NIE Networks DS3 System Impact Study

Project No: 11960
Document Version: 3.1
Date: 6 September 2018

Version History

Date	Version	Author(s)	Notes
05/09/18	3.1	Paul Morris Dr Avinash Aithal	Public version

Final Approval

Approval Type	Date	Version	EA Technology Issue Authority
Business	06/09/18	3.1	Mark Sprawson

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Executive summary

Background to the Project

The electricity system across Northern Ireland and the Republic of Ireland has ambitious renewables targets, set out by both the Strategic Energy Framework in Northern Ireland and with both jurisdictions aiming to achieve 40% 'Renewable Energy Sources of Electricity' (RES-E) in 2020. Hence, the 'Delivering a Secure Sustainable Electricity System (DS3)' programme has been put in place to ensure the secure, safe operation of the power system in Northern Ireland and Ireland in this low carbon future.

The DS3 programme has identified the need for developing and integrating additional System Services in the Single Electricity Market (SEM) to meet the challenges of operating the electricity system in a secure manner while achieving the renewable energy policy objectives. Traditionally, System Services have almost exclusively been provided by large-scale generation that was connected to the transmission system. However, over the past few years, there has been a significant increase in the uptake of distributed energy resources (DERs) connected to the electricity distribution networks. DERs, therefore, could supply an increasing proportion of whole system support services in the future.

System services have a beneficial effect on the overall balance between electrical supply and demand andcan be delivered from either exporting network users who rapidly increase their export or importing network users who rapidly decrease the amount of power they are consuming. In both cases, the rapid change in network loading will have an impact on the voltage received by other users and also change the loading on the circuits owned by NIE Networks. Both of which represent a risk to the quality and reliability of supply experienced by network users, this risk only becomes an actual problem if the network capability to host services is exceeded.

Scope and Objectives

The objective of this project was to assess the likely capability of NIE Networks' electricity distribution system to accept the deployment of System Services at new and at existing customer premises from a range of technologies. Seven candidate networks, four 11 kV feeders and three 33 kV networks, were identified to study the impact caused by the operation of DER in the delivery of System Services. These networks were selected as case studies and are not intended to act as a generalisation of all networks.

The hosting capability was investigated by quantifying the available capacity for each service and investigating limiting factors across the seven representative networks across a number of different scenarios of generation output and electrical demand consumption. Capacity to host System Services becomes limited when their deployment would result in unacceptable voltage quality or loading of circuits outside of capability.

The threshold capacities were determined to be set at the point where either loading or voltage quality problems would be expected, affecting the safety, quality and security of supply for all other customers across the selected 11 kV and 33 kV network groups.

This investigation considered the network capacity available during normal system operation (NSO) and one first circuit outage (N-1) condition on NIE Networks' system across several electrical consumption scenarios.

Key Project Learning

This project developed a view that across existing 33 kV and 33/11 kV networks the capacity to host System Services is finite and variable. The factors which influence the available capacity include:

- The amount of electrical power being consumed, which changes over daily and seasonal cycles on a minute to minute basis.
- How much power is being exported by local generators. Some of which will be able to decide how much power and when to export, whereas others, such as wind turbines will export power in accordance with the wind resource and hence will infrequently export at 100% of rated capacity.
- The configuration of the network and which circuits are available and on load. Outages on different circuits will have varying effects upon the available capacity for each customer.

Figure 1 summarises the results from the 33kV network groups that were studied. The plots indicate the maximum allowable capacity of System Services, at different pre-event generation levels. Table 1 summarises the maximum capacity of the 11 kV network groups that were studied to host System Services.

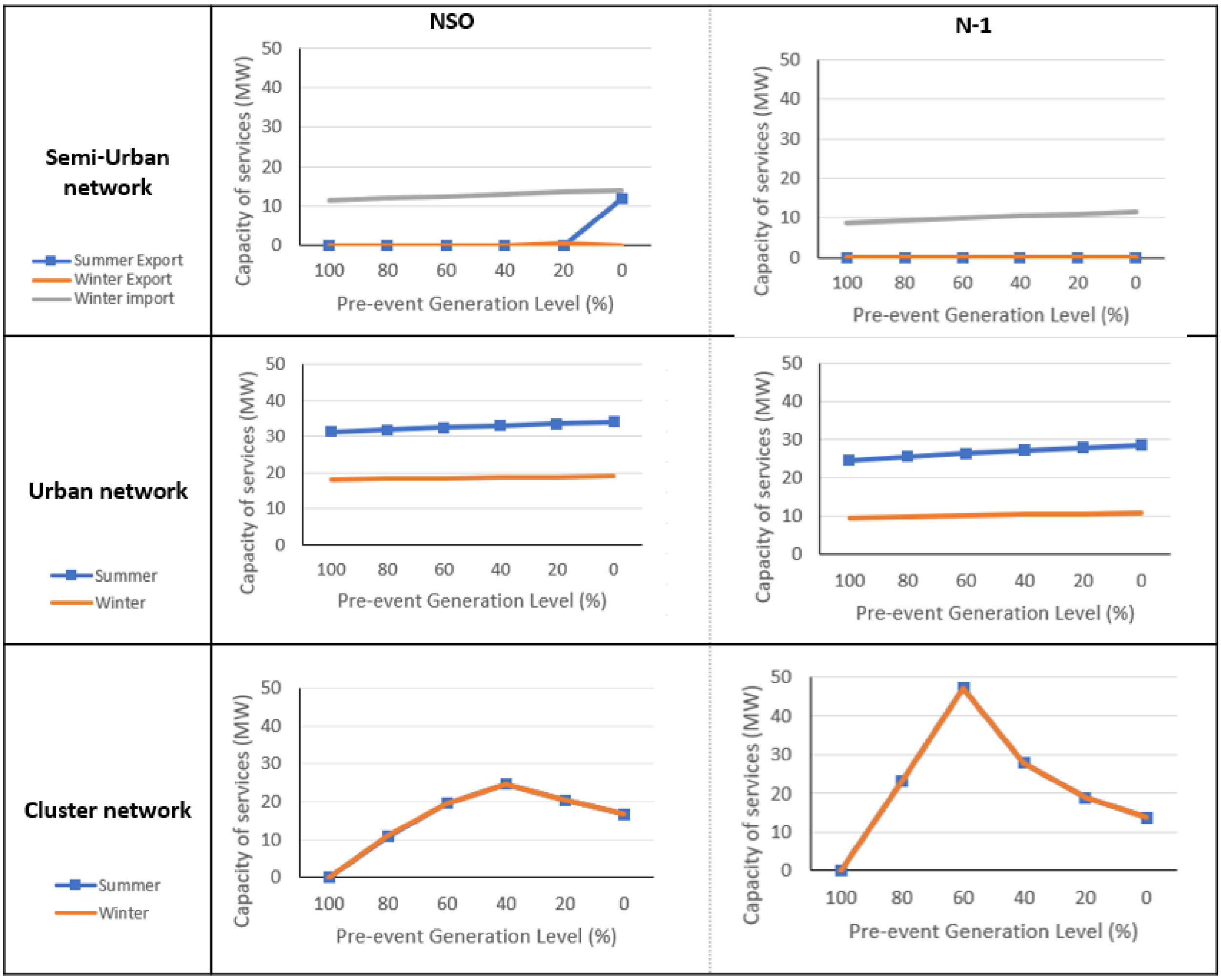

Figure 1 Capacity to host system services across 33 kV networks

Table 1 Capacity to host System Services on 11 kV Network

Network	Electrical Demand Condition	Capacity to host system services
11 kV Urban feeder	Summer	0.61 MW
	Winter	0.4 MW
11 kV Commercial feeder	Summer	1.54 MW
	Winter	0.55 MW
11 kV Semi-Rural feeder	Summer	0.05 MW
	Winter	0.07 MW
11 kV Rural feeder	Summer	0.01 MW
	Winter	0.05 MW

In all cases, it was observed that influence between the variables and capacity were complex and non-linear. It was observed that reducing the amount of power exported by generation did not always create more capacity for system services.

This was due to the fact that which variable became the limiting factor was influenced by the amount of power exported by generation. For example, when generation was modelled as exporting at 100% of rated capacity, the network was most likely to be limited by the requirement to maintain voltages to within +6% of nominal, whereas under circumstances when generators were operating at low output, the capacity for system services was most likely to be limited to avoid a step change in voltage that is too large.

For 33 kV networks, it was observed that the most common capacity limitations were because of either the requirement to maintain steady state voltage or to avoid a voltage step change greater than 3%. For this reason, in many cases, the System Services tested faced the same limiting factors, hence there was no differentiation in capacity between the various System Services.

This analysis demonstrated that the amount of electrical power consumption of customers and power factor of embedded generation also had a strong influence on the capacity to host System Services.

This analysis also demonstrated that urban or densely populated 11 kV feeders were likely to be able to host more DER than rural 11 kV feeders. The barriers to hosting DER on rural networks were almost exclusively down to voltage problems.

This analysis has provided an insight into the factors that determine the quantity of capacity that may be available within NIE Networks' for system services. Because of the significance of: minute to minute electrical demand, generation reactive power behaviour and the prevailing outage pattern, discussion has also been presented with regard to whether the available system capacity for hosting can be usefully expressed in the form of fixed look-up tables to represent all network conditions or whether this would unnecessarily curtail system access.

This analysis leads to a questioning of whether there may be stronger benefits to the industry if the capacity to host system services was actively managed and re-assessed on a dynamic basis or whether a simpler yet more rigid approach using fixed tables is more advantageous overall. The former approach would certainly be more expensive to implement yet would offer greater levels of access.

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1. Background & Introduction

Northern Ireland Electricity Networks Limited (NIE Networks) is the electricity asset owner of the transmission and distribution infrastructure and Distribution Network Operator (DNO) in Northern Ireland. NIE Networks deliver electricity to 860,000 customers in Northern Ireland.

The Northern Ireland electricity distribution and transmission networks are heavily influenced by the all-Ireland electricity operational and trading arrangements. These arrangements are being developed with the intention of facilitating high penetrations of non-synchronous and distributed energy resources, part of which is known as the DS3 programme.

1.1 The DS3 Programme

The Irish Strategic Energy Framework (SEF) has ambitious renewables targets, set out by both the Strategic Energy Framework in Northern Ireland and the Renewable Energy Directive in the Republic of Ireland with both jurisdictions aiming to achieve 40% 'Renewable Energy Sources of Electricity' (RES-E) in 2020. Hence, the 'Delivering a Secure Sustainable Electricity System (DS3)' programme has been put in place to ensure the secure, safe operation of the power system in Northern Ireland and the Republic of Ireland in this low carbon future.

The DS3 programme has identified the need for developing and integrating additional System Services in the Single Electricity Market (SEM) to meet the challenges of operating the electricity system in a secure manner while achieving the renewable energy policy objectives.

1.2 System Services

System Operator for Northern Ireland (SONI) and EirGrid (forming the Single Electricity Market Operator (SEMO)) have licence and statutory obligations to ensure sufficient System Services are available to enable the continuous balancing of electricity supply and demand guaranteeing the stability and security of the electricity system.

System Services are used by SEMO to ensure that the network frequency remains within acceptable limits during planned and unplanned system events. Traditionally, System Services have almost exclusively been provided by large-scale generation that was connected to the transmission system.

The significant presence of distributed energy resources (DER) in the electricity distribution networks displacing transmission-connected generation means that DER will have to supply an increasing proportion of whole system support services.

It is therefore important to understand the materiality of the impact caused by the operation of DER on the distribution network because of the delivery of System Service instructions. To this end, as part of the DS3 programme, this work has quantified and assessed the technical impact that different System Services may cause on the NIE Networks' Distribution System.

In total, there are 14 System Service products available to balance the system. This report considers the impact of seven of these services, as defined in Table 2. This report has focused upon seven of these products rather than all 14 as the slower system services such as DSU operation are already well understood through previous studies.

Table 2 Definition of DS3 System Services

Product		Deployment	Duration of deployment
Fast Frequency Response	(FFR)	Full deployment in 2 seconds from Event	Event +10 seconds
Primary Operating Reserve	(POR)	Full deployment in 5 seconds from Event	Event + 15 Seconds
Secondary Operating Reserve	(SOR)	Full deployment in 15 seconds from Event	Event + 90 Seconds
Tertiary Operating Reserve 1	(TOR1)	Full deployment in 90 seconds from Event	Event + 5 Minutes
Tertiary Operating Reserve 2	(TOR2)	Full deployment in 5 minutes from Event	Event + 20 Minutes
Replacement Reserve Desynchronised	(RRD)	Upon instruction at an agreed ramp rate	20 Min to 1 hour
Replacement Reserve Synchronised	(RRS)	Upon instruction at an agreed ramp rate	20 Min to 1 hour

1.3 Procurement of System Services

During instances when the demand consumption in a network mismatches the amount of generation production, the frequency of the mains waveform will depart from the nominal 50 Hz. Mismatches can be caused by unexpected loss of generation amongst several other causes.

To ensure that the system frequency always remains within acceptable parameters, the system operator will ensure that there are sufficient services available on the system to recover the system frequency back within acceptable limits in the event of a mismatch.

Because different technologies have different endurance and frequency response characteristics it is common for different System Services to be deployed at different stages throughout a frequency event. Figure 2 illustrates this idea by showing how the different DS3 services would deliver their response at different stages of frequency restoration.

To ensure that the frequency can be restored, system operator forecasts how much of the System Services, defined in Table 2, will be needed to maintain acceptable frequency. The system operator will then contract with sufficient quantities of service suppliers to meet this target.

Once System Services contracts have been agreed, there are technical frameworks which decide how each of the services is triggered and regulated.

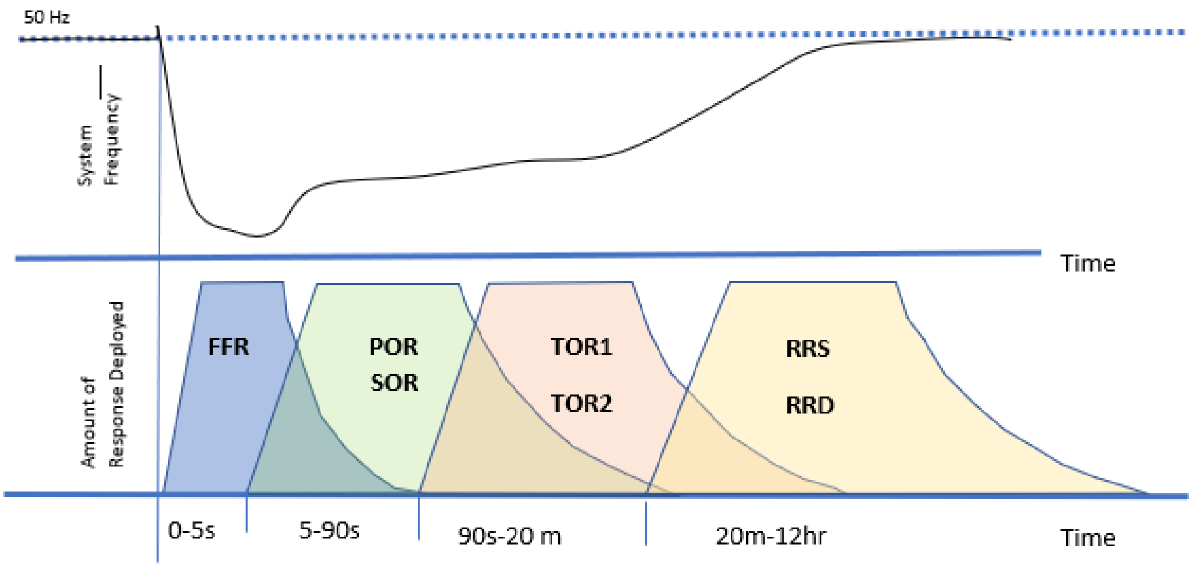


Figure 2 Deployment of response during an event

1.3.1 Deployment throughout a frequency event

System Services are typically deployed following a deviation in system frequency. The faster System Services are triggered by an automatic system which monitors the system frequency whereas slower System Services such as RRS or RRD require an instruction to be sent from the system operator to the provider before delivery will commence.

Automatic frequency control systems generally follow one of two approaches:

- Dynamic response, where devices constantly monitor the system frequency and vary the power export in a manner that is proportional to the change in system frequency
- Static response where devices constantly monitor the network frequency and trigger some form of fixed response when the system frequency falls beneath, or increases over, a fixed and constant value.

The implications of Dynamic and Static response in this study are discussed in 1.3.2.

1.3.2 Dynamic versus static response

Some services are termed as dynamic response as already described. Providers of dynamic response can have near-immediate ramp rates or much slower delivery rates depending on the technology providing the response. Generators and battery storage systems are good examples of dynamic response providers.

Dynamic provision is typically provided by linear power frequency characteristic known as “Droop”. These droop characteristics may also have a dead band within which deployment of response will not occur. By changing the linear gradient of the power frequency characteristic, the amount of reserve deployed for a given frequency change can be altered.

Some services providers are described as static. Static response is best described as a fixed quantity of response that is delivered each time the network frequency transgresses a certain limit. The amount of response delivered is not influenced by the size of the change in frequency, although it is possible to stagger many static providers to increase the amount of response deployed should the frequency continue to fall. Static response tends to be associated with demand-side response where demand is instantly reduced i.e. a step response.

It is important to understand that the DS3 arrangements are technology agnostic and permit provision of the services in Table 2 from static and dynamic providers alike.

This conclusion is important as it means that FFR, POR, SOR, TOR could be delivered by providers who can change their import in a near instantaneous profile such as demand side response or battery storage systems (who also can conduct step changes in their export). This would be in addition to generators who can also deliver these services but who would change output at a slower rate.

