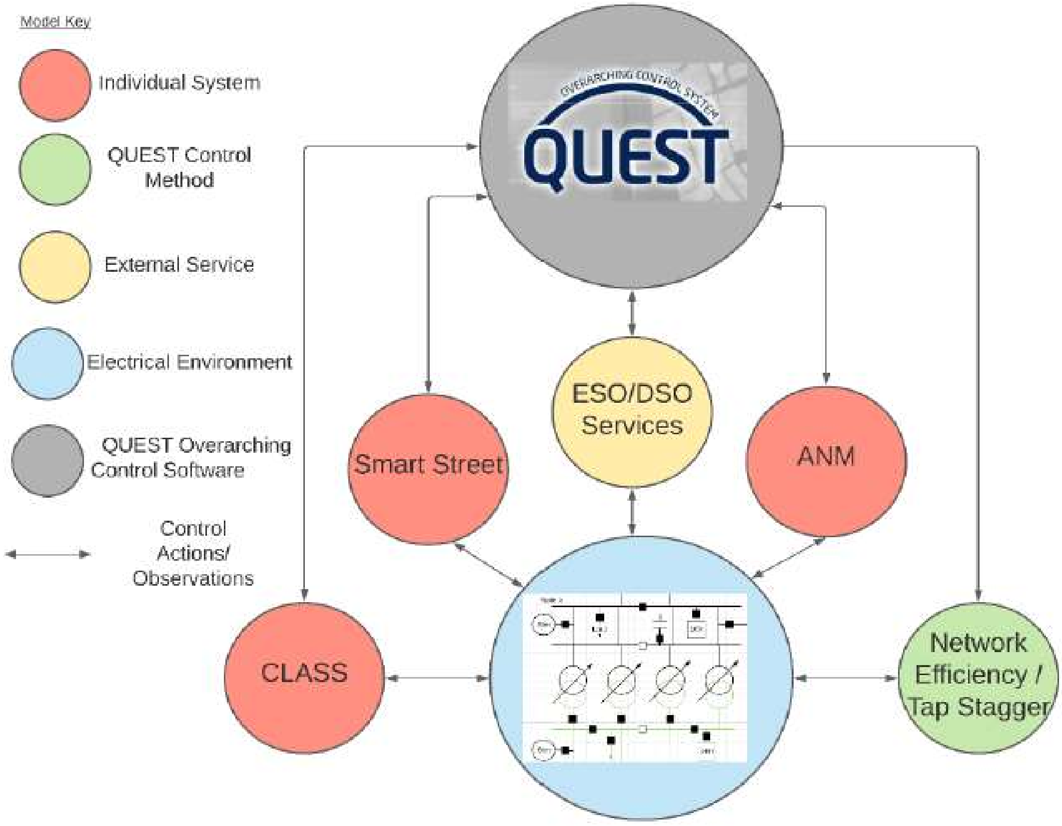
2.6 QUEST Modelling Regime Report Overview

The QUEST Modelling regime document is split into two parts that details how the modelling regime above can be achieved:

Determining Network Model Adequacy

The electrical network simulation is implemented via an IPSA+ network model. The model has been analysed to determine whether it can achieve the controls and accurate observations required to meet each individual system’s control method objectives. The high-level structure of the modelling regime is presented in Figure 2.6.1

Figure 2.6.1: High-level Structure of the modelling Regime



Test Bench Process

A test bench process has been created to deliver the modelling regime realised in python9, where.

A: A Python method has been created to execute time-series scenario analysis to the simulated electrical network, allowing for operational behaviour from typical load and generation profiles to be applied.

B: Python based representations of Schneider Electric's and SGS's operational systems and the algorithms of each individual system's control method, as well as QUEST control methods and ESO/DNO services have been created and can be applied to the IPSA+ simulation of the electrical network.

C: The time-series scenario analysis is extended to enable blends of all control methods to be applied in parallel to identify conflict and examine effects on the network key performance indicators.

D: Finally, the proposed QUEST software architecture is created as a python representation. Applying an overarching control method to coordinate conflicts between individual system control method and control methods applied as part of QUEST. This will allow algorithm optimisation and validation of the QUEST overarching control method. Furthermore, it will enable examination of the network key performance indicator impacts, as a result of the coordination method.

The achievement of both these parts detailed within the modelling regime document demonstrates a successful modelling regime for supporting development of the QUEST architecture design as well as providing evidence to satisfy the QUEST project objectives.

2.7 QUEST Modelling Regime Main Outputs

The objective of the QUEST software can be summarised as: control and coordinate conflicts across multiple system objectives operating upon the ENWL network and provide voltage optimisation where possible.

This can be broken down into three core objectives:

1. Coordinate operation of system voltage control and optimisation systems.
2. Identify and avoid potential conflicts between multiple systems, ensuring appropriate configuration of key voltage control and optimisation systems at all times.
3. Enhance operational efficiency.

In order to achieve these core objectives, the QUEST software architecture must be created and applied operationally to the live electrical network. However, before this can be achieved, there must be a way to model QUEST's software operation on the distribution network, to determine if it can achieve its core objectives. The QUEST modelling regime was created for this project purpose and is realised as a test bench process which will enable satisfaction of these objectives to be tested in a safe simulated environment.

Within the modelling regime document, a steady state electrical network simulation has been created that encapsulates the general load and DER behaviour applied, as well as the:

- Control requirements
- Observation requirements, and
- Accuracy requirements

of all the control methods that are currently operating on the ENWL network and potential control method to be applied, all of which will be coordinated by QUEST. To test each control method, or new control methods included as part of QUEST, a python representation of the

QUEST architecture was created within the modelling regime report as a representation of each control method.

