CORNWALL INSIGHT

COMPLETE STRATEGY

NG ESO and WPD

TECHNICAL & COST BENEFIT ANALYSIS OF THE NOMINATED TEST CASES AND RESPECTIVE SOLUTIONS

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GLOSSARY

Abbreviation	Meaning
ANM	Active Network Management
BaU	Business as Usual
BOAs	Bid/Offer Acceptances
BM	Balancing Mechanism
BS	Balancing Service
CBA	Cost Benefit Analysis
CEP	Clean Energy Package
CLASS	Customer Load Active System Services
ENW	Electricity North West
DC	Dynamic Containment
DG	Distributed Generation
DLH	Dynamic Low High
DNO	Distribution Network Operator
DPL	DIgSILENT Programming Language
EV	Electric Vehicle
FFR	Firm Frequency Response
GB	Great Britain
GEMS	Generation Export Management Systems
LIFO	Last In First Off
NG ESO	National Grid Electricity System Operator
NIA	Network Innovation Allowance
STOR	Short Term Operating Reserve
TRL	Technology Readiness Level

VDL	Voltage Dependent Load
WPD	Western Power Distribution

CONTENTS

EXECUTIVE SUMMARY

Active Network Management (ANM) schemes are becoming increasingly widespread on GB distribution networks. The schemes vary in complexity and scale, but share a common objective - to enable Distributed Generation (DG) to be connected to distribution networks quicker and at lower cost. This is achieved by actively managing DG output to avoid breaching existing network limits, rather than undertaking expensive network reinforcement. ANM schemes benefit consumers by minimising the costs of connecting new (often low carbon) generation, which helps to decarbonise the network and reduce costs to consumers.

In recent years, National Grid Electricity System Operator (NG ESO) has increased the use of distributed assets for the provision of Balancing Services (BS). This has caused an increased risk of conflict between BS and ANM schemes. In some circumstances, ANM actions counteract the effect of BS procured by NG ESO. But in some cases, there are also unnecessary restrictions on the participation of ANM generators in BS, reducing market liquidity and increasing consumer costs.

This NG ESO and Western Power Distribution (WPD) Network Innovation Allowance (NIA) innovation project undertaken by WSP, Cornwall Insight, and Complete Strategy intends to optimise coordination between ANM systems and NG ESO's operation of BS. The previous work of the project (as reported in the two previous project reports) has identified a number of Test Cases to understand the potential conflicts between the provision of BS and ANM schemes, and identified a shortlist of solutions to resolve those conflicts.

The solutions have been categorised into four main groups, covering:

- Reconfiguration of ANM schemes;
- Improved information exchanges;
- Changes to market rules; and
- Customer Load Active System Services (CLASS)-specific solutions

This report evaluates the aforementioned range of solutions and describes a detailed assessment of the options with high potential for future implementation, based on their ability to address the counteractions between BS operation and ANM functions.

First, a further shortlisting exercise has been undertaken by assessing the merit of each option and its inherent risks against a set of assessment 'Impact Criteria'.

The result of the assessment showed favourable solutions within all groups albeit with significant variability in the readiness of solutions compared to their long-term benefits. The shortlisted solutions are:

- Parallel decrementing instructions (i.e. instructions to reduce generation output) from NG ESO to BS provider and DNO (“W1”) under which DNOs would receive a parallel instruction with dispatch of BS by NG ESO and therefore take action to ensure its ANM system did not counteract that dispatch
- Improved communication with generators on the likelihood of ANM curtailment (“X1”) under which generators would receive curtailment forecasts from DNOs, enabling them to ensure BS can be delivered before bidding
- Risk-based BS valuation (“Y1”) under which NG ESO would receive curtailment forecasts from DNOs to be factored into BS dispatch
- CLASS scheme and ANM separation (“Z1”) ensuring only one of CLASS or ANM is active at any given time
- CLASS visibility of ANM and coordination (“Z2”) enabling CLASS and ANM to operate simultaneously in a coordinated manner

Subsequently, a technical evaluation and Cost-Benefit Analysis (CBA) of the shortlisted solutions was performed

For the technical assessment, part of the WPD South West licenced area was selected as a case study, enabling the modelling of different test cases and solutions. For the CBA, a combination of BS data from 2019 and 2020 has been used, and the reduction in the total cost of each BS estimated by quantifying the cost of counteracted BS and the benefit of greater BS liquidity. The majority of the benefits identified in the CBA are observed in the Balancing Mechanism, but there are benefits for other BS also.

The simulation, modelling, and results have demonstrated that the proposed solution W1 is technically feasible to ensure the delivery of BS decrementing effect, as requested by NG ESO, by temporarily deactivating the ANM control actions during the BS settlement periods identified by NG ESO. The CBA has also shown material benefits from that solution, ranging from an estimated benefit of £30-45m/year from reduced counteraction and increased BS liquidity.

Solution X1 and Y1 don’t required modelling and simulation studies for demonstrating their technical feasibility, and the CBA for these solutions showed materially benefits, ranging from £79-110m/year for X1 and £100-140m/year for Y1 (more than double of W1).

Solution Z2 can provide an effective coordination between CLASS control and ANM control to operate within different voltage bands and avoid any possible counteractions between the two schemes. CLASS can deliver frequency response services during normal voltage operation bands. The ANM will react only if the voltages are brought outside of the permissible limits due to demand reduction/increase following voltages deliberately changed to decrease/increase demand to provide frequency responses. When voltages are restored to permissible levels by the ANM, CLASS can then take prominence. The CBA related to this solution has shown that the total benefit of reduced counteraction in the FFR market can reach up to £347,000. This was based on some data from 2019.

Further investigation of the barriers to deployment of each solution will be undertaken under the next workstream of the project, alongside consideration of the most effective way to overcome these barriers. We will subsequently conclude on the most favourable solutions and develop a detailed delivery plan for deployment.

1 PROJECT OVERVIEW

WSP[1], Cornwall Insight[2] and Complete Strategy[3] are undertaking a Network Innovation Allowance (NIA) funded project on behalf of National Grid Electricity System Operator[4] (NG ESO) and Western Power Distribution[5] (WPD). The project investigates the optimal coordination of Active Network Management (ANM) schemes on both the distribution and transmission networks with Balancing Services (BS) markets.

1.1 BACKGROUND

NG ESO's Future Energy Scenarios[6] (FES) and System Operability Framework[7] (SOF) show that the installed capacity of Distributed Generation (DG) increased to 31GW in 2018 and is set to rise by a further 38GW to 69GW by 2030 across all FES scenarios. This significant growth of DG together with the development and adoption of smart grid technologies means that network operators, both transmission and distribution, have the need and the means to more actively manage flows on their networks.

DG often connects in clusters on the distribution network, in many cases due to natural resources and land availability (e.g. high concentrations of solar in the South West and high concentrations of wind in Scotland). As a result, it has the potential to breach operational limits on both the local distribution network, where it is connected, but also on the upstream transmission network in that area.

The volatility of renewable power generation makes the process of balancing the network more challenging and this is likely to be intensified as more sources are incorporated into the power network to meet net zero.

ANM is one of key technologies widely adopted on the GB electricity network to enable connection of DG and renewables to distribution networks quicker and at lower cost. ANM schemes are normally designed and operated to control the output of DG to avoid breaching existing network limits, while avoiding the need for expensive network reinforcement solutions.

However, as the number and scale of ANM schemes increases, so does the volume of existing distributed resources which are not controlled by ANM schemes (so called non-curtailable generators[8]) connected within the networks managed by ANM schemes. This gives rise to an increased risk of conflict between delivering BS and ANM schemes. ANM actions can counteract the effect of the BS procured by NG ESO from non-curtailable generators. This report presents a number

1 https://www.wsp.com/en-GB
2 https://www.cornwall-insight.com/
3 https://complete-strategy.com/
4 https://www.nationalgrideso.com/
5 https://www.westernpower.co.uk/
6 http://fes.nationalgrid.com/
7 https://www.nationalgrideso.com/insights/system-operability-framework-sof
8 It refers to generation which is downstream of a constraint being managed by an ANM scheme but is not itself controlled by that ANM.

of key shortlisted solutions which can potentially be used to address the conflicts between BS schemes operation and ANM schemes and assesses their relative merits.

1.2 PURPOSE OF THIS REPORT

This report concludes the fourth phase of the project as shown in Figure 1-1:

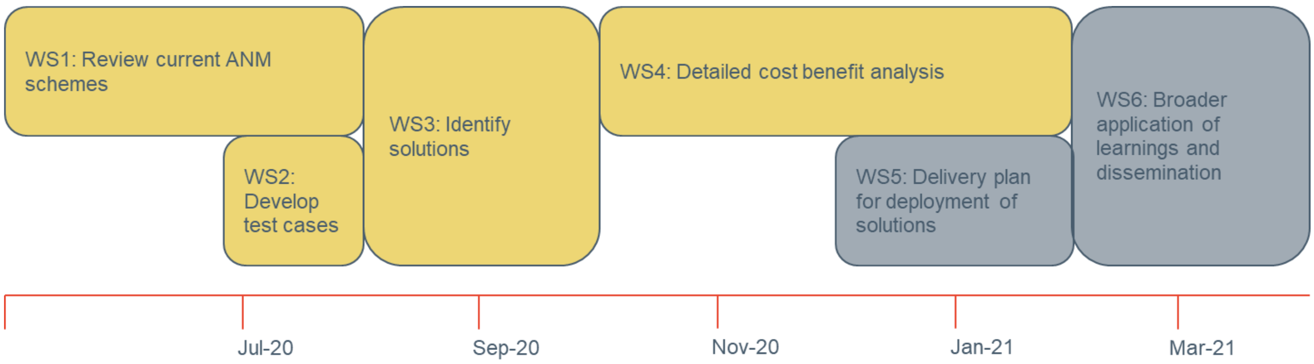

Figure 1-1 - Focus of report

The main areas of the report focus are:

- Assessing solutions shortlisted in WS3, to establish viability against technical and commercial criteria, and establish most favourable solutions.
- Conducting a technical assessment and cost benefit analysis on solutions which are deemed most favourable/viable – to ensure no conflict between BS and associated ANM schemes and determine the magnitude of benefits.

1.3 REPORT STRUCTURE

The report structure is as follows:

- Overview of test cases (defined in WS1) and respective solutions (defined in WS3) (Section 2);
- Establishing assessment criteria to be employed for further shortlisting solutions (Section 3);
- Developing the assessment matrix and assessment of solutions (Section 4);
- Overview the nominated solutions methodologies (Section 5);
- Assessment of the technical merit of nominated solutions (Section 6);
- Calculation of the cost benefit for nominated solutions (Section 7); and,
- Concluding results and recommendations (Section 8)

2 OVERVIEW OF TEST CASES AND RESPECTIVE SOLUTIONS

2.1 TEST CASES

This section presents the network Test Cases that were established after reviewing and analysing relevant literature, internal discussions, and technical workshops with the project team, NG ESO and WPD teams, as well as other stakeholders through bilateral discussions and the Advisory Group.

Table 2-1 summaries the Test Cases established in WS1 - full detail on Test Cases can be found in the WS1 and WS2 reports[9]:

Table 2-1 - Summary of Test Cases

Test Case	Type of Test Case	Description
1A	ANM system counteracts BS provided by DER or transmission connected resources	Incrementing service action from a non-curtailable generator in an ANM area is counteracted by an ANM generator
1B		Decrementing service action from a non-curtailable generator in an ANM area is counteracted by an ANM generator
1C		Service action from a non-curtailable generator in a GEMS area is counteracted by a GEMS generator
2A	ANM system counteracts BS provided by DNO using CLASS system	Demand reduction through a lowering of tap position (through CLASS) is counteracted by downstream ANM scheme
2B		Demand boost through a raising of tap position (through CLASS) is counteracted by downstream ANM scheme
2C		Reactive power absorption through tap stagger (through CLASS) is counteracted by downstream ANM scheme
2D		Demand reduction through disconnection of one transformer is counteracted by downstream ANM scheme
3A	Non-delivery or non-participation by DER in BS due to ANM risks	ANM generator curtailed and defaults on BS
3B		ANM generator unable to access BS markets

After deliberations with stakeholders, the following Test Cases 1B, 1C, 2A, 2D and 3B were seen as most pivotal and thus focus was given to these during the assessment.

9
Optimal coordination of active network management schemes with balancing services market available at https://www.westernpower.co.uk/downloads-view/164437

2.2 PROPOSED SOLUTIONS

This section provides an overview of the wide-ranging solutions that have been identified previously in the WS3 report. Table 2-2 groups together and summarises the solutions, including their high-level impacts on NG ESO, the DNOs, and generators (both non-curtailable generators in ANM areas and ANM generators). Furthermore, Table 2-2 also provides a high-level assessment of the pros and cons of each solution. It also goes on to recommend whether the solutions should be investigated in greater detail through a full cost/benefit analysis (CBA). Full detail on all solutions can be found in the WS3 report[10].

Table 2-2 - Summary of WS3 solutions and recommendations

Solution Category	Solution	Effect on Parties and Operational Impacts	WS3 Recommendation
W – Reconfiguration of ANM schemes	W1 – Parallel decrementing instruction to DER and ANM	NG ESO – coordinator, medium-high impact DNOs – reconfiguration, medium impact Generators – better access to Balancing Services, low impact	Further consideration in WS4
	W2 – Preparatory incrementing instruction to ANM	NG ESO – coordinator, medium-high impact DNOs – reconfiguration, medium impact Generators – better access to Balancing Services but increased curtailment for some, medium impact	Further consideration in WS4, but initial view that high curtailment is likely to erode benefits
	W3 – Bring ANM curtailment ahead of Gate Closure	NG ESO – additional parameters in BM dispatch, medium impact DNOs – ANM redesign and forecasting, very high impact Generators – better BM access but increased curtailment for some, medium impact	Further consideration in WS4, but initial view that this solution is unlikely to deliver benefits
X – Improved information exchange	X1 – Improved communication with generators	NG ESO – update terms of Balancing Services, low impact DNOs – improved communications and continual forecasting, high impact Generators – much greater operational information, high impact	Further consideration in WS4, specifically to understand pros and cons of this solution vs Y1
Y – Changes to market rules	Y1 – Risk-based Balancing Services valuation	NG ESO – coordinator of new framework, very high impact DNOs – forecasting and better ESO comms, high impact Generators – better access to Balancing Services, low impact	Further consideration in WS4, specifically to understand pros and cons of this solution vs X1
	Y2 – Framework for allocating network capacity	NG ESO – modify Balancing Services terms, low impact DNOs – design and implement framework, very high impact Generators – participation in market, high impact	No further consideration as overlaps with UKPN Energy Exchange project
Z – CLASS solutions	Z1 – CLASS to ANM coordination	NG ESO – status quo, low impact DNOs – coordinator (if using CLASS in load dominated areas), high impact Generators – status quo, low impact	Already deployed by ENWL, so will be used as “reference case” for other solutions
	Z2 – CLASS visibility of ANM	NG ESO – status quo, low impact DNOs – coordinator (if using CLASS in load dominated areas), high impact Generators – status quo, low impact	Further consideration in WS4

These outcomes are used as the starting point/basis of assessment in Section 4.

10 Optimal coordination of active network management schemes with balancing services market – identification of solutions

3 CONSIDERATIONS FOR SOLUTIONS ASSESSMENT CRITERIA

This section provides an overview of the criteria proposed to assess the viability and merit of each of the solutions identified for further assessment in WS3. These criteria are also used in Section 4 to develop the assessment matrix which will then be used to score each solution.

Broadly speaking, it is critically important that any solution is practical, affordable and reliable, which the assessment criteria aim to confirm.

3.1 THE TECHNOLOGY READINESS LEVEL (TRL)

The Technology Readiness Level (TRL) delivers a consistent approach for assessing the readiness of technologies for use as Business as Usual (BaU). The 'readiness' value increases during the development of a technology and ranges from TRL1 to TRL9. Figure 3-1, illustrates the differing levels of TRL and how it increases as technology develops.

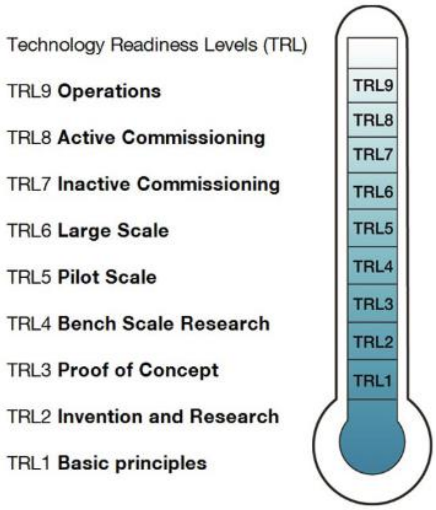

Figure 3-1 - Technology Readiness Levels[11]

This will provide a benchmark for the maturity of technology to assess the risk involved in deployment of each solution. When scoring each solution, the TRL will be used to assess the key components of each solution as an indication to inform if the approach can be relied upon if deployed.

3.2 REGULATORY READINESS

It is important to assess if each of the proposed solutions fall within the requirements of the existing licences and industry codes, most notably the electricity transmission and/or electricity distribution licenses, the Grid Code and the Balancing Settlement Code, or if modifications or new clauses are

11 Guidance on Technology Readiness Levels available at https://www.gov.uk/government/news/guidance-on-technology-readiness-levels

required. The need for significant regulatory changes may pose delays to the implementation of the shortlisted solutions.

As such, when scoring and shortlisting the various solutions, a gap analysis will be carried out to identify the compliance of each option with the current Code and Licence requirements and the modifications that would be required before they could be implemented.

3.3 COMMERCIAL READINESS

Commercial readiness assesses whether the commercial mechanism is in place, if alterations to current mechanisms are required, or new mechanisms are needed in order to implement the solution. This includes assessment of aspects financial/balancing mechanisms e.g. Balancing Mechanism, short time operating reserve (STOR) and Frequency response.

In this regard, scoring and shortlisting of solutions will evaluate their suitability with current commercial mechanisms and the magnitude of and divergence.

3.4 COMPLEXITY (SCALE OF CHANGES)

The complexity of the proposed solutions will be included within the scoring criterion to measure the effort required to implement the new solutions. This criterion gives focus to infrastructure requirements and the communication required.

Solutions which vary in design radically from current equipment/infrastructure and communications, that require the procurement and installation of new state of the art technology or the use of complex controllers and algorithms, will be deemed as more complex.

On the other hand, solutions which require little change from the current applications in terms equipment/infrastructure and communications, but perhaps require slight alterations to existing parameters without a full and detailed re-design, will be deemed less complex.

3.5 IMPACT OF CURTAILMENT LEVEL

The impact on curtailment considers the extent to which the solution will impact the frequency, magnitude and duration of curtailment on the networks. For example, some solutions to enabling BS provision require ANM schemes to “hold headroom” which would lead to higher curtailment. High curtailment comes with an associated opportunity cost, particularly when considering renewables generators with low marginal cost – if those generators are curtailed, NG ESO may be forced to bring other, non-renewable and higher marginal cost generators onto the system.

4 ASSESSMENT MATRIX & SOLUTIONS SHORTLISTING

4.1 IMPACT MATRIX

Within this section of the report, the Assessment Matrix used to score and shortlist solutions is described, and the scoring of each solution is detailed. Supporting evidence has also been provided to justify the scoring assigned against each criterion for each solution.

4.2 ASSESSMENT MATRIX

This subsection provides the categorisation and development of the assessment matrix. The assessment matrix uses the criterion stipulated in Section 3 and marks each based on the 'impact' criteria. The descriptions and scoring categories for impact are provided in Table 4-1:

Table 4-1 - Impact scoring matrix

Impact Criteria	Very low	Low	Moderate	High	Very high
TRL	8-9 (Active commissioning & operations)	6-7 (Larger scale & in active commissioning)	5 (Pilot scale)	3-4 (Proof of concept & bench scale research)	1-2 (Basic principles & innovation and research)
Regulatory Readiness	Fits within existing industry Codes and Licences.	The status of some minor elements is not explicitly clear within existing Codes and/or Licences	Some modifications to clauses of Codes and/or Licences will be required in order to operate the solution	New Code and/or Licence clauses or sections required to operate the solution	Unlikely that modification of the associated frameworks will be granted
Commercial Readiness	Fits within existing commercial arrangements	The status of some minor elements is not explicitly clear within existing commercial arrangements	Some modifications to commercial arrangements will be required in order to operate the solution	Significant modification to existing commercial arrangements is required to operate the solution	Required changes to commercial arrangements are unlikely to be agreed by the Parties involves
Complexity	Tried and tested, simple and easy to integrate	Standard equipment, few challenges technically and integration is relatively straightforward	Some challenges with equipment or with integration (new physical components in set up or new configuration)	Novel/relatively new system, integration is complex	Novel system, integration is complex and customer participation is required
Impact of levels of curtailment	Very limited, if any, change expected to frequency and duration of curtailment compared to status quo	Slight increase in frequency and/or duration for a small subset of generators	Slight increase in frequency and/or duration for many generators; or significant increase in frequency and/or duration for a subset	Significant increase in frequency and/or duration of curtailment for a large number of generators	Major increase in frequency and duration of curtailment across most ANM schemes
Impact scoring	1	2	3	4	5

Taking the scorings for each of the criteria from Table 4-1 and calculating the total impact score provides a quantifiable comparison of each of the solutions and aids in establishing their merit. Solutions with overall lower impact scoring are preferable.

4.3 SOLUTION ASSESSMENT AGAINST THE IMPACT MATRIX

This subsection details the scoring that has been assigned to each of the proposed solutions and the supporting evidence influencing the scoring against each criterion.

4.3.1 SOLUTION W1 – PARALLEL DECREMENTING INSTRUCTION TO DER AND ANM

Under this solution, ANM schemes is required to hold headroom when instructed by NG ESO to do so, to avoid removal of ANM curtailment counteracting a decrementing service instructed by NG ESO. For W1 solution, the instruction will be sent to ANM control in real time.