1.4 NIE Networks' challenge

In its role as distribution network operator in Northern Ireland, NIE Networks is conscious of expectations placed upon it that it will maintain an acceptable quality of supply to customers. However, if not properly managed, the participation of DER in System Services has the potential to worsen any or all of the safety, security and or quality of supply parameters.

NIE Networks is also conscious of DER stakeholder expectations that the distribution network should seek to minimise its influence on the operation of the DER market.

Clearly, these two requirements work in conflicting directions. Section 2 explains how this report explores how strongly these requirements conflict.

2. Scope and Objectives

2.1 Objectives of this project

- Investigate what penetrations of System Services from DER would need to be witnessed within typical 33 kV and 11kV networks before either loading or voltage quality problems would be expected. This investigation should be made by conducting a network impact assessment upon a selection of case study networks at both 33 kV and 11 kV.

    - It should be remembered that allocation of System Services may be made at sites that are already connected to the NIE Networks system as well as new connections.

    - Because System Services can be tendered for by an array of different technologies i.e. Battery, Demand Side Response, Synchronous machine; the approach to deciding upon the available capacity should be applicable to all technologies.

    Consideration was made as to whether the service assessment should be technology agnostic. This is the same approach as EirGrid's Volume Capped Consultation where providers must be able to provide a bundled service up to TOR2. Alternative approaches were considered but were dismissed on the basis that there would be no reliable means of ensuring that the assumptions regarding technology mix did not underestimate the likely ramp rate from service providers.

- The aim of this work is to inform NIE Networks of the impact of System Services on the Distribution Network if unfettered access is allowed. This may help inform NIE Networks of the necessary arrangements that must be in place to ensure that customers receive high safety, quality and security of supply whilst simultaneously enabling the system service markets to develop.

3. Approach

The following steps were taken to establish the limiting amount of System Services that can be allocated into each network group:

1. Consider what should be the rules that decide when no more System Services should be allocated into a network group; this is as described in section 4. These rules are based on requirements for NIE Networks to maintain acceptable standards of steady state voltage, voltage step parameters and network loading.

2. NIE Networks specified that the System Services investigation should be applied across seven different networks. Three of these networks were representations of 33 kV Bulk Supply Point (BSP) networks extending from the 110/33 kV transformers down to the 11 kV busbars at the primary substations. The additional four networks were representations of 11 kV feeders.

   It should be stressed that these groups should be treated as case studies and are not a means to make a generalisation about the available capacity across distribution networks.

   These seven networks are summarised in Table 3.

Table 3 Networks Studied

Network Name	Description
33 kV Semi-Urban network	33 kV BSP with five 33/11 kV primary substations and five 33 kV connected generators
33 kV Urban network	33 kV BSP with 15 33/11 kV primary substations and no 33 kV connected generators
33 kV Cluster network	Cluster substation with 5 wind farms
11 kV Urban feeder	11kV feeder supplying urban areas with small-scale embedded generation
11 kV Rural feeder	Rural 11 kV feeder with small-scale embedded generation
11 kV Commercial feeder	11kV feeder supplying urban areas with small-scale embedded generation
11 kV Semi-Rural feeder	Rural 11 kV feeder with small scale embedded generation

3. The networks described in Table 3 will have varying amounts of demand and generation within them. Because of this, the networks will have different loadings and voltage profiles at different times of day and year, which means that the available capacity to accept System Services will vary.

   Each network has different characteristics regarding how much power the source substation exported or imported and flows through circuits within the network group. For this reason, each network needs to have a different set of study conditions that are used to explore the extremities of the available capacity. Table 4 records the conditions against which each network was studied. In all cases, the term “maximum or minimum export” relates to the power flow across the source substation within the network group.

Table 4 Network Conditions Studied

Network Name	Winter Maximum Export	Winter Maximum Import	Summer Minimum Import	Summer Maximum Export
33 kV Semi-Urban network	Yes	Yes	Not applicable	Yes
33 kV Urban network	Not applicable	Yes	Yes	Not applicable
33 kV Cluster network	Yes	Not applicable	Not applicable	Yes
11 kV Urban feeder	Not applicable	Yes	Yes	Not applicable
11 kV Rural feeder	Not applicable	Yes	Yes	Not applicable
11 kV Commercial feeder	Not applicable	Yes	Yes	Not applicable
11 kV Semi-Rural feeder	Not applicable	Yes	Yes	Not applicable

4. Design an automation script which can be applied to calculate System Service allocation limits based on the rules developed in step one. This script is further described in section 6.

5. Conduct the analysis by applying the automation script to the 15 load flow models summarised in Table 4. This script analyses approximately 62 bus bars against the study cases in Table 4 which then produces 164 limit cases. Each limit case reviews 32 independent thermal and voltage tests per each System Service studied (5248 individual limits).

6. Review the results to decide:

    - What is the learning from this analysis regarding a protocol for allocation of System Services?
    - What is the learning from this analysis regarding how instruction sets might be used to improve the amount of System Services that can be allocated into a network?
    - What is the learning from this analysis regarding what network measures might be used to improve the amount of System Services that can be allocated into a network?

4. Network Limits

Section 1 acknowledges that NIE Networks must design and operate their network in a manner that ensures:

- Customers are supplied with an electricity waveform that meets acceptable parameters
- NIE Networks equipment is operated within acceptable loading conditions.

This section reviews the rules that should be used to study limits for System Service allocation and how they are incorporated into the analysis script.

4.1 Voltage Quality

When considering whether the voltage delivered by the network is adequate, NIE Networks must use the following standards.

4.1.1 The Electricity Safety, Quality and Continuity Regulations (Northern Ireland) 2012

These regulations place a duty on all network owners to ensure that the voltage supplied to customers connected at 11 kV or 33kV remains within a tolerance of ±6% of nominal under all steady state conditions.

4.1.2 Engineering Recommendation P28/2, Voltage fluctuations and the connection of disturbing equipment to transmission systems and distribution networks in the United Kingdom, 2017.

Repetitive changes in the behaviour of customer load, change in the output of generation or changes in the configuration of the overall system has the potential to introduce voltage sags, voltage dips and voltage swells upon the mains waveform. Engineering Recommendation P28 seeks to define the required quality of the waveform over a period of seconds.

This standard uses the following terminology:

Step Voltage changes

This refers to the observed change in RMS voltage 5 seconds after the switching or dispatch event. The change in the steady state voltage between the instant before service deployment and 2 seconds afterwards must not exceed 3%, as shown in Figure 3.

Rapid Voltage Change

Rapid voltage changes influence the network voltage over several cycles but are complete by 5 seconds. These changes are typically caused by motor starting/stopping, equipment energisation, switching of large loads, tripping of generation, tap changer operation.

There are different limit profiles allowable depending on whether the cause of the voltage change is classed as: very infrequent (< 1 event per month), infrequent (<4 events per calendar month) or frequent which captures any events which repeat on a more regular basis.

Figure 3 demonstrates the maximum allowable deflection in voltage that may be applied to each category (i.e. the voltage disturbance must remain within the area that has been plotted to be considered compliant).

It will be seen that in all cases, the voltage deviation must recover to within ±3% of nominal within 2 seconds of the disturbance. It should be observed that this value aligns with the limit for voltage step.

Reference to the definition of FFR in Table 2 shows that one single FFR event would be expected to have a total duration of at least 10 seconds, with the full commencement of FFR delivery within 2 seconds of the event. Comparison of this FFR definition against Figure 3 shows that a frequent event would have to fall within the ±3% contour within 100ms of the event commencing. For this reason, this study will adopt the view that all voltage changes associated with the simultaneous deployment of System Services must comply with the definition of frequent rapid voltage change as shown in Figure 3.

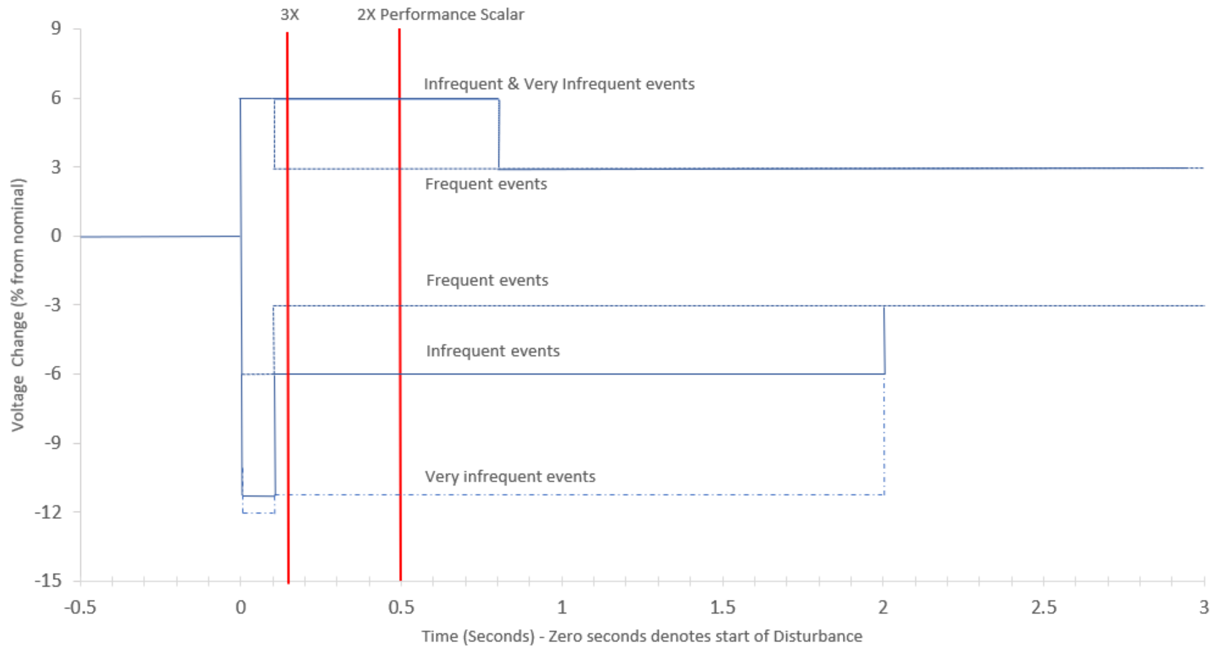


Figure 3 P28 limits for rapid voltage changes

Voltage Flicker

Voltage Flicker is the result of a repetitive change in consumer export or import. Flicker has traditionally been associated with equipment such as welders, repeated motor starts and arc furnaces. More recent examples of flicker-causing equipment include stall regulated wind turbines and battery storage that is cycling between import and export several times per hour.

The severity of voltage flicker is dependent upon the magnitude, rate of change and the frequency of occurrence for the voltage fluctuations.

The severity of flicker is quantified using flicker severity levels, Pst and Plt, where Pst is the short-term flicker severity measured over a 10-minute interval and Plt is long-term flicker severity measured over a 2-hour interval.

The P28 standard for flicker also shows that the most generous limit available for flicker phenomena is a change of 3% and would only be available to devices that changed output with a frequency of less than once every 500 seconds. Devices which changed status more frequently than this would be subject to limits less than 3%. Slightly greater tolerances can be applied to devices which ramp up and ramp down and slower rates also.

During the development of the methodology, it was acknowledged that different services would have different ramp rates which they would have to provide to be compliant with the service description. For example:

- FFR providers would be likely to have a near instantaneous ramp rate upon commencement of delivery. It is likely that this technology will be delivered almost exclusively from battery inverter technology.

- POR, SOR and TOR1 services might be delivered from a variety of providers including battery technology, demand-side response or generation that is already synchronised to the system.

Consideration was made to whether a review of ramp rates could be included to improve the limit that would be applied in the assessment. A decision was made not to include this feature in the final assessment as:

1. It would not support a protocol that was technologically agnostic;

2. The ±3% voltage contour at one second for rapid voltage changes (as shown in Figure 3) would still need to be respected regardless.

4.1.3 G59 Generator interface protection

Section 7.11 of the Distribution Code[1] seeks to put in place mitigations that remove the possibility of unacceptable interactions between the distribution network and embedded generation. Unacceptable interactions in this context refer to the unintended creation of unearthed power islands sustaining themselves.

Accidental power islands are unacceptable because they tend to lose continuity with their single point of neutral earthing and as such represent a major hazard to the public. Mitigations against unintentional power islands include putting in place electrical protection at the interface between embedded generation and the rest of the system to ensure that embedded generation trips itself off the system in the event of unacceptable conditions. Part of this electrical protection package includes an overvoltage element to disconnect the generation in the event of the network voltage exceeding 1.1 per unit for 500 ms. This overvoltage element presents a side effect, which is if the network operator was to temporarily allow network voltages to drift above 1.1 per unit, there would be widespread tripping of an embedded generation that was aiming to restore a network frequency event. Deployment of system services can push voltages in an upward manner.

Because widespread tripping of embedded generation due to a voltage excursion is unacceptable, the script which investigates the allocation of DS3 System Services must seek to avoid generation being tripped in this manner as it would undermine the plans by which the system operator expects to restore network frequency.

NIE Networks manage this risk by ensuring that their 33 kV system never reaches above 1.06 per unit voltage and protecting LV generation by ensuring that their 11 kV system never reaches above 1.03 per unit to ensure that LV connected generation is always fed with acceptable voltages (due to the inherent voltage boost within 11/LV transformers).

4.1.4 Harmonic distortion

Engineering recommendation G5/4-1, Assessment of Harmonic Voltage Distortion and Connection of Non-Linear Equipment to the Electricity Supply System in the UK, seeks to prescribe a process which ensures that new connections to the distribution network do not result in the distribution network exceeding harmonic limits.

Unacceptable harmonic distortion would result in damage or underperformance to electrical devices owned by customers and network operators.

[1] http://www.nienetworks.co.uk/documents/d-code/distribution-code-issue-4-11-may-2018.aspx

Unacceptable harmonic distortion from System Services would occur when either:

1. There is an increase of harmonic currents, at a particular order, injected into a part of a network that has a high harmonic impedance, at the same harmonic order as the currents

2. There is an increase of harmonic currents, at a particular order, injected into a part of a network that will resonate at the same harmonic order and thus amplify the distortion and project it across the network.

The deployment of System Services may influence the harmonic currents injected into the network, but it is unlikely to have an impact on the harmonic impedance of the system.

The influence of System Services upon the harmonic currents injected into the network is dependent on the technology delivering the response, for example:

- Increasing the output from power electronic devices may cause an increase in harmonic currents injected into the network. Which harmonic orders were injected would depend on the design and settings of the equipment in question. It should also be understood that some harmonic devices absorb some harmonics rather than injecting them too. The actual harmonic spectrum of injections or absorption is specific to each power electronic device.

  There is also a question of whether the current emissions are in phase or out of phase with neighbouring devices. This might mean that the amount of harmonic currents flowing into the network was less than expected due to harmonic cancellation.

- Synchronisation of additional generation, which would have the effect of absorbing harmonic currents and reducing distortion.

- Reduction of electrical demand as a means of demand-side response would have a debatable effect on harmonic emissions. For example, switching off a motor that was controlled by a power electronic drive would reduce the harmonic currents exported into the system, whereas switching off a resistive load would reduce the amount of local harmonic damping power.

It is the opinion of EA Technology, that in general terms, disturbance to the steady state mains voltage or voltage steps is a more immediate risk than that of harmonic distortion.

It is also of note that the net impact of devices connected within a customer's installation upon the distribution network should have been assessed by the G5/4 process. Even in conditions where a customer's Maximum Export Capacity (MEC) is not increased, the addition of any new power electronic devices, such as battery storage, should also be assessed against the G5/4 process. As an example, this would mean that the G5/4 process would grant NIE Networks an opportunity to study the harmonic effects of new equipment even when the customer had expressed a choice not to increase the MEC of their site.

4.2 Circuit Capability

In addition to maintaining voltage quality, NIE Networks must ensure that the flow upon the circuits remains within acceptable limits.

NIE Networks apply ratings on to their circuits to ensure that they are always run within the capability and do not cause damage to equipment or present unacceptable risk to the public. These ratings, for the purpose of this report, are termed as steady state limits and can be applied indefinitely, but change depending on the season.

4.3 Proposed analysis rules

This discussion proposes that the following analysis rules should be included into the DS3 System Service analysis script:

- Delivered voltage should remain beneath:
  - 1.06 per unit under steady-state conditions at 33 kV
  - Although the declared voltage at 11 kV should not exceed 1.06 per unit, to protect LV customers against delivered voltages being too high, the 11 kV system must not rise above 1.03 per unit (with the exception of normal AVC transformer tap regulation)
- Step changes in voltage must always remain within +3% of nominal and absolute voltage never exceed an absolute value of 1.1 per unit % of nominal
- Steady State circuit rating values must be respected always

5. Load flow models

This section describes the load flow models used to review study cases described in Table 4.

5.1 Load Flow Model

The networks were studied within the IPSA power flow analysis package. A balanced load flow model was used to study the network under a discrete number of snapshots.

5.2 Representation of Network Components

NIE Networks provided EA Technology with their electronic model of the seven network groups to be used. EA Technology imported this model into IPSA. These models contained a full node and branch representation of the models to be analysed. These sections discuss how network components were represented within this analysis.

Cable and Overhead lines

The electronic model provided by NIE Networks contained seasonal ratings for all cable and overhead line circuits. These ratings were assumed to be suitable for steady-state conditions and include all available rating enhancements that took account of the daily cycle of electrical load. These steady state ratings describe the maximum power that may be allowed to flow upon a circuit without time limitation.

