Smart Network Design Methodologies

Multi-Voltage Level Novel Analysis

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Contents

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0.1 Document history

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Executive Summary

Voltages on distribution networks are typically modelled using a silo approach, with voltages being assessed separately across EHV, HV and LV networks. Such an approach doesn't facilitate voltage behaviour or solutions to voltage issues being analysed in a holistic way and can result in simplified assumptions being applied which may result in inefficient network planning. With electrification of heat and transport and increasing embedded generation connecting to HV and LV networks, a holistic, multi-voltage approach to voltage assessment can provide a more cost-effective response to specific network issues. It can also be used to inform and future proof voltage management policy, supporting an evolution to a whole-systems network planning and operation approach.

TNEI Services Limited (TNEI) and Northern Powergrid (NPg) have collaborated on an innovative multi-voltage level network study that has developed and tested an efficient methodology for building, testing, validating and implementing a Multiple Voltage Level (MVL) model. This has involved the complex combination of a range of data fields sourced from different NPg systems and the process has been verified on two representative NPg networks. These models have then been used to explore holistic voltage behaviour across voltage levels under a range of interdependent network load states and topologies – defined by network planning related Use Cases.

A number of voltage management solutions have been identified, assessed and then, for a subset, analysed using the representative network models to resolve voltage issues due to increased levels of embedded generation and demand. Solutions have been focussed on resolving specific design issues whilst also informing strategic voltage policy solutions including plant specifications and target voltage operating points. Whilst it is recognised that only two NPg networks have been modelled and hence there are some limitations in terms of wider rollout, the results provide some key observations, learning and recommendations on how this approach could provide significant value if applied as a business as usual approach. These are set out below:

- The MVL modelling approach provides most value for HV and LV models; the addition of EHV networks to the models does not provide significant additional value apart from enabling a more detailed review of the compliance of a network with the requirements set out in Engineering Recommendation P10. For example, a HV and LV MVL model allows the cross-voltage level impact of connection of generation at HV combined with high uptake of PV at LV to be more accurately modelled as well as potential voltage management solutions.
- The present NPg voltage policy appears to be suitable for existing and future loading conditions under credible operational regimes, although it should continue to be reviewed as network loading changes. The allocation of voltage drop across the HV and LV voltage levels appears to be broadly appropriate for both urban and rural networks. However, with heat and transport electrification and increased penetration of embedded PV, rural networks are likely to be more affected by voltage issues and may require a more detailed assessment and/or a review of the design principles. There is potentially a case for different voltage design policies for rural and urban networks, however, this can lead to lack of clarity for networks that are difficult to classify. This should be explored further.
- The tap range of primary transformers can generally accommodate a wide range of loading conditions although for the representative networks analysed, the primary transformer tap changers are typically operating towards the higher end of the tapping range, potentially reducing the amount of generation headroom.
- The assumptions related to the modelling of tapchanger deadband can be material in those situations where network voltages are approaching their upper or lower limits. The risk associated with tapchange relays spending a significant amount of time at the extremes of the deadband range should be considered in more detail.

- The specification of and the loading on supply point transformers is such that the requirements of EREC P10 are satisfied.
- The modelling of NPg networks could be improved to better capture voltage behaviour e.g. by including susceptance values in the network models.

It should be noted that that the two networks studied are not likely to be fully representative of the wide and varied range of network characteristics across NPg so we recommend further verification of these observations and recommendations following application of the MVL on other networks. The required MVL networks can be created efficiently using the methodology developed within this project and described in this report.

There are several voltage management solutions that can be implemented readily using equipment that is already installed or currently being installed as part of a voltage control enhancement project.

- Load drop compensation could be implemented to cover various future demand and generation conditions at HV and LV although the application would be network specific and would need to consider the loading patterns of all feeders connected to those networks – LDC is more effective where loading patterns are fairly similar under normal and under contingency conditions.
- Target voltage settings on new AVC relays fitted with remote communications could be changed remotely on a seasonal basis. The MVL modelling approach can be deployed to develop an improved understanding of when to deploy target voltage changes and/or LDC, how application of these solutions might interact including during contingency conditions, and how application of these solutions could best be reflected in both the planning and design process.

Inline voltage regulators can be implemented to address feeder specific voltage issues and may also enable new outage topologies to be considered.

For localised LV voltage issues, manually changing the HV/LV substation tap settings may be a suitable short-term solution for issues arising from demand or generation. A wider scale rollout of HV/LV transformers equipped with OLTCs may provide a more flexible future proof solution that can also help to manage losses better, although the additional cost does need to be offset against the additional headroom / legroom created and the likelihood that the extra capacity will be utilised within the planning period. Where there is a requirement to replace a HV/LV transformer due to asset condition or excessive load, the deployment of an OLTC should be considered.

Any network design or strategic policy that involves implementing voltage management solutions should also consider the impact on network losses.

As the volume of embedded generation increases, the potential for using the generators voltage / reactive power performance capability should be considered and it is recommended that further work is carried out to establish the best way to utilise the enhanced generator capability now required from Power Generation Modules that are compliant with EREC G99.

1 Introduction

Voltages on distribution networks are typically modelled using a silo approach, with voltages being assessed separately across EHV, HV and LV networks using separate network models and software used across voltage levels. When power system studies are carried out, simplifying assumptions are necessary to represent the uncertainties of voltage variation with load and generation at higher voltage levels within the local and wider network. These uncertainties may result in rudimentary and deterministic assumptions being made when assessing voltage regulation. There is anecdotal evidence, from on-site measurements, that suggest that these assumptions may lead to over-reinforcement in urban areas and under-reinforcement in some rural networks. Also, when assessing the holistic effects of advanced voltage control techniques such as Load Drop Compensation (LDC), the way existing design tools are used is not fit for purpose as each voltage level is typically modelled independently.

This study explores a more holistic approach to assessing the impact of a range of network load states and topologies on voltage. This has enabled recommendations to be made relating to network modelling and voltage control solutions and management techniques as an outcome of the study. It also looks to verify existing equipment specifications and network design/planning assumptions based on analysis of multi-voltage models for two representative network models.

1.1 Objectives

The objectives of this study are as follows:

- Develop an efficient methodology for building, testing, validating and implementing a Multiple Voltage Level (MVL) model that aligns with existing network models, asset and operational data available from NPg. Test the MVL on two representative network models with consideration of representation of model interfaces (to other networks not modelled) and boundaries (with higher voltage levels). Models must be suitable for use within NPg.
- Use the MVL models to explore holistic voltage behaviour across voltage levels under a range of interdependent network load states and topologies including:
    - Existing voltage variation across voltage levels, under credible but challenging First Circuit Outage (FCO) conditions for peak demand and summer minimum/peak generation.
    - Voltage variation across voltage levels under increasing demand / generation scenarios that result in voltage violations beyond statutory limits.
- Explore a number of existing and novel voltage management solutions that are viable for NPg networks including:
    - **Design Solutions:** Range of discrete solutions / combination of solutions that could be applied.
    - **Strategic Solutions:** More holistic long-term solutions to the existing silo design approach such as policy changes, recommendations on the most effective voltage control management solutions, plant specifications and target voltage operating points to provide guidance for design engineers.

1.2 Use Cases

There are seven core use cases relevant to this study, the applicability of which is described below. The use cases have been extracted from the "Smart Network Design Methodologies – Use Cases, June 2018"[1].

Table 1 Use Cases for MVL Methodology

Use Cases	Multi-voltage model application
2.1 Identify and mitigate voltage violations risks – LV	Voltage issues at LV exacerbated by voltage issues at higher voltage levels e.g. voltage drop along HV feeder already near limit and further load increases due to LCT connections on LV network results in exceedance of limit
2.2 Identify and mitigate voltage violations HV/EHV	Voltage drop along HV feeder already near limit and further load increases due to LCT connections on LV network results in exceedance of limit at HV under certain network contingency conditions
3.1.1 Model new connections – Generation LV	New generation connections at LV cause voltage rise issues at LV that may be best resolved by solutions at HV.
3.1.2 Model new connections – Generation HV/EHV	Where new generation connection at HV or EHV causes voltage issues at other voltage levels i.e. LV, potentially exacerbated by the connection of embedded generation at LV
3.2.1 Model new connections – Demand Load LV	New demand connections or increase in demand at LV causes voltage issues that may be best resolved by solutions at HV.
3.2.2 Model new connections – Demand Load HV/EHV	New demand connection at HV or EHV causes voltage issues at other voltage levels i.e. LV, potentially exacerbated by demand increase at LV
6 Strategic Network Modeling	Strategic network modelling to define investment plan for NPg licence areas

1.3 Benefits

The implementation of the MVL model methodology as part of NPg Business as Usual (BAU) processes should bring the following benefits:

- Improved understanding of holistic voltage interactions across multiple voltage levels;
- Improved identification of solutions to resolve voltage issues across multiple voltage levels, both on a network specific and strategic basis; and
- Enable more efficient whole-system network planning in a changing energy system in both investment and operational planning timescales.

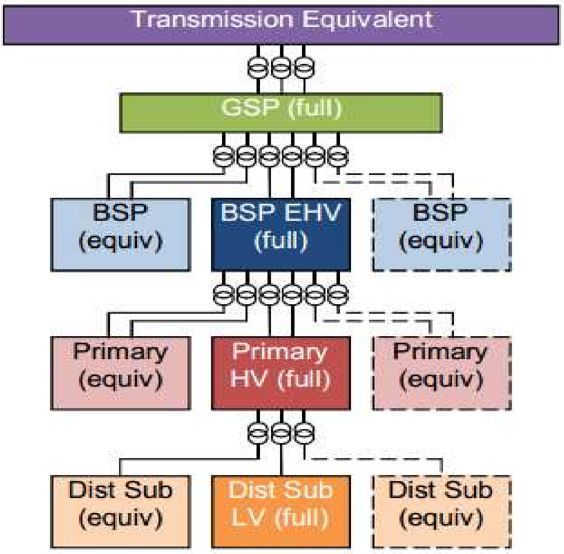
[1] https://www.northernpowergrid.com/asset/0/document/4773.pdf

2 Model Methodology

2.1 MVL Network Model Build

Two multi-voltage test networks were selected from Northern Powergrid licence areas (Northeast and Yorkshire) through application of a set of criteria, to ensure that the networks chosen were suitable to achieve the outcomes of the project. The multi-voltage networks are modelled as single, discrete networks that are connected across all voltage levels (EHV, HV and LV) with one network group modelled fully at each voltage level. The rest of the network is modelled as equivalents. This is illustrated in Figure 1 below.

Figure 1 The Network Topology



The reasoning for this was to manage model conversion time and computational effort for the study whilst retaining representation of and connectivity across all voltage levels. At HV and LV, network groups significantly increase in volume. Modelling a “slice” of network should allow voltage behaviour and a wide range of voltage management solutions to be rapidly characterised from EHV to LV, this hypothesis was tested as part of the study.

It is noted that the complete EHV or HV networks can be analysed in IPSA or DINIS if desired, however with very limited or no connectivity between EHV and HV voltage levels.

It is envisaged that multi-voltage model build and analysis is likely to support more strategic studies to inform voltage policy and specific use cases where voltage needs to be analysed across various voltage levels.

2.2 Selection of Representative Networks

The process of selection of representative networks is described here. Norton and Creyke Beck were selected as suitable rural and urban Grid Supply Points (GSPs) which were known to have voltage issues and also covering both NPg licence areas. TNEI and NPg then carried out identification and scoring of EHV and primary networks supplied from these GSPs to evaluate whether they were broadly representative of NPg networks (e.g. whether the networks are characterised as being rural or urban). This assessment was semi-quantitative, based on the experience of the NPg designer and on the following criteria:

- Number of Ground Mounted and Pole Mounted substations;
- Total customer numbers;

- Target voltage (typical/atypical);
- Total length of overhead lines (OHL) and cable; and
- MVA of connected generation (as proportion of substation demand and rating), connection arrangements to the network (typical/atypical connection circuit topology).

For secondary substations, NPg carried out the initial identification and evaluation of secondary substations based on type of substation, number of customers, substation/transformer rating, substation loading, number of phases, total aggregate embedded generation per substation, presence of link boxes to identify more urban substations, presence of SMETS1/SMETS2 smart electricity meters and total feeder length. This enable TNEI and NPg to identify an initial set of suitably representative urban and rural secondary substations and then agree the final selection based on engineering judgement.

The following networks were selected for detailed modelling:

- Norton (GSP) - Leeming Bar (132/33kV) – Thirsk (33/11kV) – Sinderby (11kV/LV) – Sinderby (LV)
- Creyke Beck (GSP) – Beverly (132/33kV) – First Avenue (33/11kV) – Cranwood (11kV/LV) – Cranwood (LV)

Separate networks were built at each voltage level and then merged to create two multi-voltage level network models. The network topologies of these models can be viewed in the figures below. LV networks were modelled as balanced three phase models. Whilst this was considered appropriate for efficiently modelling multi-voltage level behaviour in this study, it is recognised that voltage issues may be exacerbated at LV due to phase imbalance. However, the purpose here was to provide strategic recommendations on voltage management and plant specifications rather than just examining specific network voltage issues, although solutions were considered for any specific issues identified in the networks studied. The impact of phase imbalance at LV is considered within the LV report[2] for this project.