Finally, a time-series scenario analysis method was created to test a blend of each individual system's control methods applied to the electrical network simulation. This has provided the ability to test the QUEST software coordination of actions between control methods for each time step and across a time series. This functionality allows for resolving conflict between the individual system control method objectives, and balancing those resolution affects against key performance indicators, providing the ability for both control methods and QUEST's algorithms to be validated and optimised.

In the next QUEST deliverable (Trials, Design and Specification), scenario analysis will be developed to test the QUEST architecture options developed by Schneider Electric to provide validation and optimisation. Further Scenarios will also be investigated to show the long-term operational effects of QUEST on key performance indicators by analysing typical network scenarios across a year, for both existing energy scenarios and future energy scenarios. This analysis will add further evidence of QUEST's satisfaction of its core objectives.

3 NEXT DELIVERABLE (QUEST TRIALS, DESIGN AND SPECIFICATION)

The next deliverable within this project is the "QUEST Trials, Design and Specification Report" which will run from the 31 December 2021 till 30 June 2022. This deliverable will build on the success and learnings achieved in the last two deliverables to provide;

- Functional specification for chosen architecture
- Functional specification for voltage control methodology
- Trial design
- Detailed site design

The workstreams within this deliverable will be continued into the next deliverable. For example Schneider Electric will lead on the Functional specification of the chosen architecture as continuation of their work carried out in the QUEST architecture options. Smarter grid Solutions will lead on the specification for voltage control methodology as continuation of their work carried QUEST Modelling Regime.

The detailed site design will be led by Fundamentals Limited due to their AVC and feeder measurement installation expertise. The ENWL design and delivery team will take charge of the OLTCs design and installation within the trial area distribution substations. The final output being the trial design will be created by all project partners and ENWL based on the learning of all other workstreams to deliver this as a combined effort.

ENWL will provide governance on all workstreams to ensure they are processing as per the project time frame and to ensure the workstreams adheres to the overall project objectives.

4 CONCLUSIONS

- The work carried out within the QUEST Architecture Options Subphase 1&2 and Modelling Regime reports meets the requirements of this deliverable “QUEST System Design and Architecture Lessons Learned”. It conducts a thorough review of the QUEST Architecture options based on the use cases developed in the first deliverable and conducts in-depth analysis of the network model to provide understanding of challenges and theories identified within the use cases. The analysis and research conducted will allow for the functional specification of the architecture and voltage control methodology within the next project deliverable.

- Within the final discussions of the Architecture Options Subphase 2 report additional important points relating to QUEST functionality and overall objectives were mentioned that need to be addressed in the further phases of the QUEST project. These are as follows;

    - In the event of loss of system communication it is expected that the QUEST overarching control system ensures that any associated discrete voltage systems default to a safe mode setting maintaining network stability and safety. This topic needs to be explored further to understand how this process would be carried out by QUEST and how this would affect the different voltage management systems.
    - Architecture options subphase 1 and 2 of the detailed design have identified that the network modelling studies are required to identify parameters that will be required when setting up the QUEST software for operational trials.
    - Architecture options subphase 1 and 2 of the detailed design only considered CLASS full and half levels of the demand change. Further options for ¼ and ¾ Demand Reduction modes could be introduced within the CLASS Supper Tap AVC Relay and that these modes could also be included in QUEST’s trials. This will be explored in the in next phase to understand the possibility and value of introducing these modes.
    - In the architecture options subphase 2 report the transitional state from CLASS DR with Smart Street fast tapping coordination option to OC6-VR was discussed to determine whether tapping up Smart Street distribution transformers would conflict OC6 voltage reduction. It was concluded that no negative effect on OC6-VR will occur however this scenario needs to be further investigated in the phase of this project.

- Within the QUEST modelling regime analysis, a time-series scenario analysis method was created to test a blend of each individual system’s control methods applied to the electrical network simulation. This has provided the ability to test the QUEST software coordination of actions between control methods for each time step and across a time series. This functionality allows for resolving conflict between the individual system control method objectives, and balancing those resolution affects against key performance indicators, providing the ability for both control methods and QUEST’s algorithms to be validated and optimised. In the next stage, the scenario analysis will be developed to test the QUEST architecture options developed by Schneider Electric to provide validation and optimisation.

5 DEFINITIONS AND ABBREVIATIONS

Term	Definition
ADMS	Advanced Distribution Management System
ANM	Active Network Management
AVC	Automatic Voltage Control
BSP	Bulk Supply Point
CFOM	CLASS Forecast and Optimise Mode
DER	Distributed Energy Resource
DERMS	Distributed Energy Resources Management System
DB	Demand Boost (CLASS Function)
DBF	Demand Boost Full (CLASS Function)
DBH	Demand Boost Half (CLASS Function)
DR	Demand Reduction (CLASS Function)
DRF	Demand Reduction Full (CLASS Function)
DRH	Demand Reduction Half (CLASS Function)
DNO	Distribution Network Operator
EAVC	Enhanced Automatic Voltage Control
ENWL	Electricity North West Ltd.
ESO	National Grid Electricity System Operator
GUI	Graphical User Interface
HV	High Voltage (refers to ENW 6.6kV and 11kV operating voltages)
SE	Schneider Electric
SFR	Secondary Frequency Response (CLASS Function)
SGS	Smarter Grid Solutions
TS	Tap Stagger (CLASS Function)
UI	User Interface