This analysis has assumed that all circuit rating policies provided to EA Technology by NIE Networks allow for NIE Networks' protection setting policies.

Bulk Supply Point Transformers

Within the data provided by NIE Networks was a model for each 110/33 kV transformer which included the ratings that were applicable for each transformer. In all cases, this analysis assumes that these ratings may be applied equally in both flow directions.

These ratings express the capability of the transformers with full cooling and all continuous ratings and take account of any cyclic rating enhancements described by NIE Networks.

The assumptions for primary transformer automatic voltage control systems are summarised in Table 5.

Table 5 BSP and Cluster substation Automatic Voltage Control (AVC) assumptions

Substation	Voltage Target	Deadband	Time Delay	Fast Tap
Cluster Substation	100 %	±1.5%	60s initial tap 10s inter-tap	Voltage transgression 2% above dead band initiates tapping within 4 seconds
BSP substation (i.e. 110/33kV)	102 %	±1.5%	60s initial tap 10s intertap	Voltage transgression 2% above dead band initiates tapping within 4 seconds

Many of the NIE Networks transformers considered in the study offer a Fast Tap facility which initiates a tap operation within four seconds of detecting a voltage at the BSP or cluster substation that is greater than 2% above the voltage deadband. Therefore, a total voltage step of 3.5% (2% + 1.5% = 3.5%) would have to be detected at the 110/33kV BSP substation before the Fast Tap feature was initiated.

Figure 3 shows that the required voltage step performance for all occurrence frequencies requires that all upwards voltage disturbances are recovered to within ±3% within 0.8 seconds, or for frequently occurring events, within 0.1 seconds. Because the Fast Tap feature takes four seconds to operate, this feature is considered too slow to improve the voltage step performance of any network. For this reason, the effect of fast tapping is discounted from studies which investigate the impact of System Services on the compliance of the network against P28.

Primary Transformers

Within the data provided by NIE Networks was a model for each 33/11 kV transformer which included the ratings that were applicable for each transformer. In all cases, this analysis assumes that this rating may be applied equally in both flow directions.

These ratings express the capability of the transformers with full cooling continuous ratings. The assumptions for primary transformer automatic voltage control systems are summarised in Table 6. Again, a similar judgement regarding the effect of fast tap upon 11 kV Voltage step issues was made for primary transformers.

Table 6 **Primary substation AVC assumptions**

Voltage target	Deadband	Time Delay	Fast tap
102 %	±1.5%	60s initial tap 10s intertap	Voltage transgression 2% above dead band initials instant tap

Fault infeed from upstream systems

To represent the fault infeed from upstream 110 kV or 33 kV systems, NIE Networks provided assumptions for the fault infeed from the rest of the system. These assumptions are summarised in Table 7.

Table 7 **Fault level infeed assumptions**

Study network	Maximum infeed	Minimum infeed
33 kV Semi-Urban network	8.1 kA (X:R 4.4) @110kV	7.46 kA (X:R -4.28) @110kV
33 kV Urban network	17.46 kA (X:R 8.29) @110kV	13.38 kA (X:R 8.85) @110kV
33 kV Cluster network	3.49 kA (X:R 4.25) @110kV	3.46 kA (X:R 4.3) @110kV
11 kV Urban feeder	11.8 kA @33kV	
11 kV Commercial feeder	9.56 kA @33kV	
11 kV Semi-Rural feeder	3.33 kA @33kV	
11 kV Rural feeder	4.44 kA @33kV	

NIE Networks have confirmed that these assumptions reflect winter maximum plant conditions and summer minimum conditions during a planned outage of one circuit.

It is important to model these within the study as the fault level infeed is a measure of the upstream impedance. It is this impedance that influences how large the voltage step will be in the period before any upstream tap changers can respond.

Generator Models

This analysis adopted the same modelling approach used by NIE Networks to represent 33 kV and 11 kV connected generation. This approach uses the following features:

- Generators represented as being a voltage behind an impedance. This model uses the impedance details used by NIE Networks within their model.

- Generators have a fixed power factor that is compliant with the Distribution code[3]. Section 7.4.1 to section 7.6 of the Distribution Code[2] explains the reactive power range that all generators must be able to deliver.

Electrical Demand Models

Within the 33 kV networks, all electrical demand was modelled as a lumped demand that was connected to the busbars at the 11kV substation level.

All electrical demand was modelled as having constant real power and constant reactive power profile. This means that the power consumed does not alter in response to a voltage change. There was no opportunity to investigate the likely voltage dependency characteristics of the customers within the networks studied.

This assumption is conservative for voltage dips and likely to be optimistic (i.e. prone to underestimate) for calculation of voltage swells (such as those caused by deployment of response).

[2] NORTHERN IRELAND ELECTRICITY NETWORKS LIMITED, DISTRIBUTION CODE, ISSUE 4 – 17TH 11[th] May 2018

5.3 Demand and Generation Background

To allow analysis of capacity for System Services, a set of assumptions regarding demand and generation in the background network was required. Each background was selected with the intention of capturing the load flow conditions which portray how much additional capacity remains within the network to allow dispatch for further System Services.

In the case of the three 110/33 kV networks, this was done by replicating the observed loading conditions at all substations under representative snapshots. For example, for the 33 kV Semi-Urban network, the network was studied under three snapshots, which were:

- Conditions of maximum winter 110/33 kV import from the system
- Conditions of maximum winter 110/33 kV export to the system
- Conditions of maximum summer 110/33 kV export to the system

In the case of networks with no 33 kV generation connected, a winter maximum study and summer minimum study would be suitable to explain the extent of changes in available capacity over a year.

In the case of 11 kV networks, the demand pictures were based upon winter maximum demand and summer minimum demand with the output from any generation represented on the feeder in question.

6. Analysis approach

A script was developed that would automatically test the quantity of System Services each load flow model could hold without breaking the limits described in 4.3. The approach that was employed by this script is described in 6.1.

6.1 Script Mechanism

The goal of the script was to calculate how the total quantity of DS3 System Services that can be allocated in each network and respecting system limits. The steps followed by the script for the 11 kV and 33 kV networks are as described below.

6.1.1 Steps followed for 11 kV networks

The flow chart that describes the process for calculating the limits on 11 kV feeders can be found in Appendix V.

To calculate the system limits, the capacity script is applied to an 11 kV network background as described in section 5. The script follows steps 1 to 3 beneath and is summarised in Figure 4. This explores the simultaneous allocation of services at generation and demand nodes (i.e. services are placed at generation nodes as well demand nodes equally).

1. **Selection of busbars to be analysed and monitored.**
   The starting point in using the script requires the user to nominate the nodes which should have capacity checked and the nodes and circuits within the network that should be monitored.

   In this analysis, the selected nodes represented an 11 kV bus bar at the primary substation, at point 1/3 down the length of the main feeder spine, at 2/3 down the length of the main feeder spine and at all the endpoints of the feeder.

   This part of the process assumes that busbars on unloaded circuits[3] should not be monitored. This is because monitoring of these nodes would set falsely low steady state and step voltage limits due to the Ferranti effect upon unloaded circuits.

2. **Service allocation**
   Once the script has switched out a transformer, it will:
   a. Run a base case load flow to capture network loading and voltages before System Services are applied.
   b. Once the script has calculated the individual limit for each busbar, a representation of a system service provider is simultaneously placed on all nominated nodes/busbars that are to be studied.
   c. The export from all service providers is then increased at simultaneous and equal steps until network load flows are observed to have reached limits for the voltage step, the steady state voltage, the state loading and the short-term load within the network components that are being monitored. This calculation is conducted for each of the eight System Services.
   d. The export from all service providers is then increased in value and the load flow re-run until network limits have been recorded for each of the following limits: the voltage step, the steady state voltage and the state loading within the network components that are being monitored.

[3] An unloaded circuit is one that is energised but does not have any customers on. An example would include a circuit that runs between a substation with customers and a network open point at an adjacent substation. Unloaded circuits present a problem as they typically have a high voltage profile due to the capacitance of the circuit.

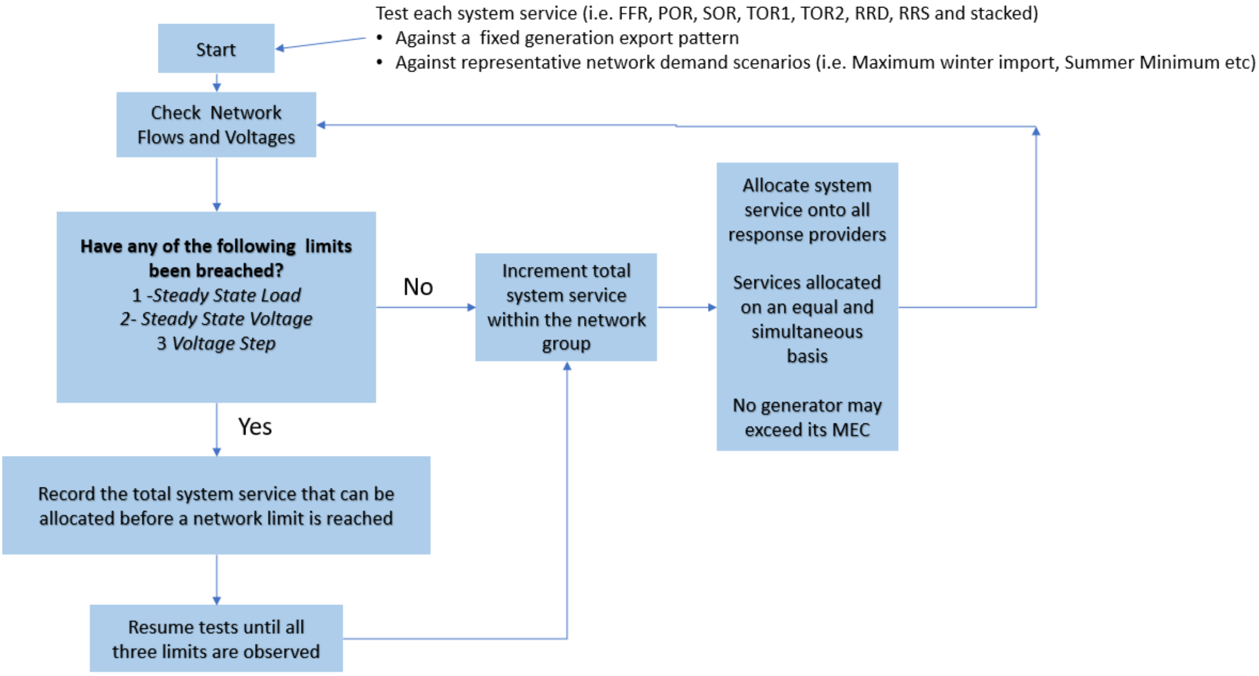


Figure 4 Simplified Flow Chart for 11 kV Network allocation

Note: During incremental allocation of system services, an equal capacity of service is assigned to all service providers within a network group during each iteration of the script.

3. Circuit outages

Following the analysis during normal system operation (NSO). The above steps are repeated with an outage to give an appreciation for the impact of abnormal conditions on the impact of System Services. For the 11 kV Feeder groups, this was done with one of the 33/11 kV primary transformers switched out.

6.1.2 Steps followed for 33kV networks

To calculate the system limits, the capacity script is applied to a network background as described in section 5. The flow chart for this process can be found in Appendix VI.

1. **Selection of busbars to be analysed and monitored.**
   The starting point in using the script requires the user to nominate the nodes which should have capacity checked and the nodes and circuits within the network that should be monitored. In this analysis, the selected nodes represented a bus bar at each 33 kV substation, 33 kV connected generator and an 11 kV bus bar at each primary substation.

   This part of the process assumes that busbars on unloaded circuits[4] should not be monitored. This is because monitoring of these nodes would set falsely low steady state and step voltage limits because of the Ferranti effect on unloaded circuits.

2. **Pro-rata busbar service allocation**

   a. The script will run a base case load flow to capture network loading and voltages before System Services are applied. If the voltage or loading was observed to be at the maximum allowed in the base case network, then there is no capacity on the network.

   b. The capacity of the system to hold system response is then tested. This test recognised that generation exports are not always at MEC. For example, renewable generators will only export in accordance with the wind or solar resource and battery owners will dispatch their batteries to export at a level commensurate with business plans, contracts and the desire to preserve battery life.

      For this reason, generators were simulated at 0%, 20%, 40%, 60%, 80% and 100% of MEC. Each of these intervals is referred to in this report as "Pre-event generation level". The export from each service provider was then incremented to test system capacity. In each iteration, the script publishes all the quantitative individual limits in terms of MW of System Service. The script also indicates the overall limiting factor and the reason behind the step limit trigger. Table 8 illustrate the format of the script output.

   c. The network capacity is then tested as per the flow chart as summarised in Figure 5 or shown fully in Appendix VI.

      System Services are added incrementally onto registered generation in the group. The amount of System Service that each generator delivers is allocated in proportion to the MEC of the generator. At each increment, the network is tested to see if it has reached any of the four limits (V step, V steady state, steady state loading, or step voltage). As soon as any one of these four limits has been reached, it is recorded.

      It should be noted that System Services are only allocated to generation in a manner that respects its installed capacity (i.e. the amount of generation after pullback plus the amount of System Services allocated onto a generator must always be less than its Maximum Export Capacity.

      In circumstances where all generation has reached its MEC and the system tests still show capacity, demand-side response is then allocated onto primary substation bus bars and this is incremented in steps until network limits have been reached.

[4] An unloaded circuit is one that is energised but does not have any customers on. An example would include a circuit that runs between a substation with customers and a network open point at an adjacent substation. Unloaded circuits present a problem for the script as they typically have a high voltage profile due to the capacitance of the circuit.

In order to apply the most realistic approach to the deployment of system services, it has been assumed that most system service providers will be deployed at sites with existing generation. For example, a customer connecting battery storage behind an existing wind or solar farm as per the NIE Networks Over-install policy.

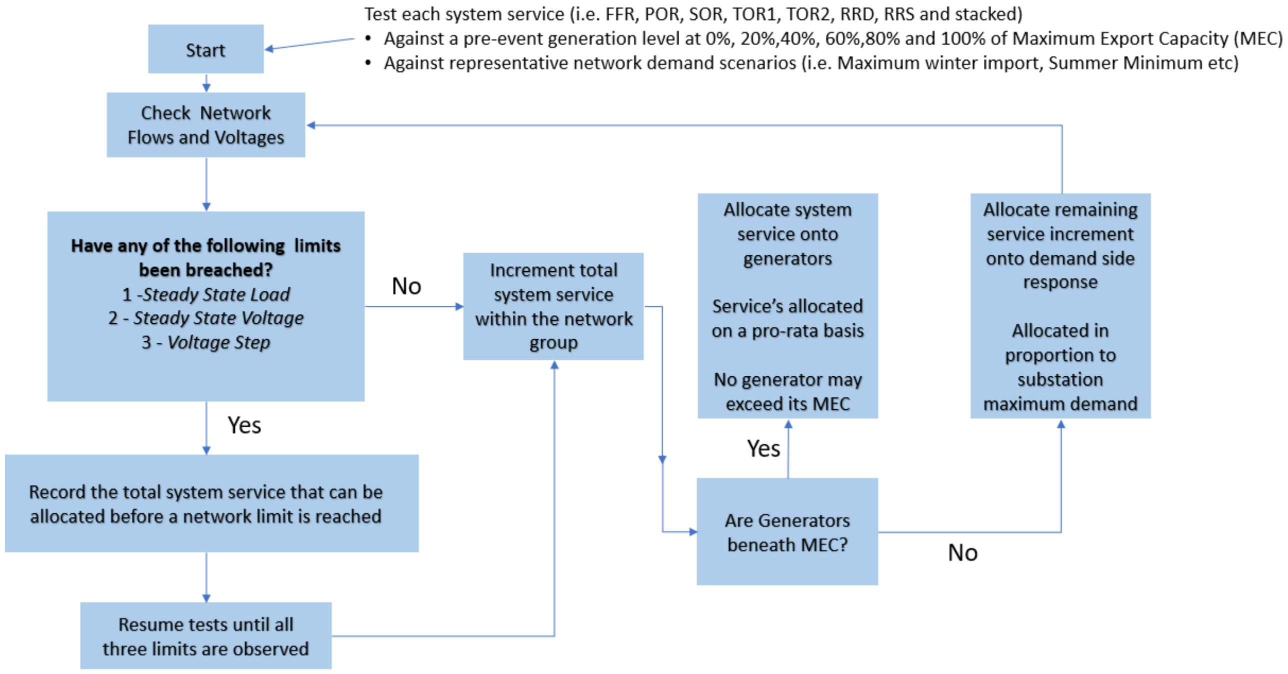


Figure 5 Simplified Flow Chart for 33 kV Network allocation

3. Circuit outages

To ensure that the script model used the same planning assumptions as NIE Networks, the capacity analysis for each bus bar was conducted under normal system operation (NSO) conditions as well as N-1 outage conditions. For the 110/33 kV networks, this was done with one 110/33 kV transformer at the 110/33 kV substation out of service.

It should be recognised that for the 110/33 kV network groups that local circuit outages may be more restrictive for certain generators than the 110/33 kV outages. It is beyond the scope of this work package to calculate limits which consider every single circuit outage. This approach has been taken as running the pull back and pro-rata analysis for each possible circuit outage would create an unfeasibly large quantity of data to assimilate and would be likely to restrict system access if one value was adopted.

It is considered a more practical alternative to recognise that these limits consider the effect of some outages, but during certain outages, the MEC of generators proximate to the outage may have to be temporarily reduced.