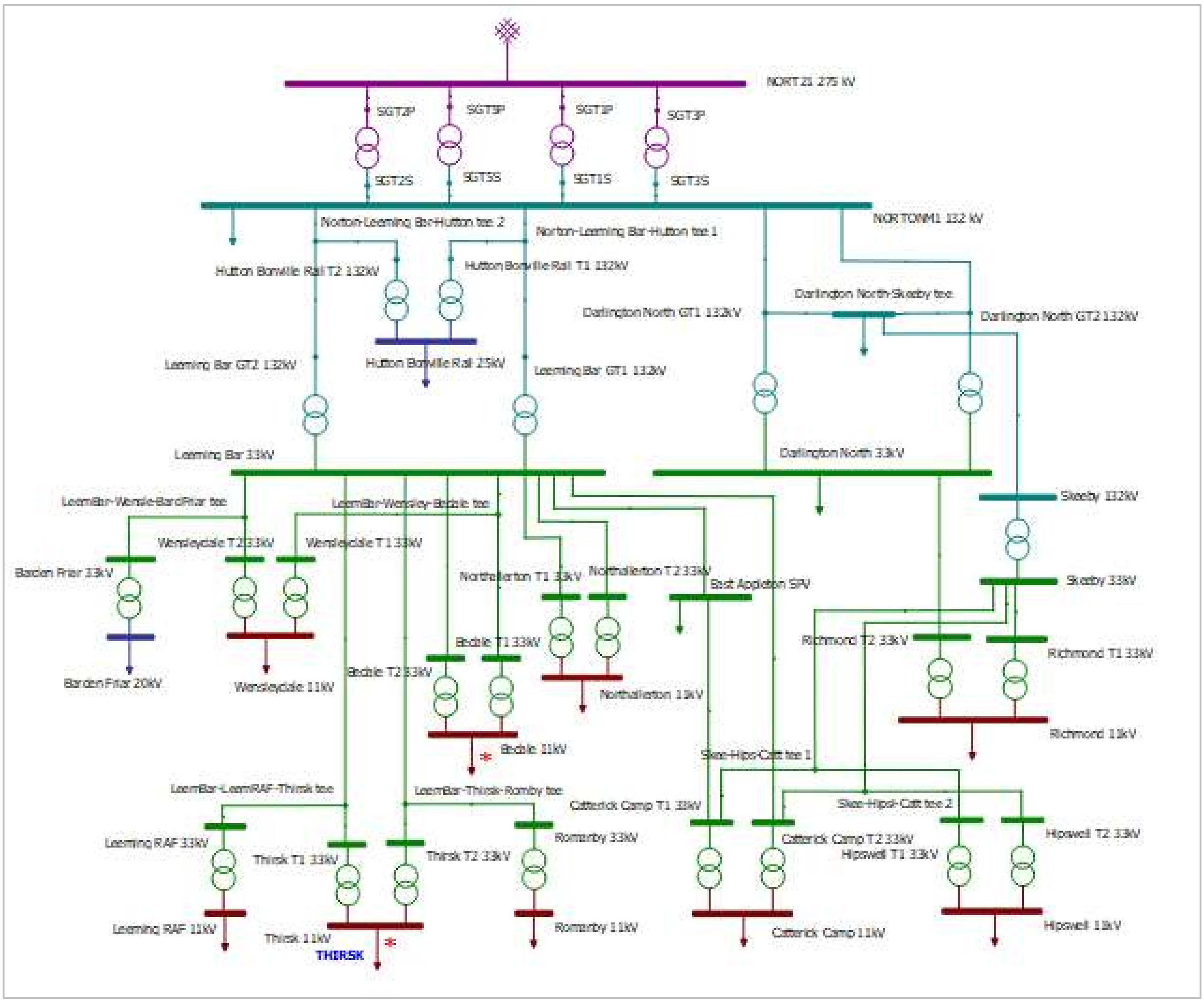
Along with the networks selected for detailed modelling, all interconnecting feeders at EHV and HV (and their corresponding substations) are modelled to enable analysis of contingency conditions.

2.2.1 Northeast Multi-Voltage Level Model

The Northeast multi-voltage level model comprises of a slice of a network from NPg’s license area in the northeast of England. This particular network is fed from the transmission network with the GSP situated at Norton. The Leeming Bar and Darlington North 132/33 kV BSPs are modelled in detail (due to interconnection at 33kV level) while other BSPs fed by the Norton GSP are modelled as equivalents as shown in Figure 2. The Thirsk 33/11 kV primary network is modelled in detail, while the other primaries are modelled as equivalents. However, the 11kV feeders interconnecting Thirsk and other primaries are included in the network model as shown in Figure 3. The Sinderby 400V network is connected to a HV feeder supplied by Thirsk primary, this HV feeder can be interconnected to Bedale primary.

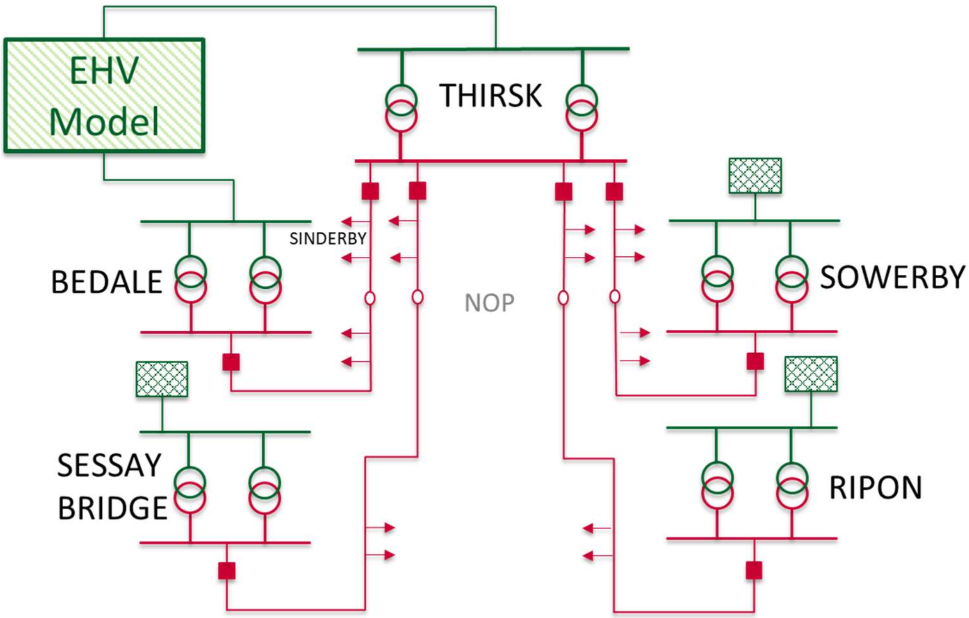
[2] 190208_PUBLIC_SNDM - Novel Analysis Techniques at LV

Figure 2 Northeast EHV Network Slice



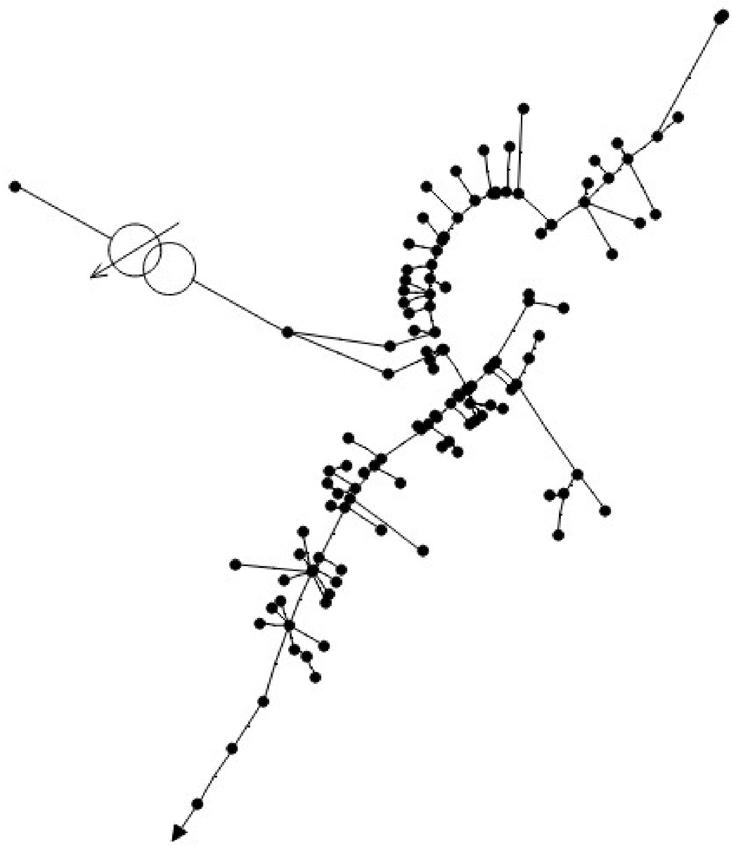
The network topology in Figure 3 shows how the HV network from Thirsk primary is interconnected with other primaries. The hatched boxes indicate equivalent infeeds to the primary substations, modelled as a slack busbars rather than being included in the EHV model. The arrows represent stylistically secondary substations connected along the feeder.

Figure 3 Thirsk HV Network Topology



The LV network model of Sinderby is shown in Figure 4. The Sinderby network is a rural network which supplies 66 customers and is supplied by the Carlton Miniott HV feeder from Thirsk primary substation.

Figure 4 Sinderby LV Network

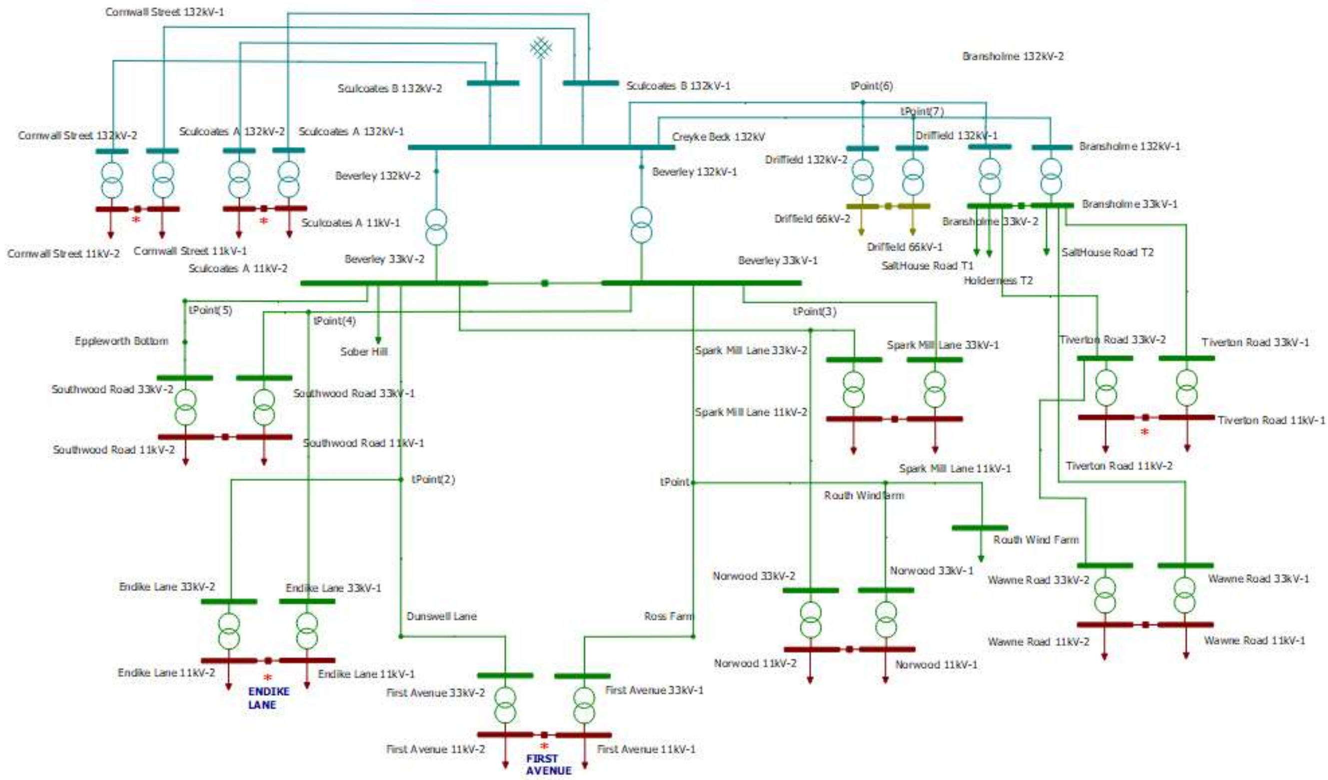


2.2.2 Yorkshire Multi-Voltage Level Model

The Yorkshire multi-voltage level model comprises of a slice of a network from NPg's Yorkshire license area. This particular network is fed from the transmission network with the GSP situated at Creyke Beck. The Beverley and Bransholme 132/33 kV BSPs are modelled in detail due to interconnection at the 11kV level, while the other BSPs are modelled as equivalents. The First Avenue 33/11 kV primary network is modelled in detail, while the other primaries are modelled as equivalents. However, the 11kV feeders interconnecting First Avenue primary and the other primaries, are included in the network mode as shown in Figure 6. The Cranwood 400V network is located on an HV feeder supplied by First Avenue primary substation, this feeder can be interconnected to Endike Lane primary.

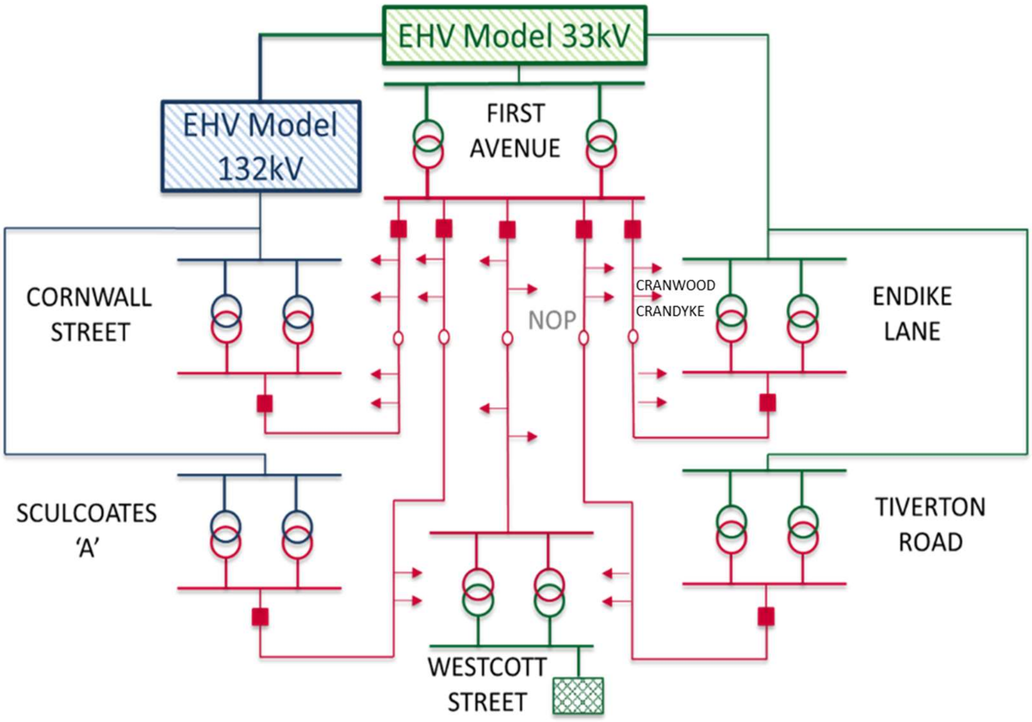
The Norton-Leeming Bar-Thirsk EHV model does not include any line susceptance values, in contrast to the Creyke Beck-Beverley-First Avenue EHV model. A sensitivity analysis was run on the First Avenue model by removing line susceptances to ascertain the impact of these not being modelled for Thirsk. The results can be observed in Annex B. The modelled voltages from both scenarios were compared; voltage differences of more than 1% at 33kV were observed in some cases. This percentage variation is material and whilst the findings of the analysis based on these models are still applicable, the inclusion of line susceptance values would improve specific applicability to Thirsk (although the objectives of the study were not focussed on resolving specific network voltage issues).