Table 4-2 - Final Scoring Matrix for solution W1 – Score: 12/25

Impact Criteria	Impact Score	Justification/comments
TRL	2 (Low impact)	To enable the functionality of holding the headroom for decrementing balancing services, suitable and direct communication channels between the NG ESO and DNO control rooms will be required. Inter-Control Centre Communications Protocols (ICCPs) are already implemented in the GB system to enable NG ESO to communicate with some DNOs[12]. On the DNO side, WPD for example have fully integrated communication paths and control mechanism of their ANM systems within its existing infrastructure[13].
Regulatory Readiness	3 (Moderate impact)	New regulatory arrangements will be required to enable NG ESO to send instructions directly to ANM systems and to require DNOs to ensure their ANM systems respond appropriately. Updates to the operational requirements and procedures of the Grid Code will be required (i.e. NG ESO control room to instruct the ANM systems, and DNOs to comply with these new requirements). Currently, the System Operator Transmission Owner Code (STC) defines clearly the procedures of the interactions required between the NG ESO and the ANM schemes implemented on transmission networks. Similar procedures will be required for interfacing the NG ESO control room to ANM schemes implemented on distribution networks. The Balancing and Settlement Code (BSC) may also require alterations to accommodate the parallel NG ESO instructions to mitigate any counteraction between BS actions and ANM actions.
Commercial Readiness	2 (Low impact)	ANM connection agreements may require updating to enable the DNO to undertake curtailment actions for the purpose of holding headroom when instructed by NG ESO.-e.g. connection agreements stating that curtailment will be applied only when the network reaches physical limits will need to be amended to enable curtailment to hold headroom.
Complexity	3 (Moderate impact)	If the ANM scheme is managing a simple network with simple constraints, the implementation of W1 would be straightforward. However, the more complex the network, the more complex it will be for NG ESO to understand what level of headroom is required to be held by the ANM system to avoid counteracting the Balancing Service. There is also additional complexity for ANM systems which need to factor in additional external inputs (the NG ESO instruction) when taking curtailment actions.

[12] https://innovation.ukpowernetworks.co.uk/wp-content/uploads/2019/05/Development-of-the-strategy-for-inter-control-communication-protocol-for-the-purposes-of-KASM.pdf
[13] https://www.westernpower.co.uk/our-network/active-network-management-anm

Impact of levels of curtailment	2 (Low impact)	ANM generators would likely see marginally more curtailment under this regime, as headroom would not be released by the ANM during the provision of a decrementing service by another generator. This is likely to be relatively infrequent and compared to a scenario in which the Balancing Service in question were not instructed has no impact – the headroom which enables curtailment to be released only exists as a result of the Balancing Service being instructed.
Total Scoring	**12/25**	

4.3.2 SOLUTION W2 – PREPARATORY INCREMENTING INSTRUCTION TO ANM

Under this solution, ANM systems would be required to hold headroom when instructed by NG ESO prior a Settlement Period equivalent to potential incrementing Balancing Service downstream of the ANM constraint in that Settlement Period.

Table 4-3 - Final Scoring Matrix for solution W2 – Score: 15/25

Impact Criteria	Impact Score	Justification/comments
TRL	2 (Low impact)	See Table 4-2
Regulatory Readiness	3 (Moderate impact)	See Table 4-2
Commercial Readiness	3 (Moderate impact)	See Table 4-2 In addition, ANM connection agreements needs to consider the impact of Pre-BS Settlement curtailment (i.e. reducing output of ANM generators to allow incrementing BS) alongside the requirements for original curtailment strategies such as Full Pre-event and Post-event curtailments.
Complexity	3 (Moderate impact)	See Table 4-2
Impact of levels of curtailment	4 (High impact)	The ANM scheme will create a headroom by reducing outputs of another ANM generator to allow the delivery of an incrementing balancing service which may be instructed in a given settlement period. This could have a very significant impact on curtailment – for example headroom would need to be held on every ANM scheme with a generator connected downstream which has submitted an ANM offer. It will also have a significant impact on efficiency, as the headroom held for that Offer may never be used if the offer is not Accepted.
Total scoring	**15/25**	

4.3.3 SOLUTION W3 – BRING FORWARD ANM CURTAILMENT AHEAD OF GATE CLOSURE

This solution would require DNOs to determine the level of ANM curtailment required for each Settlement Period at a pre-determined point in time ahead of that Settlement Period to allow generators submitting bids and the NG ESO to dispatch with certainty on ANM curtailment and counteraction risk.

Table 4-4 - Final Scoring Matrix for solution W3 – Score: 19/25

Impact Criteria	Impact Score	Justification/comments
TRL	4 (High impact)	This solution represents a radical change in the way that the ANM scheme needs to operate, and it will require reconfiguration of the ANM control algorithms, new/improved and effective forecasting tools, and reliable communication links (e.g. ICCP) to accurately forecast network flow and ANM curtailment level before Gate Closure. It will also require new communications links with generators and NG ESO in order for the DNO to signal the curtailment which will be required ahead of time.
Regulatory Readiness	4 (High impact)	New regulatory arrangements will be required to stipulate the timing and acceptable tolerance for the DNOs forecasting of curtailment, and the way in which those forecasts are communicated to NG ESO. Changes will then be required to regulatory arrangements underpinning the procurement of Balancing Services to enable NG ESO to account for the DNOs' forecasts of ANM curtailment when instructing Balancing Services.
Commercial Readiness	3 (Moderate impact)	This solution creates contractual issues for DNOs and viability concerns for generators if curtailment suddenly increases significantly, where the business case for generators was likely based on low projected curtailment. This may also require 'lead times' to be altered due to any changes to gate closure times, Conversely, some generators may benefit from this change as unknown non-delivery risk would be reduced (generators would know whether or not they will be curtailed).
Complexity	4 (High impact)	Due to the fundamental change in the operation of ANM schemes by DNOs, and precise forecasting requirements and timing of the information ahead of Gate Closure, solution W3 is very likely to present operational implications for the NG ESO. Also, the solution could potentially create pressures at the time at which the DNO releases its ANM curtailment information, and NG ESO's control room may have already taken many decisions ahead.
Impact of levels of curtailment	4 (High impact)	The solution would only resolve the issues if curtailment were effectively "firm" when communicated to NG ESO, which is likely to require ANM curtailment to be so conservative that the benefit of ANM will be undermined. This would result in significantly higher levels of curtailment and would undermine the benefit of ANM schemes, which enable high utilisation of network capacity by curtailing in real time.
Total scoring	**19/25**	

4.3.4 SOLUTION X1 – IMPROVED COMMUNICATION WITH GENERATORS

This solution would require DNOs to continually forecast curtailment risk for each generator behind each of their ANM schemes. Generators would then be expected to withdraw from participation in services that had a high risk of being undeliverable due to curtailment, potentially enforced by regulatory changes.

Table 4-5 - Final Scoring Matrix for solution X1 – Score: 14/25

Impact Criteria	Impact Score	Justification/comments
TRL	3 (Moderate impact)	This solution would have a material impact on DNO operations, both through the large amount of forecasting required and the high level of complexity in ANM systems, which would need to be simplified for a half-hourly forecast. It would also require reliable communication channels with generators (i.e. DNOs to develop new operational communication links with the generators) to enable the associated DNO to communicate forecast curtailment. On the operational forecasting tools (short-term) side, most DNOs are progressing work in this area which could in turn be an enabler for this solution. For example, WPD has developed and trialled an operational forecasting project the Advanced Planning Tool (TEF) as part of the Low Carbon Network Fund (LCNF) Network Equilibrium project to foresee the expected power flow and determine expected network constraints for the following two days.
Regulatory Readiness	3 (Moderate impact)	New regulatory arrangements will be needed to stipulate the timing and forecast information which DNOs are required to communicate to generators. There may also need to be an over-arching regulatory requirement on generators to act upon that information, albeit the way in which they choose to act may be best left to generators' commercial considerations.
Commercial Readiness	3 (Moderate impact)	Unlike some other solutions, the X1 solution would have limited impact on commercial arrangements between DNOs and generators. But it would impact the trading strategies of generators in wholesale and Balancing Services markets and may impact competitive dynamics in those markets.
Complexity	4 (High impact)	This is a relatively complex solution, requiring continuous short-term forecasting from DNOs and interpretation of those forecasts by generators when making decisions on which Balancing Services to offer.
Impact of levels of curtailment	1 (Very low impact)	This solution would not impact the frequency and duration of ANM curtailment.
Total scoring	**14/25**	

4.3.5 SOLUTION Y1 – RISK-BASED BALANCING SERVICES VALUATION

This solution requires DNOs to provide forecasts to NG ESO on the likelihood of ANM curtailment for each DER for each period ahead of time and around Gate Closure for NG ESO to factor into its Balancing Service procurement and dispatch decisions.

Table 4-6 - Final Scoring Matrix for solution Y1 – Score: 16/25

Impact Criteria	Impact Score	Justification/comments
TRL	3 (Moderate impact)	This solution will require Communication technologies such as ICCP and Distributed Network Protocol 3 (DNP3) for comms, messaging and data exchanges to enable NG ESO to have "highly granular forecasts from DNOs on ANM curtailment for each period" ahead of time and around Gate Closure.
Regulatory Readiness	5 (Very high impact)	This would require NG ESO to create a risk-based balanced services valuation framework differing materially from existing arrangements where all (e.g.) Bids and Offers are valued equally. It would also require a significant change to the way in which non-delivery penalties (or with-holding of payments) are applied, with non-delivery penalties only applying if non-delivery is not caused by a network issue.

		The existing industry codes and market rules would need to be significantly amended to implement this solution.
Commercial Readiness	3 (Moderate impact)	The competitive dynamics in Balancing Services Markets could be impacted, since the solution may result in a loss of transparency as NG ESO factors in the risk of non-delivery due to network issues into its dispatch decisions. NG ESO may need to review and amend service terms to allow for the change in procurement of affected Balancing Services.
Complexity	4 (High impact)	This solution will require continuous short-term forecasting from DNOs. Based on those forecasts, NG ESO would need to create a risk-based framework, considering information from the DNOs on the curtailment risk for each ANM scheme and factoring in this risk for each Balancing Service. This means Y1 solution may require radical changes for DNO on forecasting and data exchange, and major change for NG ESO to redesign/change the rules for BS market and design a new valuation scheme.
Impact of levels of curtailment	1 (Very low impact)	This solution would not impact the frequency and duration of ANM curtailment.
Total scoring	**16/25**	

4.3.6 SOLUTION Z1 – CLASS AND ANM SEPARATE OPERATION

This solution requires real-time monitoring of the CLASS and ANM systems by the DNO to ensure that only one of those systems is active in any given network location at a given time. This would require careful decision making and coordination by the DNO regarding which of the schemes should lead the actions based on the nature of the shared area (i.e. if the area is dominated by demand, CLASS scheme will lead during the settlement period, and if the area is dominated by curtailable generation, the ANM scheme will lead).

Table 4-7 - Final Scoring Matrix for solution Z1 – Score: 9/25

Impact Criteria	Impact Score	Justification/comments
TRL	2 (Low impact)	ENWL (the only DNO using CLASS) already deploys this solution, so the technology is proven and ready to be rolled out more widely.
Regulatory Readiness	2 (Low impact)	In ENWL CLASS project, a review of the National Electricity System Security and Quality of Supply Standard, SQSS, and other relevant standards and codes was undertaken to determine if changes were required for the CLASS methodology to be employed. The results concluded that no changes were necessary when CLASS and ANM schemes are not operated simultaneously[14]. Thus, the only regulatory change needed to implement this solution would be a requirement on DNOs to not operate CLASS and ANM simultaneously.
Commercial Readiness	1 (Very Low impact)	ANM will not be active during the settlement period and activation of CLASS (thus no curtailment will be experienced), and the impact on current commercial arrangements will be very low.
Complexity	2 (Low impact)	This solution requires implementation of conflict management techniques to operate one scheme at a time, which is relatively simple to implement
Impact of levels of curtailment	2 (Low impact)	ANM generators may, in rare instances, be curtailed more frequently to allow for the provision of services to NG ESO by CLASS implemented. Therefore, there should be relatively small increases in curtailment for ANM generators with this solution.
Total scoring	**9/25**	

[14] https://www.enwl.co.uk/globalassets/innovation/class/class-documents/class-summary-factsheet.pdf

4.3.7 SOLUTION Z2 – CLASS VISIBILITY OF ANM AND COORDINATION

This solution requires real-time monitoring and coordination of the CLASS and ANM systems. The solution proposes the operation of each scheme at different voltage bands. CLASS is to deliver the required services (e.g. frequency response) during normal voltage levels and the ANM will be automatically activated only if the voltages are forced to operate outside of the permissible limits due to CLASS actions. However, to enable this solution, ANM needs to hold the headroom during CLASS action (i.e. during normal voltage operation band). This can potentially avoid any possible counteractions between the two schemes and conflicts between thermal and voltage constraints requirements. Table 4-8 - Final Scoring Matrix for solution Z2 – Score: 12/25

Impact Criteria	Impact Score	Justification/comments
TRL	3 (Moderate impact)	This solution requires real-time monitoring of CLASS and ANM systems by the DNO, with the addition of some forecasting of ANM actions to be incorporated into CLASS decision making.
Regulatory Readiness	3 (Moderate impact)	Following the review of SQSS, and other relevant standards and codes by the ENW CLASS project, no changes were necessary when CLASS and ANM schemes are not operated simultaneously[14]. For Z2 when CLASS and ANM operate in a coordinated way, simultaneous real time operation, relevant codes and standards would require review and may require modifications on the requirements of coordination actions.
Commercial Readiness	1 (Very low impact)	This solution would not impact generators as ANM schemes and CLASS would continue to act normally.
Complexity	4 (High impact)	This solution relies on real-time coordination which will require effective monitoring, communication, and coordinated control actions to deliver the BS by CLASS assets and ensure the delivery of ANM systems functionality.
Impact of levels of curtailment	1 (Very low impact)	This solution would not impact generators, as ANM schemes would continue to act as normal and the performance is compensated by the CLASS performance.
Total scoring	**12/25**	

4.4 RECOMMEDATIONS FOR SHORTLISTED SOLUTIONS

A simple Red, Yellow, and Green colour code was used to summarise the shortlisted solutions against impact criteria (see Table 4-9). Red represents high impact (i.e. impact score 4-5), Yellow represents moderate impact (i.e. impact score 3), and Green represents low impact (i.e. impact score 1-2).

Table 4-9 – Summary of shortlisted solutions

Rank	Solution type	Impact Criteria					Total Score
		TRL	Regulatory Readiness	Commercial Readiness	Complexity	Impact of levels of curtailment	
1	Z1: CLASS ANM coordination	2	2	1	2	2	9 ✓
2	Z2: CLASS visibility of ANM	3	3	1	4	1	12 ✓
3	W1 Parallel decrementing ESO-ANM interface	3	3	2	3	2	13 ✓
4	X1: Improved Comms with generators	3	3	3	4	1	14 ✓
5	W2: Preparatory ESO-ANM interface	3	3	3	3	4	16 ✗
6	Y1: Risk-based BS	3	5	3	4	1	16 ✓
7	W3: Bring forward ANM curtailment	4	4	3	4	4	19 ✗

From the impact scorings for each solution type and a technical workshop with the project team, the following conclusions were drawn:

- Solutions that would lead to significant increases in ANM curtailment (W3 and W2) have been eliminated as any benefits will likely be eroded by higher curtailment.
- Y1 scores poorly due to regulatory challenges, however, it has the potential to be an efficient long-term solution, so consideration will be given to this solution, even though its scoring is one of the highest.
- The low scoring of Z1, Z2, W1 and X1 merit further investigation and will be taken forward for detailed assessment.

5 DEVELOPMENT OF SHORTLISETED SOLUTIONS

Four solutions have been shortlisted for further development:

5.1. **Reconfiguration of ANM schemes (solution W1):** This solution focuses on modifying the design, where necessary, of existing and new ANM schemes to either allow for NG ESO instructions to the ANM scheme in real time. Figure 5-1 shows the flow chart of solution 'W1' sequences where a new communication path between NG ESO control room and ANM control will be required. The example used shows a non-curtailable generator providing a decrementing service to NG ESO, but this could in theory also be an ANM generator providing that decrementing service, which would be subject to that ANM generator not itself being curtailed.

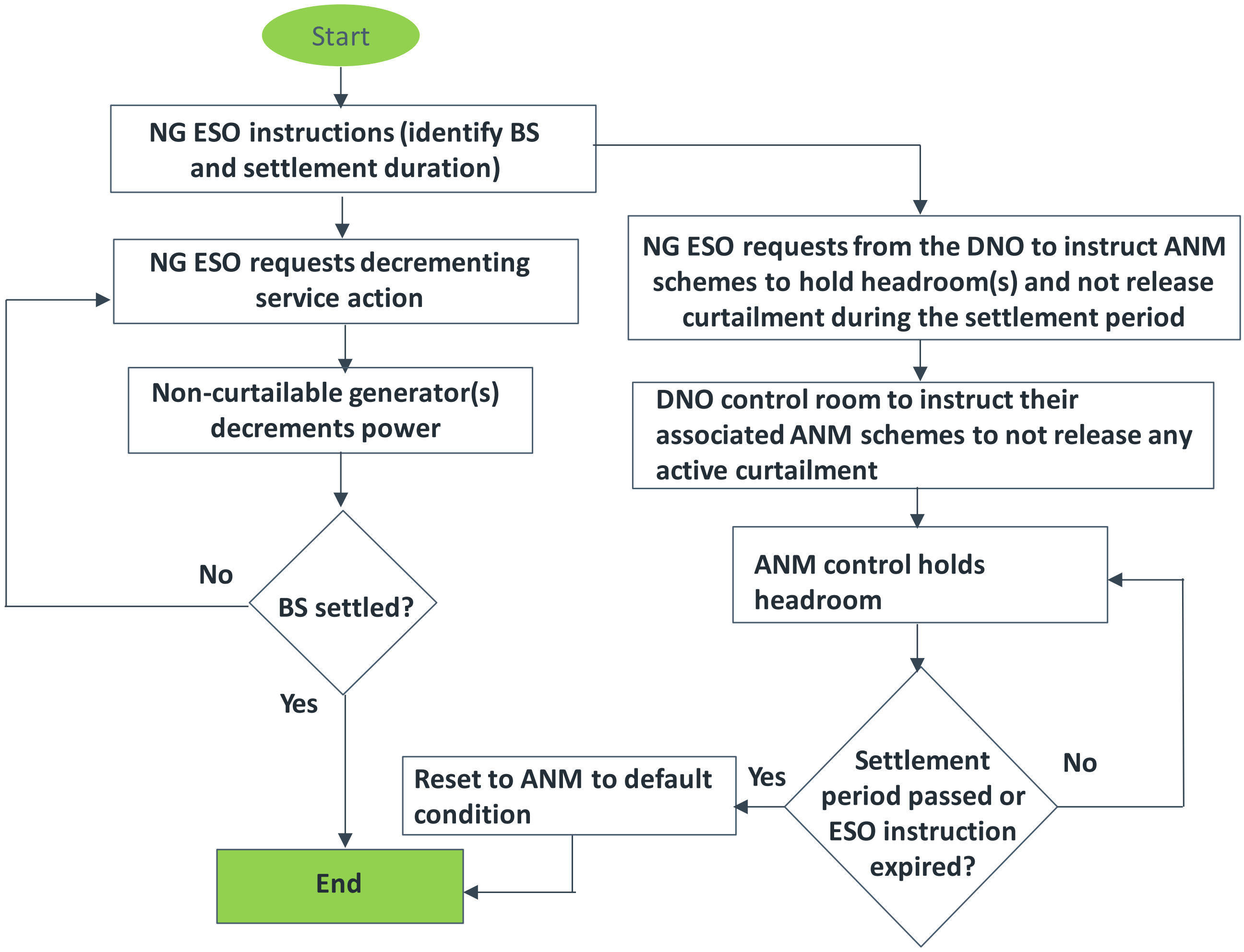

Figure 5-1 - W1 solution flow chart

5.2. **Improved information exchanges and coordination (solution X1):** This focuses on improving communication between ANM schemes and ANM generators, allowing generators to take informed decisions. DNOs would likely issue forecasts to generators over a range of timeframes (month ahead, week ahead, day ahead and hour ahead timescales), enabling generators to commit assets to different services based on their varying procurement timeframes.

As shown in Figure 5-2, X1 is primarily focused on the DNO using prognostic modelling to approximate the likelihood of ANM curtailment. Dependant on the anticipated forecast, the ANM generator and non-curtailable generators in the area will or will not be able to participate in BS.