Therefore, in addition to the limits published by this report, it should be expected that NIE Networks will need to issue additional instructions to individual system service providers during local 33 kV network outages. For example, some network outages will require a 100% reduction from one generator because they have a single point of connection, whereas, in some complex 33 kV network groups, there may be a requirement to reduce system service provision beyond the outage conditions presented in this report due to the fact that the 33 kV outage limits available capacity in a subset of the overall 33 kV network group.

Running the script upon a background network provides the outputs summarised in Table 8.

Table 8 33 kV script output

	Pre-event Generation Level	Limit	Allocated Service						
Network	100% of MEC	Quantitively limit (MW)	FFR	POR	SOR	TOR1	TOR2	RRD	RRS
		Limiting Factor							
		V-Step G59 Flag (Step/limit)							
	80% of MEC	Quantitively limit (MW)							
		Limiting Factor							
		V-Step G59 Flag (Step/limit)							
	60% of MEC	Quantitively limit (MW)							
		Limiting Factor							
		V-Step G59 Flag (Step/limit)							
	40% of MEC	Quantitively limit (MW)							
		Limiting Factor							
		V-Step G59 Flag (Step/limit)							
	20% of MEC	Quantitively limit (MW)							
		Limiting Factor							
		V-Step G59 Flag (Step/limit)							
	0% of MEC	Quantitively limit (MW)							
		Limiting Factor							
		V-Step G59 Flag (Step/limit)							

6.2 Assumptions made by the script

This script does not make any distinctions between how influential different busbars are upon a network problem. Instead, the assumption is made that the moment the network reaches a loading condition, no more services can be allocated into the group.

6.3 Uncertainties addressed by the script

When deciding how to approach this task, several sources of uncertainty were considered. The following sections describe these uncertainties, how they would influence the calculation and what was done to mitigate them.

Where will the DS3 System Services providers be located?

Given the interest in supplying DS3 services to the market, this process recognised that it would be unrealistic to assume that all System Services within any given network group would be located at one location. It seems much more realistic to assume that the System Services will be spread across a network group. There is significant uncertainty regarding forecasting where the System Services would be delivered from and how much there will be.

This uncertainty was overcome by ensuring that the script can calculate how much: FFR, POR, POR2, SOR, TOR1 & TOR2, RRS and then RRD could be placed at each substation of interest before network quality was compromised using the allocation rules explained in section 6.1.

Stacking of System Services

To explore the possibility that one provider might stack services, a further service condition was added which explored the effect on network quality of a provider which assumed that the services were delivered across the FFR through to the RRD period.

Static versus Dynamic System Services

Each type of system service can be delivered by Static and Dynamic providers. (The difference between static response and dynamic response is explained in section 1.3.2.)

Static providers of response or dynamic response that has ramp rate approaching a step change, will have the greatest impact upon the measurement of voltage step changes. System Services such as RRD or RRS which have the opportunity to ramp slowly over several minutes rather than seconds will have less impact upon the voltage quality.

To ensure that results presented by this analysis are technology agnostic, the choice was made to assume that all service provision has a near step response rather than a ramped response. This assumption is conservative but is justified given the fact that there is no strong evidence that justifies the likely balance of dynamic versus static service providers. This assumption is expected to have a higher impact on the slower service provisions such as RRS and RRD but a much lower impact on the faster services such as FFR and POR.

7. Results and discussion

7.1 33 kV Cluster network

The results from the 33 kV Cluster network under Normal System Operation (NSO) conditions are summarised in Table 9. It is important to understand that these limits show the total amount of system services that can be allocated, assuming that only one service type is being delivered. If the assumption needs to be made that service providers will deliver a varied portfolio, then the RRS service represents the maximum quantity of service that can be held in the group.

It can be seen that the maximum allowable quantity of system service is equal across each system service, it can also be seen that the pre-event generation levels influence the total allowed quantity of System services.

This table shows that when generators are operating at MEC the limiting factor tends to be the requirement to maintain an acceptable steady state voltage. Load flow modelling demonstrated that the limiting factor was the voltage. Under low levels of pre-event generation, the limiting factor changed to become the requirement to avoid a voltage step change greater than 3%. Comparison of Table AIII.1and Table AIII.2 in Appendix III shows that the voltage step and steady state voltage limits are influenced by the amount of planned generation export, but not the seasonal conditions. This is commensurate with the fact that there is no electrical demand within this network group.

Table 9 33 kV Cluster network (NSO) results at different levels of generation export

Season	Pre-event Generation Level	The quantitative limit for Allocated Service (in MW)							Limiting factor
		FFR	POR	SOR	TOR1	TOR2	RRD	RRS	
Summer	100%	0	0	0	0	0	0	0	Vss[5]
	80%	10.94	10.94	10.94	10.94	10.94	10.94	10.94	Vss
	60%	19.60	19.60	19.60	19.60	19.60	19.60	19.60	Vss
	40%	24.73	24.73	24.73	24.73	24.73	24.73	24.73	Vstep
	20%	20.38	20.38	20.38	20.38	20.38	20.38	20.38	Vstep
	0%	16.76	16.76	16.76	16.76	16.76	16.76	16.76	Vstep
Winter	100%	0	0	0	0	0	0	0	Vss
	80%	10.89	10.89	10.89	10.89	10.89	10.89	10.89	Vss
	60%	19.61	19.61	19.61	19.61	19.61	19.61	19.61	Vss
	40%	24.70	24.70	24.70	24.70	24.70	24.70	24.70	Vstep
	20%	20.39	20.39	20.39	20.39	20.39	20.39	20.39	Vstep
	0%	16.79	16.79	16.79	16.79	16.79	16.79	16.79	Vstep

These results are shown graphically in Figure 6 for the FFR service, although the actual total service that can be assigned is the same across all services. It should be noted that in this graph, there is no thermal limit depicted as there is insufficient generation connected within the group to exceed trigger a thermal rating and the script will not allocate System services above the MEC of generation within the case study network. The inclusion of additional generation or demand side response into the network group would demonstrate activation of this limiting factor.

[5] VSS indicates that the limitating factor in this case that the Steady State Voltage requirement. Vstep would indicate that the limiting factor was the requirement to avoid a 3% step change in voltage

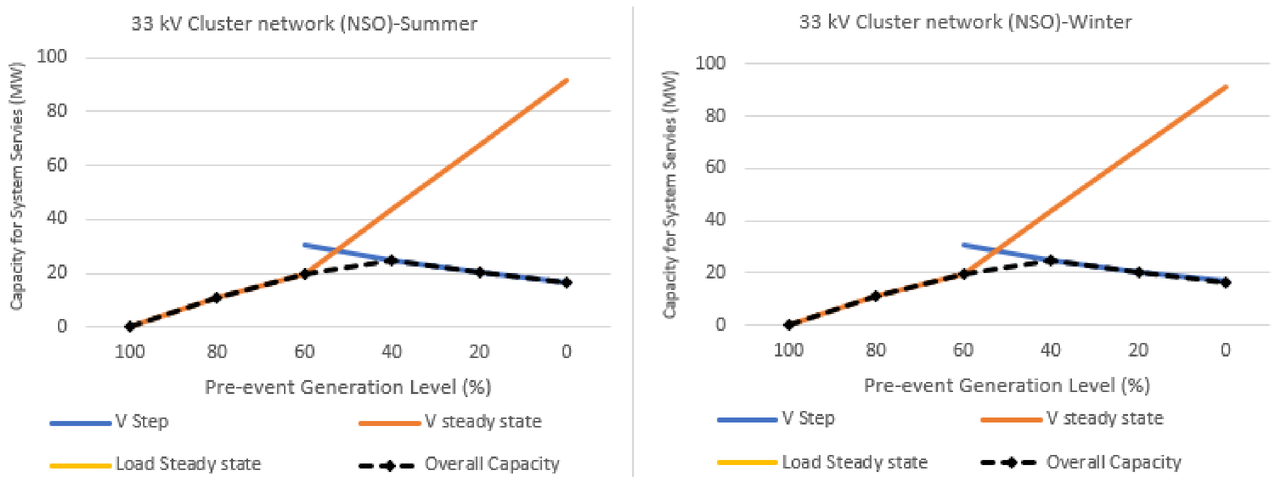


Figure 6 33 kV Cluster network NSO condition, breakdown of individual limits [6]

Table 10 depicts the results for the 33 kV Cluster network under N-1 conditions.

The table shows that the available capacity at this BSP is highly influenced by the pre-event generation level and that the effect is not linear.

It should be noted that N-1 loss of the transformer has a complicated effect on the system limits, some of which are worsened, some of which are improved. This means that NIE Networks will not be able to rely upon simple linear approximation models to calculate how much capacity is available.

It is noticeable that the voltage step is slightly higher under NSO conditions than N-1 which may seem counterintuitive. This is explained by the fact that a voltage step should be fully expressed in terms of two components, the observable change in voltage and the change in the phase angle of the voltage received. Results can be produced that demonstrate that under N-1 conditions that the overall vector change in voltage is greater than under NSO conditions, but because the P28 standard is only focussed on the change in amplitude of the waveform the script has focussed on only this parameter.

Table 10 33 kV Cluster network (N-1) results at different levels of pullback

Season	Pre-event Generation Level	The quantitative limit for Allocated Service (in MW)							Limiting factor
		FFR	POR	SOR	TOR1	TOR2	RRD	RRS	
Summer	100%	0	0	0	0	0	0	0	Load ss
	80%	23.33	23.33	23.33	23.33	23.33	23.33	23.33	Load ss
	60%	47.23	47.23	47.23	47.23	47.23	47.23	47.23	Load ss
	40%	27.80	27.80	27.80	27.80	27.80	27.80	27.80	V step
	20%	18.86	18.86	18.86	18.86	18.86	18.86	18.86	V step
	0%	13.73	13.73	13.73	13.73	13.73	13.73	13.73	V step
Winter	100%	0	0	0	0	0	0	0	Load ss
	80%	23.33	23.33	23.33	23.33	23.33	23.33	23.33	Load ss
	60%	47.23	47.23	47.23	47.23	47.23	47.23	47.23	Load ss
	40%	27.69	27.69	27.69	27.69	27.69	27.69	27.69	V step
	20%	18.86	18.86	18.86	18.86	18.86	18.86	18.86	V step
	0%	13.75	13.75	13.75	13.75	13.75	13.75	13.75	V step

[6] The figure corresponds to FFR, however is representative of other system services.

The plots shown in Figure 7 show that the overall limit is a composite of the individual limits. It should be noted that under low levels of generation pull-back, there were insufficient levels of capacity available with which to stress the network to detect limits. This was because the script rules demanded that each wind farm respect its individual MEC and should not export more power than this figure.

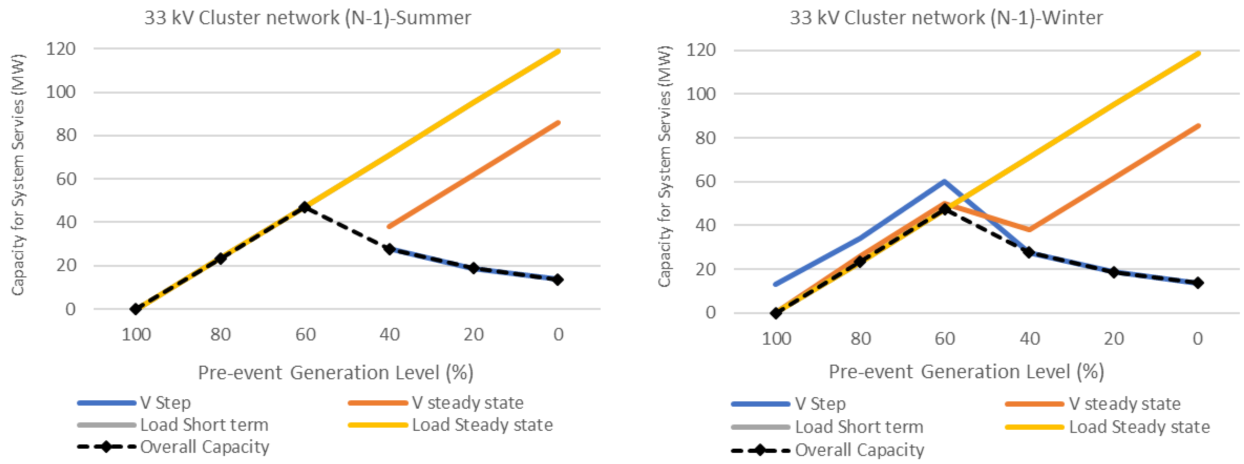


Figure 7 33 kV Cluster network (N-1) condition, breakdown of individual limits [7]

This section has shown that the maximum available system service limits in the 33 kV Cluster network group are:

- Influenced by the level of pre-event generation, but that this is not a linear relationship.
- Influenced by how many transformers are on load at the 110/33 kV substation and that the effect of switching out a transformer on limits may be an improvement at some levels of wind generation, but a worsening effect at other levels.
- Likely to have different limiting factors at different generation levels and different transformer configurations.

It could also be further shown that the generator reactive power assumptions were influential upon these results.

Because there are no clear set of limits that are an improvement over the other set, this raises the question as to which set of limits should be used and when. For example, if the network operator implemented the N-1 limits during NSO conditions in preparation for an unplanned loss, then this would unnecessarily limit system services during periods of low wind production but would require rapid post-fault action to update applicable limits upon loss of the transformer. Failure to do so would see network limits for allowable system services breached, especially during high wind power conditions. A 'One Size fits all' approach to setting system access limits at a particular substation is likely to be restrictive in comparison to the amount of system access likely to be granted using dynamic limits based on real-time availability of the network.

[7] The figure corresponds to FFR, however is representative of other system services.

7.2 33 kV Semi-Urban network group

As already discussed, the 33 kV Semi-Urban network group contains both demand and generation. There is a significant amount of 33 kV connected generation, which in some cases, is connected at the peripheries of this network and is an electrically long way from the 110/33 kV substation.

The results from the 33 kV Semi-Urban network case study under NSO conditions are summarised in Table 11 with full results in Appendix I.

These results show the maximum amount of response that could be allocated within this 33 kV Semi-Urban network. These values described the total amount of a system service that can be allocated into the semi-urban network group assuming that only one service is to be provided from within the group. If the assumption is to be made that the services are stacked to provide response throughout the recovery period (i.e. provision of FFR, then POR, SOR into the reserve period), then the RRS service would use the correct ratings to express the capacity available if all users in the group stacked their service provision from FFR to RRS.

Table 11 33 kV Semi-Urban network (NSO) results at different levels of pullback

Demand Condition	Pre-event Generation Level	The quantitative limit for Allocated Service (in MW)							Limiting factor
		FFR	POR	SOR	TOR1	TOR2	RRD	RRS	
Summer Export	100%	0	0	0	0	0	0	0	Vss
	80%	0	0	0	0	0	0	0	Vss
	60%	0	0	0	0	0	0	0	Vss
	40%	0	0	0	0	0	0	0	Vss
	20%	0	0	0	0	0	0	0	Vss
	0%	11.79	11.79	11.79	11.79	11.79	11.79	11.79	V step
Winter Export	100%	0	0	0	0	0	0	0	Vss
	80%	0	0	0	0	0	0	0	Vss
	60%	0	0	0	0	0	0	0	Vss
	40%	0	0	0	0	0	0	0	Vss
	20%	0.40	0.40	0.40	0.40	0.40	0.40	0.40	Vss
	0%	0	0	0	0	0	0	0	Vss
Winter Import	100%	11.28	11.28	11.28	11.28	11.28	11.28	11.28	V step
	80%	11.88	11.88	11.88	11.88	11.88	11.88	11.88	V step
	60%	12.44	12.44	12.44	12.44	12.44	12.44	12.44	V step
	40%	12.97	12.97	12.97	12.97	12.97	12.97	12.97	V step
	20%	13.47	13.47	13.47	13.47	13.47	13.47	13.47	V step
	0%	13.94	13.94	13.94	13.94	13.94	13.94	13.94	V step

This table describes the available capacity under winter export, summer export and winter maximum import conditions. The winter and summer export conditions describe the electrical consumption patterns expected during the time when maximum seasonal export is to be expected (i.e. winter minimum demand and spring minimum demand). The winter import conditions represent the electrical consumption pattern under winter maximum demand conditions. Maximum winter import in this network group was typically observed to occur around 17:00 hours whereas maximum winter export in this network group typically occurred in the early hours of the morning.

It is notable that the summer export capacity is higher than the winter export capacity. This is explained by the assumption that the condition of summer export has a higher electrical consumption than the winter maximum export condition. This is considered justified on the basis of reviewing real-time data which showed that the time of maximum winter export occurred at 04:30 in the morning whereas the time of maximum summer export occurred at 07:00 in the morning. These observations are considered to be representative of the typical loading patterns as is can be shown from observed data that peak winter exports tend to happen in the period of 00:00 to 04:30

hours whereas peak exports during the spring, summer and autumn seasons tend to occur during lulls in electrical consumption throughout typical waking hours of 07:00 to 22:00.

This table shows that there are no differences in the amount of capacity across the different system service products.

It can also be seen that under the two export cases there is minimal capacity for System Services until there is a significant reduction in the planned export from generation. In these two cases, the limitation at high levels of generation export is because of the requirement to maintain an acceptable network voltage profile at 33 kV.

Load flow analysis demonstrated that the busbars most likely to trigger this limitation at the extremities of the network. The voltage profile at these nodes is influenced, to an extent, by the real power exported by the connected generation. Once these generators have reduced export to virtually non zero, then the capacity to host system services in this network group becomes limited by the requirement to avoid an unacceptable voltage step.