Figure 5 Yorkshire EHV Network Slice



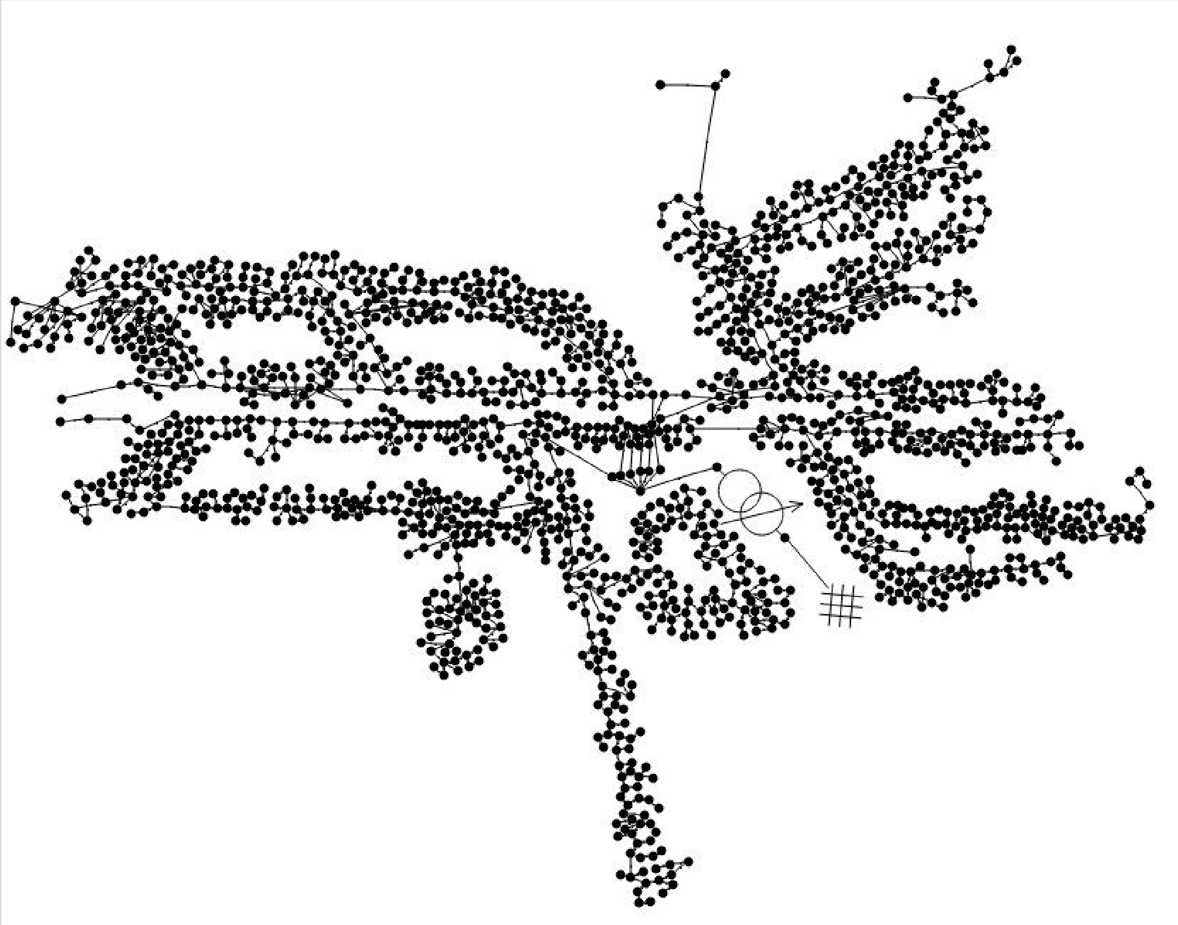
The network topology in Figure 6 shows how the HV Network from the First Avenue primary network is interconnected with other primary substations.

Figure 6 First Avenue HV Network



The LV model is of the Cranwood 400kV network. The Cranwood network is an urban network which supplies 629 customers and is supplied by the Cranwood HV feeder from First Avenue primary substation.

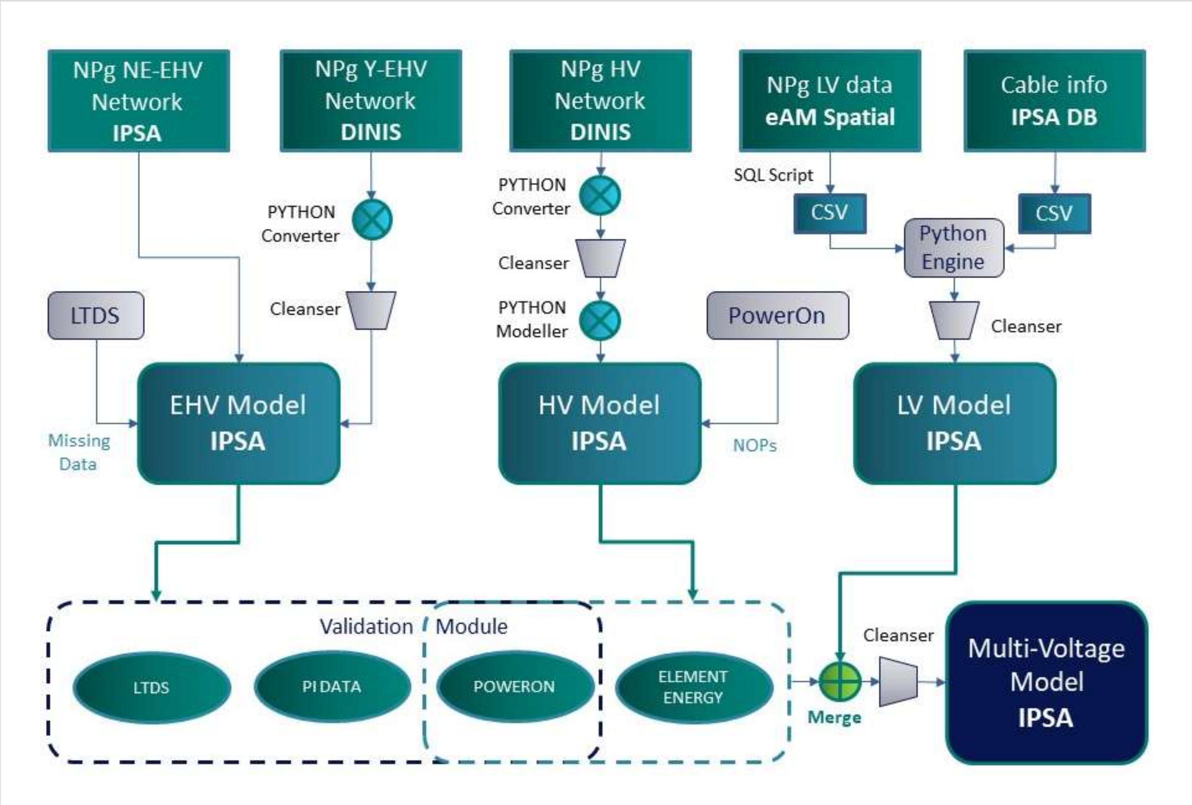
Figure 7 Cranwood LV Network



The above networks were merged together to create the respective multi-voltage level models. Figure 8 summarises how the multi-voltage level network models were built, illustrating the various data sources and processes. The EHV models were extracted from the master IPSA and DINIS models for NPg Northeast and NPg Yorkshire respectively. The following data sources were used to resolve data gaps and validate the models:

1. NPg's Long Term Development Statement (LTDS) & PowerOn – Used to validate network connectivity and the network Normally Open Points (NOPs). The network component parameters in the model were also verified against data from the LTDS & PowerOn.
2. SCADA PI Data – Used to provide model loads for equivalent networks in various scenarios. Also used to verify the loading of networks where these were modelled in full. In this case, the load flow was run within IPSA and the power flow across the transformers in IPSA is compared with the corresponding PI data.
3. Element Energy Load Growth Data – Used to provide the equivalent LV loads (for LV networks not modelled in full) and to verify the numbers of customers connected.
4. eAM Spatial data & IPSA cable database – Used to create the LV network using SQL and Python.

Figure 8 Creating the Multi-Voltage Level Network



2.3 Load Scenarios

Load scenarios were developed with the aim of exploring voltage behaviour across voltage levels in the MVL model, including with deployment of voltage management solutions. These are in the context of the Use Cases and are shown in Table 2.

Table 2 Load Scenarios

Use Case	Use Case Description	Scenario				
		A	B	C	D	E
		Peak Demand / No Generation HV N-1	Peak Demand / No Generation EHV N-1	Peak Demand / No generation + New HV Demand HV N-1	--	--
		Minimum Demand / Peak Generation HV N-1	Minimum Demand / Peak Generation EHV N-1	--	Minimum Demand / Peak Generation + New PV at LV HV N, N-1	Minimum Demand / Peak Generation + New HV Generation HV N, N-1
2.1	Identify and mitigate voltage violations - LV	Yes	Yes			
2.2	Identify and mitigate voltage violations - HV/EHV	Yes	Yes			
3.1.1	Model new connections - Generation - LV				Yes	
3.1.2	Model new connections - Generation - HV/EHV					Yes
3.2.1	Model new connections - Demand Load - LV	Yes, with load scaling				
3.2.2	Model new connections - Demand Load - HV/EHV			Yes		
6	Perform Strategic Network Modelling Analysis	Yes	Yes			

Specific peak demand and summer minimum demand / peak generation scenarios were developed for each representative multi-voltage level network. The selection of the conditions that best represented peak demand and summer minimum demand / peak generation is described below. SCADA data for selected timestamps was then extracted from PI.

2.3.1 Peak Demand

For each multi-voltage level network model, the following process was carried out to select the most appropriate timestamp representative of peak demand conditions.

- Extract MVA for the primary substation modelled and for the corresponding EHV substation (e.g. First Avenue and Beverley) for each timestamp over a one-year period (2017/2018).
- Select the timestamp of maximum MVA for the primary substation and check that the loading of the EHV substation is similarly high, so consistent with peak demand across the BSP. Peak demand typically occurs in the evening during winter months.
- Extract load (net demand) for all substations and feeder currents for the selected peak demand timestamp.
- Extract demand import and generation export for EHV and HV connected demand and generation customers for the selected timestamp.

- Set the output from intermittent generation to zero.
- Set HV/LV substation equivalent loads to corresponding maximum substation loads extracted from the Element Energy Load Model.
- Scale HV/LV substation loads uniformly to sum to corresponding HV feeder measurements at the selected peak demand timestamp.
- Generate LV loads for LV network/s modelled in full from the customer demand model[3].
- Scale initial LV loads uniformly to sum to the corresponding scaled HV/LV substation load.
- Copy all loads into the power flow model.

2.3.2 Minimum Demand / Peak Generation

- Select the timestamp of minimum MVA for the primary substation modelled and check that the loading of the EHV substation is similarly low so consistent with peak demand across the BSP. Minimum demand typically occurs in the daytime during summer months.
- Follow similar steps as for peak demand scenario however intermittent generation output is set to maximum export.

2.3.3 Implementation into Business as Usual

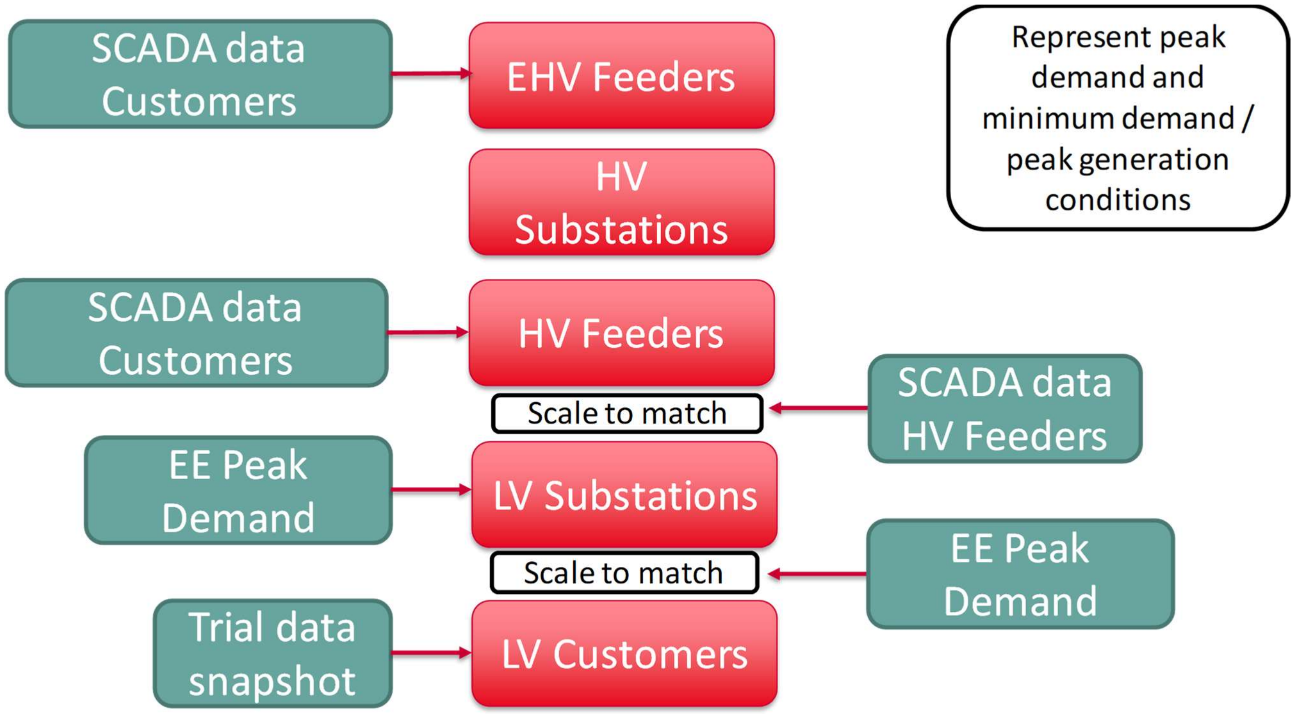
The timestamp could be selected either on the basis of primary substation load when the focus of analysis is the HV network or on the basis of the 132/33kV substation load when the focus of analysis is the EHV network or a timestamp representative of both, given that the network is being analysed across multiple voltage levels. However, the peak demand for both primary and EHV substations was found to be closely aligned in any case. It should also be noted that there are sometimes gaps in the SCADA data for both active and reactive power, which could make it difficult to get a complete dataset for the network at any one timestamp.

2.3.4 Inputs

Inputs are summarised in the diagram below.

[3] Presented in "Smart Network Design Methodologies: Novel Analysis Techniques at Low Voltage Final Report", based on customer profiles sampled from the CLNR dataset.

Figure 9 Inputs to the Model



3 Voltage Management in NPg

Distribution networks should be designed so that the voltage at customer terminals are within statutory voltage limits for all reasonably expected operational conditions apart from those considered to be exceptional, consistent with security of supply standards.