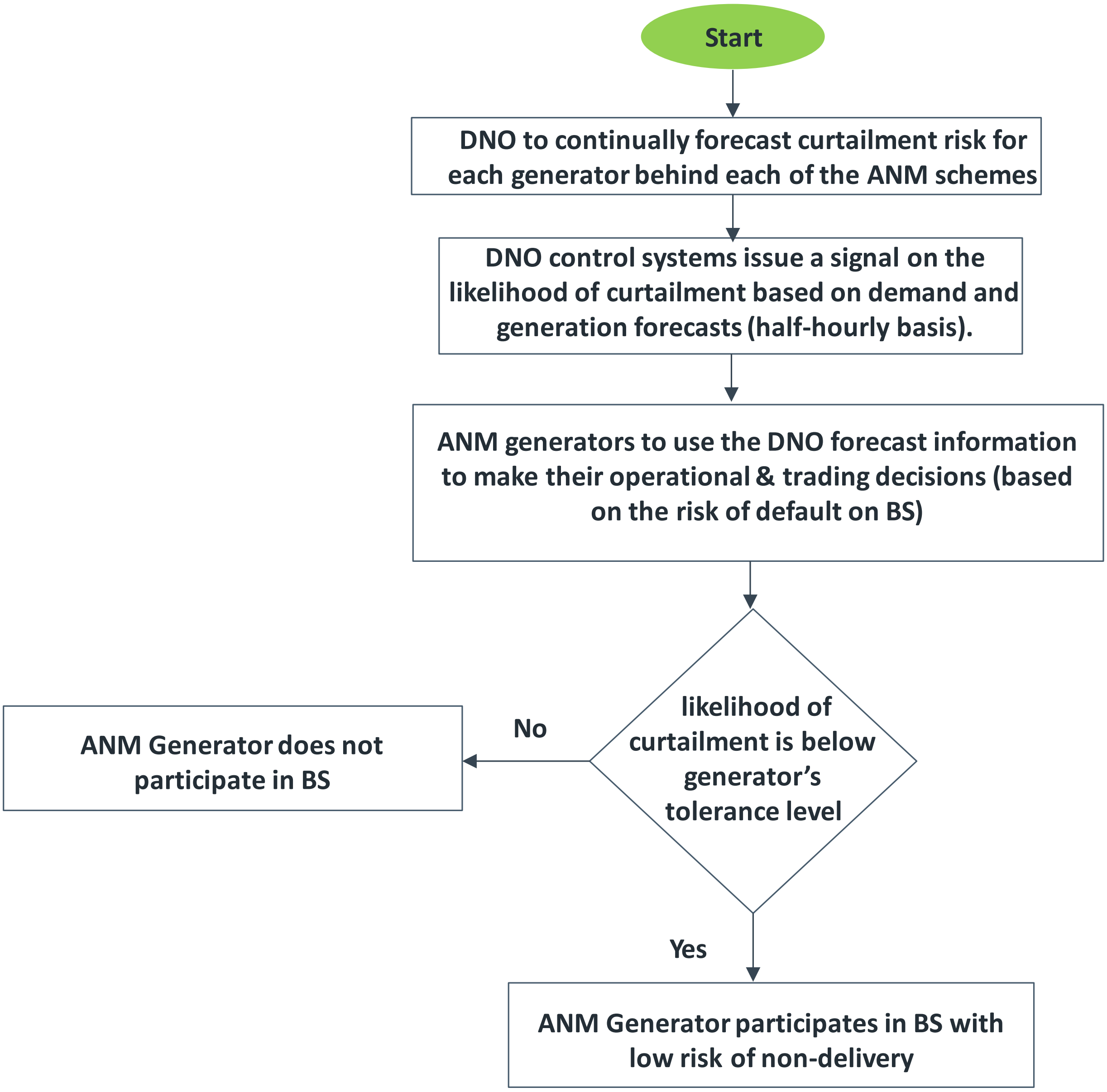

Figure 5-2 - X1 solution flow chart

5.3. Changes to market rules (solution Y1): This solution looks to market-based remedies by accounting for non-delivery risk due to ANM in the processes used for procurement of Balancing Services. The associated flow chart of solution Y1 is given in Figure 5-3.

Solution Y1 looks at ways of 'splitting' risk between stakeholders dependant on who is responsible for ANM not being able to provide required output i.e. if ANM is requested to provide increased output and if there are no issues with the power network and no ANM curtailment, non-delivery penalties will apply. However, if non-delivery is because of a fault on the network, a waiver on penalties will be imposed and the generator will be paid as if the service was delivered.

For NG ESO, a risk-based framework would be established, taking into account information from the DNOs on curtailment risk for each ANM scheme, and factoring in this risk for each Balancing Service.

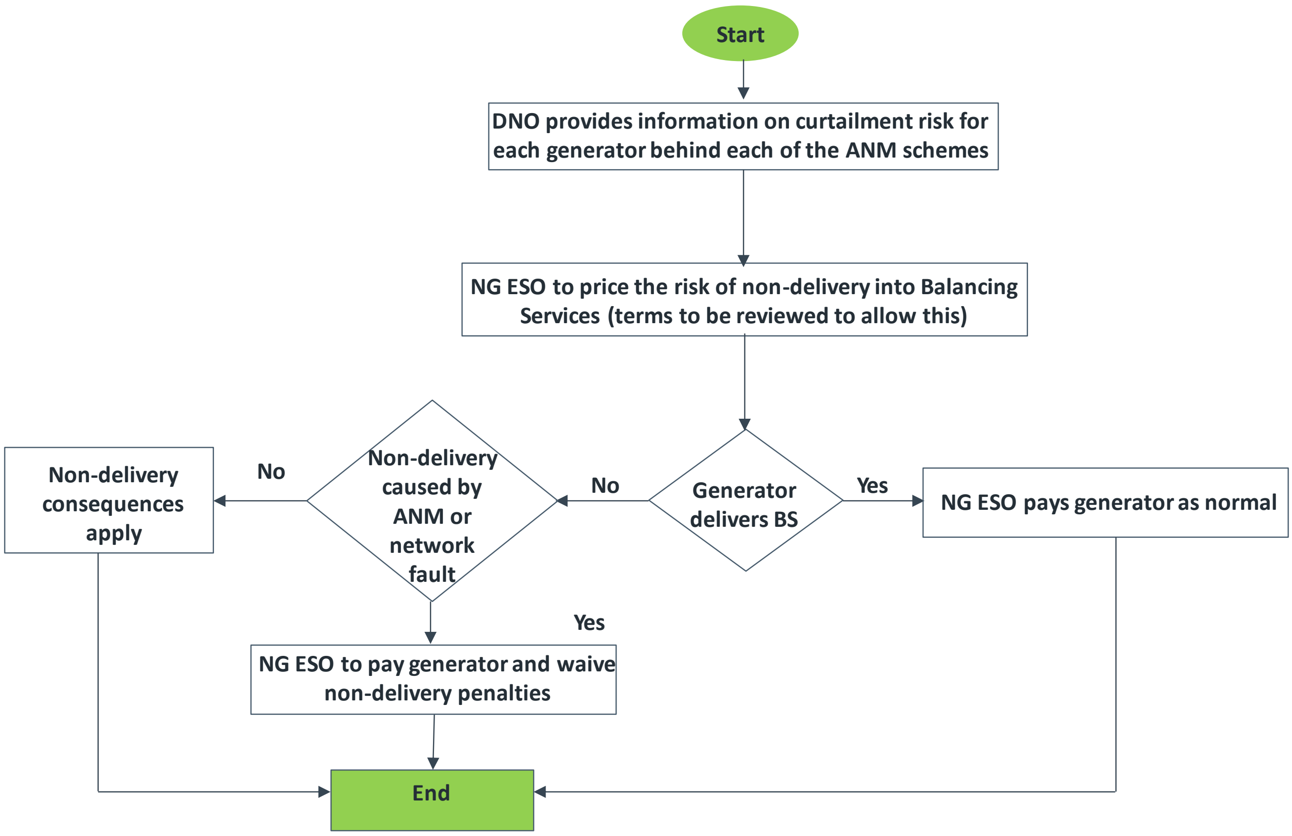

Figure 5-3 - Y1 solution flow chart

Coordination with CLASS systems (solutions Z1 and Z2):

These solutions focus on align information between ANM and CLASS schemes, coordinate actions to avoid conflicts, and apportion compensation where necessary. Z1 (see Figure 5-4) covers the current methodology applied in ENW's network where either CLASS or ANM work separately. Z2 looks into the mechanisms working dependant on voltage observed on the network.

For solution Z1, only ANM or CLASS works during each settlement period. The selection is based on the level of demand on the system. If demand is dominant, ANM will be applied; whereas if generation is dominant, CLASS will take presidence. Whilst, solution Z2 considers better coordination between

ANM and CLASS dependant on the voltage performance of the system observed. For instance, if the voltage goes outwith normal system boundaries, ANM will take presidence and it will increase/decrease output to bring the voltage back into permissable levels. Once voltage is restored at the monitored busbar to normal voltage levels, CLASS will take priority. This solution will also require ANM conrol to hold thermal limits headroom during the CLASS settlement period to avoid counteraction during normal voltage operation band.

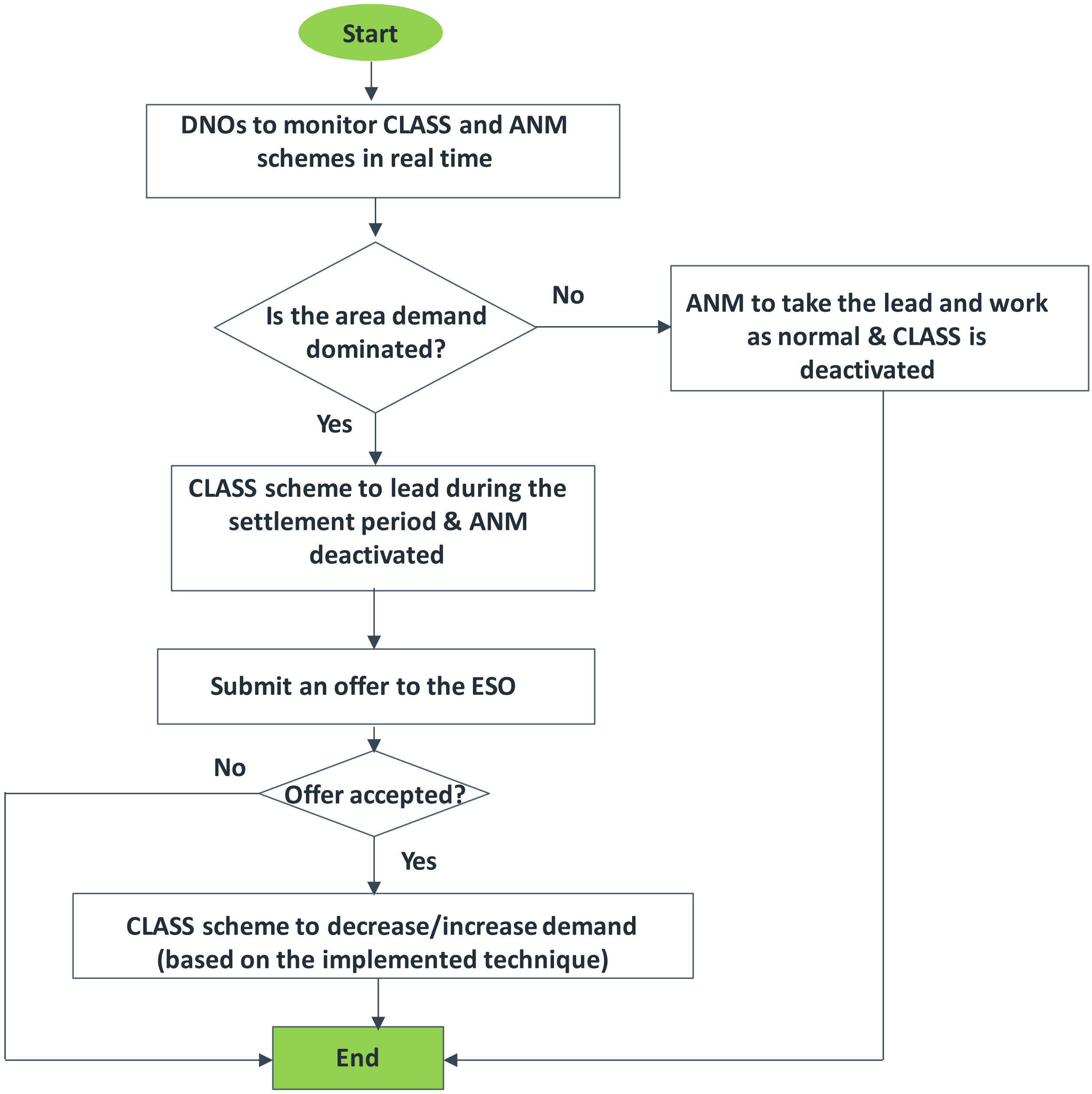

Figure 5-4 - Z1 solution flow chart

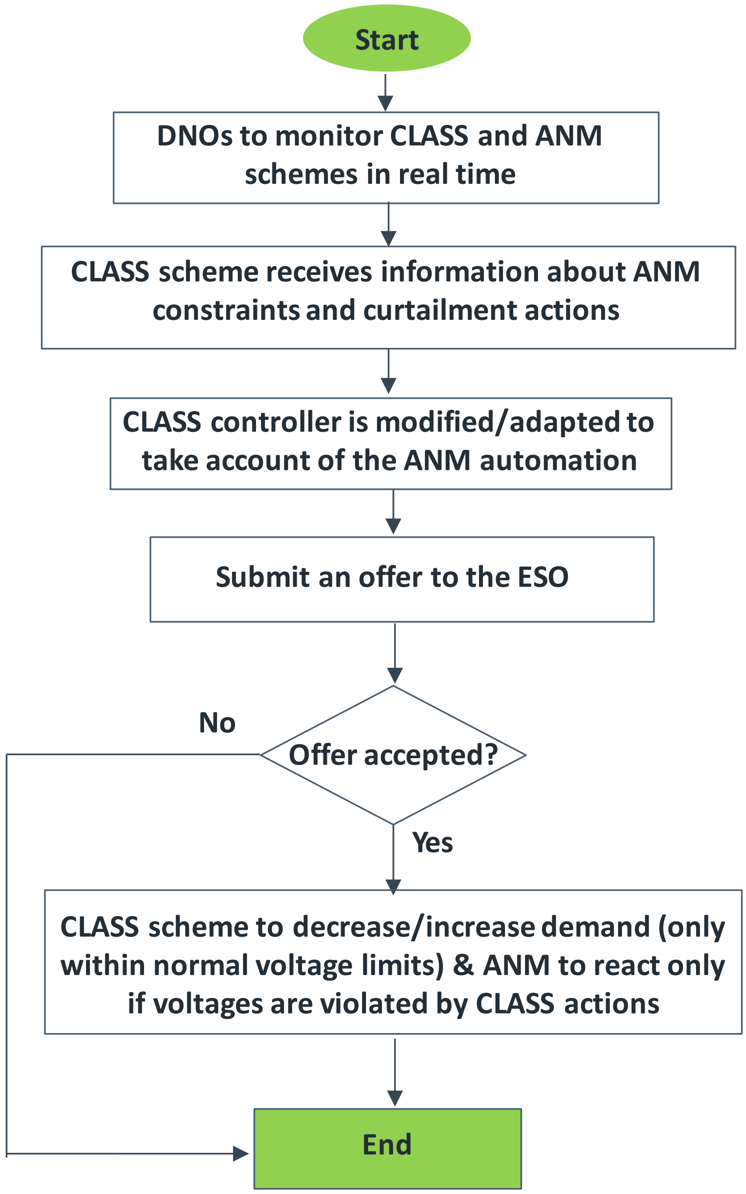

Figure 5-5 - Z2 solution flow chart

6 TECHNICAL ASSESSMENT OF THE NOMINATED SOLUTIONS

6.1 TEST NETWORK – CASE STUDY

In consultation with WPD, the South West 132kV/11kV distribution network (North Tawton BSP) was selected as a Case Study to model and study the identified project distribution Test Cases 1B, 2A, and 2D (described previously in Table 2-1) using DIgSILENT.

A further case study was considered for Test Case 1B, where two 132kV connections were incorporated into the network to assess how this would impact ANM loadings.

6.2 TEST CASES MODELLING REFINEMENT

The project Test Cases detailed in the project WS3 and listed in Section 2 of this report were initially modelled and studied using DIgSILENT and a simplified test network (presented previously to NG ESO and WPD in WS4.1 Report).

Within this report, the Test Cases models have been refined and improved, considering the following:

- More representative curtailment strategies for the development of the ANM scheme model (e.g. full pre-event curtailment strategy as a central strategy).
- Increased test network detail with more suitable configuration to enable the testing of the selected solutions under reasonable curtailment strategies.

The methodology of the Test Cases modelling development and studies is described in the following subsections.

6.2.1 MODEL DATA

All the model technical parameters and data are based on actual values which have been provided by WPD. Thus, outcomes provided should be representative of an actual network and demonstrate how ANM could operate within the studied network.

6.2.2 MODEL ASSUMPTIONS

The following assumptions have been considered during the modelling development and simulation studies:

- The models of BS and ANM schemes do not represent real examples. They have been added (‘hypothetically’) to the case study to showcase the conflicts between the BS and ANM schemes.
- The assumed size of the generation for the BS and ANM schemes have been selected to present the ANM constraints and showcase the conflicts between the two schemes in the best possible way.

- The size of the network loads connected at the 11kV busbar does not reflect the real network loading conditions, and it was selected with the size that fits for the purpose of this study.
- It was assumed that for Test Case 1B that if ANM generation was requested to increase after the settlement period, its output would increase until the loading of monitored lines reached the thermal level prior to the decrement of the non-curtailable generation.
- For modelling of Test Case 1, two lines labelled as L5 and L7 in Figure 6-1 were selected as assets managed by the modelled ANM scheme.
- For assessment of CLASS and AMN conflicts (Z2), one part of the assessment considered a transformer being taken out of service. During the evaluation, tap changer variation was not implemented in order to demonstrate AMN impact in shorter time frames.
- For assessment of Test Case 1B where an additional 132kV connection was incorporated in the network; the connection was assumed to be at sub 6 (shown in Figure 6-1).
- All ANM generators' power factors were set at a unity power factor for modelling Test Case 1 to avoid operation of voltages outside acceptable limits.

6.2.3 MODELLING OF ANM SCHEME

As aforementioned, ANM solutions were applied to a test model agreed with WPD (shown in Figure 6-1), which replicates part of WPDs' network.

The following steps were undertaken to model the ANM scheme and initially set up the model prior to conducting analysis of the shortlisted solutions identified in Section 5:

- **Step 1:** Identifying thermal constraints (based on steady-state thermal ratings). This included N-1 scenarios where one line was taken out of service. This aided the determination of maximum initial loadings of ANM generators possible without overloading the network.
- **Step 2:** Using the results of Step 1, the key thermal constraints limiting generation output were determined. Once established these 'choke points' (lines L5 and L7) were monitored. This enabled the calculation of the possible loading of ANM to rebalance the systems when a decrement in non-curtailable generator output was applied.
- **Step 3:** Identify event outages with maximal impact. This involved the assessment of each line outage on the power system. It was observed that outages of Line 1 and Line 6 (see Figure 6-1) were most detrimental and thus were selected to determine the curtailment levels required of ANM generators during normal operation.
- **Step 4:** Assess thermal overloads with N-1 post-fault/event loading conditions without ANM curtailment. It was established that when Line 1 (labelled as L1 in Figure 6-1) was taken out of service, overloading of L5 (see Figure 6-1) was observed at 167.8% and Line 7 at

151%. When Line 6 was taken out of service, overloading of L7 was observed at 111% and L5 at 102.3%.

- **Step 5:** The necessary Pre-event ANM curtailment was then determined to ensure there were no overloads condition between the fault occurring and the ANM system re-curtailing generators to the new running arrangement. This was performed using a Last in First Off (LIFO) methodology.
- **Step 6:** An additional 132kV connection to the test network was incorporated to understand the impact of different network loading condition on the Test Cases and their corresponding solutions performance.

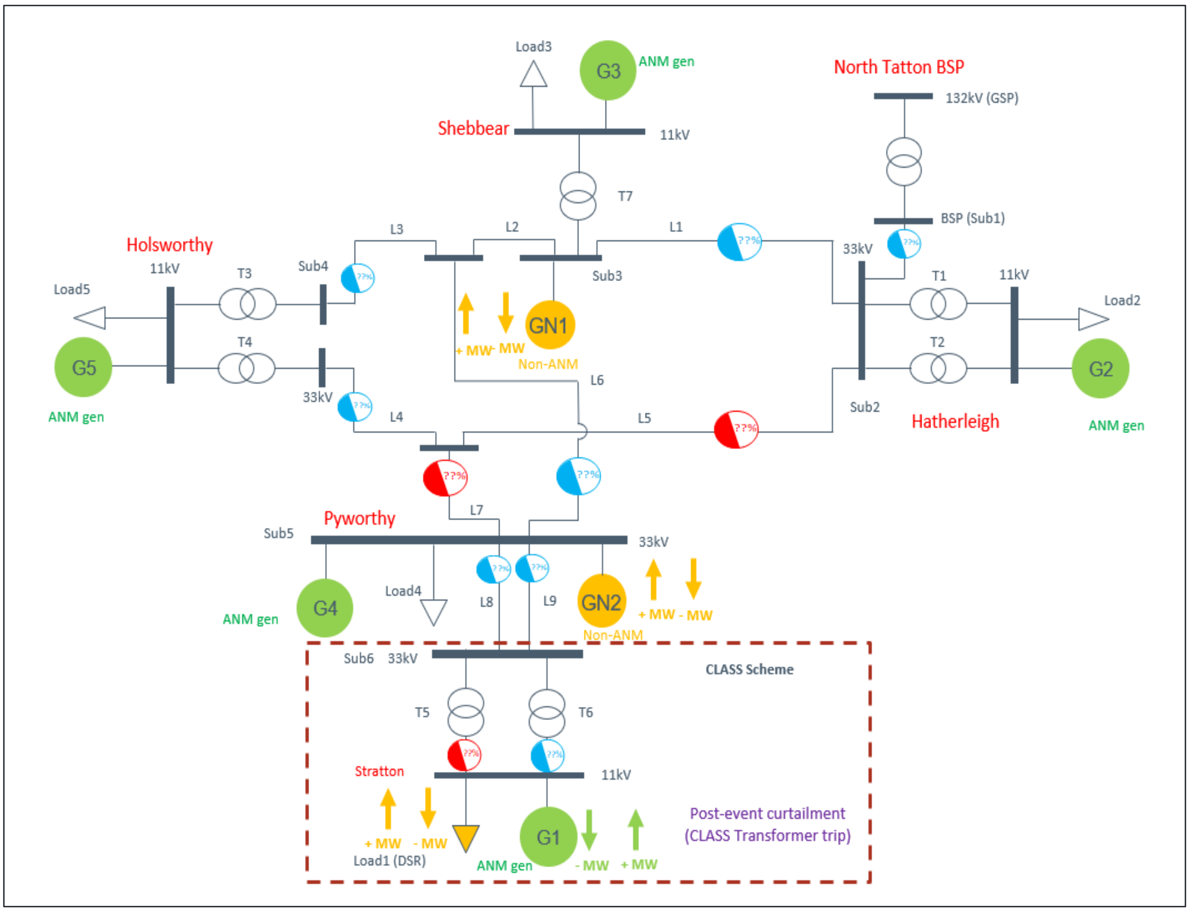

Figure 6-1 – Schematic layout of the test network model

The initial real power outputs for ANM generators are shown in Table 6-1.

Table 6-1 – Initial ANM MW loading

ANM Generator	G1	G2	G3	G4	G5
Generator capacity (MW)	10	12	12	44	18.75
Real Power Output (MW)	10	12	12	38.5	0

For the simulative work for Test Case 1B with additional 132kV, the following network layout was employed. The previously mentioned steps were also applied with the resultant ANM generators shown in Figure 6-2. All ANM generators were set to full output apart from ANM Generator G8.