A sensitivity study was also undertaken to investigate the effect of generation power factor on the voltage profile within this network. It was found that small changes in power factor would have a large impact on the steady state voltage at the extremities of the network. This demonstrates that reactive power assumptions are significant in this analysis. But it should be remembered that all generation is expected to meet the reactive power requirements as per the distribution code connection criteria hence there is limited scope to vary the power factor at generation sites.

This shows that in addition to electrical demand consumption and real power generation the available capacity for system services in the network is also influenced by reactive power instructions passed to generators. Depending on the size of the generation, the reactive power control and reactive dispatch instructions may not need to be fixed across time. This means that a fixed look-up table approach to allocating system services is likely to underestimate available capacity, whereas actively managing the network capacity would maximise system access.

A further breakdown of how thermal loading and voltage limits influence the overall capacity for system services limits is shown in Figure 8. This graph relates the behaviour of capacity for FFR, but the behaviour of the voltage indices shown will be applicable to all of the services. It can be seen reducing the power exported from generation has only a weak influence on both the steady-state voltage and step change limits.

In addition to summer and winter maximum export conditions, Table 11 also describes the overall limits under the winter maximum import conditions (i.e. represents winter maximum electrical consumption conditions). It can be seen under these conditions that steady-state voltage is no longer the biggest constraint and the overall limitation is driven by the requirement to avoid unacceptable voltage step. There is also a very large margin between the voltage step limit and the next most limiting condition. Again, it can be seen from Figure 8 that the amount of capacity available for system services is not strongly influenced by generation export.

Comparison of the amount of capacity for system services between the two export conditions and the single import condition shows that the amount of electrical demand consumption is very influential on the capacity for system services. During the winter peak conditions at least 2.8 times more electrical power is consumed within the group than under the export conditions.

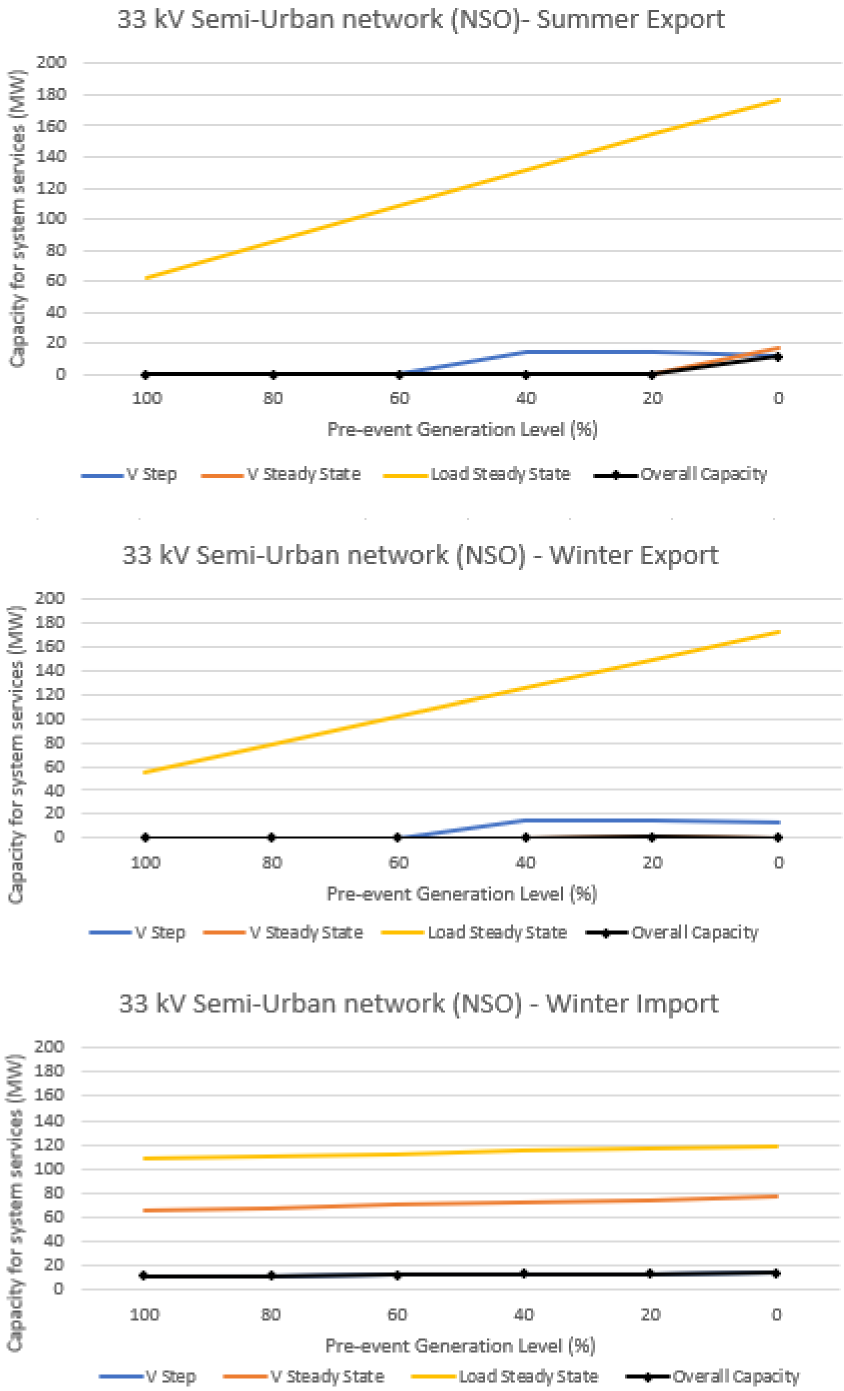


Figure 8 33 kV Semi-Urban network NSO condition, breakdown of individual limits[8]

The overall results for available capacity to host System Services under N-1 conditions can be seen in Table 12. The N-1 condition that was simulated was an outage of one of the two main 110/33 kV transformers (as discussed in section 6.1.2.).

[8] The figure corresponds to FFR, however is representative of other system services.

It can be seen that there is no difference between the available capacities across the different types of System Services. It can also be seen that there are low amounts of System Services available for the two export cases.

Like the NSO condition, the results for the summer export and winter export condition show that the steady state voltage requirements are the limiting factor.

When the network is under winter peak import conditions, it becomes easier to avoid high voltage on the 33 kV network and as a result, the limiting factor becomes the need to avoid unacceptable voltage changes.

Table 12 33 kV Semi-Urban network (N-1) results at different levels of generation pullback

Demand Condition	Pre-event Generation Level	The quantitative limit for Allocated Service (in MW)							Limiting factor
		FFR	POR	SOR	TOR 1	TOR 2	RRD	RRS	
Summer Export	100%	0	0	0	0	0	0	0	Vss
	80%	0	0	0	0	0	0	0	Vss
	60%	0	0	0	0	0	0	0	Vss
	40%	0	0	0	0	0	0	0	Vss
	20%	0	0	0	0	0	0	0	Vss
	0%	0	0	0	0	0	0	0	Vss
Winter Export	100%	0	0	0	0	0	0	0	Vss
	80%	0	0	0	0	0	0	0	Vss
	60%	0	0	0	0	0	0	0	Vss
	40%	0	0	0	0	0	0	0	Vss
	20%	0	0	0	0	0	0	0	Vss
	0%	0	0	0	0	0	0	0	Vss
Winter Import	100%	8.68	8.68	8.68	8.68	8.68	8.68	8.68	V step
	80%	9.33	9.33	9.33	9.33	9.33	9.33	9.33	V step
	60%	9.94	9.94	9.94	9.94	9.94	9.94	9.94	V step
	40%	10.50	10.50	10.50	10.50	10.50	10.50	10.50	V step
	20%	11.02	11.02	11.02	11.02	11.02	11.02	11.02	V step
	0%	11.49	11.49	11.49	11.49	11.49	11.49	11.49	V step

This section has shown that the available capacity within the Semi-Urban network is strongly linked to the amount of electrical demand in the network. This section has also shown that the amount of export from generation does influence the available capacity, but with a much weaker link that is not linear. It should also be realised that the quantities which limit the available headroom for system services are not constant and different factors become the most limiting depending on the prevailing network conditions.

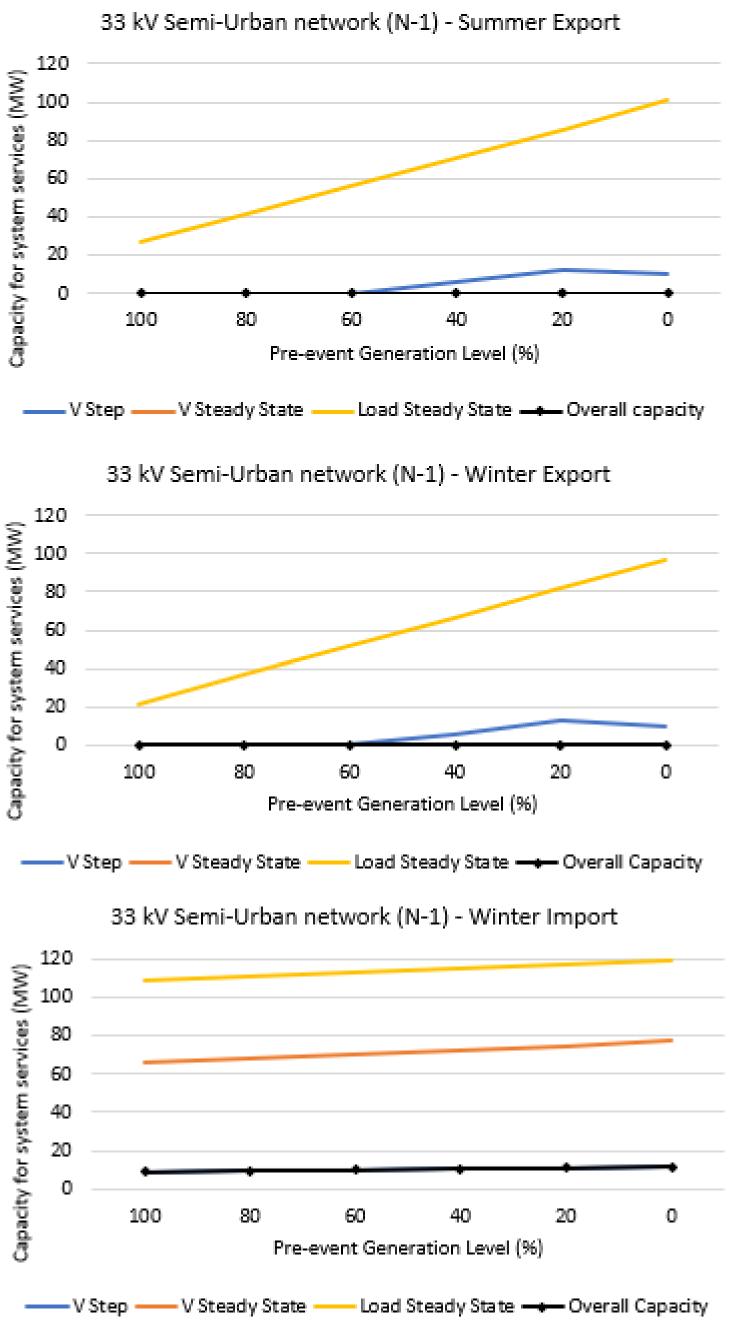


Figure 9 33 kV Semi-Urban network (N-1) conditions, breakdown of individual limits[9]

[9] The figure corresponds to FFR, however is representative of other system services.

7.3 33 kV Urban group

The results of the 33 kV Urban network case study under NSO conditions, against different levels of generation pull back, are summarised in Table 13. The full results can be found in Appendix II.

It should be remembered that the Urban network is a load dominated group with no 33 kV generation. All embedded generation in this group is connected at 11kV.

Table 13 33 kV Urban network (NSO) results at different levels of pullback

Demand Condition	Pre-event Generation Level	The quantitative limit for Allocated Service (in MW)							Limiting factor
		FFR	POR	SOR	TOR1	TOR2	RRD	RRS	
Summer	100%	31.27	31.27	31.27	31.27	31.27	31.27	31.27	V step
	80%	31.96	31.96	31.96	31.96	31.96	31.96	31.96	V step
	60%	32.58	32.58	32.58	32.58	32.58	32.58	32.58	V step
	40%	33.14	33.14	33.14	33.14	33.14	33.14	33.14	V step
	20%	33.65	33.65	33.65	33.65	33.65	33.65	33.65	V step
	0%	34.09	34.09	34.09	34.09	34.09	34.09	34.09	V step
Winter	100%	18.05	18.05	18.05	18.05	18.05	18.05	18.05	V step
	80%	18.33	18.33	18.33	18.33	18.33	18.33	18.33	V step
	60%	18.54	18.54	18.54	18.54	18.54	18.54	18.54	V step
	40%	18.73	18.73	18.73	18.73	18.73	18.73	18.73	V step
	20%	18.88	18.88	18.88	18.88	18.88	18.88	18.88	V step
	0%	18.99	18.99	18.99	18.99	18.99	18.99	18.99	V step

Table 13 shows that in general, the urban network offers more capacity for system services than the other two 33 kV network case studies. It should be noticed that the limiting factor is not the steady state voltage limit but because of the voltage step issue.

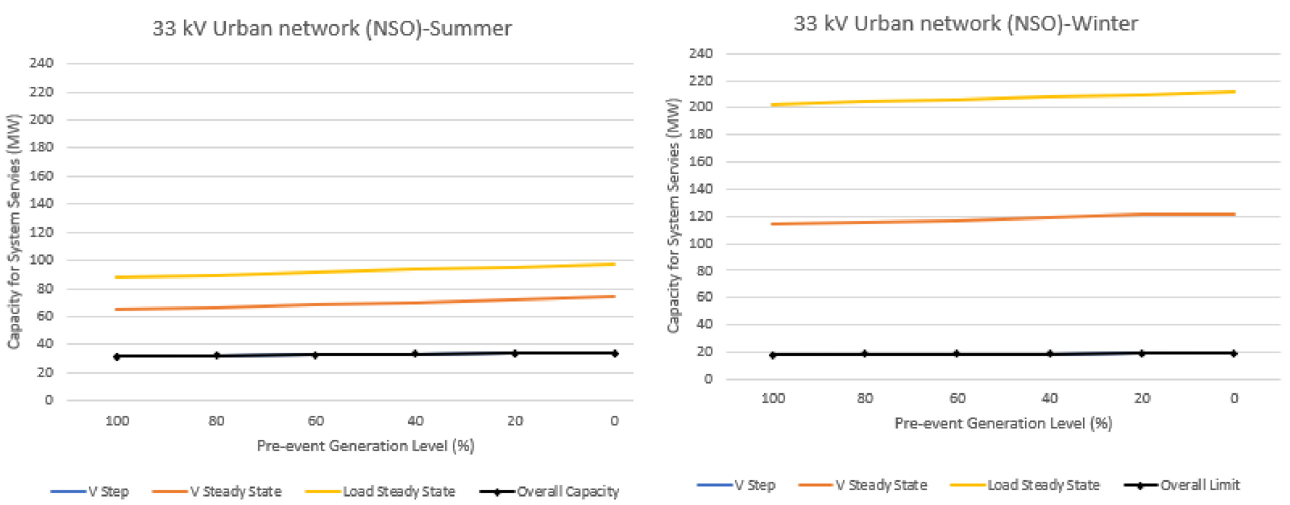


Figure 10 33 kV Urban network NSO condition, breakdown of individual limits[10]

Figure 10 shows how the overall limit for the 33 kV Urban network group under NSO is influenced by the four different limits. It can be seen that under both winter and summer NSO conditions, there

[10] The figure corresponds to FFR, however is representative of other system services.

is a high margin between the most limiting quantity, which is Voltage step, and the next most limiting condition which is the steady state voltage limitation.

Table 14 shows the overall limit for the 33 kV Urban network group under N-1 conditions. The outage condition studied was an outage of one of the two main 110/33 kV transformers. Again, as for the NSO conditions, the voltage step limit is the most restrictive factor.

Table 14 **33 kV Urban network (N-1) results at different levels of pullback**

Demand Condition	Pre-event Generation Level	The quantitative limit for Allocated Service (in MW)							Limiting factor
		FFR	POR	SOR	TOR1	TOR2	RRD	RRS	
Summer	100%	24.62	24.62	24.62	24.62	24.62	24.62	24.62	V step
	80%	25.58	25.58	25.58	25.58	25.58	25.58	25.58	V step
	60%	26.45	26.45	26.45	26.45	26.45	26.45	26.45	V step
	40%	27.24	27.24	27.24	27.24	27.24	27.24	27.24	V step
	20%	27.95	27.95	27.95	27.95	27.95	27.95	27.95	V step
	0%	28.58	28.58	28.58	28.58	28.58	28.58	28.58	V step
Winter	100%	9.65	9.65	9.65	9.65	9.65	9.65	9.65	V step
	80%	9.98	9.98	9.98	9.98	9.98	9.98	9.98	V step
	60%	10.26	10.26	10.26	10.26	10.26	10.26	10.26	V step
	40%	10.4	10.4	10.4	10.4	10.4	10.4	10.4	V step
	20%	10.6	10.6	10.6	10.6	10.6	10.6	10.6	V step
	0%	10.8	10.8	10.8	10.8	10.8	10.8	10.8	V step

Figure 11 depicts a breakdown of the behaviour of the individual limits. It can be seen that there is a large margin between the most limiting factor and the next most limiting factor. It can also be seen that the amount of power being exported by generation before the event does not have a strong influence on the capacity for system services. This is partly due to the fact that the Urban network group has a relatively low quantity of generation, which is all connected at 11 kV.