Voltage is managed on NPg networks through existing standards and policy. A key principle is that HV and LV networks are designed based on allocating the overall permitted voltage drop across and between the HV and LV networks such that design work on the HV and LV network can be carried out in isolation from each other. Where this may lead to unjustified reinforcement or excessive customer costs, a bespoke analysis jointly considering the voltage drop on the HV and LV networks may be considered. However, with increasing electrification of heat and transport and connection of distributed energy resources impacting the LV network, a more holistic approach may be required. The options in relation to a more holistic approach are considered in this report.

Table 3 gives the standard voltage settings for NPg networks.

Table 3 Standard Voltage Settings for NPg

Voltage Level	Standard Target Voltage	Statutory Voltage Limits at Point of Supply	AVC Relay and Line Drop Compensation Installed
132kV (EHV)	134kV (101.5%) at GSP	+/- 10%	Yes
66kV (EHV)	66kV (100%) at GSPs and BSPs	+/- 6%	Yes
33kV (EHV)	33kV (100%) at GSPs and BSPs	+/- 6%	Yes
20kV (HV)	22kV (100%) GSPs* 20.1kV (100.5%) BSPs and Primaries	+/- 6%	Yes
11kV (HV)	11.1kV (100.9%) BSPs and Primaries	+/- 6%	Yes
230V/400V (Single phase/ three phase LV)	250V/433V (108.25%) 8.25% voltage boost due to 11kV/433V transformer	+10% / -6%	No

* Only 20kV GSP is Fourstones, which has a target voltage of 20.1kV.

3.1 Existing voltage standards, specifications and policy

NPg use the following standards and policy for voltage management.

- Engineering Recommendation P10 provides recommendations for the Voltage Control at Bulk Supply Points (BSPs);

- Engineering Recommendation P1/3 provides recommendations for the values of reactance, tapping range, overvoltage and cyclic output rating for supply transformers;
- IMP/001/913 Code of Practice for the Economic Development of the EHV System;
- IMP/001/912 Code of Practice for the Economic Development of the HV System; and
- IMP/001/911 Code of Practice for the Economic Development of the LV System.

There are further policy documents relating to specific voltage solutions e.g. HV voltage regulators.

3.1.1 Engineering Recommendation P10

In Engineering Recommendation P10, it states that with all BSP transformers (132/33kV and 132/11kV) in service, at a substation equipped with two such transformers, it must be possible for the supply voltage of the 33kV (or 11kV) busbars to be 5% above the nominal voltage under peak load conditions i.e. with a load of 130% of the nominal firm transformer capacity (this allows for load transfer under abnormal system operating conditions whilst maintain voltage within limits). With the same total loading conditions and with only one transformer in service (i.e. largest unit out of commission) it must be possible to maintain the nominal voltage at the supply busbars. It also indicates that AVC and line drop compensation should be provided on transformers at all new supply points or at existing supply points where the transformer capacity is being uprated.

3.1.2 Engineering Recommendation P1/3

Engineering Recommendation P1/3 provides recommendations for the values of reactance, tapping range, overvoltage and cyclic output rating for 275/33kV, 132/33kV and 132/11kV supply point transformers, under recommended voltage conditions and assumed 33kV & 11kV fault levels and power factor. It states that all transformers shall have an on-load tapping range of +10% to -20%. (This range will be provided in 18 steps of 1.67%).

3.1.3 IMP/001/913

NPg Code of Practice IMP/001/913 section 3.5.2 specifies the voltage tapping range specifications for primary transformers.

Table 4 Voltage tapping range specifications for transformers

Transformer Voltage (kV)	Northern Powergrid Northeast	Northern Powergrid Yorkshire
66 or 33/11.5	+10%/-10% in 16 steps (+8x1.25/-8x1.25) or +5.72%/-17.16% in 16 steps (+4x1.43/-12x1.43)	+10%/-10% in 16 steps (+8×1.25/-8×1.25) or +5.72%/-17.16% in 16 steps (+4x1.43/-12x1.43)
66 or 33/20	+10%/-10% in 14 steps (+7x1.5/-7x1.5)	N/A

3.2 HV and LV network design principles

For HV and LV network design, NPg uses the following principles:

- The maximum calculated voltage drop on the LV network (i.e. on the main and service) should not exceed 6%. Typically, the voltage drop on a service would be no more than 0.3% (based on a typical 20m service and 4kW demand) and in many cases can be ignored.
- The voltage at the LV terminals of the HV to LV transformer under HV first circuit outage conditions should be a minimum of 230V (100%). This is based on an 11.1kV target voltage (100.9%), 4.5% voltage drop on the 11kV feeder under first circuit outage conditions, -2.5% HV/LV transformer tap, 2% voltage drop across the transformer at full load, and the EHV to HV transformer operating at the mid-point of its deadband.
- Where the HV voltage drop under first circuit outage conditions is more than 4.5%, this may be acceptable provided the LV networks supplied from the HV network has a suitably small voltage drop.
- There is at least 3.5% headroom for generation at LV (or 1.5% if the Primary substation AVC is at the top of its deadband).

The following table show the voltage drops under the following three scenarios:

- No load;
- High load (Intact system); and
- High load (11kV first circuit outage).

Table 5 show the voltages at each point of interest, based on the network design policy, when the primary 11kV busbar voltage is at the bottom, middle and top of its deadband. From these we can see that there is no legroom for additional load under high load and 11kV first circuit outage conditions. Figure 10 shows the voltage drops across the HV and LV networks diagrammatically with the HV busbar voltage at the middle of its deadband. These tables illustrate that the impact of the deadband is quite material, particularly when the HV busbar is at the bottom of the 2% deadband under high load outage conditions.

Table 5 Voltages on the HV and LV systems with HV busbar voltage at different points in deadband

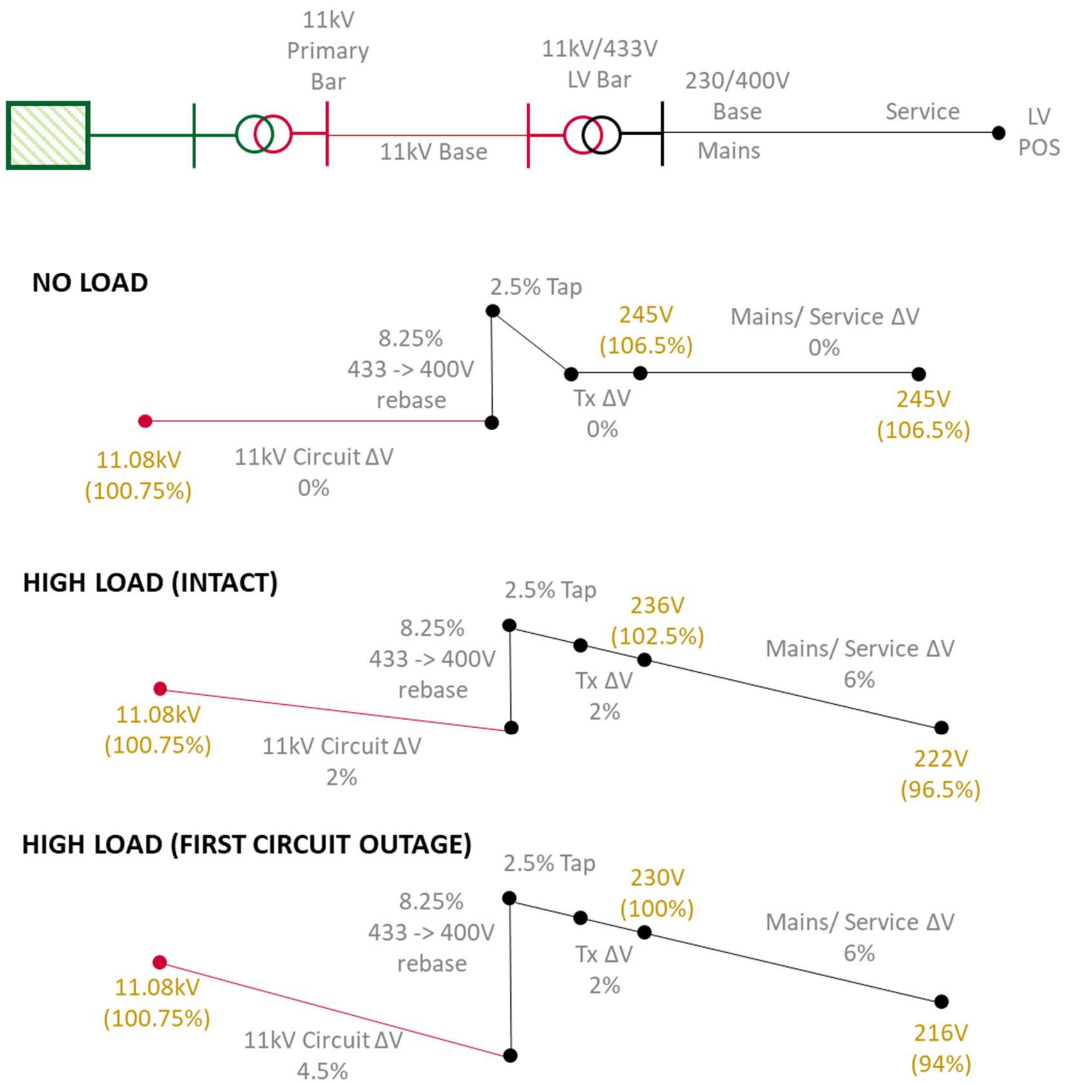
With HV Busbar in middle of deadband					
Scenario	**11kV Primary Bar**	**TX Terminals**	**LV POS (Feeder End)**	**Headroom**	**Legroom**
No load (Intact and 11kV first cct outage)	11.1kV (101%)	245V (106.5%)	245V (106.5%)	+8V (3.5%)	
High load (Intact)	11.1kV (101%)	236V (102.5%)	222V (96.5%)		6V (2.5%)
High load (11kV first cct outage)	11.1kV (101%)	230V (100%)	216V (94%)		0V (0%)

With HV Busbar at top of 2% deadband[4]					
Scenario	**11kV Primary Bar**	**TX Terminals**	**LV POS (Feeder End)**	**Headroom**	**Legroom**
No load (Intact and 11kV first cct outage)	11.3kV (103%)	250V (108.5%)	250V (108.5%)	+4V (1.5%)	
High load (Intact)	11.3kV (103%)	239V (104.5%)	227V (98.5%)		11V (4.5%)
High load (11kV first cct outage)	11.3kV (103%)	235V (102%)	221V (96%)		5V (2%)

With HV Busbar at bottom of 2% deadband					
Scenario	**11kV Primary Bar**	**TX Terminals**	**LV POS (Feeder End)**	**Headroom**	**Legroom**
No load (Intact and 11kV first cct outage)	11.0kV (99%)	240V (104.5%)	240V (104.5%)	+12V (5.5%)	
High load (Intact)	11.0kV (99%)	231V (100.5%)	217V (94.5%)		1V (0.5%)
High load (11kV first cct outage)	11.0kV (99%)	225V (98%)	212V (92%)		-5V (-2%)

[4] Whilst there are some tap change controls with a 2% deadband, 1.5% is more common.

Figure 10 Voltage Drop with HV busbar voltage in middle of deadband



3.3 Thirsk

The voltage settings for the Thirsk network transformers are shown below in Table 6.

Table 6 Voltage Settings for Thirsk Network

Transformer	Nameplate Nominal Voltage	Target Operating Voltage	Tapping Range and Step Size	AVC Relay Deadband (+/-%)
Norton GSP	275/132kV	133kV (non-standard)	-15 to 15 (1.67%)	1.25%
Leeming Bar	132/33kV	32.7kV (non-standard)	-20 to 10 (1.67%)	1.67%
Thirsk	Primary	11.1kV	-15 to 4.5 (1.5%)	1.5%

	(33/11.5kV)			
Bedale	Primary (33/11.5kV)	11.1kV	-10 to 10 (1.25%)	1.25%
Sinderby	Secondary (11kV/433V)	2.5% fixed tap position	-5 to 5 (2.5%)	--

When the nominal voltage of the network is different from the transformer secondary winding nameplate nominal voltage, the tap position has been modified using the following equation, where $V_{lv\ tx}$ and $V_{hv\ tx}$ are transformer nameplate nominal voltages, $V_{lv\ sys}$ and $V_{hv\ sys}$ are network nominal voltages and the $Tap_{old\%}$ is the original tap position.

$$Tap_{new\%} = \left(\frac{V_{hv\ tx} V_{lv\ sys} \left(1 + \frac{Tap_{old\%}}{100}\right)}{V_{lv\ tx} V_{hv\ sys}} - 1 \right) \times 100\%$$

A base voltage of 11.0kV was used at HV in the IPSA model so the tapping range and step size on the Thirsk 33/11.5kV transformer was set to -18.7% to -0.04% (1.435% step) in the IPSA model.

A base voltage of 400V was used at LV in the IPSA model so the tapping range on the Sinderby 11kV/433V transformer was set to -3.003% to -12.24% (2.309% step) in the IPSA model.

3.4 First Avenue

Table 7 Voltage Settings for First Avenue Network

Transformer	Nameplate Nominal Voltage	Target Voltage	Tapping Range and Step Size	AVC Relay Deadband (+/-%)
Creyke Beck GSP	275/132kV	136kV (non-standard)	Not Modelled	--
Beverley	132/33kV	33kV	-20 to 10 (1.667%)	1.5%
First Avenue	Primary (33/11.5kV)	11.1kV	-10 to 10 (1.25%)	1.5%
Crandyke and Cranwood	Secondary (11kV/433V)	0% fixed tap position	-5 to 5 (2.5%)	--

3.5 Voltage management techniques

When voltage issues arise due to load growth or new demand or generation connections, a range of solutions is available to mitigate this. The solutions are described in more detail below and summarised in Table 9 which includes novel solutions being considered for use in future.

A number of different AVC relays are currently used in NPg, with varying LDC functionality and configurable settings. An AVC upgrade program is being implemented throughout the RIIO-ED1 regulatory period to replace all the existing AVC relays (except Siemens MicroTAPP relays) with either Siemens SuperTAPP SG or Maschinenfabrik Reinhausen (MR) Tapcon relays.

3.5.1 Change of target voltage at EHV/HV

Automatic voltage control (AVC) schemes are used on NPg primary transformers and above in order to automate and optimise operation of the on-load tap changers. The main purpose of an AVC scheme is to maintain the target voltage at the substation busbars under varying load condition via tap-operations. There is a need to co-ordinate the bandwidth or deadband with the magnitude of the voltage change associated with a tap change operation i.e. the deadband range e.g. +/- 1.5%, needs to be larger than the tap step, as well as considering the time delay. A balance needs to be struck between maintaining the target voltage and keeping the number of tap operations within reasonable limits; excessive tap changer operations reduces the life of the tap changer.