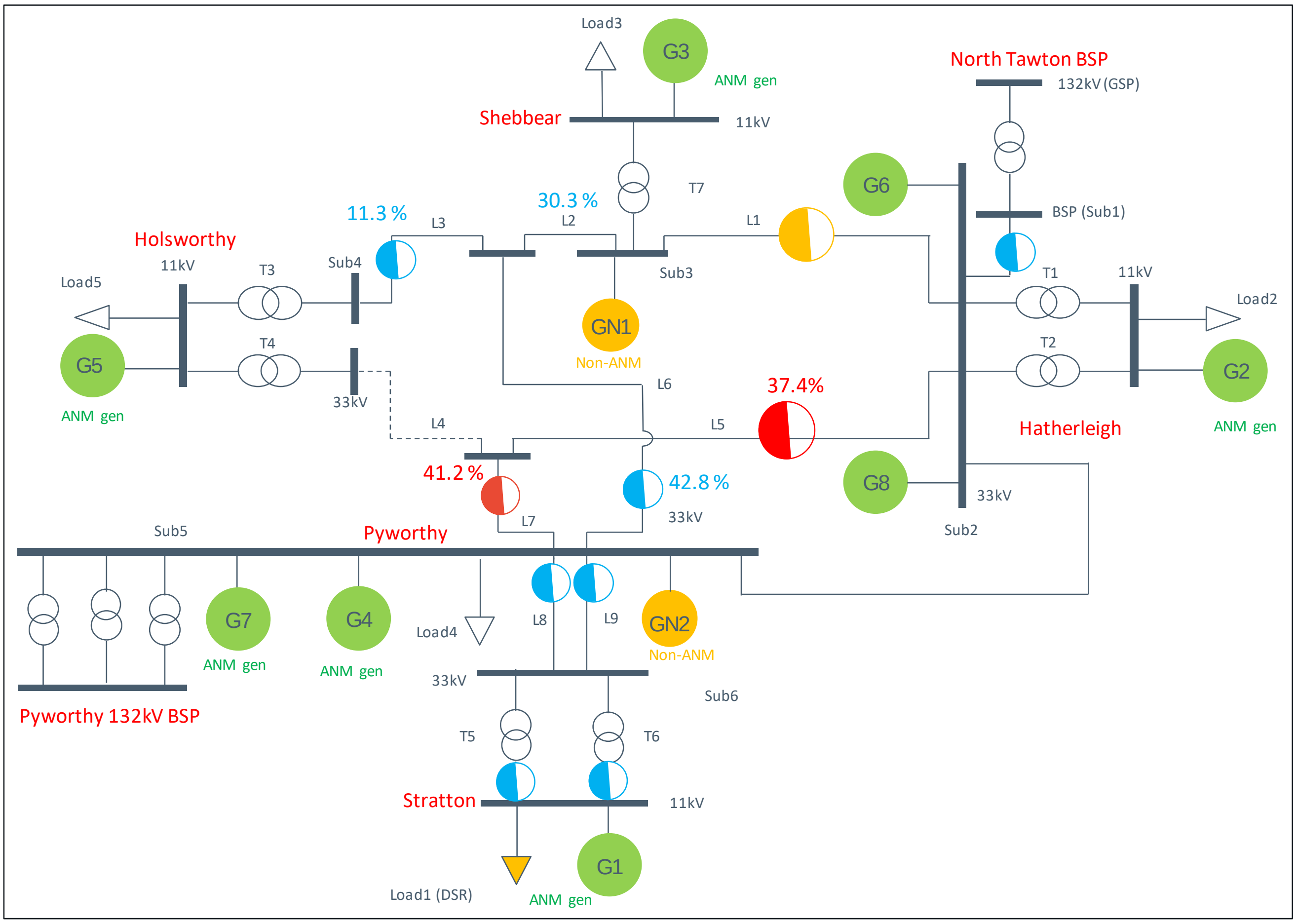

Figure 6-2 – Schematic layout of the test network model with additional 132kV connection

Table 6-2 - Initial Generator loadings

ANM Generator	G1	G2	G3	G4	G5	G6	G7	G8
Generator capacity (MW)	10	12	12	44	18.75	2	18.75	30
Real Power Output (MW)	10	12	12	38.5	0	2	18.75	15

For Z1 and Z2 solutions – the assessment of integration/conflict of the CLASS and ANM, a similar initial set up was undertaken prior to conducting simulative work. The one major difference being that transformers (shown as T5 and T6 in Figure 6-2) steady-state thermal limits were monitored rather than lines L5 and L7 and that the 11kV bus (shown as Stratton in Figure 6-2) were monitored to determine if CLASS or ANM should be given precedence.

The demand controlled by CLASS was modelled as a lumped voltage dependant load. For simplification, it was assumed that ANM generator G1 and CLASS demand (see Figure 6-2 and Table 2-1) were connected to the same bus.

Table 6-3 - Initial loading/generation of CLASS ANM area

Element	ANM generator G1	Voltage Dependant Load
Capacity (MW)	10	-30
Real power output (MW)	10	-30

6.3 MODELLING AND SIMULATION OF SHORTLISTED SOLUTIONS

From technical perspective, the simulation of the shortlisted solution was limited to W1 solution and Z solutions. This is because solution X1 and Y1 don't required modelling and simulation studies for demonstrating their technical feasibility.

The modelling of each solution (i.e. W1 and Z solutions) was achieved by using a script developed in DIgSILENT Programming Language (DPL).

6.3.1 MODELLING OF SOLUTION W1 (DECREMENTING SERVICE)

W1 solution was studied in simulation to address the conflicts between decrementing BS and ANM actions at distribution level (i.e. Test Case 1B).

Decrementing service vs ANM actions

In this case, W1 solution was studied under the following conditions:

I. Delivering the decrementing service by non-curtailable generators located at different locations, and this involved:

- Decrementing services provided by a non-curtailable generator located at upstream of the lines managed by the ANM (i.e. the non-curtailable generator labelled as GN1 in Figure 6-1).
- Decrementing services provided by a non-curtailable generator located at downstream of the lines managed by the ANM (i.e. the non-curtailable generator labelled as GN2 in Figure 6-1).

II. Using different configurations of the selected test network, and this included:

- All feeders (shown in Figure 6-1) are in services
- Feeder L1 (see Figure 6-1) is out of service
- Feeder L6 (see Figure 6-1) is out of service

III. Changing the test network operating condition and network constraints, and this included:

- Supplying the test network from two 132kV grids instead of one

To achieve this, the developed DPL automation script conducted an initial load flow and collected the output levels of the generators and the thermal loading of lines being monitored (L5 and L7).

To emulate the delivery of decrementing BS, a reduction in generation of the non-curtailable units was then evoked. This was achieved by decrementing 4MW of non-curtailable generator 1 for the upstream (in respect to the location of L5 and L7 managed by the ANM) case and non-curtailable generator 2 for the downstream case. The non-curtailable generator 1 and 2 are shown in Figure 6-2 as GN 1 and GN2 respectively. The effects of the decrement on the thermal loadings of the ANM area lines for each case was observed. At this stage, the ANM held its headroom and the outputs of the ANM generators remained unchanged until the settlement period is passed.

Within the developed model, a command signal to request the ANM output to stay constant, or if desired, the ANM to react to the new network condition (post-BS service) was added to the script.

The subsequent figures show results when a decrement is applied to non-curtailable generator 1 (upstream location) or non-curtailable generator 2 (downstream location) under three different configurations of the test network (i.e. all feeders are in service, L1 is out of service and L6 is out of service).

Decrement service provided by non-curtailable generator 1 (upstream)

As shown in Figure 6-3 to Figure 6-5 (top), when the non-curtailable generator was instructed to decrement its output from 5MW to 1MW, the ANM held the headroom and its generators did not release any output power during the settlement period (shown as 0-4 on the horizontal axis in Figure 6-3). When the settlement period passed, the non-curtailable generator reset to its original status. The results of the change of the loading condition of the feeders managed by ANM (i.e. L5 and L7) during and post the BS settlement period are shown in Figure 6-3 to Figure 6-5 (bottom).

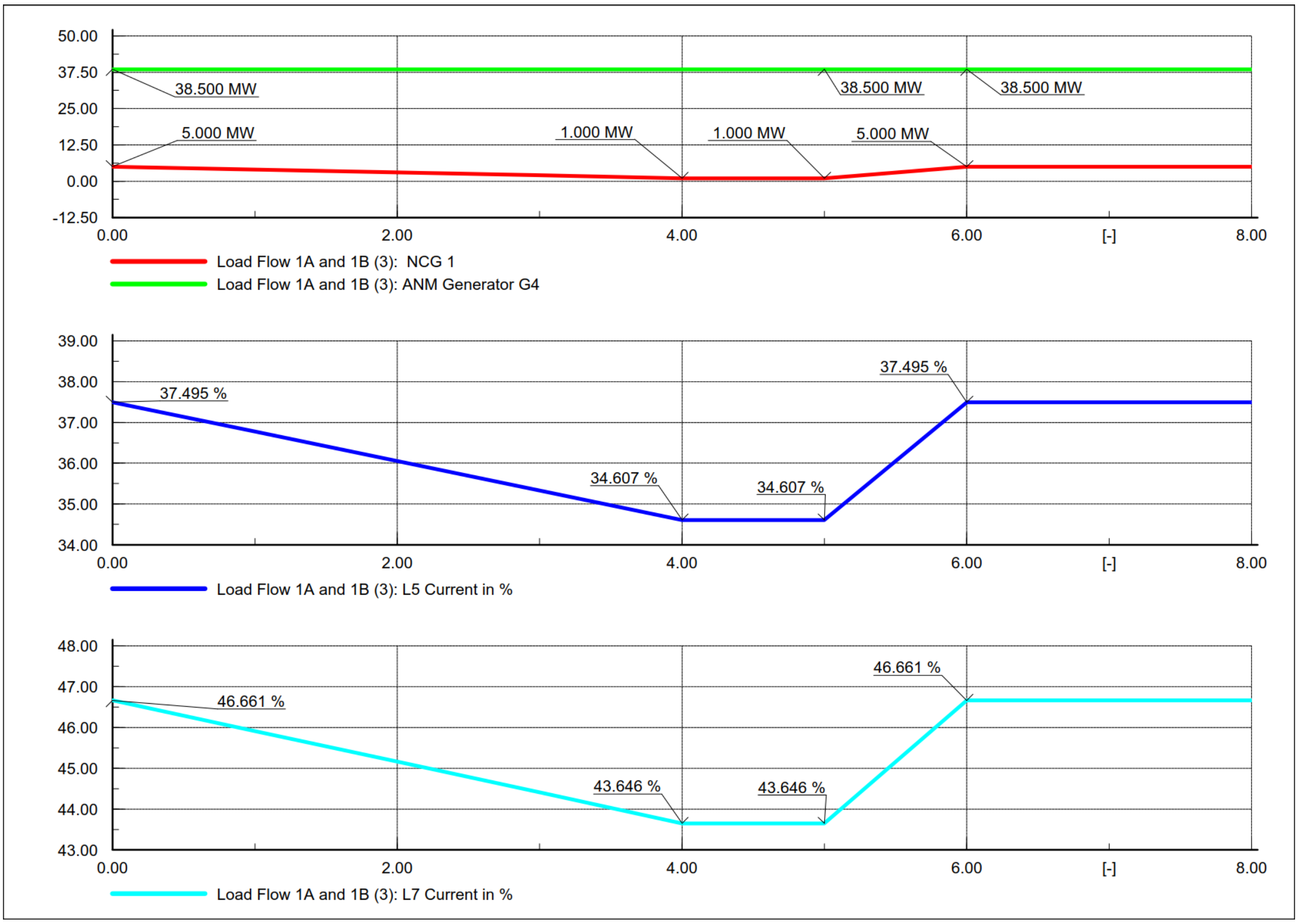

Figure 6-3 - W1: Non-curtailable generator 1 decrement and all cables in service

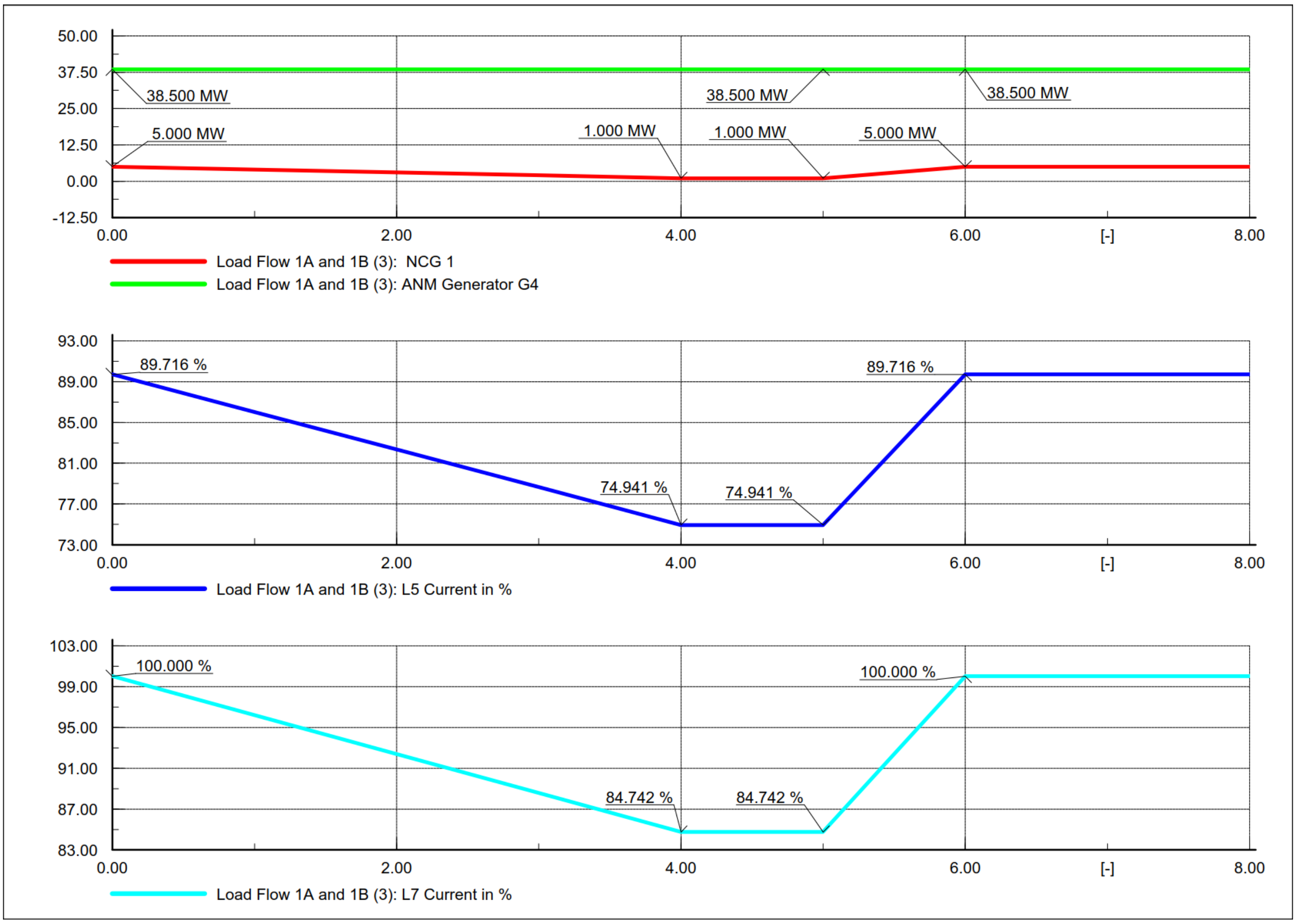

Figure 6-4 - W1: Non-curtailable generator 1 decrement and L1 out of service

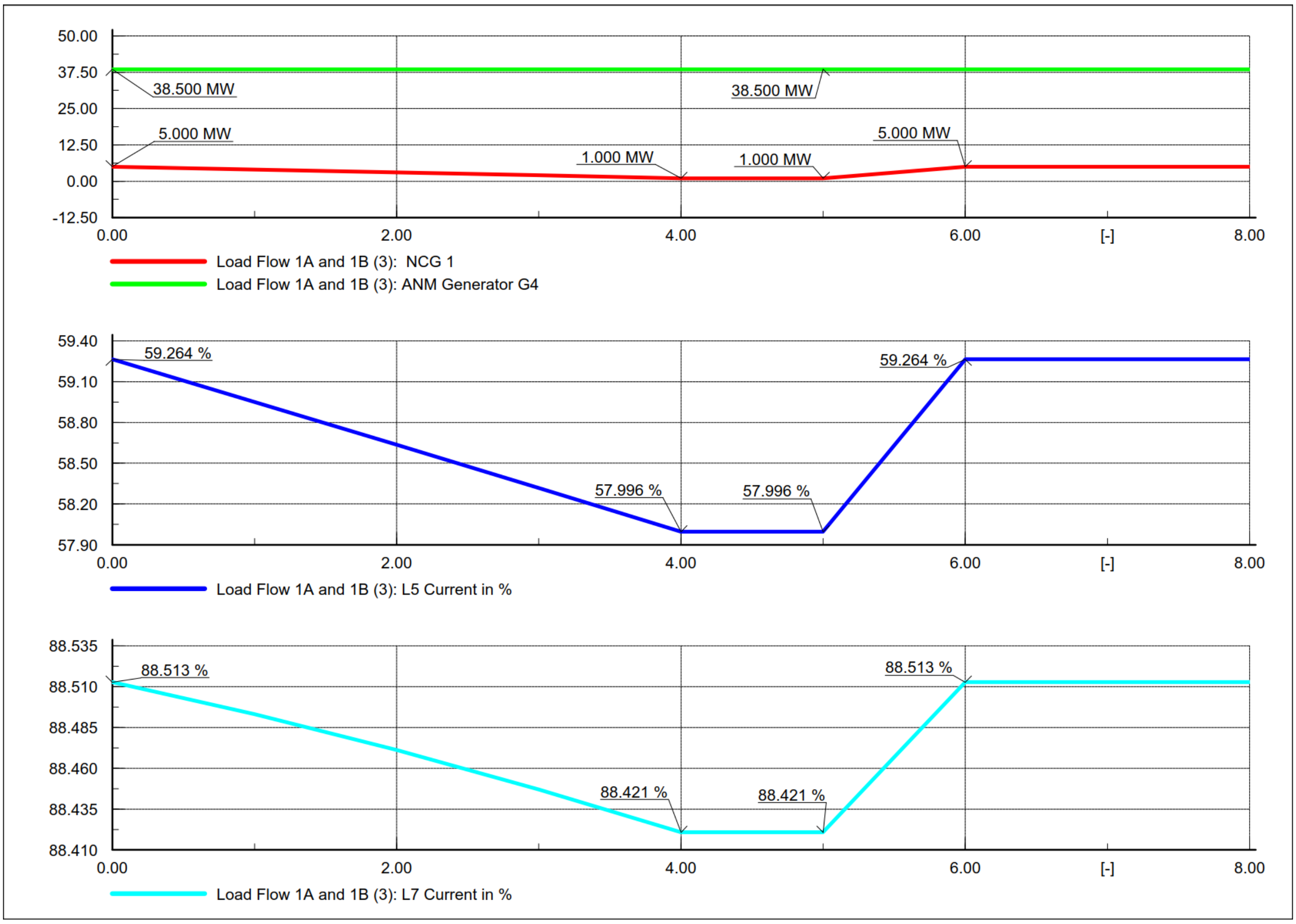

Figure 6-5 - W1: Non-curtailable generator 1 decrement and L6 out of service

Decrement service provided by non-curtailable generator 2 (downstream)

Similar to the previous case and as can be seen from Figure 6-6 to Figure 6-8, the ANM does not respond to the reduction non-curtailable generator output initially, and its generators output stays constant. When the settlement period has passed, the non-curtailable generator reacted to bring its output to its pre-settlement period status.

As observed in Figure 6-3 to Figure 6-8, the impact on the ANM monitored feeder loadings (when the decrement BS was delivered by non-curtailable generator 1 (upstream)) was marginal in comparison to non-curtailable generator 2. This means the location of which non-curtailable generator is selected to provide BS could potentially be considered as a factor for optimising the post-settlement period operation/curtailment of the relevant ANM scheme.