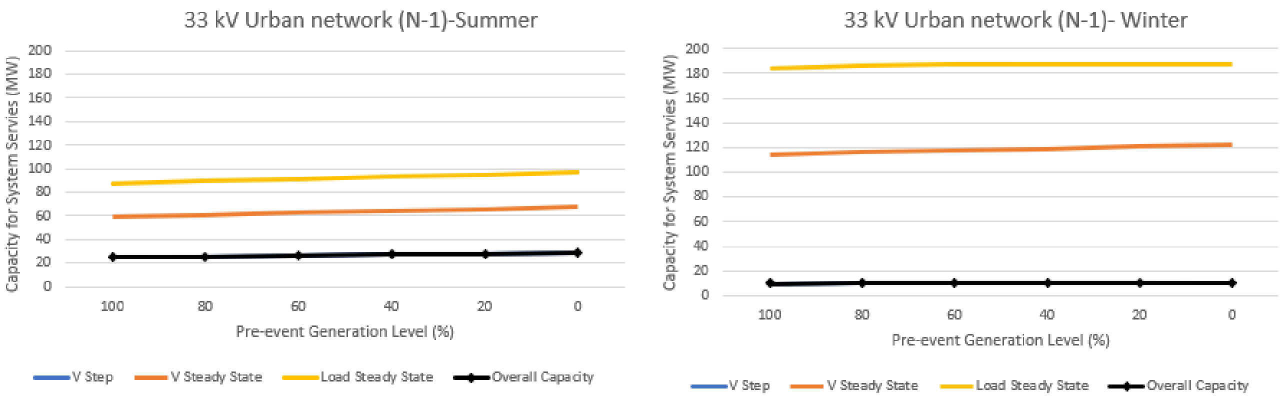


Figure 11 **33 kV Urban network (N-)1 condition, breakdown of individual limits**[11]

Comparison of the NSO to N-1 condition shows that there is a significant difference in the available capacity. There is less capacity for system services under N-1 conditions than NSO conditions. Because an N-1 loss can happen on an unplanned basis, this work raises a requirement to understand how much system services are applied under NSO conditions. For example, a conservative approach

[11] The figure corresponds to FFR, however is representative of other system services.

would apply N-1 conditions during NSO conditions to be prepared for an unplanned loss. This would limit the amount of services that can be held upon the system.

An alternative approach would be to actively manage the system. This would allow a greater level of system services to be held at 33 kV under NSO conditions, but in the event of an unplanned loss of grid transformer, then there would be a requirement to announce the reduction in system access to affected users and ensure that the TSO can obtain access to sufficient system services elsewhere on the system.

7.4 11 kV Rural feeder

The results from the analysis of the 11 kV rural feeder are summarised in Table 15 and depicted in Figure 12. This approach follows a different methodology from the 33 kV networks as the connected generation is assumed to be operating at 100% of MEC.

The result shows how much of each service can be allocated assuming simultaneous allocation of services across the group and how each of the network parameters contributes to this limit. Unlike the 33 kV network groups, the 11 kV rural network consists of one single primary substation and one of the radial 11 kV feeders that is connected to it.

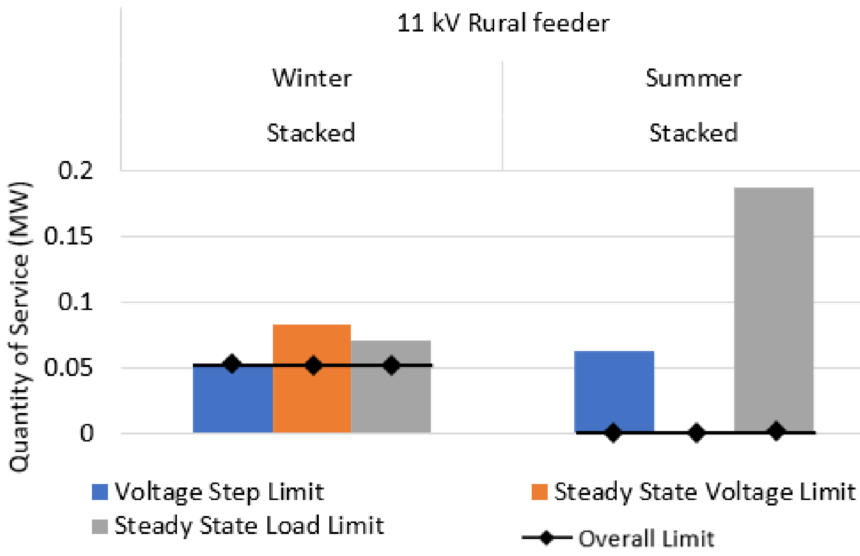


Figure 12 Graph of 11 kV rural feeder results

Table 15 11 kV rural feeder results

Demand Condition	The quantitative limit for Allocated Service (in MW)				
	Service	Voltage Step Limit	Steady State Voltage Limit	Steady State Load Limit	Overall Limit
Winter	Stacked	0.05	0.08	0.07	0.05
Summer	Stacked	0.06	0	0.19	0

Under winter conditions, the most limiting factor is the requirement to avoid a voltage step that is greater than 3%.

Under summer conditions, the voltage profile of the feeder lies just beneath the maximum allowable voltage of 1.03 per unit which implies that the steady-state voltage restriction would not allow any System Services to be allocated to the feeder under base case summer conditions.

In summary, the amount of System Services which can be allocated onto the 11 kV rural feeder is limited by the voltage performance of the feeder and in summer, there is no remaining capacity. It should be observed that the feeder studied already has embedded generation connected and that the capacity which was available on this feeder has already been allocated to an existing customer.

7.5 11 kV Semi-Rural feeder

The results from the 11 kV semi-rural feeder are summarised in Table 16 and depicted in Figure 13. The results show how much of each service can be allocated assuming simultaneous allocation of services across the group and how each of the network parameters contributes to this limit.

Unlike the 33 kV network groups the 11 kV semi-rural model comprised of one single primary substation and one of the radial 11 kV feeders that is connected to it. The one by one allocation tests investigated available capacity at each of the 11 kV network open points, at locations 1/3 and 2/3 down the main spine of the feeder and on the primary bus bars at main 33/11 kV substation. These test points totalled 11 locations along the entire length of the 11 kV feeder.

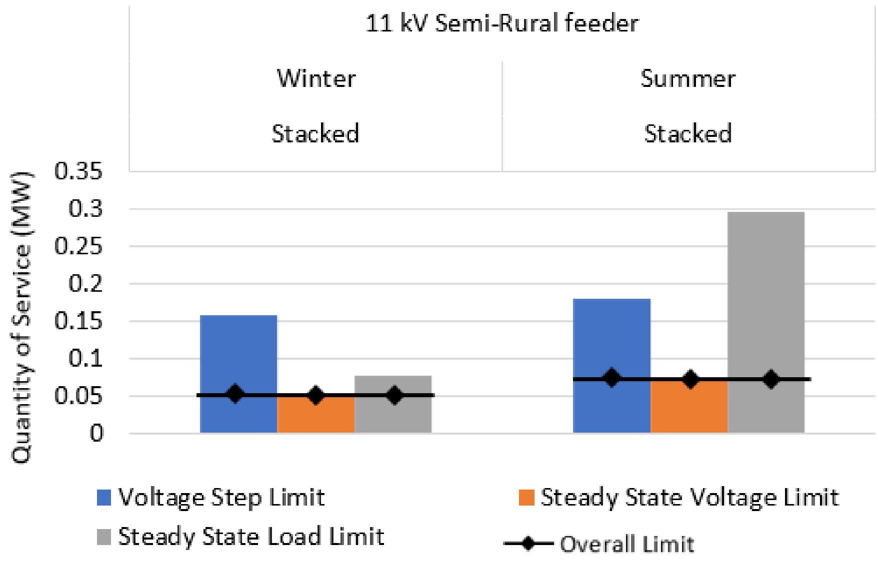


Figure 13 Graph of 11 kV Semi-Rural results

Table 16 11 kV Semi-Rural feeder results

Demand Condition	The quantitative limit for Allocated Service (in MW)				
	Service	Voltage Step Limit	Steady State Voltage Limit	Steady State Load Limit	Overall Limit
Winter	Stacked	0.16	0.05	0.08	0.05
Summer	Stacked	0.18	0.07	0.30	0.07

The most limiting factor, during both seasons, under simultaneous allocation was caused by the necessity to preserve steady state voltage along the feeder. The locations most remote from the primary substation were the most sensitive to this effect.

7.6 11 kV Commercial feeder

The results from the 11 kV Commercial feeder are summarised in Table 17 and depicted in Figure 14. This graph shows how much of each service can be allocated assuming simultaneous allocation of services across the group and how each of the network parameters contributes to this limit.

Similar to other 11 kV feeders the Commercial feeder model comprised of one single primary substation and one of the radial 11 kV feeders that was connected to it. The one by one allocation tests investigated available capacity at each of the 11 kV network open points, at locations 1/3 and 2/3 down the main spine of the feeder and on the primary bus bars at the 33/11 kV substation. These test points totalled 5 locations along the entire length of the 11 kV feeder.

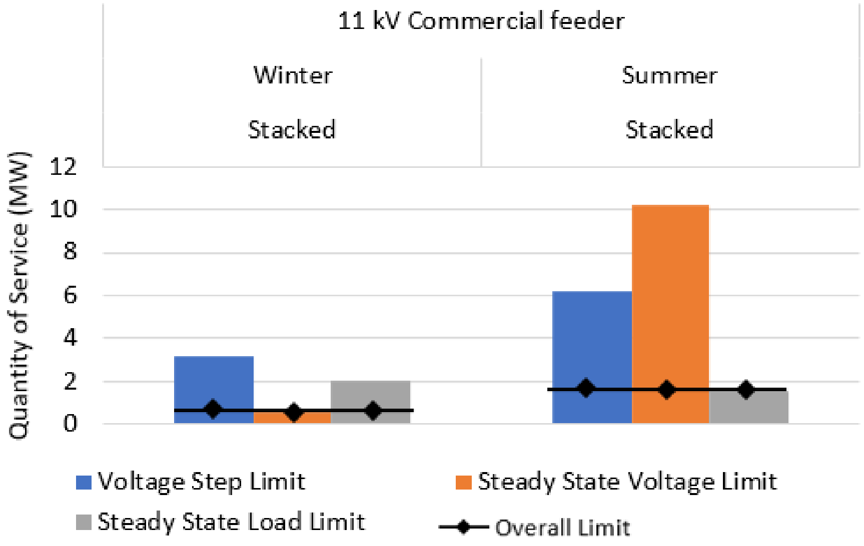


Figure 14 **Graph of 11 kV Commercial feeder results**

Table 17 **11 kV Commercial feeder results table**

Demand Condition	The quantitative limit for Allocated Service (in MW)				
	Service	Voltage Step Limit	Steady State Voltage Limit	Steady State Load Limit	Overall Limit
Winter	Stacked	3.19	0.55	2.06	0.55
Summer	Stacked	6.24	10.2	1.54	1.54

Unlike the previous two feeders, which had a low customer density and long distances, this feeder was tightly spaced. This means that there was a lower propensity for feeder voltage issues and that there is more possibility for thermally driven problems.

In general, there is greater potential for deployment of System Services in this network although the steady state voltage requirements still prove to be the most limiting factor.

7.7 11 kV Urban feeder

The results from the 11 kV Urban feeder are summarised in Table 18 and depicted in Figure 15. This graph shows how much of each service can be allocated assuming simultaneous allocation of services across the group and how each of the network parameters contributes to this limit.

Similar to the other 11 kV networks groups the Urban model comprised of one single primary substation and one of the radial 11 kV feeders that was connected to it. The simultaneous allocation tests investigated available capacity if the response was allocated all at the same time, at each of the 11 kV network open points, at locations 1/3 and 2/3 down the main spine of the feeder and on the primary bus bars at the 33/11 kV substation. These test points totalled 11 locations along the entire length of the 11 kV feeder.

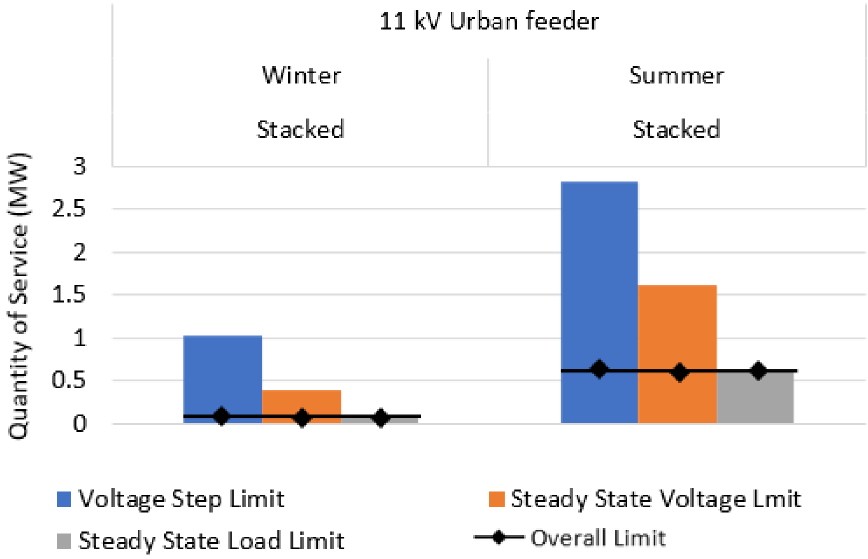


Figure 15 Graph of 11 kV Urban feeder results

The most limiting condition under winter conditions is steady-state voltage. The thermal loading limit, in this case, was discounted as it was a thermal import issue that would have been improved by system services.

Under summer conditions, the most limiting condition is caused by power flow limitations upon the first leg of the feeder (i.e. the section of the feeder which terminates upon the primary bus bars).

This study shows that on geographically dense feeders thermal loading problems can begin to influence the available limits in addition to voltage problems.

Table 18 11 kV Urban feeder results

Demand Condition	The quantitative limit for Allocated Service (in MW)				
	Service	Voltage Step Limit	Steady State Voltage Limit	Steady State Load Limit	Overall Limit
Winter	Stacked	1.02	0.4	0.08	0.08
Summer	Stacked	2.83	1.63	0.62	0.62

8. Conclusions

8.1 33 kV Networks

This analysis has conducted case study investigations into the available capacity to host system services in the 33 kV Urban, Semi-Urban and Cluster network groups. Because these are case studies they can be used to opine upon the variability of capacity and the key influences, but not to make generalisations about the rest of the network.

Because of uncertainty as to which system users will wish to provide System Services, and what type, an approach which assumed that deliver would be shared pro-rata across users on the basis of size was used. The results from this analysis have shown that the capacity to host system services within 33 kV and 11 kV network groups is finite and variable and in some cases has non-linear relationships with key influences.

This analysis has shown that the most common network parameters which limit the quantity of system services are either the need to avoid exceeding steady state voltage limits or alternatively the requirement to avoid exceeding a 3% step change in voltage.

This analysis has demonstrated the amount of capacity available in each network under different snapshots of network electrical consumption and also under different outage conditions. It has been observed that these outages studied are illustrative and that it is expected that outages of individual 33 kV circuits can result in system access restrictions that are even tighter.

This report has also made discussion of the practicality of providing a fixed quantity of system access, for every customer, for every feasible outage and proposed the view that an ongoing dynamic assessment would provide better access to the system than the use of fixed capacity allocation tables.

This analysis has studied the effect of prevailing generation output upon the capacity to host system services and concluded that reducing the amount of power exported by generation is not always the most influential driver of capacity to host system services. This analysis has also discovered that the prevailing network electrical consumption or reactive power instructions to generation can be just as influential.

This analysis has also investigated the capacity for system services under NSO conditions and N-1 conditions. The methodology used was limited to studying one common N-1 outage which was the outage of a 110/33 kV transformer at the source BSP. The results showed that the effect of transitioning from a system under NSO arrangements to the N-1 system with a 110/33 kV outage had had a significant effect on the available system capacity.

This analysis has also shown that the effect of pulling back generation upon the capacity for system services is not always linear. This means that in any operational context a full network model will be required to assess network capacity for system services and that use of fixed lookup tables or linear approximations would be likely to restrict system access unduly.

The results show that one of the influences between a worsening or improving effect is how much power is being exported by generation, which is again not a linear effect. There are likely to be other factors such as electrical demand consumption or reactive power instructions to generations that may also influence the capacity for services in the N-1 condition.

Because the capacity available to host system service capacity is finite and influenced by a number of factors, this means that to avoid exceeding the capability of their network the allocation of system services to customers will need to be managed in terms of where it is allocated, how much is allocated, what type of service is allocated and when it is required to be held.

This raises several dilemmas that the network operator will need to manage as more system services are placed upon the 33 kV or 11 kV systems.

- Firstly, because the capacity is sensitive to an N-1 versus NSO system, should the network operator set limits on the basis of an N-1 or NSO system? The network operator might choose to develop a capability that allows rapid reassignment of system services in the event of the network changing; alternatively, the network operator might take an approach which limits system access on the basis of the worst view from NSO and N-1 conditions.
- Secondly, it should be remembered, that this analysis has only looked at one network outage at the 110/33 kV BSP and then pro-rated the availability N-1 capacity across the system service providers. In reality, there will be occasional planned outages on every single circuit. This will mean that there will be a different quantity of system service available for each N-1 condition. Furthermore, it might not be possible to allow all generators to pro-rata the available capacity for each outage condition as they might have to be part-loaded as a precaution against overloads during the local 33 kV outage. This in effect means that the headroom to host system services is strongly coupled with the 33 kV outage planning and network management process.
- Finally, because the network limits are so strongly influenced by reactive power instructions sent to generators and also the minute to minute network demand, there is an opportunity to maximise opportunities to host system services where limits are updated upon a view of the prevailing network conditions. It would be feasible to manage at least NSO conditions using fixed look-up tables, but in the long run, such an approach may prove to restrict system access.