NPg policy indicates that lower voltage busbars will be controlled by means of Automatic Voltage Regulator (AVR) relays and the transformer tap position automatically adjusted as appropriate to maintain the target voltage.

The target voltage should be selected such that the voltage on the system it is supplying stays within statutory limits under all normal operational scenarios. The target voltage for the majority of the 11kV and 20kV networks at the source substation busbar is 11.1kV and 20.1kV respectively with the aim of maintaining the voltage at customers' point of supply within statutory voltage limits when supplying load and to allow sufficient headroom for the connection of generation.

3.5.2 Load drop compensation

In a standard voltage management scheme, the target voltage is constant and independent of the load on the transformer and of the load on any of the feeders. The target voltage should be such that i) when the transformer and all feeders are supplying maximum demand and ii) when supporting maximum generation export, the voltage at customers point of supply is within statutory limits.

Traditionally, the target voltage has been set to avoid voltage drop below statutory limits during times of high demand. However, this limits the voltage headroom available to support export from generation at times of low load and, under these conditions, a lower target voltage may be more appropriate.

In a Load Drop Compensation (LDC) scheme, the target voltage is increased as the load on the transformer increases. This can be confused with Line Drop Compensation which focuses on voltage management for loading of a specific feeder. LDC allows the target voltage to be adjusted to meet the requirements of both high demand and high generation conditions across the network, through configuration of the AVC relay. However, it does not work so well if HV feeders have differing characteristics or loading levels leading to differing target voltage requirements e.g. one feeder with high demand (requiring a high target voltage) and another feeder with high generation export (requiring a low target voltage), making it difficult to determine an appropriate setting that works successfully in all operational scenarios.

In determining the applicability of LDC, NPg policy states firstly to ensure that a harmonised target voltage of 11.1kV is applied. If this does not create sufficient headroom for generation conditions then based on system modelling studies (and the AVC relay functionality available) reduce the target voltage by between 1% and 3% and apply LDC settings to increase the voltage by between 1% and 3% in accordance with the pairings shown in Table 8.

Table 8 LDC boost & Target Voltage

LDC Boost	Target Voltage
3%	Harmonised target voltage - 3% (10.8kV)
2%	Harmonised target voltage - 2% (10.9kV)
1%	Harmonised target voltage - 1% (11.0kV)

3.5.3 Tap change on HV/LV transformers

In NPg LV networks, the HV/LV transformers typically have a voltage ratio of 11kV/433V, i.e. providing a no-load voltage (on nominal tap) of 8.25% above the nominal 400V voltage. They are typically fitted with off load tap changers with a tap range of -5% (voltage boost) to 5% (voltage buck) (in 2.5% steps), with recent NPg policy changing this to -2.5% (voltage boost) to 7.5% (voltage buck) for new transformers to enable greater connection of embedded generation. Establishing the setting of the tap changer needs to consider the position of the transformer in the 11kV network, and the likely peak demand and minimum demand/peak embedded generation conditions under network normal and contingency conditions. The transformer tap position is set on commissioning or possibly changed very infrequently if there are customer voltage complaints, as it can only be changed when the transformer is de-energised. HV/LV transformers equipped with on-load tap changer would be considered a novel technology on NPg networks.

3.5.4 Interconnection with adjacent network (load shifting)

Interconnection with adjacent networks can be used to shift demand or generation and thus, mitigate voltage violations. This technique can be considered in a scenario where the NOP of two HV feeders providing interconnection between two different primaries, or the same primary substation, is shifted to reapportion the sharing of load. This does require the loading conditions of the interconnecting feeders to be different e.g. load shifting from a heavily loaded feeder on to a lightly loaded feeder. This could be implemented as a permanent (business as usual solution) or real-time or seasonal load shift under normal or contingency conditions. The impact on network losses should also be evaluated, as typically NOPs are established to minimise network losses.

3.5.5 Change generator voltage / reactive power control characteristics

Where there is significant generation connected, it may have an effect on the voltage management on that network. Generator controllers are usually set to fix the power factor and let the terminal voltage vary, or fix the voltage and let the power factor vary, within limits. These two control options are generally referred to as PQ and PV control mode respectively. Generators are normally set to operate in PQ mode, where under normal operation conditions the generator will not lead to voltage constraints. Further details are provided in the NPg Code of Practice for the Economic Development of Distribution Systems with Distributed Generation, IMP/001/007.

Where the application of standard voltage control techniques, bespoke AVC settings, or LDC are insufficient to manage the voltage in areas of the network with high numbers of generation connections, it may be possible for generators to operate in PV mode to reduce voltage rise on feeders by importing reactive power and limiting voltage at their point of supply.

The recent introduction of ENA EREC G99 means that new generators need to be capable of providing a wider range of reactive power / voltage control modes depending on their size and whether they are a synchronous machine or non-synchronous machine. This gives DNOs more options to specify generator operating regimes. These could be implemented at the connection design stage of through Active Network Management schemes.

3.5.6 In-line voltage regulator

In-line HV voltage regulators can be used to maintain voltages on HV feeders under system intact and first circuit outage conditions, during resupply for an outage on an HV feeder. Bi-directional capability is required to achieve this. In-line HV regulators can be cost effective where localised control of voltage is needed for multiple LV systems supplied from the same HV source and can be installed in the main HV line or on HV spurs. Where the use of an in-line HV regulator has an adverse effect on circuit loading, shunt capacitor banks may be a more suitable alternative. NPg's existing voltage management policy indicates that the optimal choice of device to address localised HV voltage issues in a rural area is an in-line HV voltage regulator.

When considering the installation of an in-line HV voltage regulator into an HV circuit that already contains one or more in-line HV voltage regulators, the interaction between the individual voltage regulators should be assessed to confirm that appropriate settings can be applied to all the voltage regulators to ensure that the network voltage is properly managed in all credible scenarios. Network studies will be required to ensure that the required settings can be applied for the normal operating condition and credible outage scenarios.

In LV networks, where several LV feeders are connected to a single HV to LV substation and one or two of the feeders have materially high voltage drop at times of high load or materially high voltage rise at times of high generation export, then an in-line LV regulator may be considered as an alternative to traditional reinforcement or the application of an HV / LV transformer equipped with an OLTC.

3.5.7 Capacitor banks

NPg's existing voltage management policy indicates that shunt capacitors may be a solution to control voltages at the end of a long HV feeder where there is little prospect for voltage rise issues associated with generation.

Shunt connected capacitors have advantages and disadvantages compared to in-line regulators:

- Capacitors can only boost system voltage rather than reduce it. Voltage boost is typically required for high demand or high impedance systems, but reduces their application in areas which are or are expected to become high in generation;
- Capacitors increase the system voltage at the point of connection hence increasing the system voltage both upstream and downstream of the connection point. Voltage regulators can only manage (increase and decrease) the voltage downstream of their connection point to the system;
- Capacitors can provide the reactive power drawn by customers demand or the distribution system closer to the point where it is required, thus reducing system losses;
- If excess capacitance is installed to meet the local requirement reactive power can be forced back up the system potentially increasing system losses and creating voltage rise issues on adjacent parts of the system; and
- Capacitors tend to require a building and switchgear which can give rise to practical issues on site; modern voltage regulators can be pole mounted. Hence in-line HV regulators solutions tend to be less expensive than switched capacitor installations.

At LV, whilst NPg has limited practical experience of LV capacitors, Electricity North West trialled their use as part of their Low Carbon Networks Fund Project 'Voltage Management on Low Voltage Busbars'.

3.5.8 STATCOMS

STATCOMs can be used to increase the voltage performance of a network under conditions ranging from full load to no-load through reactive power management. These devices can be used to regulate the voltages at the receiving end of the network.

Currently, Northern Powergrid has no practical experience in deploying STATCOMs.

3.5.9 Demand Side Response

Customer demand side response can be deployed to reduce demand and thus improve voltage and has been trialled in a number of recent network innovation projects. This may be implemented via Time of Use tariffs for general DSR or establishing specific DSR contracts with aggregators or individual customers for specific demand reduction services. To be effective at LV, there would need to be a high uptake of local customers in that area (and specific LV feeder) with sufficient flexible load which is may be quite challenging to achieve at present. Flexibility contracts are now becoming more commercialised and are already business as usual across the industry at EHV. However, at HV and LV, localised demand side response services are not yet available as a business as usual technique.

3.5.10 Solution Summary

Solutions have been assessed for testing in this study on the basis of existing usage in NPg and other GB DNOs, relative cost and ease of implementation, as shown in Table 9 and represented by a green, amber and red in "Ease of Deployment" status. This status is based on engineering judgements informed by latest NPg and industry experience. It was not the focus of the study to carry out an exhaustive assessment of the benefits of a wide range of voltage control and management solutions but to explore viable design and strategic solutions. Solutions which are business ready with proven benefits are appropriate to assess here to provide relevant recommendations on more holistic voltage control. This includes more traditional methods e.g. LDC at the primary transformer or a altering a fixed tap for secondary transformers and more innovative techniques e.g. voltage control using a secondary OLTC transformer, to resolve an LV voltage issue.

Generally, when evaluating the suitability of a solution to resolve a voltage issue, a technical and cost assessment is undertaken following preparation of a list of options, consistent with Use Cases. The NPg HV design code of practice indicates that a new network design should meet the generation/demand requirements for the next 10 years (based on forecasts) and should be economic.

Voltage management can be applied as a single solution, as a combination of solutions or as a strategic approach that changes the voltage management design philosophy e.g. changing a transformer plant specification such as the tapping range or step size or changing the way voltage drops are allocated at each 132kV/EHV/HV/LV voltage level.

Table 9 Summary of voltage control solutions

Voltage Control Solution	Network Location	Existing usage	Relevant Policies	Ease of Deployment	Applicability	Assess in Smart Network Design Methodology
Change of target voltage at EHV/HV substation	Substation	Existing solution (not to exceed 11.3 kV as per NPg policy IMP/001/915/002).	NPg IMP/001/913 NPg IMP/001/915/002		Wider HV network voltage issues	Yes
Load Drop Compensation	Substation	Existing capability, applies voltage change to all feeders from a substation based on the transformer load. NPg policy (IMP/001/915/002) states that if there are existing, or forecast voltage regulation problems on an HV system then load drop compensation (LDC) is the most cost effective and it should be considered in the first instance.	NPg IMP/001/915/002		Network wide voltage issues	Yes
Tap change on HV/LV Transformers	Substation	Manual tap change[5] or On-load tap changers (OLTC). OLTC can be specified to	NPg IMP/001/911		LV network voltage issues	Yes

[5] Some transformers may already have bespoke tap settings to resolve local issues, this report is more focussed on wider strategic tap setting changes

Voltage Control Solution	Network Location	Existing usage	Relevant Policies	Ease of Deployment	Applicability	Assess in Smart Network Design Methodology
		automatically control the voltage on the LV side of an HV/LV transformer. This is starting to be considered for deployment by industry.				
Interconnection with adjacent network (load shifting)	Feeder	Backfeeds used at EHV and HV for security of supply. Worst case voltage drop conditions under N-1. Solution could be alternative backfeed where possible. Could be one-off change or periodic with appropriate remote control.	EREC P2/7 NPg IMP/001/913 NPg IMP/001/912 NPg IMP/001/911		Feeder specific voltage issues	Yes
		At LV, this could be shifting of customer load onto another feeder if a suitable normally open points exist. It would be a one-off change currently as it would need LV remote control.				
Change generator voltage / reactive power control characteristics	Feeder	This could be a requirement for generators to operate in PV mode or at different power factors under certain conditions.	EREC G99 IMP/001/016 IMP/001/915 IMP/001/007/002		Typically generation related voltage issues or possibly high demand conditions depending on load characteristics.	Yes

Voltage Control Solution	Network Location	Existing usage	Relevant Policies	Ease of Deployment	Applicability	Assess in Smart Network Design Methodology
In-line voltage regulator	Feeder	HV voltage regulators are used to maintain voltages on HV systems under system intact and first circuit outage conditions. Regulators are more flexible if they have bi-directional capability and comms.	NPS/003/020 IMP/001/912		HV feeder or LV network voltage issues	Yes
Capacitor banks	Feeder	Capacitors in limited use in NPg on HV networks. Ease of deployment based on HV capacitors. Capacitors at LV tested in innovation projects (e.g. Smart Street), not proven/rolled out at large scale yet.	NPg IMP/001/912 NPg IMP/001/915/002		Feeder and downstream network voltage issues (although a capacitor will affect the voltage profile along the whole feeder)	No, due to existing limited usage and higher cost
STATCOMS at EHV/HV/LV	Substation	Tested in innovation projects, not rolled out/proven at large scale yet. More suitable at higher voltage levels for dynamic voltage response due to cost and only being effective on networks with higher X/R ratios	n/a		Feeder and downstream network voltage issues	No
Demand Side Response	Substation	Being tested in innovation projects. BAU at EHV but not rolled out at a large scale yet at HV and LV. Ability to provide material, locational	EREC P2/7 NPg IMP/001/912		Could be network wide or feeder specific voltage issues	No, the technical effect of this could be replicated by

Voltage Control Solution	Network Location	Existing usage	Relevant Policies	Ease of Deployment	Applicability	Assess in Smart Network Design Methodology
		voltage response not yet proven.				reducing or increasing demand
Active Network Management		Active Network Management (ANM) schemes are now becoming business as usual at EHV to manage new generation connections in constrained areas, typically to manage voltage or thermal constraints by DNOs to date.	EREC P2/7 NPg IMP/001/016		Could be network wide or feeder specific voltage issues	No the technical effect of this could be replicated by changing generation output

4 Holistic Voltage Behaviour Assessment

4.1 Introduction

In order to analyse holistic voltage behaviour across distribution voltage levels prior to deployment of any voltage management solutions, a number of load scenarios were analysed for each representative multi-voltage network model as per Table 2. These include winter peak and summer minimum with high generation conditions and several network topologies including no contingency (base case) and contingency conditions at HV and EHV voltage levels. One of the advantages of using this approach is that no assumptions need to be made in relation to the voltages at interfaces across voltage levels.

4.2 Scenario Results – Thirsk

Voltage results for Thirsk are given in Table 10 for various scenarios under peak demand and minimum demand / peak generation conditions.