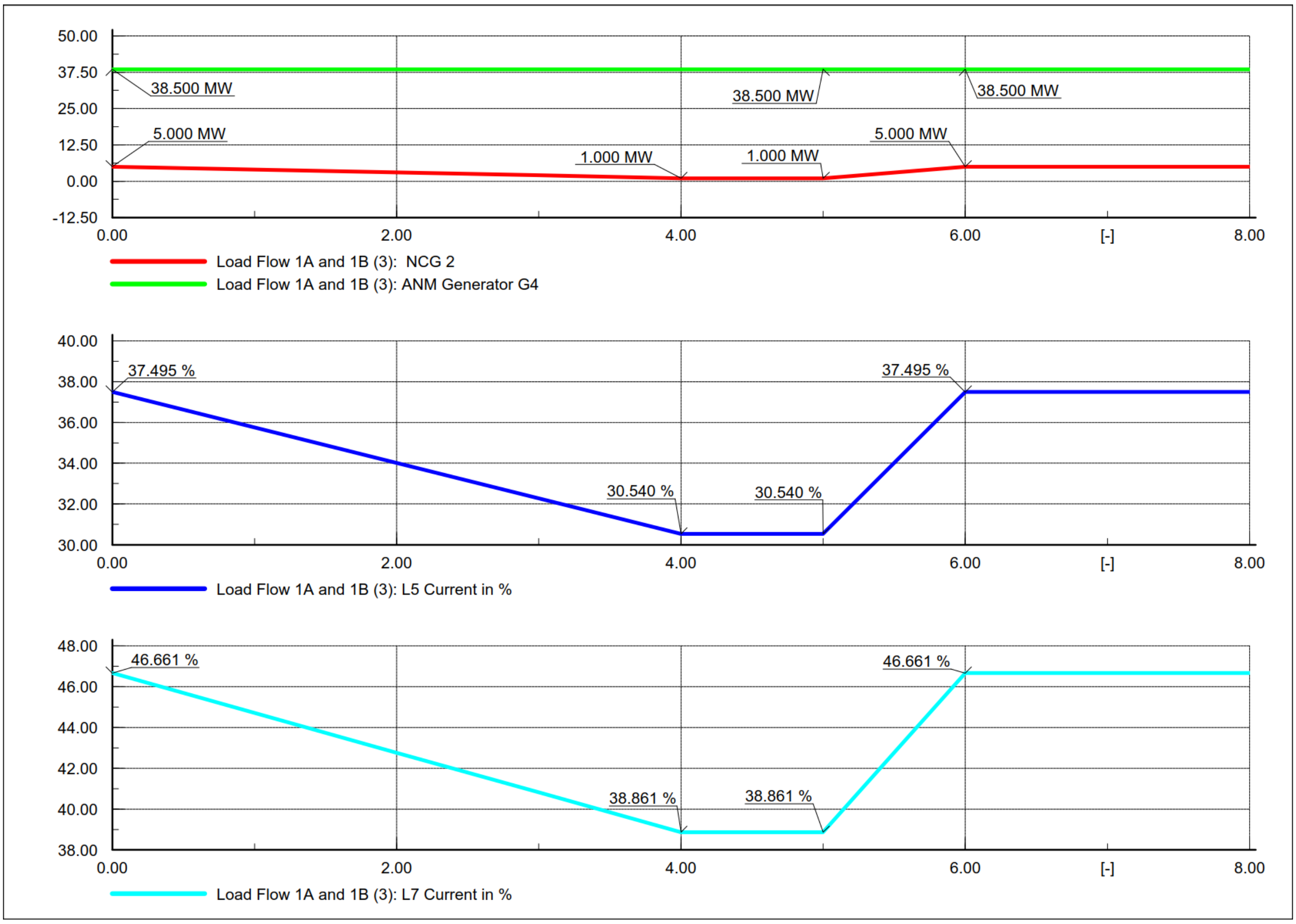

Figure 6-6 - Non-curtailable generator 2 decrement and all cables in service

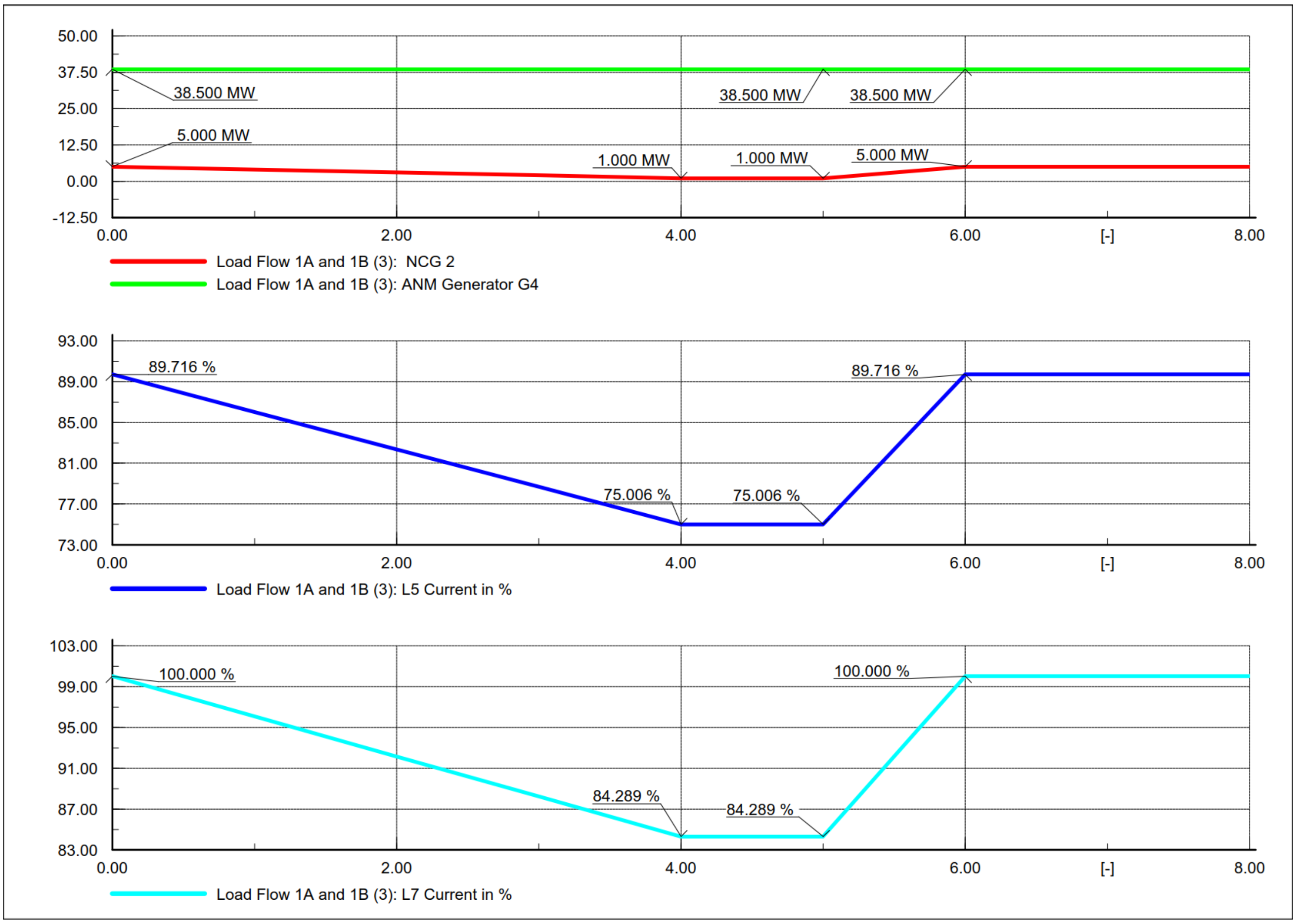

Figure 6-7 - W1: Non-curtailable generator 2 decrement and L1 out of service

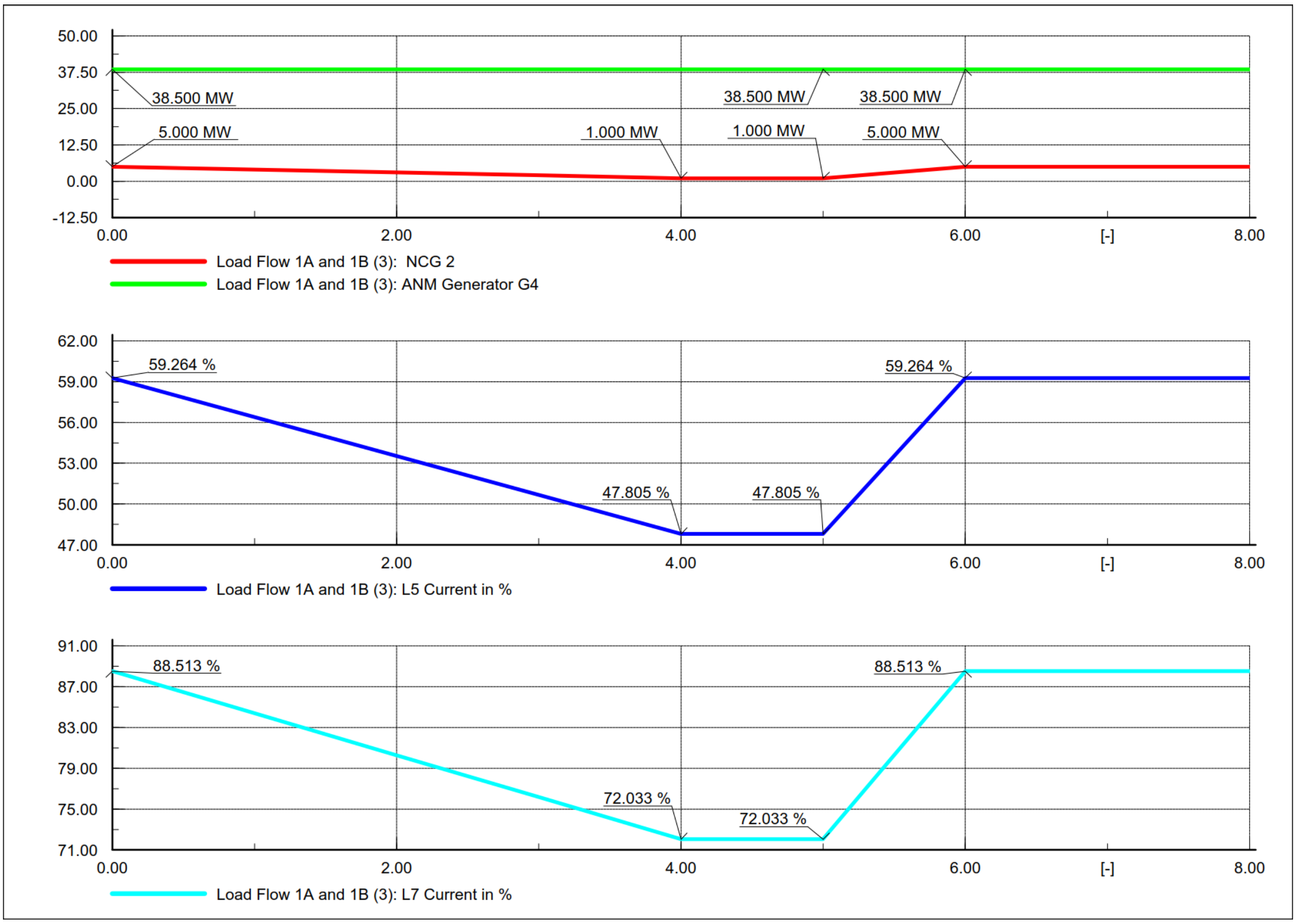

Figure 6-8 - W1: Non-curtailable generator 2 decrement and L6 out of service

With an additional 132kV connection to the distribution test network

When there are two 132kV connections connected to the distribution test network as presented previously in Figure 6-2, more generation can be connected to the ANM area in comparison to supplying the test network from one 132kV connection (see Figure 6-1). The following results show the response of solution W1 under this circumstance when the BS was provided by non-curtailable generator 1 (upstream) and non-curtailable generator 2 (downstream).

Decrement service provided by non-curtailable generator 1 (upstream)

As shown in Figure 6-9 to Figure 6-11, when non-curtailable generator 1 is reduced to deliver decrementing BS, ANM does not respond to this reduction, and Its generators outputs stay constant. Following the settlement period, the non-curtailable generator returned to its original status.

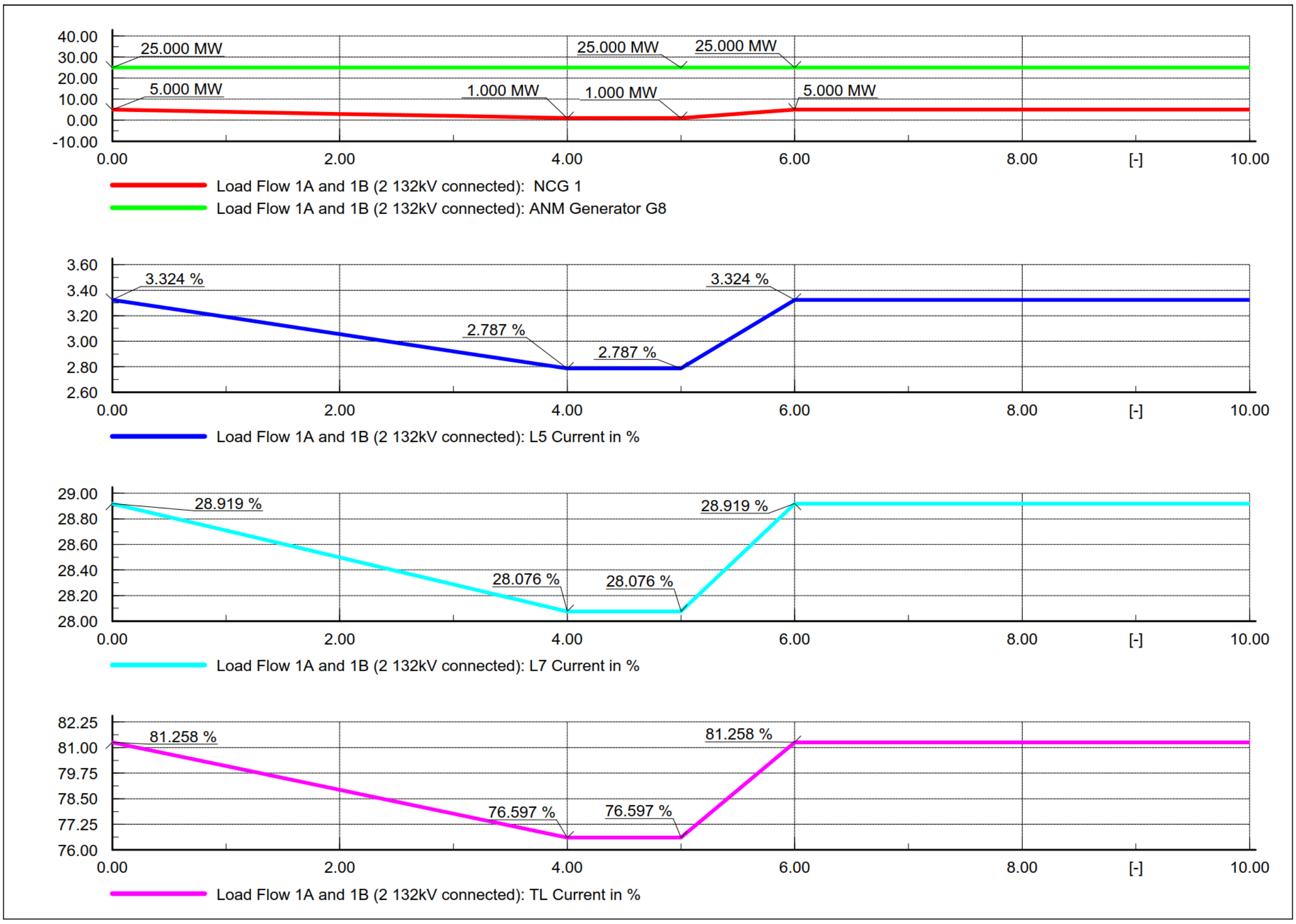

Figure 6-9 - W1: Non-curtailable generator 1 decriment and all cables in service

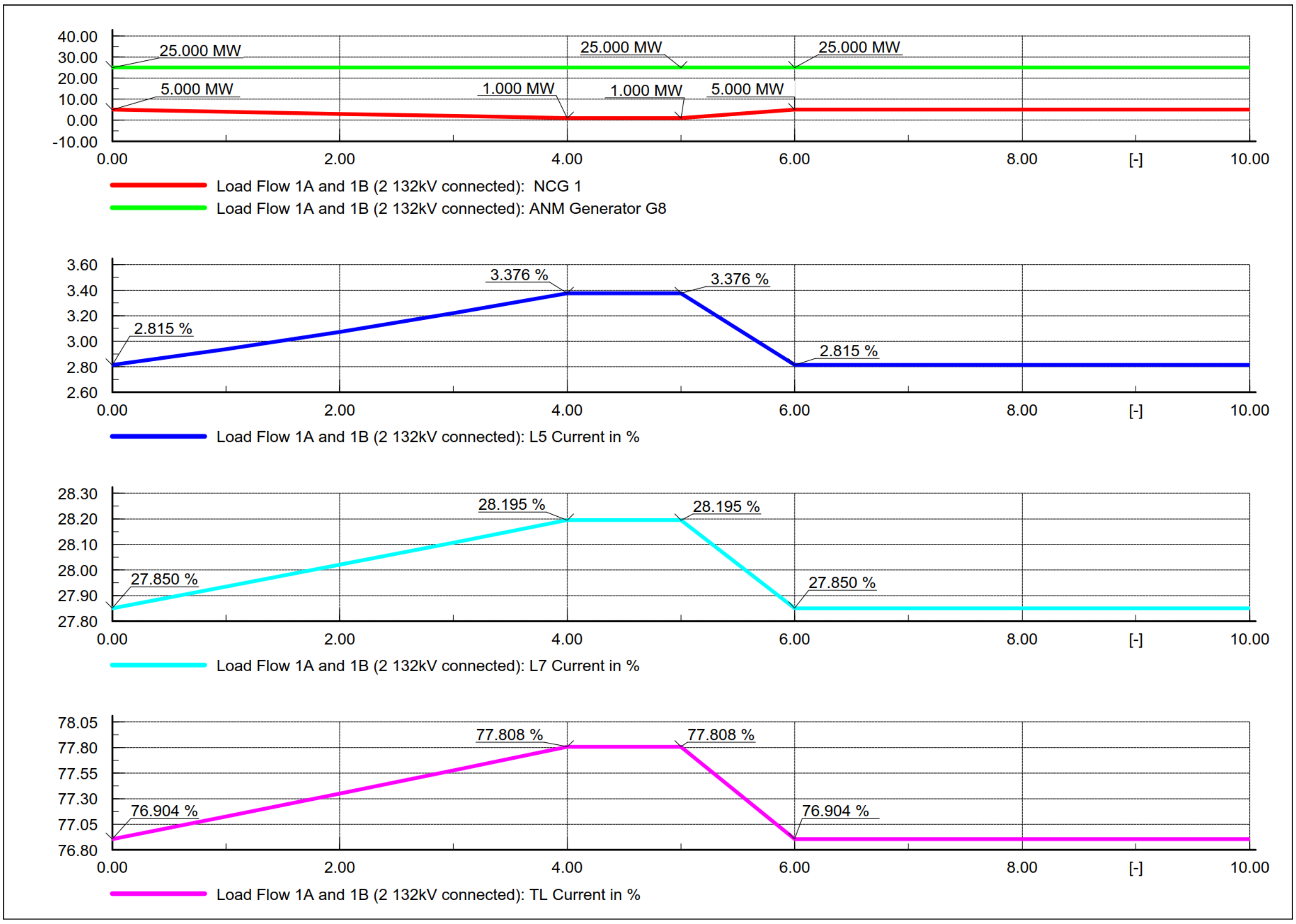

Figure 6-10 - W1: Non-curtailable generator 1 decriment and L1 out of service

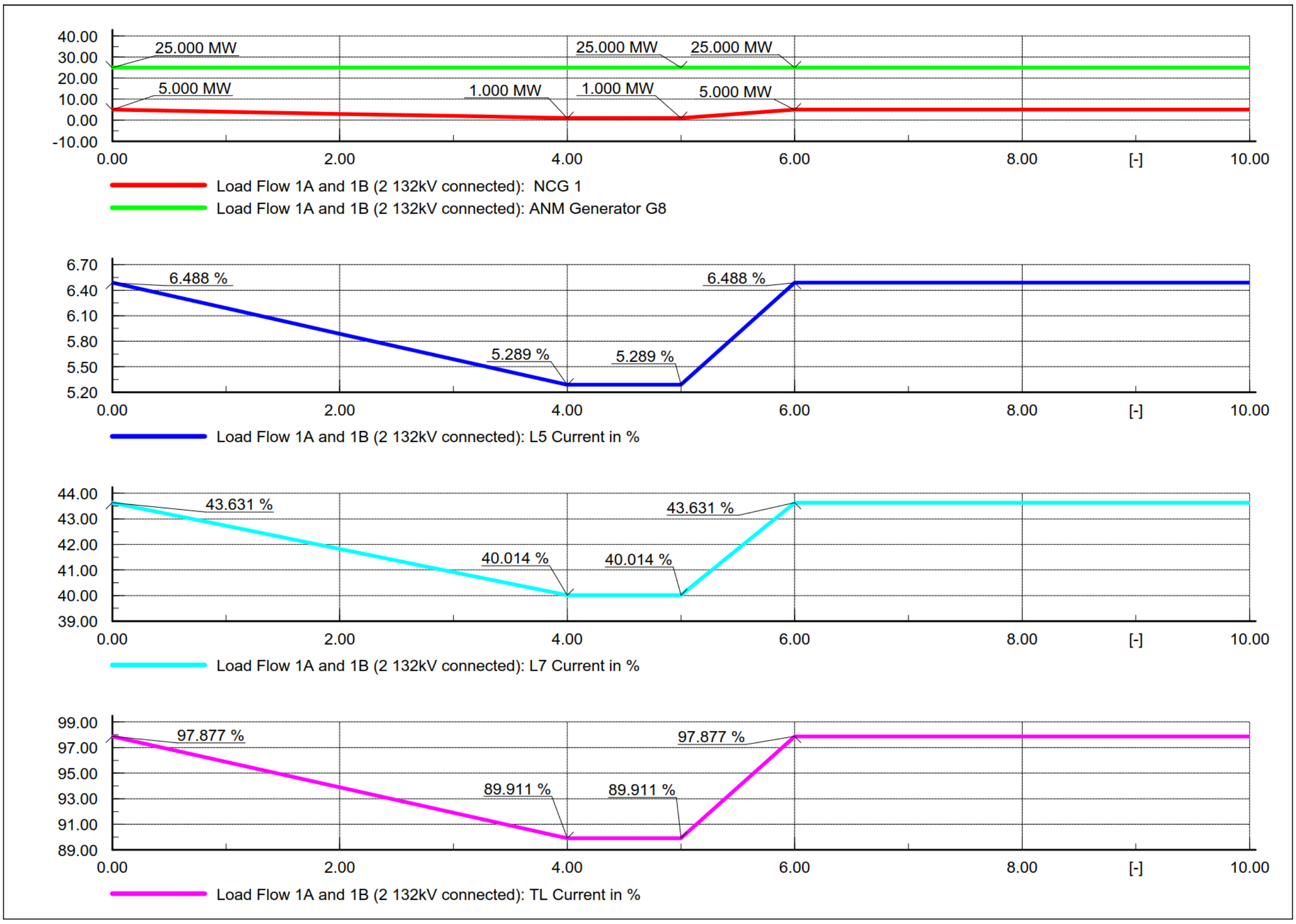

Figure 6-11 - W1: Non-curtailable generator 1 decriment and L6 out of service

Decrement service provided by non-curtailable generator 2 (downstream)

Figure 6-12 to Figure 6-14 illustrate the impact when non-curtailable generator 2 is reduced. ANM, like the previous case does not respond to the decrementing of generation during the settlement period.