8.2 11 kV Networks

The behaviour of 11 kV networks regarding accepting System Services is different from the 33 kV networks because of the radial nature of 11 kV feeders. It is for this reason a simplified approach has been used.

The overview of results for 11 kV feeders is shown in Figure 16.

In general, the sparsely populated 11 kV feeders which connected large numbers of customers over a long distance demonstrated that the main barriers to the connection of System Services were voltage related whereas 11 kV feeders that are more tightly packed began to show thermal loading problems instead of voltage problems.

The Commercial and Urban 11 kV feeders both show a capability to accept System Services whereas the rural 11 kV feeders show a minimal to no capability to accept new System Services. In some cases, this is because these feeders already had generation connected to them and had consumed the existing capacity.

The Commercial and Urban feeders both also show a pattern of being able to accept a greater allocation of System Services during the summer.

This analysis has shown that there may be an opportunity to connect System Services in urban areas but the deployment of services in rural areas may encounter barriers from the need to maintain an acceptable voltage profile. This analysis has also shown that in some cases, use of short-term ratings may help overcome some network restrictions at 11 kV.

This investigation has also shown that the capacity to host system services at 11 kV is also influenced by seasonal electrical demand. This analysis has shown that in some cases, use of short-term circuit ratings can be used to improve system access.

In two out of the four cases, the voltage performance of the 11 kV feeder already serves to limit capacity to host system services. This means that mitigation approaches that reduce the voltage profile along the feeder are likely to be more effective than other alternatives.

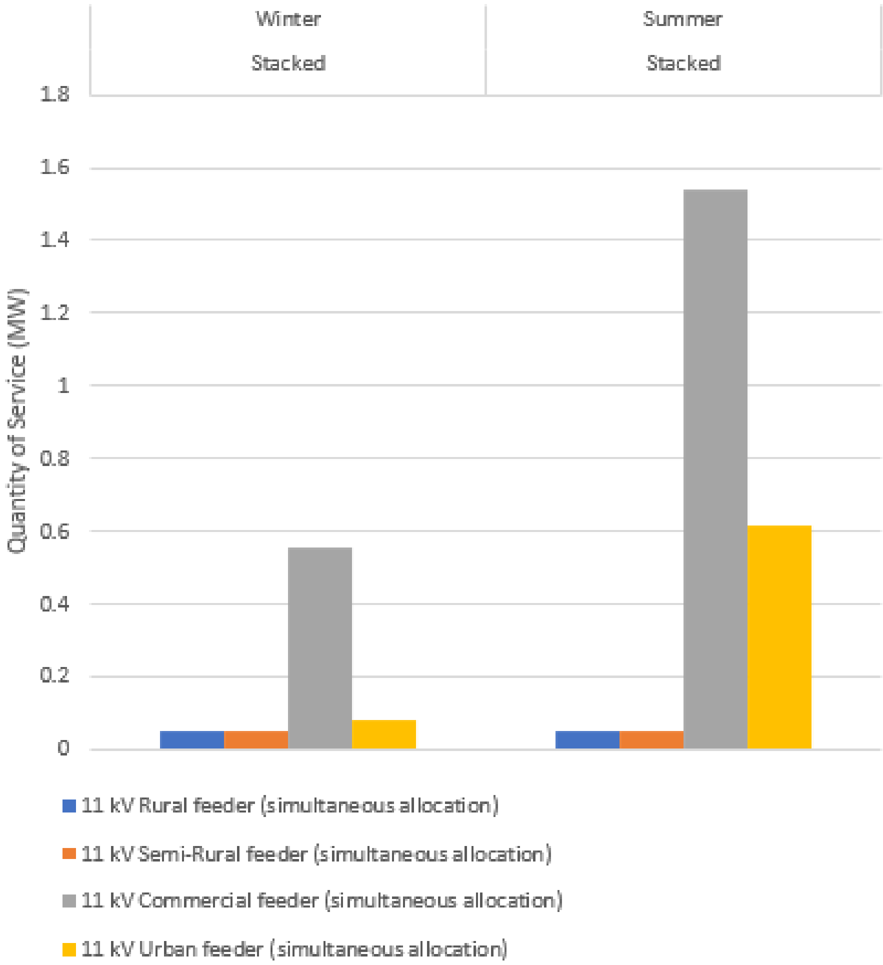


Figure 16 Overview of 11 kV results

There is one further network operational limitation with regard to hosting system services at 11 kV. This is due to the fact that the capacity to host system services on an 11 kV feeder will change depending on whether they are being fed from their normal feeding path or via an abnormal feeding path. Quite often an 11 kV customer or LV connected customer will not be aware as to which feeding path they are connected to and furthermore it is conventional practice for Network Operators, globally, to rely upon manually updated records of which feeding path an 11 kV or LV service provider is connected to. This means that any instruction set which regulates system services and 11 KV or LV may need to be conscious of when an 11 kV feeder transits from NSO conditions to N-1 conditions. Without this visibility of network status, there is a possibility that the safety, quality and security of supply parameters would be breached.

Appendix I 33 kV Semi-Urban network Results

Normal System Operation (NSO)

Table AI.1 **33 kV Semi-Urban network Summer Export (NSO)**

	Pre-event Generation Level	Limit	Capacity for Allocated Service (MW)						
			(FFR)	(POR)	(SOR)	(TOR1)	(TOR2)	(RRD)	(RRS)
Summer Export	100%	Quantitative limit (MW)	0	0	0	0	0	0	0
		Limiting factor**	V ss	V ss	V ss	V ss	V ss	V ss	V ss
		V step-G59 flag	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit
	80%	Quantitative limit (MW)	0	0	0	0	0	0	0
		Limiting factor**	V ss	V ss	V ss	V ss	V ss	V ss	V ss
		V step-G59 flag	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit
	60%	Quantitative limit (MW)	0	0	0	0	0	0	0
		Limiting factor**	V ss	V ss	V ss	V ss	V ss	V ss	V ss
		V step-G59 flag	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit
	40%	Quantitative limit (MW)	0	0	0	0	0	0	0
		Limiting factor	V ss	V ss	V ss	V ss	V ss	V ss	V ss
		V step-G59 flag	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit
	20%	Quantitative limit (MW)	0	0	0	0	0	0	0
		Limiting factor	V ss	V ss	V ss	V ss	V ss	V ss	V ss
		V step-G59 flag	V-Step	V-Step	V-Step	V-Step	V-Step	V-Step	V-Step
	0%	Quantitative limit (MW)	11.79	11.79	11.79	11.79	11.79	11.79	11.79
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	V-Step	V-Step	V-Step	V-Step	V-Step	V-Step	V-Step

**Multiple limiting factors (Vss and V Step)

Step changes in voltage must always remain within +3% of nominal and absolute voltage never exceed an absolute value of 1.1 per unit % of nominal. The G59 flag indicates the nature of violation observed due to a step change.
V-Limit corresponds to a voltage above 1.1pu and
V-step corresponds to a voltage rise of ≥3% due to a step change.

Table AI.2 33 kV Semi-Urban Network Winter Export (NSO)

	Pre-event Generation Level	Limit	Capacity for Allocated Service (MW)						
			(FFR)	(POR)	(SOR)	(TOR1)	(TOR2)	(RRD)	(RRS)
Winter Export	100%	Quantitative limit (MW)	0	0	0	0	0	0	0
		Limiting factor **	V ss	V ss	V ss	V ss	V ss	V ss	V ss
		V step-G59 flag	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit
	80%	Quantitative limit (MW)	0	0	0	0	0	0	0
		Limiting factor **	V ss	V ss	V ss	V ss	V ss	V ss	V ss
		V step-G59 flag	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit
	60%	Quantitative limit (MW)	0	0	0	0	0	0	0
		Limiting factor **	V ss	V ss	V ss	V ss	V ss	V ss	V ss
		V step-G59 flag	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit
	40%	Quantitative limit (MW)	0	0	0	0	0	0	0
		Limiting factor	V ss	V ss	V ss	V ss	V ss	V ss	V ss
		V step-G59 flag	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit
	20%	Quantitative limit (MW)	0.40	0.40	0.40	0.40	0.40	0.401	0.401
		Limiting factor	V ss	V ss	V ss	V ss	V ss	V ss	V ss
		V step-G59 flag	V-Step	V-Step	V-Step	V-Step	V-Step	V-Step	V-Step
	0%	Quantitative limit (MW)	0	0	0	0	0	0	0
		Limiting factor	V ss	V ss	V ss	V ss	V ss	V ss	V ss
		V step-G59 flag	V-Step	V-Step	V-Step	V-Step	V-Step	V-Step	V-Step

**Multiple limiting factors (Vss and V Step)

Table AI.3 33 kV Semi-Urban Network Winter Import (NSO)

	Pre-Event Generation Level	Limit	Capacity for Allocated Service (MW)						
			(FFR)	(POR)	(SOR)	(TOR1)	(TOR2)	(RRD)	(RRS)
Winter Import	100%	Quantitative limit (MW)	11.28	11.28	11.28	11.28	11.28	11.28	11.28
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	V-Step	V-Step	V-Step	V-Step	V-Step	V-Step	V-Step
	80%	Quantitative limit (MW)	11.88	11.88	11.88	11.88	11.88	11.88	11.88
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	V-Step	V-Step	V-Step	V-Step	V-Step	V-Step	V-Step
	60%	Quantitative limit (MW)	12.44	12.44	12.44	12.44	12.44	12.44	12.44
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	V-Step	V-Step	V-Step	V-Step	V-Step	V-Step	V-Step
	40%	Quantitative limit (MW)	12.97	12.97	12.97	12.97	12.97	12.97	12.97
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	V-Step	V-Step	V-Step	V-Step	V-Step	V-Step	V-Step
	20%	Quantitative limit (MW)	13.47	13.47	13.47	13.47	13.47	13.47	13.47
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	V-Step	V-Step	V-Step	V-Step	V-Step	V-Step	V-Step
	0%	Quantitative limit (MW)	13.94	13.94	13.94	13.94	13.94	13.94	13.94
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	V-Step	V-Step	V-Step	V-Step	V-Step	V-Step	V-Step

Circuit outage Operation (N-1)

Table AI.4 33 kV Semi-Urban Network Summer Export (N-1)

	Pre-Event Generation Level	Limit	Capacity for Allocated Service (MW)						
			(FFR)	(POR)	(SOR)	(TOR1)	(TOR2)	(RRD)	(RRS)
Summer Export	100%	Quantitative limit (MW)	0	0	0	0	0	0	0
		Limiting factor	V ss	V ss	V ss	V ss	V ss	V ss	V ss
		V step-G59 flag	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit
	80%	Quantitative limit (MW)	0	0	0	0	0	0	0
		Limiting factor	V ss	V ss	V ss	V ss	V ss	V ss	V ss
		V step-G59 flag	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit
	60%	Quantitative limit (MW)	0	0	0	0	0	0	0
		Limiting factor	V ss	V ss	V ss	V ss	V ss	V ss	V ss
		V step-G59 flag	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit
	40%	Quantitative limit (MW)	0	0	0	0	0	0	0
		Limiting factor	V ss	V ss	V ss	V ss	V ss	V ss	V ss
		V step-G59 flag	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit
	20%	Quantitative limit (MW)	0	0	0	0	0	0	0
		Limiting factor	V ss	V ss	V ss	V ss	V ss	V ss	V ss
		V step-G59 flag	V-Step	V-Step	V-Step	V-Step	V-Step	V-Step	V-Step
	0%	Quantitative limit (MW)	0	0	0	0	0	0	0
		Limiting factor	V ss	V ss	V ss	V ss	V ss	V ss	V ss
		V step-G59 flag	V-Step	V-Step	V-Step	V-Step	V-Step	V-Step	V-Step

Table AI.5 33 kV Semi-Urban Network Winter Export (N-1)

	Pre-event Generation Level	Limit	Capacity for Allocated Service (MW)						
			(FFR)	(POR)	(SOR)	(TOR1)	(TOR2)	(RRD)	(RRS)
Winter Export	100%	Quantitative limit (MW)	0	0	0	0	0	0	0
		Limiting factor	V ss	V ss	V ss	V ss	V ss	V ss	V ss
		V step-G59 flag	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit
	80%	Quantitative limit (MW)	0	0	0	0	0	0	0
		Limiting factor	V ss	V ss	V ss	V ss	V ss	V ss	V ss
		V step-G59 flag	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit
	60%	Quantitative limit (MW)	0	0	0	0	0	0	0
		Limiting factor	V ss	V ss	V ss	V ss	V ss	V ss	V ss
		V step-G59 flag	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit
	40%	Quantitative limit (MW)	0	0	0	0	0	0	0
		Limiting factor	V ss	V ss	V ss	V ss	V ss	V ss	V ss
		V step-G59 flag	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit	V-Limit
	20%	Quantitative limit (MW)	0	0	0	0	0	0	0
		Limiting factor	V ss	V ss	V ss	V ss	V ss	V ss	V ss
		V step-G59 flag	V-Step	V-Step	V-Step	V-Step	V-Step	V-Step	V-Step
	0%	Quantitative limit (MW)	0	0	0	0	0	0	0
		Limiting factor	V ss	V ss	V ss	V ss	V ss	V ss	V ss
		V step-G59 flag	V-Step	V-Step	V-Step	V-Step	V-Step	V-Step	V-Step

Table AI.6 33 kV Semi-Urban Network Winter Import (N-1)

	Pre-event Generation Level	Limit	Capacity for Allocated Service (MW)						
			(FFR)	(POR)	(SOR)	(TOR1)	(TOR2)	(RRD)	(RRS)
Winter Import	100%	Quantitative limit (MW)	8.68	8.68	8.68	8.68	8.68	8.68	8.68
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	V-Step	V-Step	V-Step	V-Step	V-Step	V-Step	V-Step
	80%	Quantitative limit (MW)	9.33	9.33	9.33	9.33	9.33	9.33	9.33
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	V-Step	V-Step	V-Step	V-Step	V-Step	V-Step	V-Step
	60%	Quantitative limit (MW)	9.94	9.94	9.94	9.94	9.94	9.94	9.94
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	V-Step	V-Step	V-Step	V-Step	V-Step	V-Step	V-Step
	40%	Quantitative limit (MW)	10.50	10.50	10.50	10.50	10.50	10.50	10.50
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	V-Step	V-Step	V-Step	V-Step	V-Step	V-Step	V-Step
	20%	Quantitative limit (MW)	11.02	11.02	11.02	11.02	11.02	11.02	11.02
		Limiting factor	V ss	V ss	V ss	V ss	V ss	V ss	V ss
		V step-G59 flag	V-Step	V-Step	V-Step	V-Step	V-Step	V-Step	V-Step
	0%	Quantitative limit (MW)	11.50	11.50	11.50	11.50	11.50	11.50	11.50
		Limiting factor	V ss	V ss	V ss	V ss	V ss	V ss	V ss
		V step-G59 flag	V-Step	V-Step	V-Step	V-Step	V-Step	V-Step	V-Step

Appendix II 33 kV Urban network Results

Normal System Operation (NSO)

Table AII.1 33 kV Urban Network summer (NSO)

	Pre-event Generation Level	Limit	Capacity for Allocated Service (MW)						
			(FFR)	(POR)	(SOR)	(TOR1)	(TOR2)	(RRD)	(RRS)
Summer	100%	Quantitative limit (MW)	31.27	31.27	31.27	31.27	31.27	31.27	31.27
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	no	no	no	no	no	no	no
	80%	Quantitative limit (MW)	31.96	31.96	31.96	31.955	31.955	31.96	31.96
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	no	no	no	no	no	no	no
	60%	Quantitative limit (MW)	32.58	32.58	32.58	32.579	32.579	32.58	32.58
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	no	no	no	no	no	no	no
	40%	Quantitative limit (MW)	33.14	33.14	33.14	33.141	33.141	33.14	33.14
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	no	no	no	no	no	no	no
	20%	Quantitative limit (MW)	33.65	33.65	33.65	33.646	33.646	33.65	33.65
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	no	no	no	no	no	no	no
	0%	Quantitative limit (MW)	34.09	34.09	34.09	34.091	34.091	34.09	34.09
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	no	no	no	no	no	no	no

Table AII.2 **33 kV Urban Network Winter (NSO)**

	Pre-event Generation Level	Limit	Capacity for Allocated Service (MW)						
			(FFR)	(POR)	(SOR)	(TOR1)	(TOR2)	(RRD)	(RRS)
Winter	100%	Quantitative limit (MW)	18.05	18.05	18.05	18.053	18.05	18.05	18.05
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	no	no	no	no	no	no	no
	80%	Quantitative limit (MW)	18.33	18.33	18.33	18.329	18.33	18.33	18.33
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	no	no	no	no	no	no	no
	60%	Quantitative limit (MW)	18.54	18.54	18.54	18.543	18.54	18.54	18.54
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	no	no	no	no	no	no	no
	40%	Quantitative limit (MW)	18.73	18.73	18.73	18.73	18.73	18.73	18.73
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	no	no	no	no	no	no	no
	20%	Quantitative limit (MW)	18.88	18.88	18.88	18.88	18.88	18.88	18.88
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	no	no	no	no	no	no	no
	0%	Quantitative limit (MW)	18.99	18.99	18.99	18.99	18.99	18.99	18.99
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	no	no	no	no	no	no	no

Circuit outage Operation (N-1)

Table AII.3 33 kV Urban Network Summer (N-1)