Table 10 Voltage results for each load scenario – Peak Demand

Scenario – Peak Demand		Contingency Description	Voltage at Thirsk or Bedale substation EHV/HV (pu)	Minimum Substation HV voltage along HV Feeders (pu)	Voltage at Sinderby substation HV/LV (pu)	Sinderby LV Minimum V (pu)	Primary Tap Position for Thirsk or Bedale substation Tap Range: 1 (-18.7) to 14(-0.04) at 1.435% - Thirsk 1 (-13.91) to 16(5.22) at 1.33% - Bedale	Load Scaling Factor
	Base Case (Peak Demand)	None	0.966 / 1.011 (Thirsk)	0.995 (Sinderby Sike SW)	0.995 / 1.038	1.027	10 (-5.785) Thirsk 9 (-3.71) Bedale	1
A1	HV N-1	Outage of Bedale Station HV feeder at Bedale Primary Substation (Carlton Miniott HV feeder picks up Bedale Station HV feeder)	0.958 / 1.013 (Thirsk T2)	0.882 (Leeming Biogas SW)	0.948 / 0.987	0.976	9 (-7.215) Thirsk	1
A2	New demand at LV HV N-1	Outage of Bedale Station HV feeder at Bedale Primary Substation (Carlton Miniott HV feeder picks up Bedale Station HV feeder)	0.922 / 1.005 (Thirsk T2)	0.787 (Leeming Biogas SW)	0.895 / 0.924	0.906	6 (-11.519) Thirsk	1.5[6]
A3	HV N-1	Outage of Carlton Miniott HV feeder at Thirsk Primary Substation (Bedale Station HV feeder picks up Carlton Miniott HV feeder) [7]	0.987 / 1.006 (Bedale T2)	0.887 (Carlton Miniott)	0.893 / 0.930	0.917	9 (-3.71) Bedale	1

[6] Scaled to trigger voltage issues on both HV and LV networks due to demand.

Scenario – Peak Demand		Contingency Description	Voltage at Thirsk or Bedale substation EHV/HV (pu)	Minimum Substation HV voltage along HV Feeders (pu)	Voltage at Sinderby substation HV/LV (pu)	Sinderby LV Minimum V (pu)	Primary Tap Position for Thirsk or Bedale substation Tap Range: 1 (-18.7) to 14(-0.04) at 1.435% - Thirsk 1 (-13.91) to 16(5.22) at 1.33% - Bedale	Load Scaling Factor
A4	HV N-1	Outage of Carlton Miniott HV feeder at Thirsk Primary Substation (Thirsk Carlton HV feeder picks up Carlton Miniott HV feeder)[8]	0.953 / 1.003 (Thirsk T2)	0.674 (Carlton Miniott)	0.682 / 0.720	0.705	9 (-7.215) Thirsk	1
B1	EHV N-1	Outage of 33kV circuit Leeming Bar-Thirsk-Leeming RAF	0.911/1.008 (Thirsk T2)	0.991 (Sinderby Sike SW)	0.991 / 1.035	1.024	5 (-12.594) Thirsk	1
C1	New demand at HV HV N-1	Addition of a 0.4 MVA demand near Sinderby in the Scenario A1 network.	0.953/1.005 (Thirsk T2)	0.872 (Bedale Station)	0.935 / 0.974	0.962	9 (-7.215) Thirsk	1

[7] Not a credible operational configuration but analysed to stress test the model.

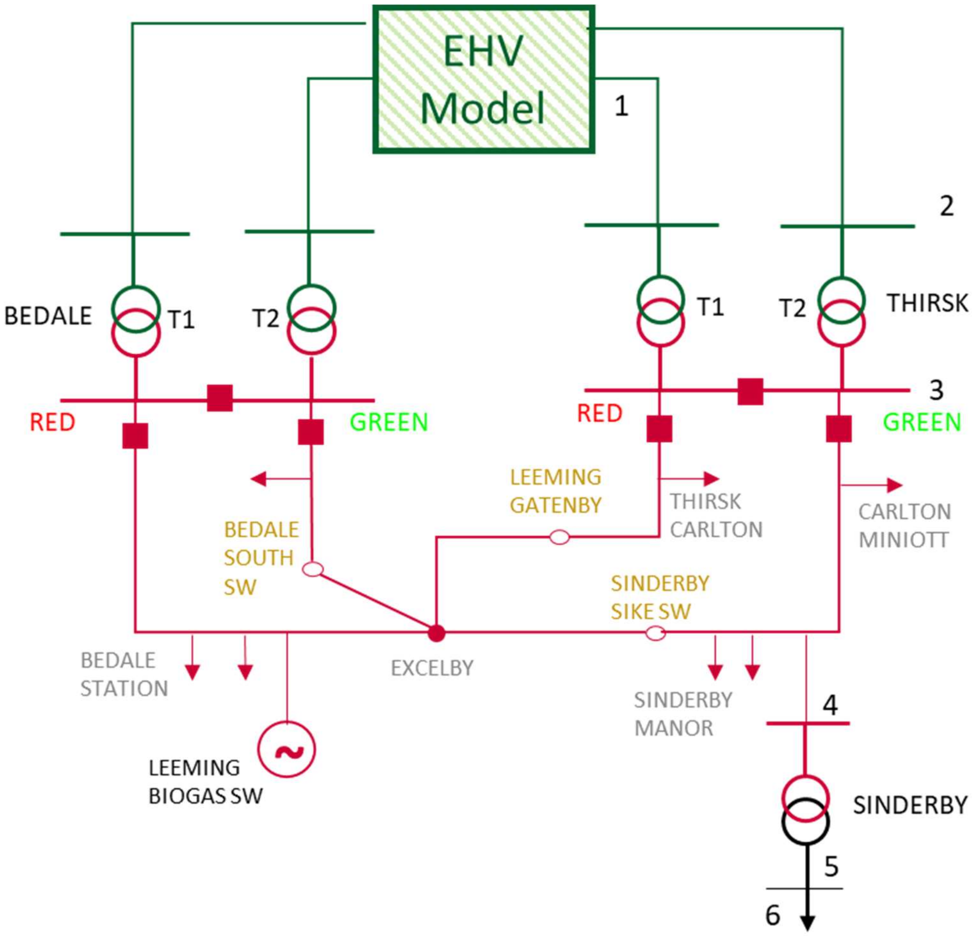
[8] Not a credible operational configuration but analysed to stress test the model.

Table 11 Voltage results for each load scenario – Summer Minimum / Peak Generation

Scenario – Minimum Demand / Peak Generation		Contingency Description	Voltage at Thirsk or Bedale substation EHV/HV (pu)	Maximum Substation HV voltage along HV Feeders (pu)	Voltage at Sinderby substation HV/LV (pu)	Sinderby LV Maximum V (pu)	Primary Tap Position for Thirsk or Bedale substation Tap Range: 1 (-18.7) to 14(-0.04) at 1.435% - Thirsk 1 (-13.91) to 16(5.22) at 1.33% - Bedale	Load Scaling Factor
	Base Case (Min Demand / Peak Generation)	None	0.987 / 1.013 (Thirsk T2)	1.012 (Carlton Miniott)	1.005 / 1.055	1.055	12 (-2.909) Thirsk	1
A5	HV N-1	Outage of Bedale Station HV feeder (Carlton Miniott HV feeder picks up Bedale Station HV feeder) with Leeming Biogas SW exporting 1.5MW generation	0.964 / 1.009 (Thirsk T2)	1.012 (Leeming Biogas SW)	0.984 / 1.026	1.026	11 (-4.344) Thirsk	1
B2	EHV N-1	Outage of 33kV circuit Leeming Bar-Thirsk-Leeming RAF	0.987 / 1.007 (Thirsk T2)	1.006 (Carlton Miniott)	0.998 / 1.047	1.047	12 (-2.909) Thirsk	1
D1	New PV at LV	50% of Sinderby Loads are assumed to have 4kW PV connected	0.989 / 1.014 (Thirsk T2)	1.013 (Carlton Miniott)	1.009 / 1.066	1.075	12 (-2.909) Thirsk	1
D2	New PV at LV HV N-1	Combination of A5 & D1	0.987 / 1.011 (Thirsk T2)	1.025 (Leeming Biogas SW)	0.997 / 1.054	1.063	12 (-2.909) Thirsk	1

Scenario – Minimum Demand / Peak Generation		Contingency Description	Voltage at Thirsk or Bedale substation EHV/HV (pu)	Maximum Substation HV voltage along HV Feeders (pu)	Voltage at Sinderby substation HV/LV (pu)	Sinderby LV Maximum V (pu)	Primary Tap Position for Thirsk or Bedale substation Tap Range: 1 (-18.7) to 14(-0.04) at 1.435% - Thirsk 1 (-13.91) to 16(5.22) at 1.33% - Bedale	Load Scaling Factor
E1	New generation at HV	New generation of 2.5MVA rated export with a PF of 0.95 is connected at Sinderby Manor SW on HV feeder	0.996 / 1.011 (Thirsk T2)	1.053 (Sinderby Manor SW)	1.051 / 1.103	1.103	13 (-1.475) Thirsk	1
E2	New PV at LV & New generation at HV	The scenarios D1 & E1 are combined in this particular case.	0.995 / 1.011 (Thirsk T2)	1.056 (Sinderby Manor SW)	1.053 / 1.113	1.121	13 (-1.475) Thirsk	1

Figure 11 Thirsk Primary Network Topology



4.3 Voltage Profiles – Thirsk

Voltage results are plotted to show the voltage profile (defined as voltage change with electrical circuit length, rather than with time) across the EHV, HV & LV networks of the representative Northeast network including Thirsk primary, along a connected electrical path. The voltage profile is based on six key nodes as listed below. Figure 11 illustrates the Thirsk primary network topology along with numbers that indicate the location of the busbars referred to in Table 12. Other key switching points are also shown.

Table 12 Voltage nodes for Thirsk

No.	Node Name	Voltage Level	Colour (Plot)
1	Leeming Bar 33kV	33kV (EHV)	Green
2	Thirsk/Bedale 33kV T2	33kV (EHV)	Green
3	Thirsk/Bedale 11kV T2	11kV (HV)	Red
4	Sinderby 11kV	11kV (HV)	Red
5	Sinderby 400V	400V (LV)	Black
6	Sinderby Feeder End	400V (LV)	Black

The voltage step-ups observed in the profile plots are due to the voltage management capabilities of the transformers.

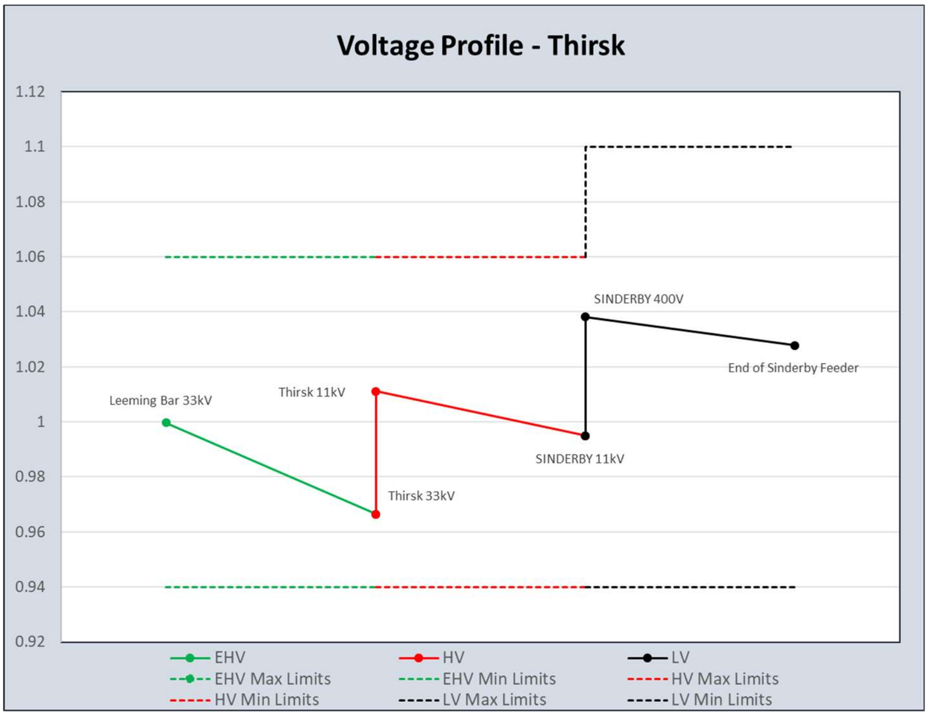
Figure 11 shows the normal running arrangement of the feeders between the Thirsk and Bedale primary substations. Consistent voltage colours have been used in Figure 11 and the voltage result graphs – Green (EHV), Red (HV) & Black (LV). The gold coloured text indicates the location of the normal open points whereas the grey text indicates the first substation along that particular feeder. The red and green transformer busbars have been indicated in the diagram consistent with the NPg busbar naming convention.

4.3.1 Peak Demand

4.3.1.1 Base Case

For the base case, under peak demand network intact conditions (no contingency at EHV or HV), voltage behaviour is as shown in Figure 12. This indicates that under normal operating conditions, all voltages are well within limits.

Figure 12 Voltage Profile for Peak Demand – Base Case Scenario



4.3.1.2 Scenario A1, HV N-1

Figure 13 illustrates the network topology where there is an outage on the circuit in between Bedale Primary and Bedale Station secondary substation[9] and the Bedale Station HV feeder load is picked up by the Carlton Miniott HV feeder connected to Thirsk 33kV green busbar. This feeder supplies the Sinderby LV network. Thirsk primary is assumed not to be de-loaded. The Leeming Biogas SW HV busbar is located on the Bedale Station Feeder just before Excelby; the biogas generator is not exporting in this scenario. Please note that whilst this is not a credible operational regime, it has been analysed to stress test the model.

[9] The open circuit breaker at Bedale is depicted by the unfilled red square symbol.