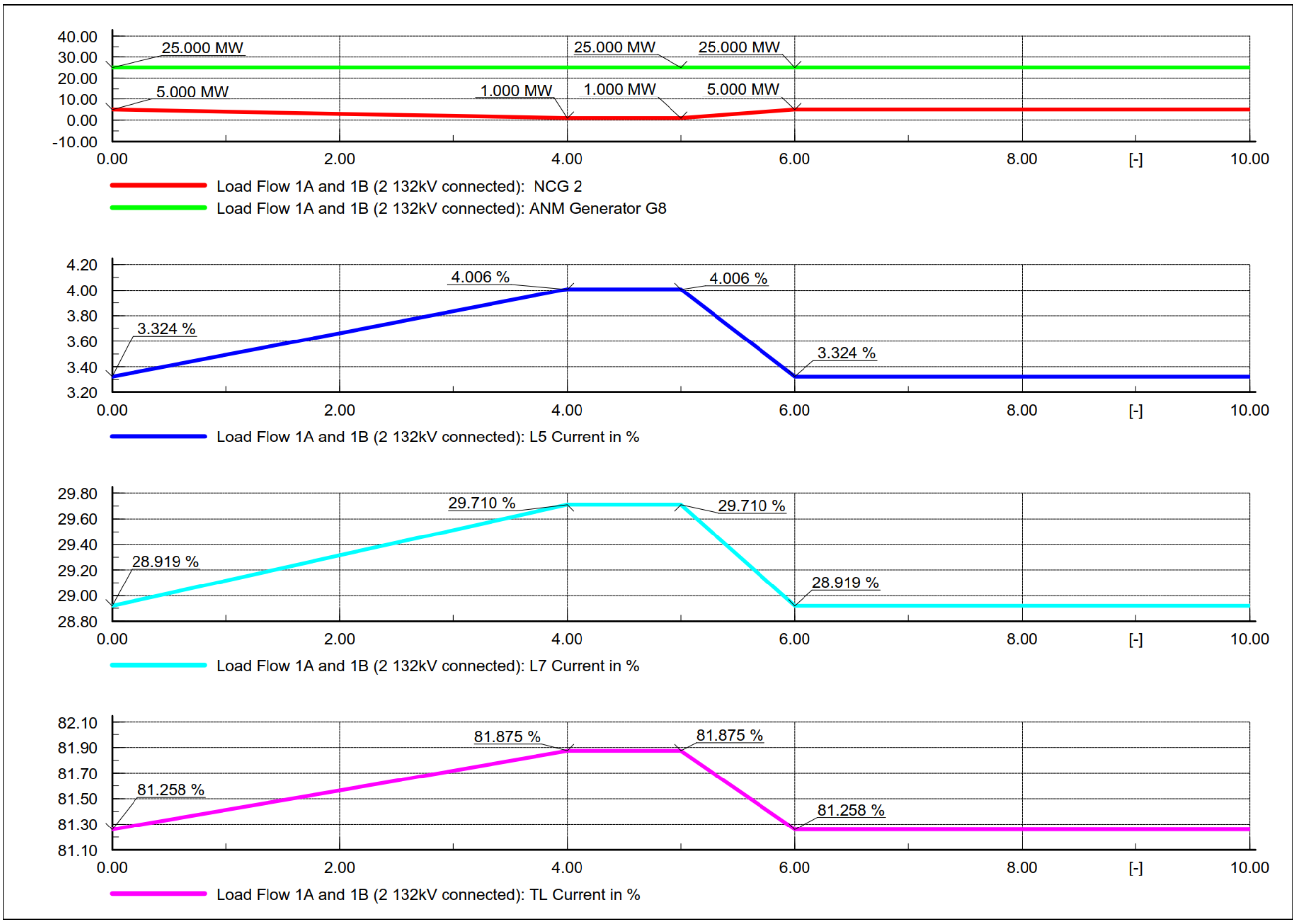

Figure 6-12 - W1: Non-curtailable generator 2 decriment and all cables in service

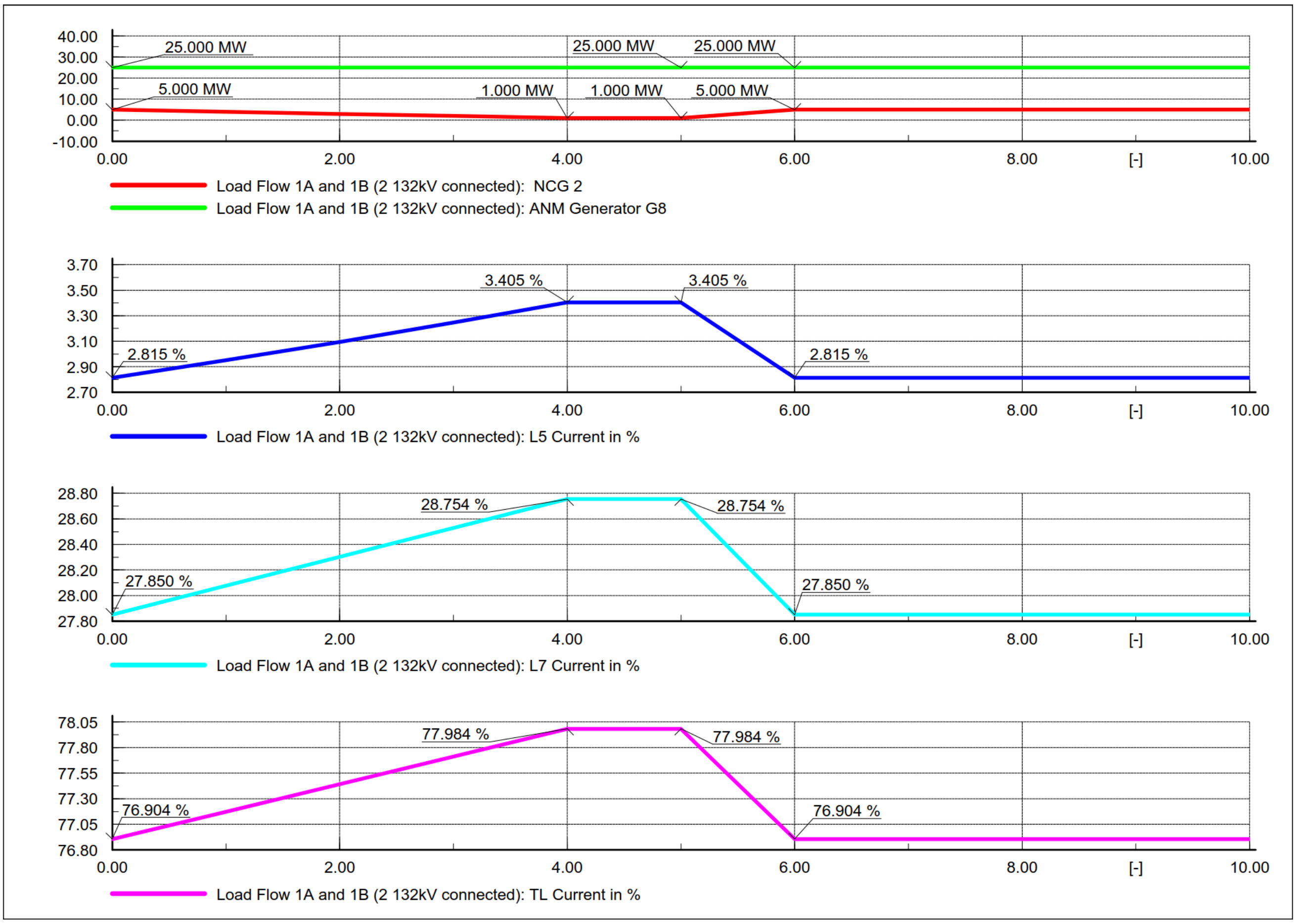

Figure 6-13 - W1: Non-curtailable generator 2 decriment and L1 out of service

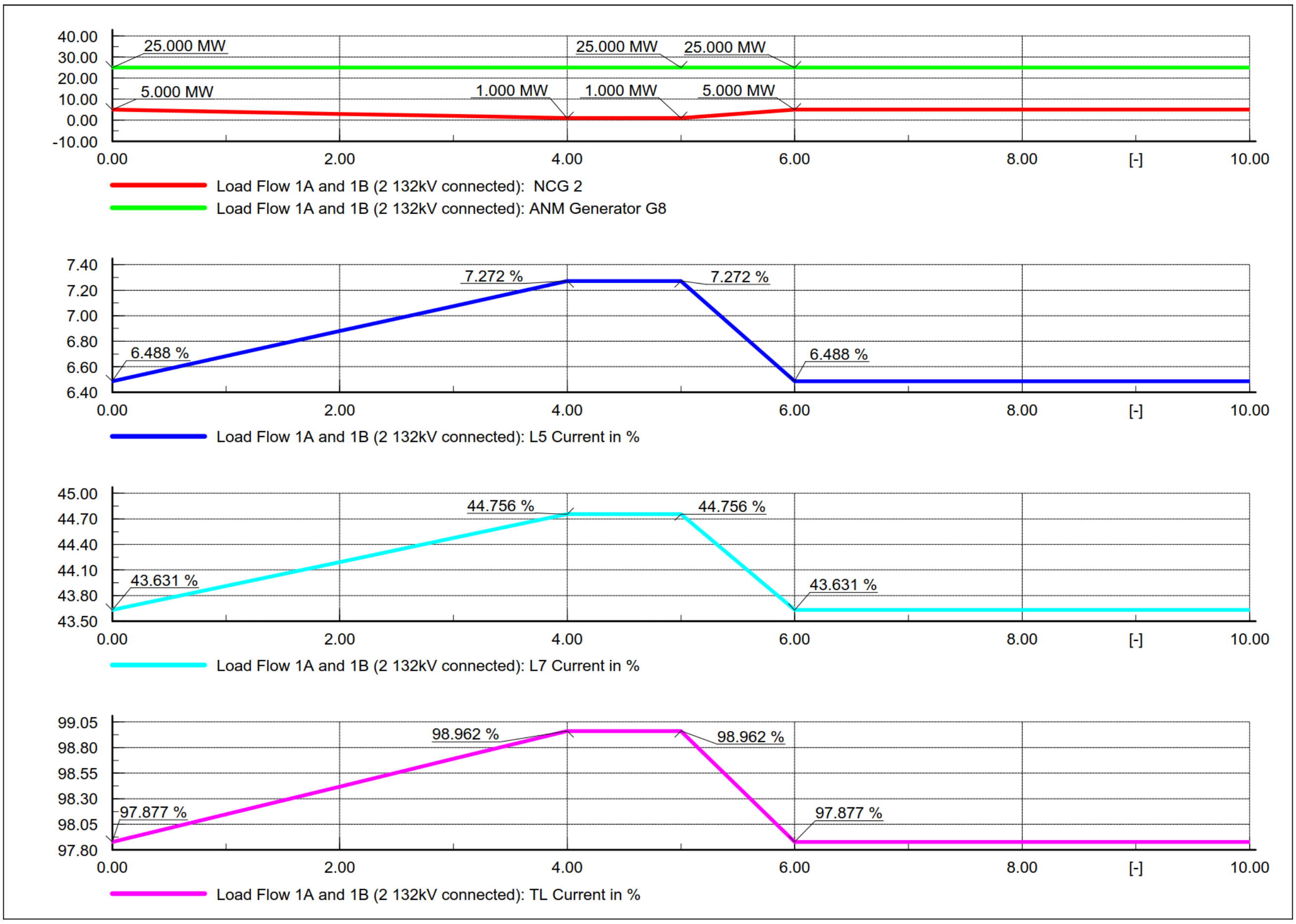

Figure 6-14 - W1: Non-curtailable generator 2 decriment and L6 out of service

To sum up, the modelling and simulation results of solution W1 have demonstrated the feasibility of implementing the sequences of the solution that are presented in Figure 5-1 in Section 5 to overcome any possible conflicts between BS operation and ANM actions. The test network and ANM models and the automation script model developed in this section have emulated the parallel instructions which can be sent by NG ESO to BS providers and ANM control, the BS settlement period, the capability of non-curtailable generators to deliver the decrementing service within the identified settlement duration, the ANM to hold its headroom, and the ANM to return to its default state following the delivery of decrementing balancing service.

The simulation results have proven that requested BS effect will not be cancelled by ANM actions if W1 solution is implemented. The operation of the decrementing service aided by W1 solution will minimise the risk of operating the system outside its normal limits during BS settlement periods. Over and above, it minimises the need for NG ESO to dispatch other BS from outside the ANM areas, hence reduce the cost of the service which is ultimately passed onto the network consumers.

6.3.2 MODELLING OF Z SOLUTIONS (CLASS ANM CORDINATION)

Solution Z1 is already implemented within ENW's network. This solution has ANM and CLASS implemented in different areas of their network. Furthermore, either CLASS or ANM is given priority at any given time – they always work separately due to the protocol implemented.

Typically, CLASS will be implemented in areas that are dominated by demand rather than generation. This means there will be limited numbers of ANM generators, and the likelihood of conflicts with ANM operation will be relatively low. However, if the number of distributed generators in an ANM areas was to increase, the probability of conflicts would increase.

The benefit of this solution is that it fully avoids CLASS and ANM actions counteracting one another and ensures service delivery. However, the complexity of communication and monitoring infrastructure between ANM and CLASS systems is likely to lead to a high implementation and operational costs; ANM generators could be unnecessarily constrained to enable the provision of CLASS services to NG ESO, presenting an opportunity cost to those generators; and generation-dominated ANM areas may preclude the use of CLASS.

Solution Z2 which represents the operation of CLASS and ANM in a coordinated manner has been modelled in this section and it is performance is compared the ENW reference case Z1.

CLASS is a voltage control scheme which controls network/substation voltages to reduce/increase demand for support frequency response. There are two common methods to achieve this by CLASS; change of transformers taps and/or trip of one transformer to increase the network impedance, hence reducing the voltage on the remaining transformer secondary. To assess Z2 solution when CLASS and ANM are implemented in the same area, a DPL automation script was developed and used for performing the following:

- **Change of voltages and demand reduction via a tap changer**
  An initial load flow was conducted with a tap setting of - 4. The code then increased the tap changer position in single tap increments. In each instance, the voltage of the LV busbar, the demand of the voltage dependant load, and the ANM generator output connected to the same bus managed by CLASS were collected and stored.

  If the voltage remained within permissible limits (between 0.94pu and 1.1 p.u), the ANM would not alter its generator output (i.e. hold its headroom and CLASS has precedence). However, if the voltage bounds are exceeded, the ANM would instruct its generator to increase/decrease its power output to bring voltage back to the allowed limit. Once voltage is back within limits, CLASS would once again take priority. If the ANM generator reached its output capability prior to restoring the voltage, it would remain at its maximum capability - in this instance 12.5MVA at 0.95 power factor allowed for a maximum output of 11.88MW.

The results of coordination between transformer tap-changer-based CLASS function and ANM scheme managing voltage constraints are given in Figure 6-15 and Figure 6-16. The ANM scheme responds only if voltages are violated by CLASS actions and corrects them to normal as demonstrated in Figure 6-16.

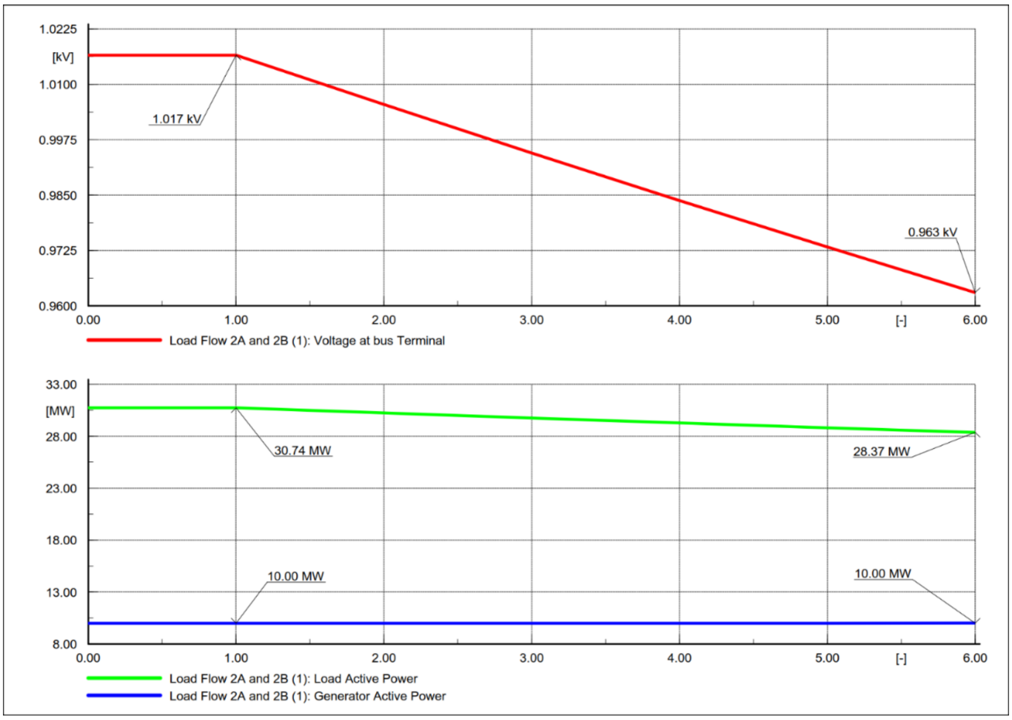

Figure 6-15 – Transformer tap changed from -4 to 1 by CLASS with no ANM reaction

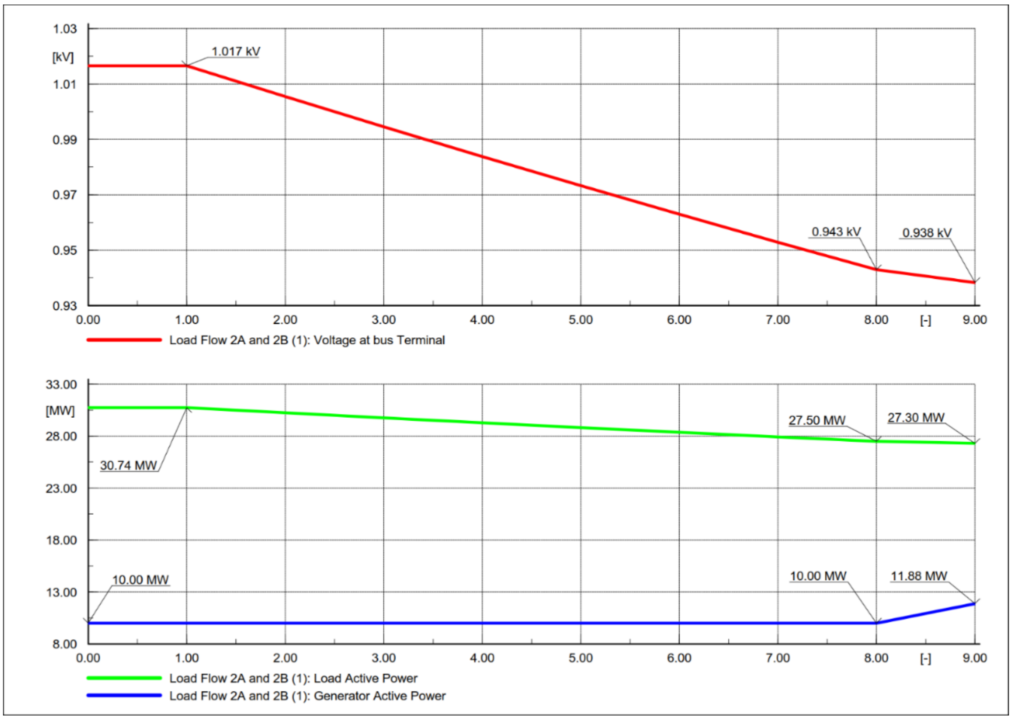

Figure 6-16 – Transformer tap changed from - 4 to 4 by CLASS vs ANM reaction

- **Change of voltages and demand reduction by taking one transformer out of service** An initial load flow was performed and the voltage of the transformer secondary, demand of the voltage dependant load, and ANM generator output were collected and stored. The main difference is that the tap changer was kept constant and one transformer (labelled as T6 in Figure 6-1) was taken out of service. This in turn, increased the impedance between the network and the 11kV bus (monitored by CLASS and ANM schemes), thus reducing the voltage observed and the associated responsive load. Dependant on the initial tap setting of the transformers, the voltage of the transformer secondary remained within or exceeded the voltage bounds, thus influencing ANM operation as shown in Figure 6-17 and Figure 6-18.