	Pre-event Generation Level	Limit	Capacity for Allocated Service (MW)						
			(FFR)	(POR)	(SOR)	(TOR1)	(TOR2)	(RRD)	(RRS)
Summer	100%	Quantitative limit (MW)	24.62	24.62	24.62	24.62	24.62	24.62	24.62
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	no	no	no	no	no	no	no
	80%	Quantitative limit (MW)	25.58	25.58	25.58	25.58	25.58	25.58	25.58
		Limiting factor	no	no	no	no	no	no	no
		V step-G59 flag	V=Step	V=Step	V=Step	V=Step	V=Step	V=Step	V=Step
	60%	Quantitative limit (MW)	26.45	26.45	26.45	26.45	26.45	26.45	26.45
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	no	no	no	no	no	no	no
	40%	Quantitative limit (MW)	27.24	27.24	27.24	27.24	27.24	27.24	27.24
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	no	no	no	no	no	no	no
	20%	Quantitative limit (MW)	27.95	27.95	27.95	27.95	27.95	27.95	27.95
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	no	no	no	no	no	no	no
	0%	Quantitative limit (MW)	28.58	28.58	28.58	28.58	28.578	28.58	28.58
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	no	no	no	no	no	no	no

Table AII.4 **33 kV Urban Network Winter (N-1)**

	Pre-event Generation Level	Limit	Capacity for Allocated Service (MW)						
			(FFR)	(POR)	(SOR)	(TOR1)	(TOR2)	(RRD)	(RRS)
Winter	100%	Quantitative limit (MW)	9.65	9.65	9.65	9.65	9.65	9.65	9.65
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	no	no	no	no	no	no	no
	80%	Quantitative limit (MW)	9.98	9.98	9.98	9.98	9.98	9.98	9.98
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	no	no	no	no	no	no	no
	60%	Quantitative limit (MW)	10.26	10.26	10.26	10.26	10.26	10.26	10.26
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	no	no	no	no	no	no	no
	40%	Quantitative limit (MW)	10.4	10.4	10.4	10.4	10.4	10.4	10.4
		Limiting factor	Load ss	Load ss	Load ss	Load ss	Load ss	Load ss	V step
		V step-G59 flag	no	no	no	no	no	no	no
	20%	Quantitative limit (MW)	10.6	10.6	10.6	10.6	10.6	10.6	10.6
		Limiting factor	Load ss	Load ss	Load ss	Load ss	Load ss	Load ss	V step
		V step-G59 flag	no	no	no	no	no	no	no
	0%	Quantitative limit (MW)	10.8	10.8	10.8	10.8	10.8	10.8	10.8
		Limiting factor	Load ss	Load ss	Load ss	Load ss	Load ss	Load ss	V step
		V step-G59 flag	no	no	no	no	no	no	no

**Multiple limiting factors , both V step and Load limit have triggered

Appendix III 33 kV Cluster network Results

Normal System Operation (NSO)

Table AIII.1 33 kV Cluster Network Summer (NSO)

	Pre-event Generation Level	Limit	Capacity for Allocated Service (MW)						
			(FFR)	(POR)	(SOR)	(TOR1)	(TOR2)	(RRD)	(RRS)
Summer	100%	Quantitative limit (MW)	0	0	0	0	0	0	0
		Limiting factor	Vss	Vss	Vss	Vss	Vss	Vss	Vss
		V step-G59 flag	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	80%	Quantitative limit (MW)	10.94	10.94	10.94	10.94	10.94	10.94	10.94
		Limiting factor	Vss	Vss	Vss	Vss	Vss	Vss	Vss
		V step-G59 flag	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	60%	Quantitative limit (MW)	19.60	19.60	19.60	19.60	19.60	19.60	19.60
		Limiting factor	Vss	Vss	Vss	Vss	Vss	Vss	Vss
		V step-G59 flag	no	no	no	no	no	no	no
	40%	Quantitative limit (MW)	24.73	24.73	24.73	24.73	24.73	24.73	24.73
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	no	no	no	no	no	no	no
	20%	Quantitative limit (MW)	20.38	20.38	20.38	20.38	20.38	20.38	20.38
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	no	no	no	no	no	no	no
	0%	Quantitative limit (MW)	16.76	16.76	16.76	16.76	16.76	16.76	16.76
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	no	no	no	no	no	no	no

n/a indicates that there are no G59 violations observed at that specific level of generation pull back.

Table AIII.2 **33 kV Cluster Network Winter (NSO)**

	Pre-event Generation Level	Limit	Capacity for Allocated Service (MW)						
			(FFR)	(POR)	(SOR)	(TOR1)	(TOR2)	(RRD)	(RRS)
Winter	100%	Quantitative limit (MW)	0	0	0	0	0	0	0
		Limiting factor	Vss	Vss	Vss	Vss	Vss	Vss	Vss
		V step-G59 flag	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	80%	Quantitative limit (MW)	10.89	10.89	10.89	10.89	10.89	10.89	10.89
		Limiting factor	Vss	Vss	Vss	Vss	Vss	Vss	Vss
		V step-G59 flag	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	60%	Quantitative limit (MW)	19.61	19.61	19.61	19.61	19.61	19.61	19.61
		Limiting factor	Vss	Vss	Vss	Vss	Vss	Vss	Vss
		V step-G59 flag	no	no	no	no	no	no	no
	40%	Quantitative limit (MW)	24.70	24.70	24.70	24.70	24.70	24.70	24.70
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	no	no	no	no	no	no	no
	20%	Quantitative limit (MW)	20.39	20.39	20.39	20.39	20.39	20.39	20.39
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	no	no	no	no	no	no	no
	0%	Quantitative limit (MW)	16.79	16.79	16.79	16.79	16.79	16.79	16.79
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	no	no	no	no	no	no	no

Circuit outage Operation (N-1)

Table AIII.3 33 kV Cluster Network Summer (N-1)

	Pre-event Generation Level	Limit	Capacity for Allocated Service (MW)						
			(FFR)	(POR)	(SOR)	(TOR1)	(TOR2)	(RRD)	(RRS)
Summer	100%	Quantitative limit (MW)	0	0	0	0	0	0	0
		Limiting factor	0	0	0	0	0	0	0
		V step-G59 flag							
	80%	Quantitative limit (MW)	23.35	23.35	23.35	23.35	23.35	23.35	23.35
		Limiting factor	Load ss	Load ss	Load ss	Load ss	Load ss	Load ss	Load ss
		V step-G59 flag	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	60%	Quantitative limit (MW)	47.23	47.23	47.23	47.23	47.23	47.23	47.23
		Limiting factor	Load ss	Load ss	Load ss	Load ss	Load ss	Load ss	Load ss
		V step-G59 flag	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	40%	Quantitative limit (MW)	27.80	27.80	27.80	27.80	27.80	27.80	27.80
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	no	no	no	no	no	no	no
	20%	Quantitative limit (MW)	18.86	18.86	18.86	18.86	18.86	18.86	18.86
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	no	no	no	no	no	no	no
	0%	Quantitative limit (MW)	13.73	13.73	13.73	13.73	13.73	13.73	13.73
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	no	no	no	no	no	no	no

Table AIII.4 33 kV Cluster Network Winter (N-1)

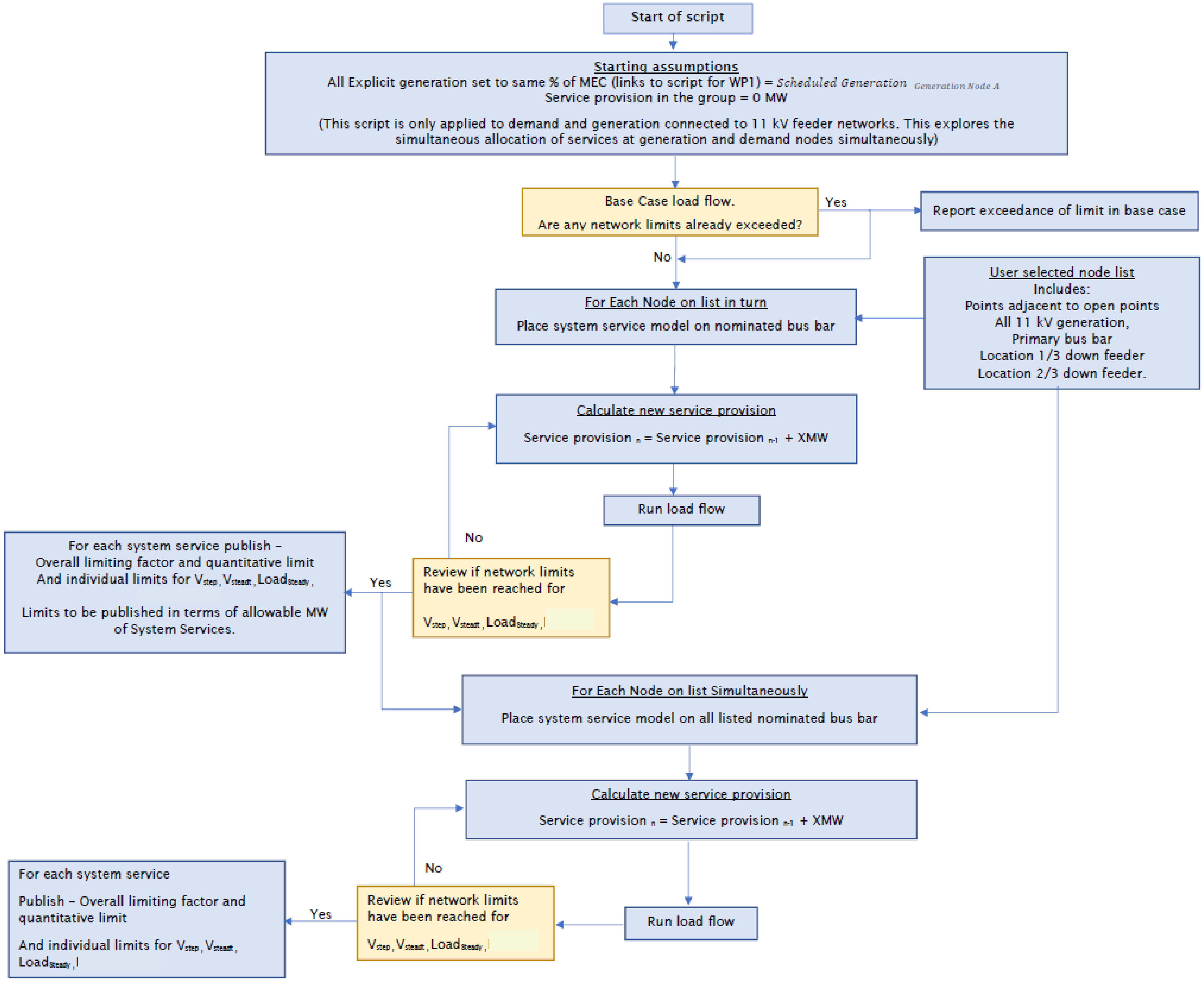
	Pre-event Generation Level	Limit	Capacity for Allocated Service (MW)						
			(FFR)	(POR)	(SOR)	(TOR1)	(TOR2)	(RRD)	(RRS)
Winter	100%	Quantitative limit (MW)	0	0	0	0	0	0	0
		Limiting factor	Load ss	Load ss	Load ss	Load ss	Load ss	Load ss	Load ss
		V step-G59 flag	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	80%	Quantitative limit (MW)	23.33	23.33	23.33	23.33	23.33	23.33	23.33
		Limiting factor	Load ss	Load ss	Load ss	Load ss	Load ss	Load ss	Load ss
		V step-G59 flag	0	0	0	0	0	0	0
	60%	Quantitative limit (MW)	47.23	47.23	47.23	47.23	47.23	47.23	47.23
		Limiting factor	Load ss	Load ss	Load ss	Load ss	Load ss	Load ss	Load ss
		V step-G59 flag	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	40%	Quantitative limit (MW)	27.69	27.69	27.69	27.69	27.69	27.69	27.69
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	no	no	no	no	no	no	no
	20%	Quantitative limit (MW)	18.86	18.86	18.86	18.86	18.86	18.86	18.86
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	no	no	no	no	no	no	no
	0%	Quantitative limit (MW)	13.75	13.75	13.75	13.75	13.75	13.75	13.75
		Limiting factor	V step	V step	V step	V step	V step	V step	V step
		V step-G59 flag	no	no	no	no	no	no	no

Appendix IV Overall Breakdown of 33 kV limits

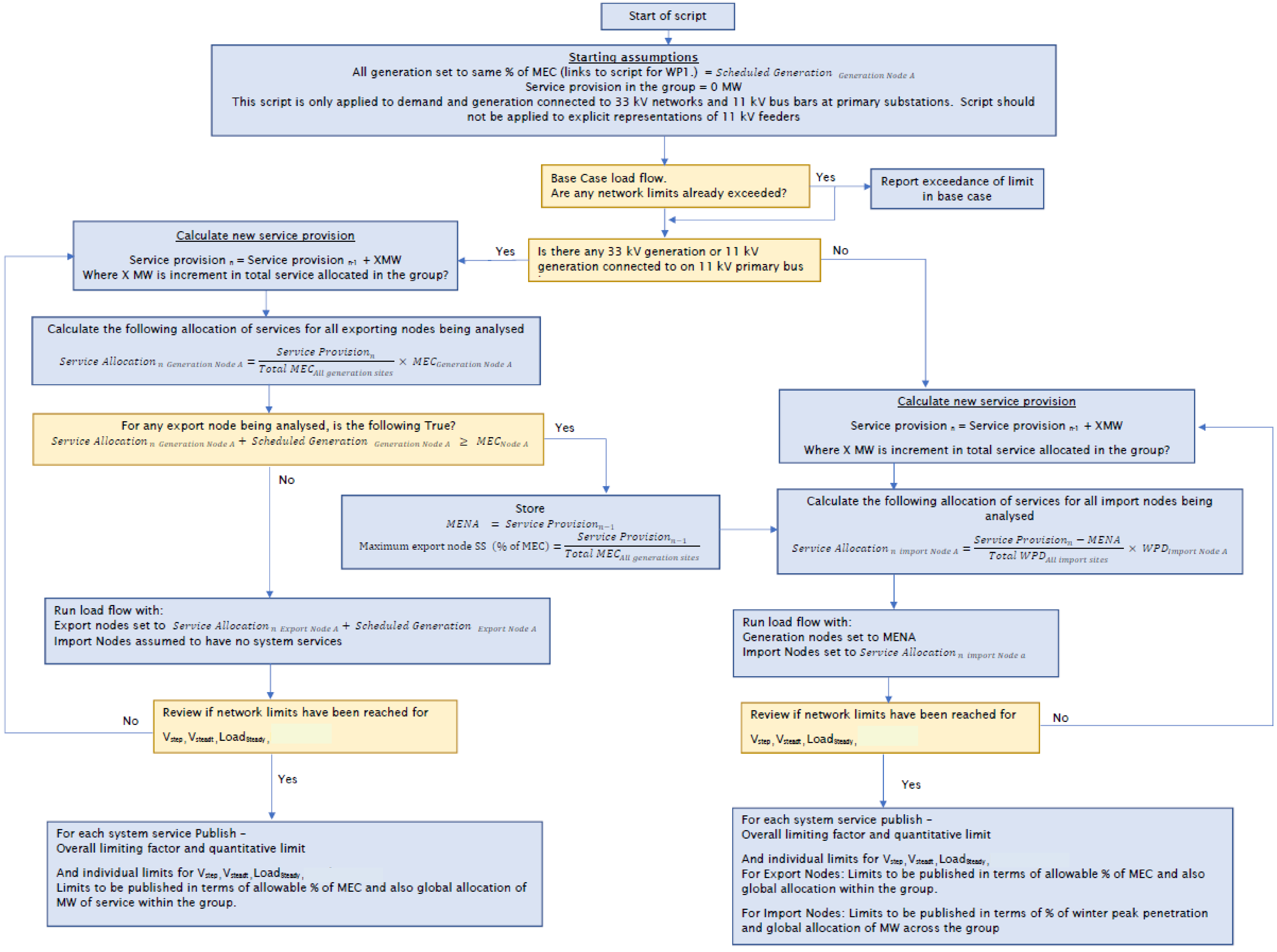
Table AIV.1 Overall breakdown of 33 kV limits

	Combined Capacity for System Services (MW) - (Demand Side and Generation Response)					
Pre-Event Generation Level (%)	**100%**	**80%**	**60%**	**40%**	**20%**	**0%**
Semi-Urban network (Summer Export)	0	0	0	0	0	11.8
Semi-Urban network (Winter Export)	0	0	0	0	0	0.4
Semi-Urban network (Winter Import)	11.3	11.9	12.4	13	13.5	13.9
Cluster network (Summer)	0	10.9	19.6	24.7	20.4	16.8
Cluster network (Winter)	0	10.9	19.6	24.7	20.4	16.8
Urban network (Summer)	31.3	32	32.6	33.1	33.7	34.1
Urban network (Winter)	18	18.3	18.5	18.7	18.9	19

Appendix V 11 kV Distributed Analysis Flow Chart



Appendix VI 33 kV Pro Rata Analysis Flow Chart



Global Footprint

We provide products, services and support for customers in 90 countries, through our offices in Australia, China, Europe, Singapore, UAE and USA, together with more than 40 distribution partners.

Our Expertise

We provide world-leading asset management solutions for power plant and networks.

Our customers include electricity generation, transmission and distribution companies, together with major power plant operators in the private and public sectors.

- Our products, services, management systems and knowledge enable customers to:
- Prevent outages
- Assess the condition of assets
- Understand why assets fail
- Optimise network operations
- Make smarter investment decisions
- Build smarter grids
- Achieve the latest standards
- Develop their power skills

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