Figure 13 Thirsk network – Bedale Station circuit outage

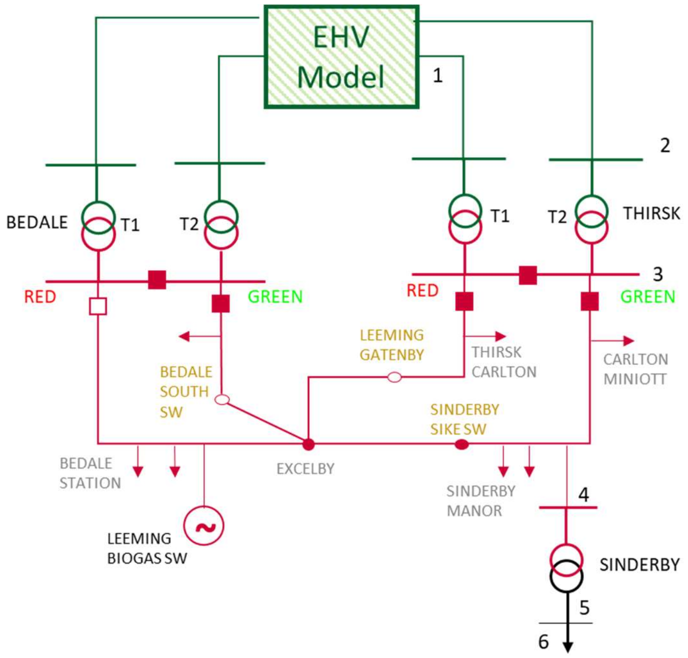
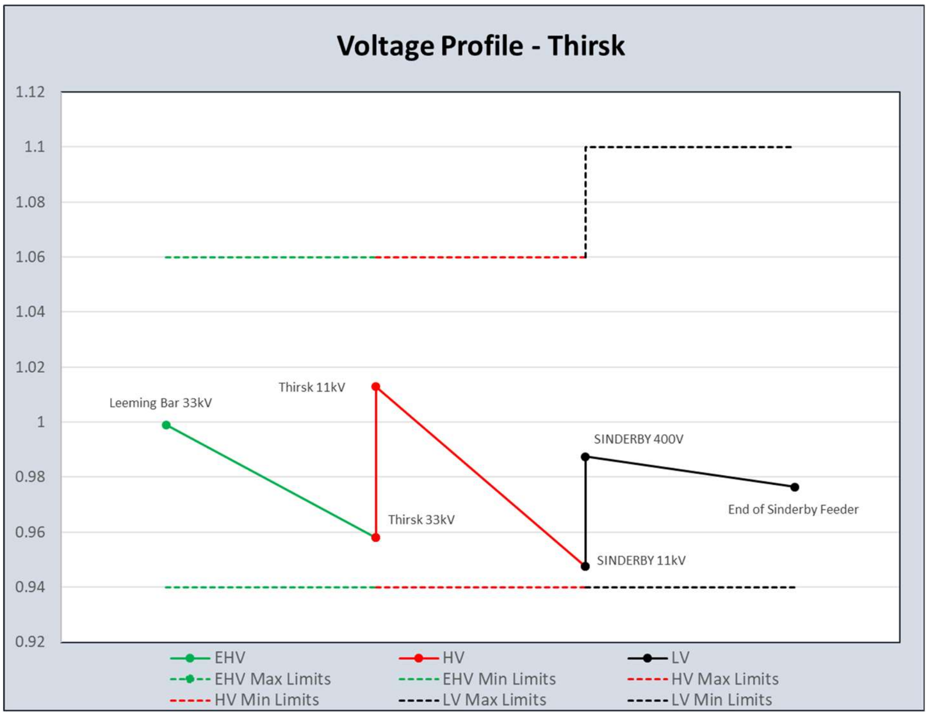


Figure 14 Voltage Profile for Peak Demand – Bedale Station Circuit Outage



The plot indicates that the voltages at both the Thirsk 33kV busbar and the Sinderby 11kV busbar are lower than the base case. However, they remain within the statutory voltage limits although not completely aligned with HV and LV system design principles (LV busbar is less than 230V). It is also observed that the Leeming Biogas SW connected to the HV feeder between Excelby and Leeming Gatenby which is now fed from Thirsk has a voltage of 0.882 pu, which is less than the statutory limit of 0.94 pu. Sinderby, which is relatively close to the supply point at Thirsk green HV busbar, is compliant. In the event of this A1 outage scenario, other switching arrangements could be employed to ensure the Leeming Biogas SW voltage remained within statutory limits.

4.3.1.3 Scenario A2, HV N-1

A scenario was explored where the loads in the network were increased by 50%, under the same contingency conditions as A1, in order to trigger voltage violations in the LV network.

Figure 15 Voltage Profile for Peak Demand – Bedale Station Circuit Outage with Load Scaling 1.5x

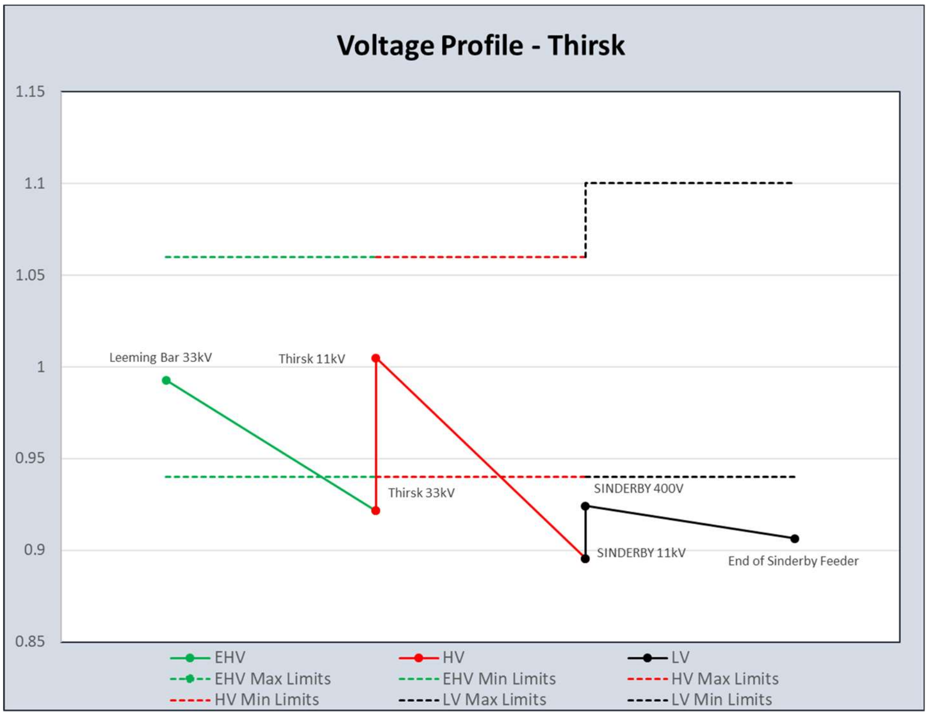


Figure 15 indicates that the voltage falls below the statutory limits at all voltage levels for this contingency condition and level of load scaling. It is also observed that the Leeming Bar SW secondary substation along the HV feeder between Excelby and Leeming Gatenby, which is now fed from Thirsk, has a voltage of 0.787 pu. As there are no customers directly connected to the 33kV feeder at Thirsk, the violation of voltage limits is perhaps less material. However, the overall reduction in voltage at primary level does impact LV customers connected to secondary substations along the HV feeders, increasingly so for secondary substations connected to the HV feeder beyond Sinderby.

4.3.1.4 Scenario A3, HV N-1

Figure 16 illustrates the network topology where there is an outage on the HV circuit between Thirsk Primary and Carlton Miniott secondary substation. The Carlton Miniott HV feeder is now fed from Bedale via the Bedale Station HV feeder. The lowest voltage in this scenario is observed at Topcliffe Stn substation which branches off from the Carlton Miniott feeder between Carlton Miniott and Sinderby. It should be noted that is a switching arrangement that is unlikely to be used in contingency conditions and has been used to stress test the model.

Figure 16 Thirsk Network – Carlton Miniott Circuit Outage

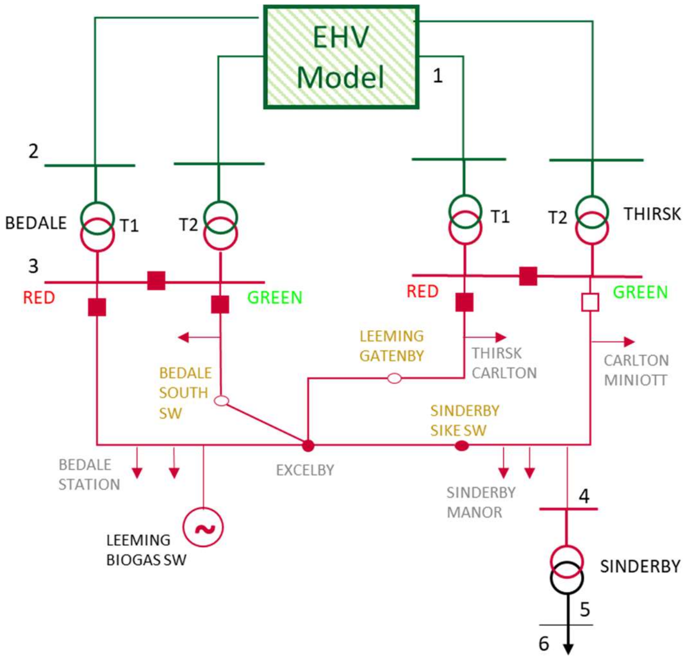
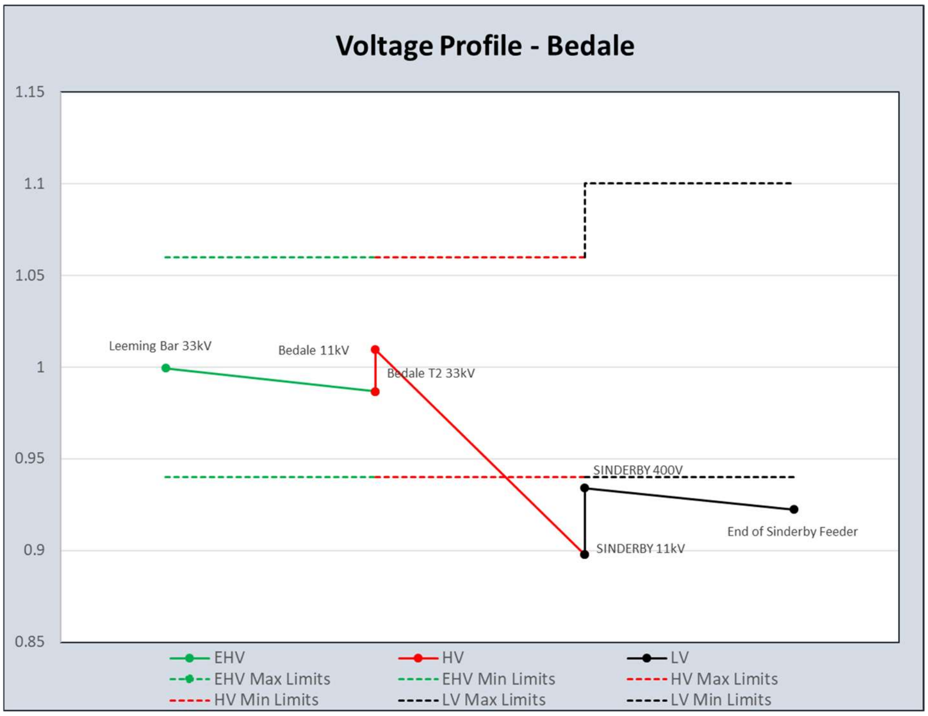


Figure 17 Voltage Profile for Peak Demand – Carlton Miniott Circuit Outage



A considerable voltage drop can be observed along the HV feeder, Sinderby is now located further along the feeder from the supply point at Bedale primary compared to A1 and A2. The voltage drops from 1.01pu at Bedale primary 11kV busbar to 0.89pu at Sinderby 11kV busbar. The minimum voltage on the HV network is observed at Topcliffe Station HV secondary substation (0.89pu) located between Sinderby Sike SW and Thirsk Primary.

4.3.1.5 Scenario A4, HV N-1

Figure 18 illustrates the network topology where there is an outage on the circuit in between Thirsk Primary and Carlton Miniott substation. This feeder is now fed from the Thirsk Carlton feeder out of Thirsk Primary. The Excelby Lords SW is switched open and the NOPs at Leeming Gatenby and Sinderby Sike SW are switched closed. It should be noted that is a switching arrangement that is unlikely to be used in contingency conditions and is mainly used for illustration to show voltage behaviour with interconnection of long rural circuits.

Figure 18 Thirsk Network– Carlton Miniott Circuit Outage with Thirsk interconnection

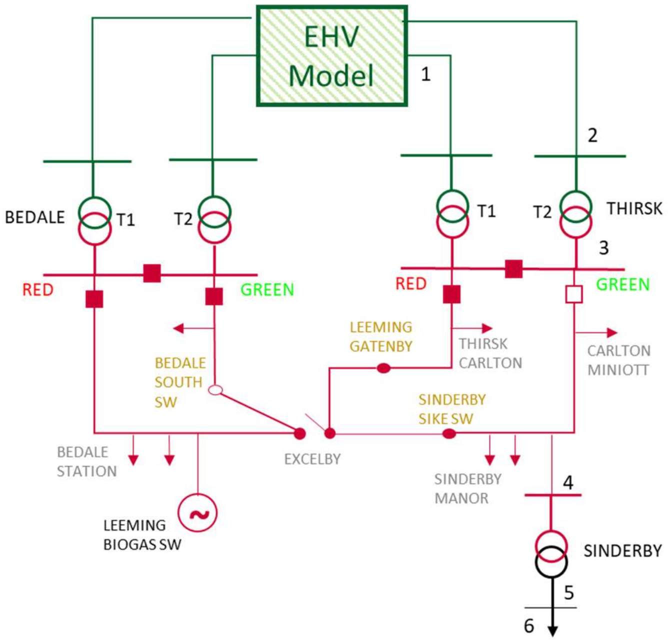
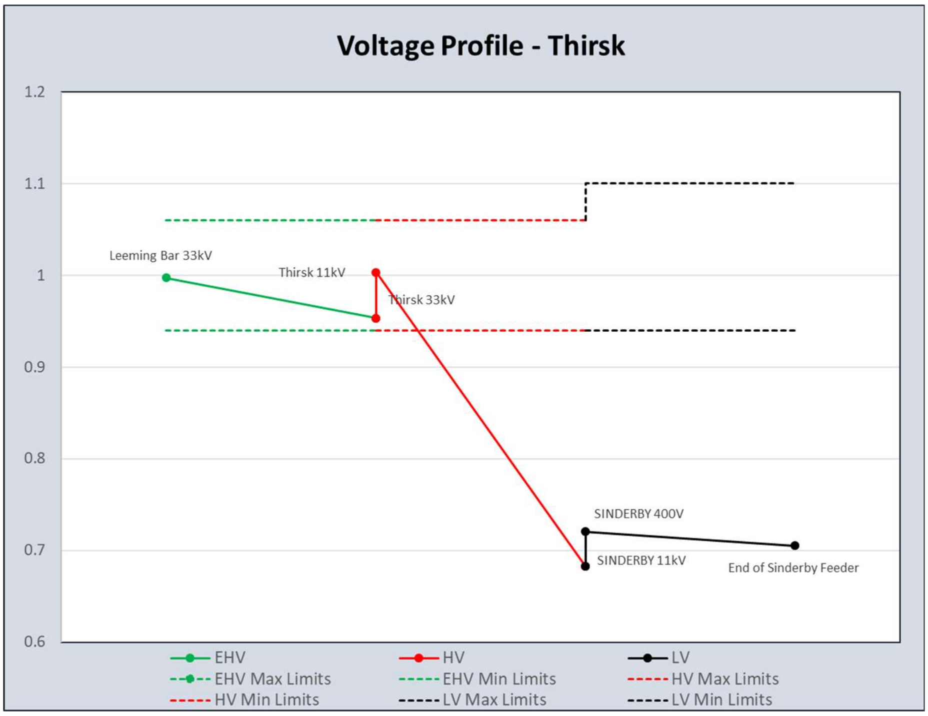


Figure 19 Voltage Profile for Peak Demand – Carlton Miniott Circuit Outage with Thirsk interconnection



4.3.1.6 Scenario B1, EHV N-1

Figure 20 illustrates the network topology where one of the 33kV circuits from the Leeming Bar BSP to Thirsk primary is switched out of service. The lowest voltage is observed on the Baldersby substation in this scenario, this is located towards the end of the Topcliffe Rush HV feeder supplied by the Thirsk primary green busbar (this feeder is not shown in the below diagram).