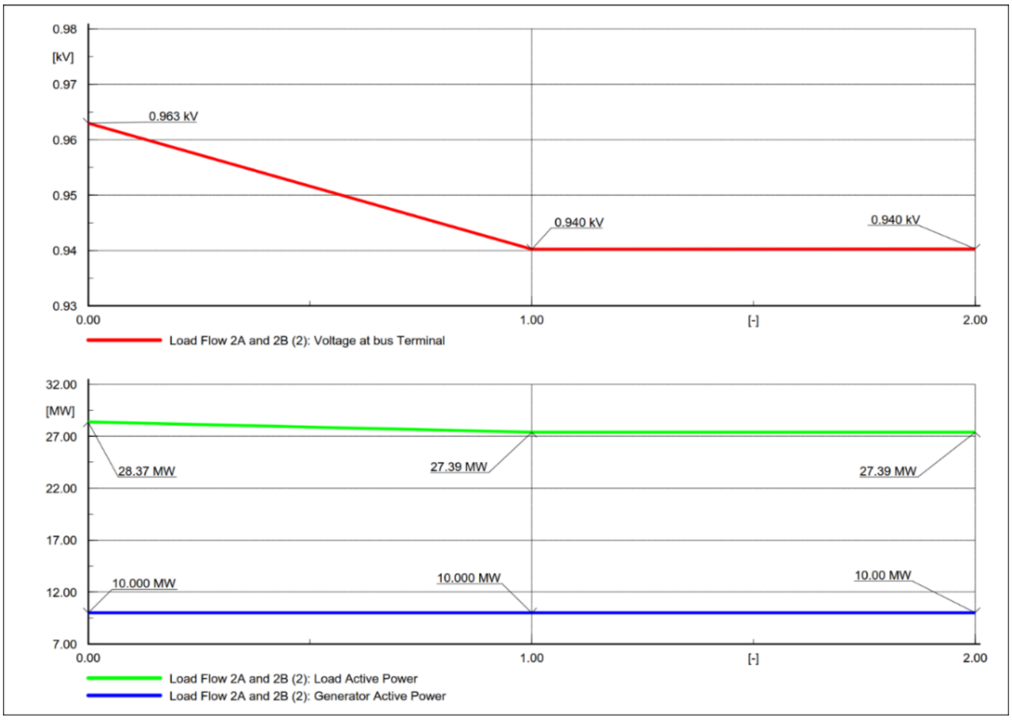

Figure 6-17 – Transformer (T6) taken out of service, initial tap position of 1 with no ANM reaction

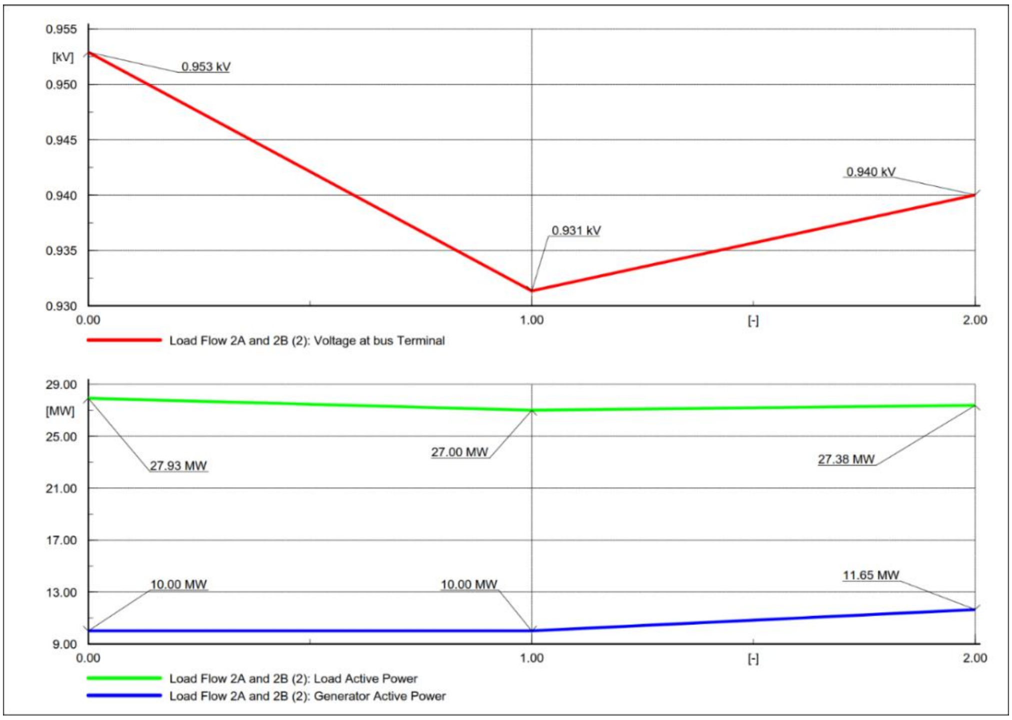

Figure 6-18 - Transformer (T6) taken out of service, initial tap position of 2 with ANM reaction

The modelling and simulation results of this subsection have shown that solution Z2 provides an effective coordination between CLASS and ANM schemes by operating them within different voltage bands. CLASS control has delivered frequency response services during normal voltage operation bands, and the ANM reacted only when the voltages were brought outside of the permissible limits due to demand reduction by CLASS. Such improvement in CLASS and ANM coordination will potentially mitigate unnecessary constrains of connecting and operating ANM generators within ‘demand-dominated’ CLASS areas and allow the implementation of CLASS in ‘generation-dominated’ ANM areas.

In general, the modelling and simulation analysis have proven the concept of W1 and Z2 solutions and their associated logic and sequences presented previously in Figure 5-1 and Figure 5-5 in Section 5. The elements that are required to enable the sequences of each solution can potentially be used to estimate a high-level cost of modification in existing NG ESO and DNOs infrastructures to implement such solutions. At the stage of writing this report, there was lack of sources for working out such cost figures. Consequently, the associated cost of each developed solution has not been included in this report and not considered within the CBA analysis. This issue will be investigated further under the next project workstream and its impact on the implementation of solutions will be considered prior to development of the final detailed delivery plan for most favourable solutions deployment.

7 COST BENEFIT ANALYSIS OF THE SELECTED SOLUTIONS

This section focuses on quantifying the benefits of the selected solutions compared to the costs of implementation. Benefits derive from reduced Balancing Services costs by resolving the issues identified in the Test Cases, while costs are primarily associated with the need for new control and communication systems to implement the solutions.

7.1 METHODOLOGY

7.1.1 OVERARCHING APPROACH

We have focused our assessment of benefits on quantifying the benefit of reduced counteraction and increased liquidity in Balancing Services. Our focus is on three Balancing Services: the Balancing Mechanism (BM), Short Term Operating Reserve (STOR) and Firm Frequency Response (FFR). The rationale for this selection is set out in Section 7.1.2.

To quantify the benefits, we have:

- Analysed historical pricing data for each of the services considered while considering how procurement of those services may evolve in the future to derive a £/MW cost of procuring Balancing Services from different technologies
- Made assumptions on the likelihood of ANM curtailment in each time period
- Used information on the capacity of different technologies behind ANM schemes.

The detail on these steps is set out in the following sections.

7.1.2 BALANCING SERVICES CONSIDERED

The three Balancing Services selected reflect a representative range of the services procured by NG ESO against which benefits could be derived from the solutions considered.

- The BM is the most widely used Balancing Service, and the most prone to counteraction risk
- FFR has been used as it is a very fast response service with short delivery
- STOR by contrast requires a relatively slow response with longer delivery

The types of Balancing Services procured and method of procurement has changed in recent years and will continue to change over the coming years. We have assessed the possible benefits using the most recent data for each service, from which we have drawn conclusions on the potential future benefits.

For the BM, a large amount of data is available. We have collected data on all Bid/Offer Acceptances (BOAs) in 2019 and 2020, filtering out those which are "system flagged" (typically those dispatched by NG ESO for constraint management).

For STOR, procurement has traditionally been through three tender rounds each year, contracting up to two years ahead. However, this approach was suspended in January 2020[15], as it was no longer compliant with the European Clean Energy Package (CEP). Under the CEP, reserve services are required to be procured no sooner than day-ahead of delivery. Day-ahead auctions are expected to commence for STOR from April 2021. As a result of these changes, full data for STOR is only available up to June 2019. For this analysis, we have used the latest full year of data available.

FFR services have also changed. Most services are procured on a monthly basis, but in a move to shorten procurement timescales, weekly auctions for two products are being trialled. These products are Low Frequency Static (LFS) and Dynamic Low High (DLH). LFS is automatically triggered when frequency falls to 49.6Hz, response is required within one second and must be sustained for 30 minutes. DLH is a dynamic service that responds to frequency in real time.

More broadly, FFR services are being replaced by NG ESO's new Dynamic Containment (DC) service. This soft-launched in October 2020, so there is not yet sufficient data to include that new service in this analysis.

7.1.3 TIME HORIZON CONSIDERATIONS

Where available, we have analysed data for 2019 and 2020. However, given the changing nature of STOR and FFR, we are restricted by data availability for these services. For STOR, the last full year of data is the year to June 2019, we have assumed that STOR data for the second half of 2018 is representative, so have derived a full year of 2019 data using actuals where possible and prior year data otherwise. For FFR, weekly auctions commenced at the start of 2020, so we have a full year of data from that year, but not 2019. We will consider the implications of these restrictions when looking at qualitative benefits later in this section.

For the BM, granular data is available for a long period of time, so we have used complete data on all BOAs for 2019 and 2020. It is useful to have two full years to compare and contrast. 2020 was clearly not a "normal" year for system operation, with unusually low demand driven by COVID-19 lockdowns. Low demand resulted in a high proportion of intermittent renewables in the generation mix at some times, particularly in the first lockdown in Spring. However, this gives us a useful snapshot of a future system dominated by intermittent renewables, and so results for 2020 may reflect a forecast of future costs for the latter half of the 2020s by which time renewables penetration is expected to have increased.

2019 was perhaps a more typical year, so may be a more representative forecast for the early part of the coming decade, bearing in mind that continued social restrictions may continue to supress demand through the start of 2021.

[15] https://www.nationalgrideso.com/document/159311/download

7.1.4 CURTAILMENT ASSUMPTIONS

Assumptions on the extent and timing of ANM curtailment are important for the impact of solutions that reduce counteraction, and for those that allow participation for ANM generators in times of low curtailment probability (for example, solution Y1).

Current information from existing ANM systems on curtailment (which suggests a level of around 1%) is unlikely to be a good indicator of future operation, given the move to more widespread ANM usage amongst DNOs, and greater proportions of renewables on the system.

So, we have diverged from using historic data for determining the times at which curtailment risk is high, and have instead assumed that curtailment is most likely at times of high embedded renewables output and low demand on the system. We have used the proportion of demand met by embedded renewables to characterise each settlement period in 2019 and 2020 into a 'green', 'amber' or 'red' band, representing low, medium and high probabilities of curtailment respectively. The percentage probabilities are notional and assigned by us to each band. The parameters used are shown in Table 7-1.

Table 7-1 - Settlement period curtailment categorisation

Proportion of system demand met by embedded renewables	Status	Proportion of settlement periods with status in 2019 2020	Assumed likelihood of curtailment
0%-15%	Green	74.4%	2%
15%-25%	Amber	15.4%	25%
25%-100%	Red	10.2%	80%

The curtailment risk by month is shown in Figure 7-1. This demonstrates a higher risk of curtailment in the summer months with a greater proportion of demand met by renewables (due to embedded solar). It also demonstrates the impact of falling demand, with a greater proportion of 'red' periods in 2020, due to supressed demand compared to 2019. This is particularly apparent in May 2020.

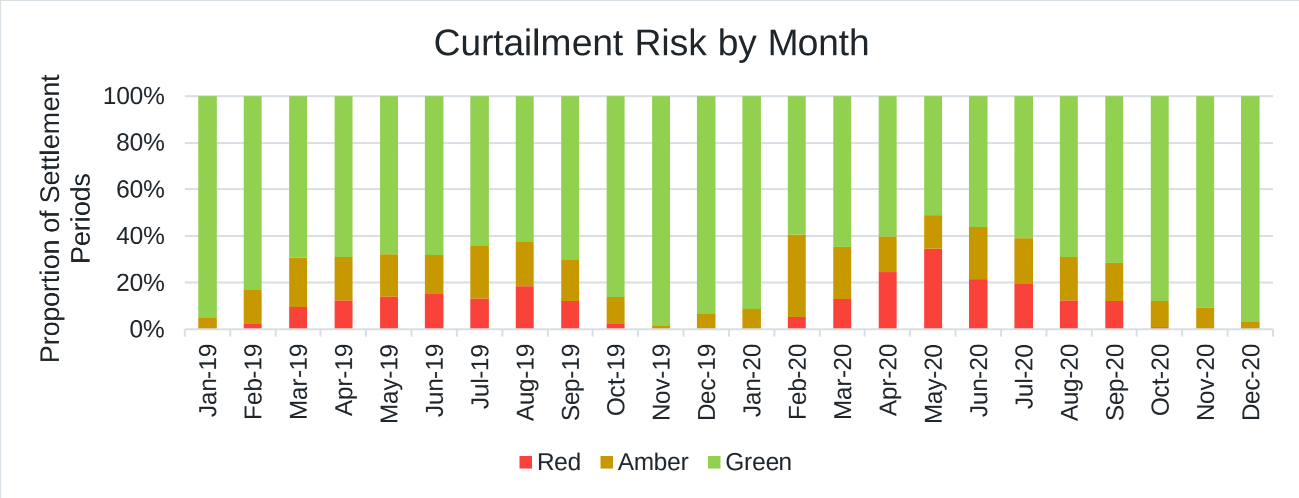

Figure 7-1 - Curtailment risk by month

Curtailment is also more likely to occur during the middle of the day, again matching a solar profile. This is demonstrated by Figure 7-2, showing how the proportion of settlement periods with each status varies throughout the day. Curtailment is most likely between 12:00 and 14:00 aligning with high solar output, but there are also numerous amber periods overnight, being driven by high wind output.

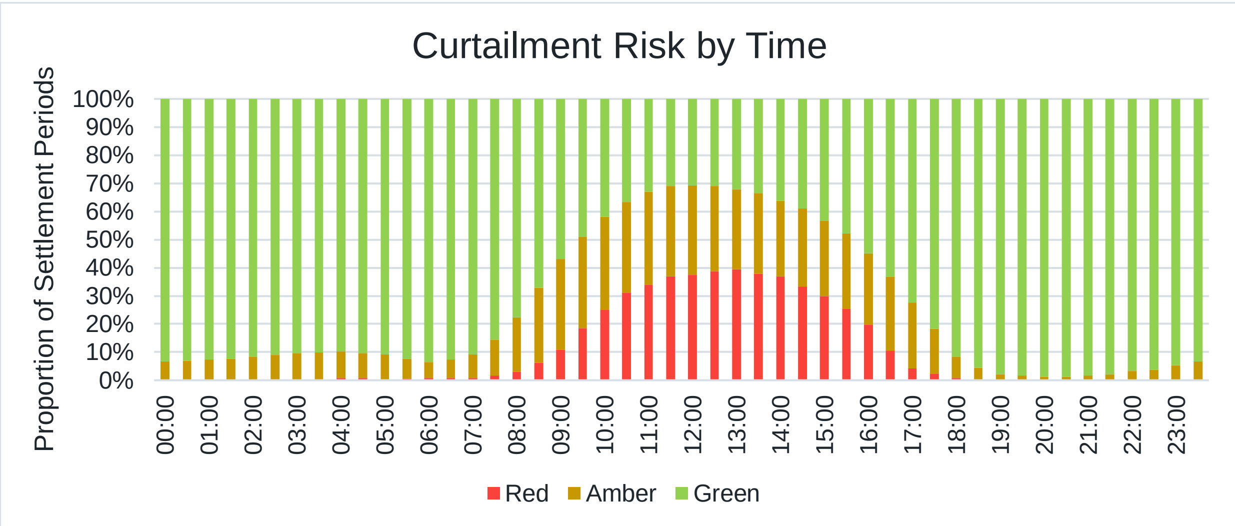

Figure 7-2 - Curtailment risk by time

The risk of curtailment in each time period (based on the status assigned) has been used to probability-weight the cost of counteraction in each time period. For example, if the cost of counteraction in a given time period were £20/MW, if that were to fall in a red period we would assume an 80% probability of counteraction in that time period and so include in the total benefit a contribution of £16/MW; conversely if it were to fall in a green period we would assume a 2% probability of counteraction and so include in the total benefit a contribution of £0.40/MW.

7.1.5 ANM CAPACITY ASSUMPTIONS

To determine the level of generation capacity either subject to curtailment by ANM schemes, or uncurtailable but behind an ANM-managed constraint, we have used both the Embedded Capacity Registers that DNOs are required to publish under the DCUSA, and direct information from DNOs themselves. Where information conflicts, discretion has been used to determine which information is most accurate based on our bilateral conversations with DNOs as part of the work for WS1 of this project. The information used is summarised in Table 7-2.

Table 7-2 - ANM generation capacity

Technology	ANM generation (MW)	Non-curtailable generation (MW)
Gas	918	347
Wind	876	1,156
Solar	3,500	5,555
Battery storage	450	0
Other	971	0

We have included connected capacity as well as generators that have accepted to connect in the future, to give a forward-looking view of ANM capacity on the system.

We have also focused primarily on gas, wind, and solar when quantifying benefits. While there is a growing volume of storage behind constraints, its behaviour is much less predictable than that of more traditional technologies. There may be additional benefits derived from storage, but our approach has been to exclude them and thus risk underestimating the benefit; rather than include with spurious assumptions and risk overstating the potential benefits.

7.1.6 BM APPROACH

BM Bid/Offer behaviour for gas, wind, and solar has been determined as follows:

- **Gas:** Bid/Offer behaviour is based on the marginal cost of generation, using gas prices, carbon prices, and typical efficiency rates and operation and maintenance (O&M) costs. We have then assumed that:
  - In settlement periods where the Day Ahead power price is more than the marginal cost of generation plus a £5/MWh margin, gas plant will choose to run (in reality this is a conservative assumption, as generators will typically run for profit lower than this £5/MWh margin). As a result, it will only provide Bids in the BM, priced at the avoided cost of generation.
  - In settlement periods where the Day Ahead power price is less than the marginal cost of generation plus £5/MWh, gas plant will choose not to run. As a result, it will only provide Offers

in the BM, priced at its marginal cost of generation plus a £2.50/MWh margin accounting for start-up costs.

- **Wind:** only Bids are provided in the BM, and only in settlement periods where wind generation was active (determined using the observed load profile of embedded wind). We have assumed that Bids are priced at the Renewable Obligation Certificate (ROC) price (effectively the lost revenue to the generator of not running) plus a small element of variable operating cost of £5/MWh.

- **Solar:** as with wind, but solar typically does not incur any variable O&M (it has no spinning turbine) so the price is set based only on the lost ROC price. Some solar will be connected under the Feed in Tariff (FiT) scheme, but this will typically be very small scale and so less likely to participate in the BM; larger scale solar which is more likely to participate in the BM is more likely to be under the ROC scheme.

The impact of counteraction has been quantified by assuming that:

- For each 1MW of BM Bid/Offer which is counteracted, NG ESO is forced to procure an additional 1MW Bid/Offer; and

- That additional 1MW Bid/Offer is procured at the marginal price, i.e. the price of the most expensive accepted Bid/Offer in the settlement period in question.

In addition, it is assumed that in periods when the system as a whole is "long" (NG ESO procures more bid volume than offer volume to achieve a net reduction in generation) that only Bids are counteracted, and vice versa. In reality this is not the case – NG ESO procures both Bids and Offers in almost all time periods as it seeks to balance supply and demand. But the simplification will, if anything, result in an under-estimate of the impact of counteracted Bids and Offers.

The impact of greater liquidity has been quantified by assuming that:

- If the Bid/Offer price for a generator of each technology is outside the marginal BOA, an additional MW of that technology would have no impact as it would not have been called

- If the Bid/Offer price for a generator of each technology is inside the marginal BOA, an additional MW of that technology would have been called and so the total cost of BOAs would have been lower – by the difference between the marginal BOA and the BOA of the technology in question

7.1.7 STOR APPROACH

For STOR, only the cost of counteraction is considered for each relevant solution. This is because STOR is already dominated by gas and diesel plant, so the benefit of increased liquidity here is likely to be small and would be difficult to meaningfully quantify.

For the reduced counteraction benefit, it is assumed that for each 1MW counteracted, NG ESO is forced to instruct, and pay a utilisation payment to, another 1MW of STOR at the marginal price.

Only gas capacity is considered here, as wind and solar are unable to compete in STOR.

7.1.8 FFR APPROACH

As for STOR, only the cost of counteraction is considered for FFR. This is because the market is dominated by battery assets, so the benefit of increased liquidity is likely to be small and difficult to quantify.

The DLH service requires response to frequency changes in real time so is typically delivered over very short (a few seconds up to a few minutes) timeframes. As such, we assume it is not possible for this to be counteracted by ANM systems in this analysis. Typically, ANM systems take curtailment actions with a lag of around one minute or greater, but some are faster acting, so by making the actual benefits may be greater through reduced counteraction of dynamic FFR, which is not quantified here.

However, the LFS service requires up to 30-minute delivery, so is at risk of ANM counteraction.

For the reduced counteraction benefit, it is assumed that for each 1MW counteracted, NG ESO is forced to pay an availability payment to an additional 1MW of LFS at the marginal price (the clearing price of the auction relevant to that period).

Only battery capacity is considered here, as that is the technology that makes up the majority of the FFR market.

7.1.9 DATA SOURCES

We have used data from following sources in our analysis:

- System demand data – NG ESO[16]
- Day ahead power prices – Nordpool[17]
- Accepted Bids and Offers in the BM – BM Reporting Service[18]
- Day-ahead gas prices – National Grid Gas[19]
- EU ETS clearing prices – procured by Cornwall Insight
- STOR tender and utilisation data – NG ESO[20]
- FFR weekly auction data – NG ESO[21]

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[16] https://data.nationalgrideso.com/demand/historic-demand-data
[17] https://www.nordpoolgroup.com/historical-market-data/
[18] https://www.bmreports.com/bmrs/?q=help/about-us
[19] https://mip-prd-web.azurewebsites.net/DataItemExplorer/Index
[20] https://www.nationalgrideso.com/industry-information/balancing-services/reserve-services/short-term-operating-reserve-stor?market-information
[21] https://www.nationalgrideso.com/balancing-services/frequency-response-services/frequency-auction-trial?market-information

- ANM generation capacity – Embedded Capacity Registers and DNOs

7.2 QUALITATIVE BENEFITS

Some of the benefits associated with the selected solutions are difficult to quantify, so are discussed qualitatively. This may be due to limited data availability or changes in system services and parameters causing uncertainty.

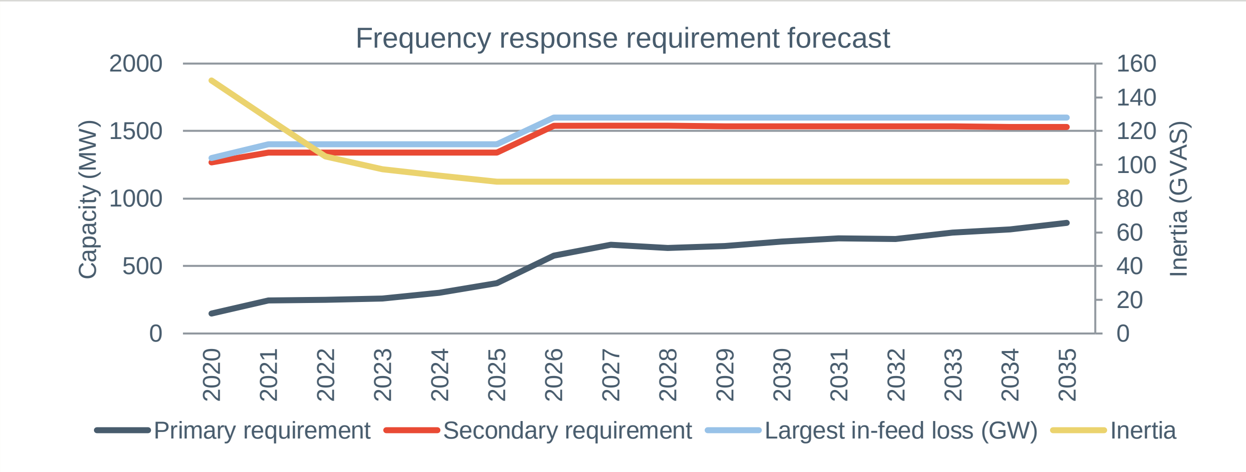
7.2.1 CHANGING BALANCING SERVICES

Balancing Services are due to undergo further changes to bring them in line with NG ESO's requirements for operating a system dominated by intermittent renewables.

One of those changes will be the amount of response and reserve service required. Cornwall Insight has undertaken a long-term forecast of the requirement for frequency response, based on changes to system inertia and the largest single infeed loss. This suggests that the need for frequency response services will increase over time, as shown in Figure 7-3.

In its Operability Strategy Report 2021[22], NG ESO states that "the need for faster acting reserve services springs from many of the same considerations […] for faster acting response services". We expect the conditions outlined in Figure 7-3 to lead to a greater need for reserve services as well as frequency response.

As a result of the increased need for response and reserve services, the benefits of allowing distributed generators to participate in these services are expected to be more material.



22 https://www.nationalgrideso.com/document/183556/download

Figure 7-3 - Forecast future requirement for frequency response

7.2.2 GENERATION MIX

The generation mix is expected to move towards a heavily renewables-driven system as part of the wider move to Net Zero, with low carbon flexible solutions, such as battery storage, becoming more important as a result.

The increased level of battery deployment will increase liquidity in frequency response markets, which will be accentuated by allowing distributed resources to participate in these markets. This benefit is not quantified due to the uncertainty around future levels of deployment and pricing for new response and reserve services.

7.2.3 ANM SCHEME ROLL-OUT

Our quantitative analysis focuses on existing generation capacity behind ANM managed constraints, resulting in a conservative assessment of benefits. As detailed in the WS1/WS2 report for this project[23], it is expected DNOs will roll-out ANM schemes more widely in the future, so the benefits of reduced counteraction would increase proportionally with the amount of generation behind ANM managed constraints.

7.2.4 CLASS ROLL-OUT

Our analysis of the solutions relating to CLASS are based on data related to provision of FFR service by ENWL using CLASS, as the only DNO to adopt the technology to date. In the time period (2019-2020) only limited amounts of service were provided, and only in 2019. As such the quantitative benefits of the relevant solutions (Z1 and Z2) are small. However, these would be expected to grow with adoption from more DNOs. CBA for the Shortlisted Solutions.

7.2.5 SOLUTION W1

Solution W1 issues a parallel instruction to the DSO as well as the generator when NG ESO instructs a decrementing service. On receipt of such an instruction, the DSO would be expected to not release any ANM curtailment in relation to a constraint upstream of the generator in question, which would avoid counteraction of any decrementing service. It would also enable NG ESO to instruct decrementing services from ANM generators with confidence that the service would not be counteracted, so we have also considered the benefit of increased liquidity by enabling Bids in the BM from ANM generators.

This solution only applies to decrementing services, so Offers in the BM, LFS FFR actions and STOR are not considered here, as they are all incrementing services (other FFR variants can be decrementing but we only consider the LFS variant here, which is incrementing).

The overall benefit of avoiding counteracted Bids for this solution is £10.6m based on 2019 data and £18.5m based on 2020 data, split fairly evenly by technology. The breakdown is shown in Figure 7-4.

[23] https://www.westernpower.co.uk/downloads-view/206443

The benefit of additional liquidity in the BM for Bids is £20.1m using 2019 data and £25.9m using 2020 data, much more heavily weighted towards gas. This is because gas Bids are much more likely to be competitive at times of high renewables output and the system is long, compared to subsidised renewables, which would price the loss of subsidy into Bids.

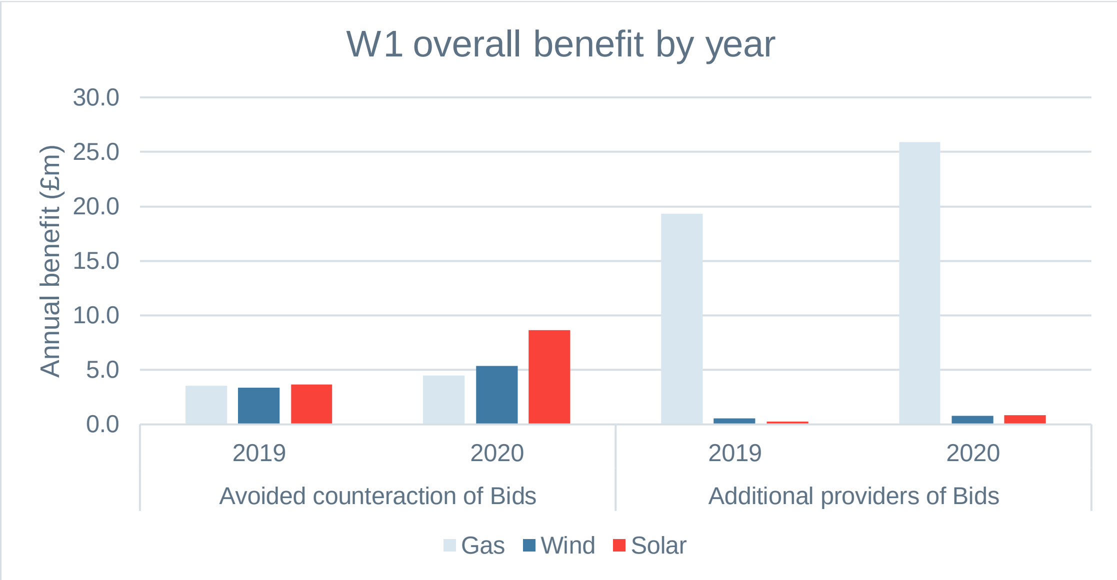


Figure 7-4 - W1 results by year

7.2.6 SOLUTION X1

Solution X1 includes improved communications between DNOs and generators on curtailment likelihood. This would then lead to generators behind ANM constraints not providing Balancing Services at times of high curtailment risk. We have quantified this by determining the benefit of removing the risk of counteraction in "red" time periods, where curtailment risk is at its highest. The solution would also enable the participation of ANM generators in Balancing Services during "amber" and "green" time periods, although as noted above, we only assess the benefit of additional liquidity in the BM because of the limited technology mix in STOR and FFR markets.

For the BM, counteraction of Bids and Offers is avoided in "red" time periods only leads to a total benefit of £21.6m using 2019 data and £47.3m using 2020 data. This is heavily weighted towards gas generation, as shown in Figure 7-5. As wind and solar are assumed to not provide Offers in the BM, and we are only considering "red" time periods, the benefit from these technologies is smaller than for solution W1. However, the benefit from gas is much greater as Offers are now included.

The increased liquidity benefit for the BM is £47.1m using 2019 data and £59.4m using 2020 data. Again, this is heavily weighted towards gas, with less benefit from solar and wind as participation is only increased in "amber" and "green" time periods. Gas generators providing Offers as well as Bids in these time periods drive the bulk of the additional benefit compared to solution W1.

For STOR the avoided cost of counteracted service is £10.3m using 2019 data, with data unavailable for 2020. This benefit is all due to gas generators as wind and solar are unable to participate.

For FFR, the avoided cost of counteracted service is £2.7m based on weekly auction LFS data for 2020. This is due to battery storage capacity as the main provider of FFR services.

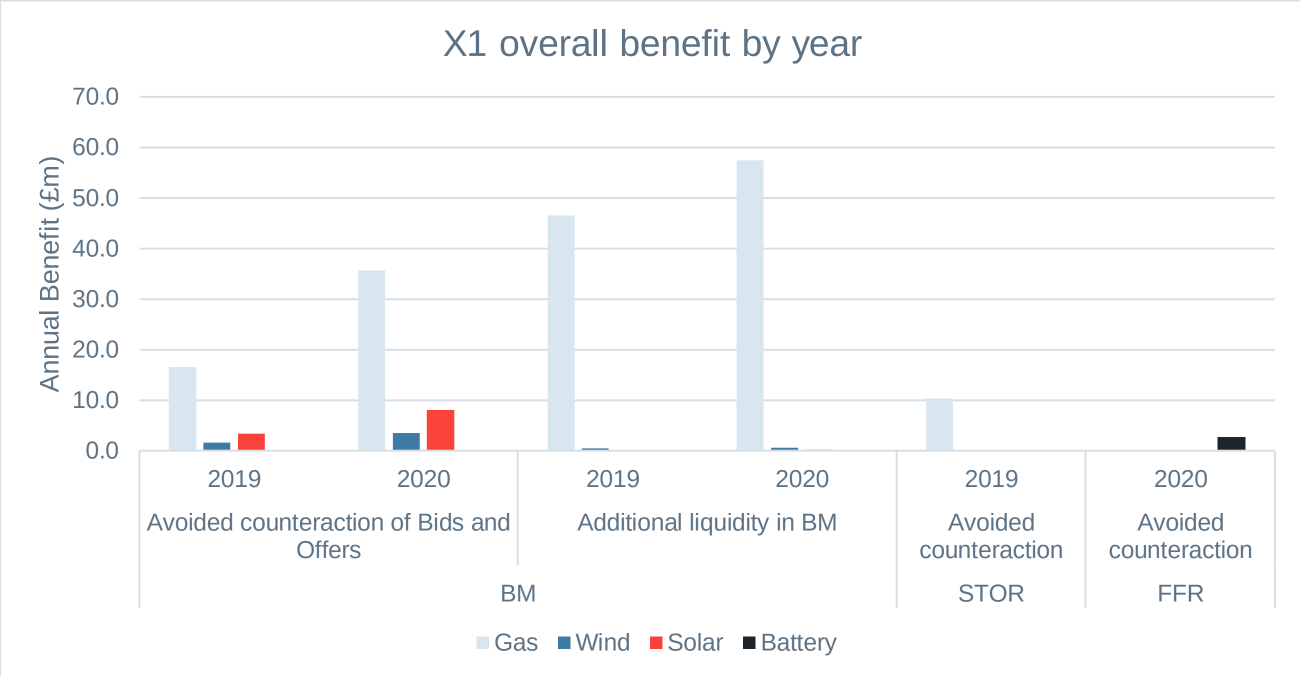


Figure 7-5 - X1 results by year and service

7.2.7 SOLUTION Y1

Solution Y1 involves a risk-based framework for procuring Balancing Services, with NG ESO procuring services with the assistance of DNO forecasting on curtailment probabilities. This removes counteraction risk for all Balancing Services, subject to uncertainty on DNO forecasts. We have approximated that uncertainty using a 5% error margin. This is a relatively small error margin but should be achievable as the DNOs will be required to forecast curtailment close to real time (e.g. shortly before gate closure) so should be able to provide accurate forecast. The solution also enables participation of ANM generators in Balancing Services in all time periods.

The benefits of avoided counteraction of Bids and Offers in the BM are greatest for this solution, at £35.1m using 2019 data and £64.3m using 2020 data, as counteraction is avoided in all time periods (subject to the forecast uncertainty). The breakdown is shown in Figure 7-6.

The benefit of additional liquidity in the BM is £50.7m using 2019 data and £68.9m using 2020 data, the higher figures again reflecting that this is the only solution allowing both Bids and Offers in all time periods.

The benefit of avoided STOR counteraction is £17.8m using 2019 data, higher than the £10.3m benefit of solution X1 as counteraction risk is removed in all time periods.

For the same reasons, the benefit of avoided FFR counteraction is also higher, at £4.3m using 2020 data for solution Y1, compared to £2.7m for solution X1.

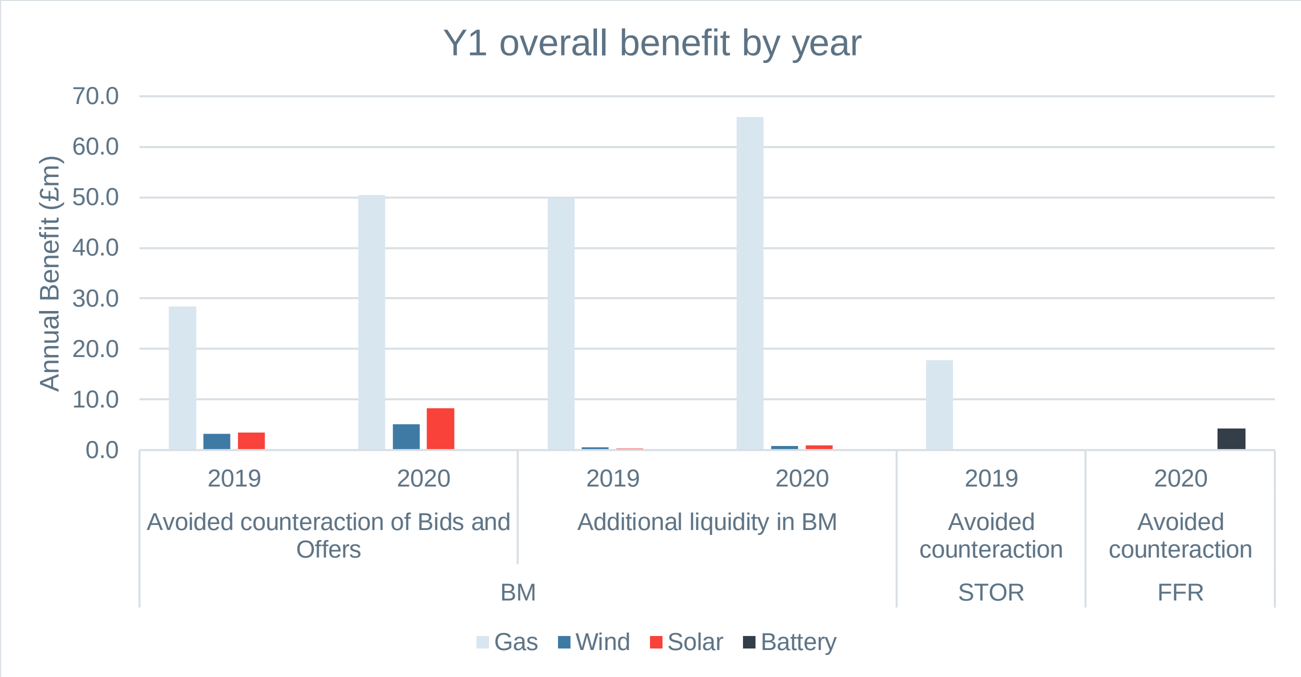


Figure 7-6 - Y1 results by year and service

7.2.8 SOLUTION Z1

Solution Z1 involves the coordination of CLASS and ANM systems. In this case, the CLASS system would monitor ANM systems and update export limits based on planned CLASS actions, avoiding ANM counteraction. This solution would avoid counteraction of Balancing Services provided by CLASS in all time periods. Coordination in this way is currently carried out by ENWL, and would be expected to be adopted by DNOs if CLASS systems are rolled out more widely.

Due to the limited roll-out of CLASS systems and low number of services provided, the benefits case is limited for this solution. ENWL is the only DNO to implement the CLASS system, and only provided static FFR services in three months in 2019. The BM and STOR markets are not affected, as CLASS is not active in these.

The total benefit of reduced counteraction in the FFR market for this solution is £529,000 using 2019 data.

7.2.9 SOLUTION Z2

Solution Z2 is similar to Z1 in that CLASS is coordinated with ANM systems. In this case, CLASS would modify its own operations when ANM is expected to curtail generation, to avoid counteraction. As such, counteraction of Balancing Services would be avoided in “red” time periods, when the likelihood of curtailment is highest.

As for solution Z1, the benefits only apply to FFR and not the BM or STOR services. The total benefit of reduced counteraction in “red” time periods is £347,000 using 2019 data.

7.3 SUMMARY OF CBA RESULTS

Table 7-3: Summary of solution benefits

Solution	Reference Year	Total benefit (£m)	BM benefit (£m)		STOR benefit (£m)	FFR benefit (£m)
			Avoided counteraction	Increased liquidity	Avoided counteraction	Avoided counteraction
W1	2019	**30.7**	10.6	20.1	-	-
	2020	**44.4**	18.5	25.9	-	-
X1	2019	**79.0**	21.6	47.1	10.3	-
	2020	**109.5**	47.3	59.4	-	2.7
Y1	2019	**103.6**	35.1	50.7	17.8	-
	2020	**137.5**	64.3	68.9	-	4.3
Z1	2019	**0.5**	-	-	-	0.5
Z2	2019	**0.3**	-	-	-	0.3

Table 7-3 shows that the highest benefits accrue from solution Y1, followed by X1 then W1. Although a full assessment of costs is not carried out in this package of work, at face value, the highest benefits come from the most complex solutions. The next work package, WS5, will evaluate barriers to these solutions, including costs.

The CLASS solutions (Z1 and Z2) have the lowest benefits, due to the limited roll-out of CLASS systems (only ENWL use CLASS) and corresponding limited BS provision from these systems. There is uncertainty over the level of adoption in future of CLASS systems, and the extent to which these solutions would be 'business as usual' arrangements. It is unlikely a DNO would implement CLASS without coordinating the system with any ANM systems.

8 RECOMMENDATIONS AND CONCLUSIONS

The report has provided an overview of wide range of options defined earlier within the project to address possible counteractions between distributed energy resources (DER) Balancing Services (BS) operation and Active Network Management (ANM) schemes. The list of these wide solutions has then been assessed against an impact matrix with different evaluation criteria. These included discussion on the readiness of each solution in terms of technology, regulatory, and commercial compared to their long-term benefits for ensuring the delivery of BS requested by National Grid Electricity System Operator (NG ESO) without conflict with other automation systems such as ANM schemes.

Solutions that were found to have a significant impact in ANM curtailment frequency were removed from the list as any benefits will likely be lowered by higher curtailment.

The shortlisted favourable solutions as recommended by this report included the following:

- The requirement for parallel decrementing instructions from NG ESO to BS provider and ANM schemes (named as “W1” solution in this report) for the ANM to hold its headroom and not to counteract the BS dispatch.
- The requirement for improving communication with generators on the likelihood of ANM curtailment (named as “X1” solution) to enable generators to receive curtailment forecasts from DNOs to ensure BS can be delivered before bidding.
- The requirement for risk-based BS valuation (named as “Y1” solution) to enable NG ESO to receive curtailment forecasts from DNOs to be factored into BS dispatch.
- CLASS scheme and ANM separation (named as “Z1” solution) for ensuring only one of CLASS or ANM is active at any given time and avoid the counteraction between the two schemes.
- CLASS visibility of ANM and coordination (names as “Z2” solution) for enabling CLASS and ANM to operate simultaneously in a coordinated manner without conflict.

The merit of the aforementioned shortlist (W1, Z1 and Z2) was studied using DIgSILENT simulation tool. A part of WPD South West licenced area was selected as a case study for modelling of different test cases and their corresponding solutions. In addition, Cost-Benefit Analysis (CBA) of the all shortlisted solutions (W1, X1, Y1, Z1, and Z2) was also performed using a combination of BS data from 2019 and 2020, and the reduction in the total cost of each BS estimated by quantifying the cost of counteracted BS and the benefit of greater BS liquidity.

The outcomes of the technical and CBA assessment have led to the following recommendations:

- The modelling and simulation results have demonstrated the benefit of creating a new communication route between NG ESO control room and ANM schemes to instruct such schemes to deactivate their control actions (i.e. hold headroom) during the BS settlement period identified by NG ESO. This has overcome the counteraction between BS operation and ANM actions which could be experienced without implementation of such solution (i.e. W1). The CBA has also estimated financial benefit from this solution ranging from £30-45m/year from reduced counteraction and increased BS liquidity.

- The CBA for improved communication with generators on the likelihood of ANM curtailment (i.e. X1) and for the risk-based BS valuation solution (i.e. Y1) have shown materially benefits, ranging from £79-110m/year for X1 and £100-140m/year for Y1.

- CLASS (scheme to provide frequency response services) and ANM coordination Z1 solution requires the two schemes to operate separately (i.e. either CLASS or ANM is given priority at any given time). This approach is currently implemented by ENWL which is the only DNO operates CLASS system. The CBA related to this solution has shown that the total benefit of reduced counteraction in the FFR market can reach up to £529,000. This was based on some data from 2019.

  From the technical perspective, the likelihood of conflicts with ANM operation using Z1 is relatively low. However, using such approach could potentially constrain ANM generators to enable the provision of CLASS services to NG ESO, presenting an opportunity cost to those generators. Also, generation-dominated ANM areas could restrict the implementation and roll-out of CLASS within these areas.

- Our technical analysis within this report has demonstrated the feasibility of implementing Z2 solution to improve the coordination between CLASS and ANM. This was achieved by operating CLASS and ANM implemented within the same area using different voltage bands. The BS can be delivered by CLASS by changing the network voltages within normal voltage limits (i.e. +10% and -6%), and the ANM will take action on curtailment only if the voltages are violated outside of the permissible limits due to demand reduction by CLASS.

  The current approach implemented by ENWL (Z1 solution) corrects the voltages outside of the limits by using transformers tap changers with no impact of ANM on this. Having the ANM coordinated with CLASS as proposed by Z2 solution, ANM could compensate the impact on the voltages caused by CLASS. ANM can also provide faster response in comparison to changing transformers taps to address voltages outside of the normal limits.

  The CBA for Z2 solution has shown £347,000 financial benefit of reduced counteraction using 2019 data. This figure is relatively low in comparison to Z1 CBA. The CBA of Z2 did not include the benefit to the ANM generators to work out the total saving and benefit to the relevant parties. The inclusion of benefit to ANM users would be required to have better and fair comparison between Z1 and Z2 benefits.

Next steps

Further investigation of the barriers to deployment of the shortlisted solutions (including potential cost associated to each solution) will be undertaken under Workstream (WS5) of the project. WS5 work will also include consideration of remedial measures to overcome the identified barriers. We will subsequently conclude on the most favourable solutions and develop a detailed delivery plan for deployment.