Figure 20 Thirsk Network – Leeming Bar Circuit Outage

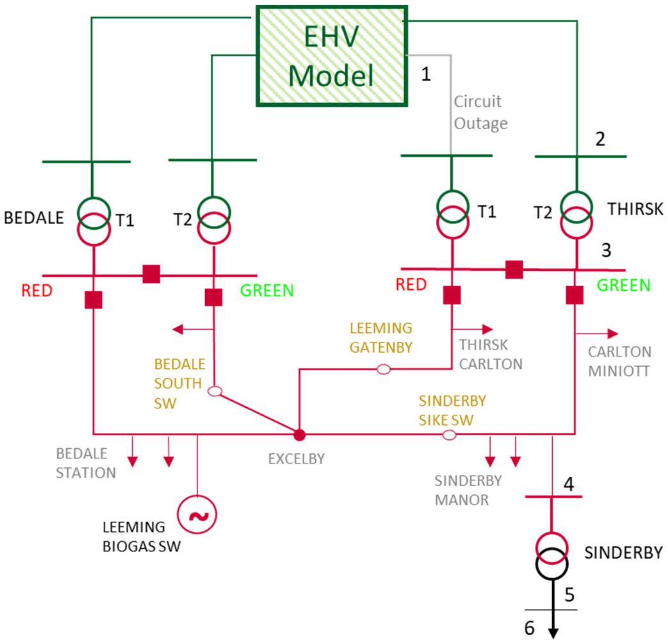
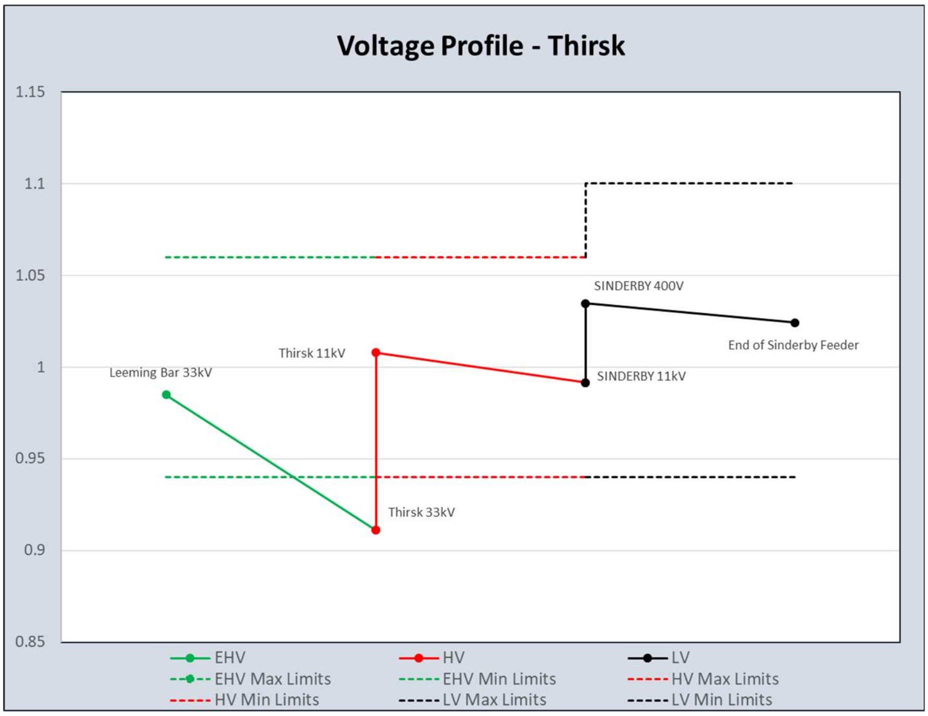


Figure 21 Voltage Profile for Peak Demand – Leeming Bar Circuit Outage



A significant voltage drop can be observed along the remaining 33kV circuit from Leeming Bar GSP to Thirsk primary due to higher loading however, this is recovered completely by voltage control at the Thirsk primary transformer, resulting in minimal impact at LV. The 11kV bus coupler at Thirsk primary is operated normally closed.

4.3.1.7 Scenario C1, New Demand at HV, HV N-1

The network topology from Scenario A1 has been considered for this study. A new demand of 0.4 MVA with a power factor of 0.95 is connected to the Carlton Miniott HV feeder just upstream of Sinderby secondary substation as indicated in Figure 22. The new demand was set at a value to result in a reasonable level of voltage drop on the HV feeder and is representative of an HV customer connection.

Figure 22 Thirsk Network – Bedale Station Circuit Outage

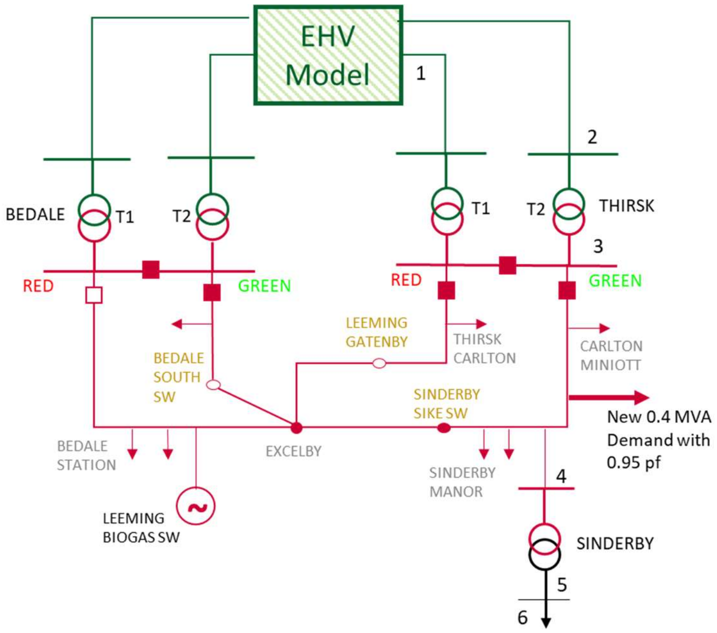
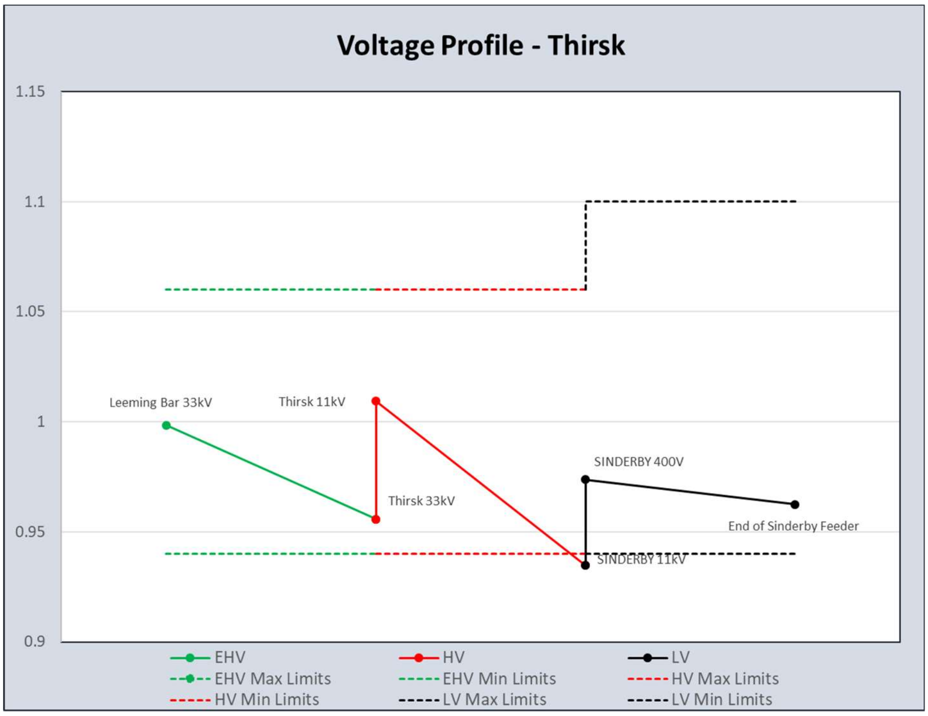


Figure 23 Voltage Profile for peak demand - Bedale Station circuit outage & New 0.4 MVA Demand



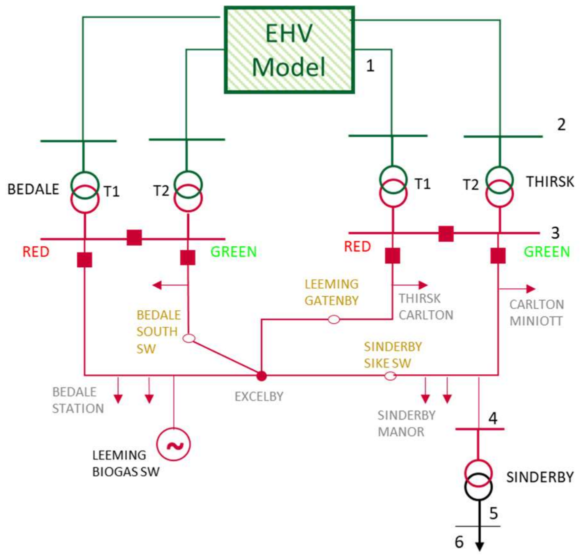
The addition of new demand results in increased voltage drop along the Bedale station-Carlton Miniott interconnected HV feeders compared to scenario A1, with voltage below statutory limits near Sinderby. The voltage boost on the secondary transformer mitigates the impact on the LV network although voltage capacity on the LV networks is reduced. This scenario illustrates the benefits of the MVL modelling approach, where the voltage on the HV side of the secondary substation busbars can be better characterised under different loading conditions and its impact modelled on the LV network feeders, without reverting to assumptions. The example also illustrates that although the voltage at Sinderby 400V (at 0.974pu) would not align with the NPg HV and LV design principles to be at least 1.0pu, voltages at the end of the Sinderby feeder are within limits.

4.3.2 Minimum Demand / Peak Generation

4.3.2.1 Base Case

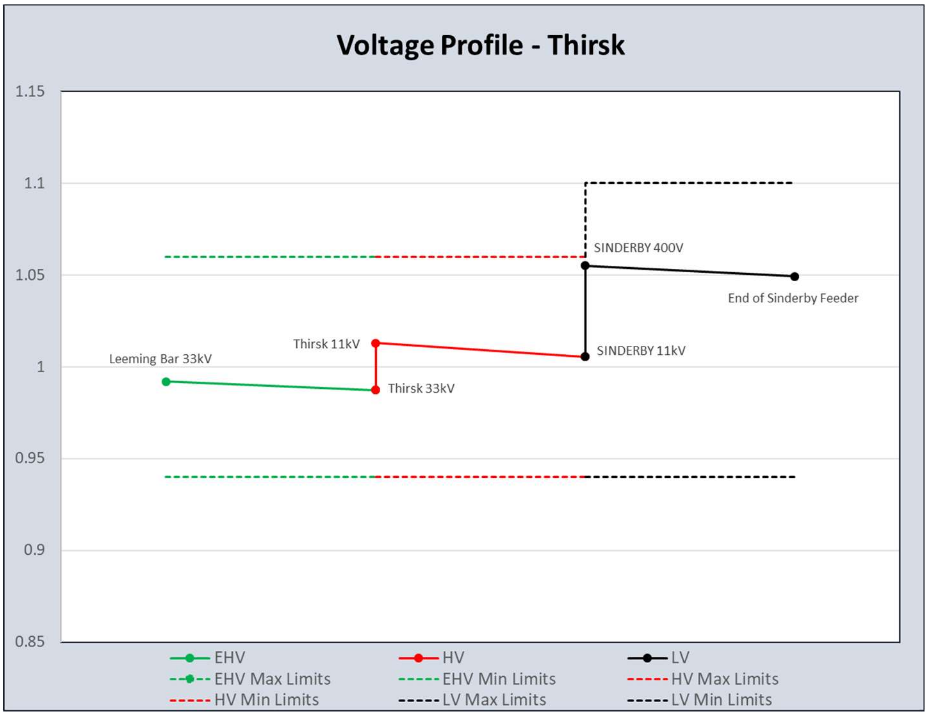
The network topology for the minimum demand / peak generation base case can be observed in Figure 24 and is the same as the peak demand base case, in intact conditions. In the Thirsk network model, there is one generator at HV, Leeming Biogas generator, with a maximum export capacity of 1.5MW located on the Bedale Station HV feeder and Sandhutton solar farm with a maximum export capacity of 5MW connected directly to Thirsk 11kV busbar. Generation is set to maximum export capacity in this scenario. However, there is an overvoltage protection at the Leeming Biogas SW site. If the voltage exceeds more than 11.8kV (1.07pu) for 150s, the generator’s metering circuit breaker will be tripped. The operation of this overvoltage protection has not been modelled.

Figure 24 Network Topology for the minimum demand / peak generation – Base Case



For the base case, under minimum demand and peak generation conditions and with no contingency at EHV or HV, voltage behaviour is as shown in Figure 25. Voltage drop is limited due to low load.

Figure 25 Voltage profile for minimum demand / peak generation – Base Case



4.3.2.2 Scenario A5, HV N-1

Figure 26 illustrates the network topology where there is an outage on the Bedale Station HV feeder between Bedale Primary and Bedale Station secondary substation and the HV feeder is back-fed from Thirsk via the Carlton Miniott HV feeder.

Figure 26 Thirsk network - Bedale Station circuit outage

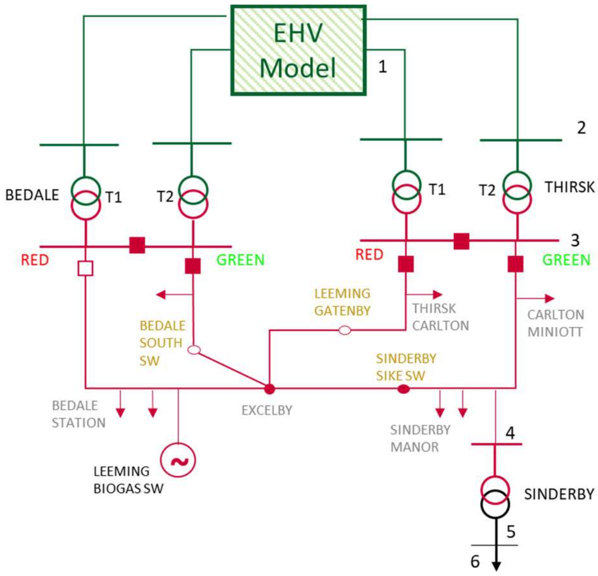
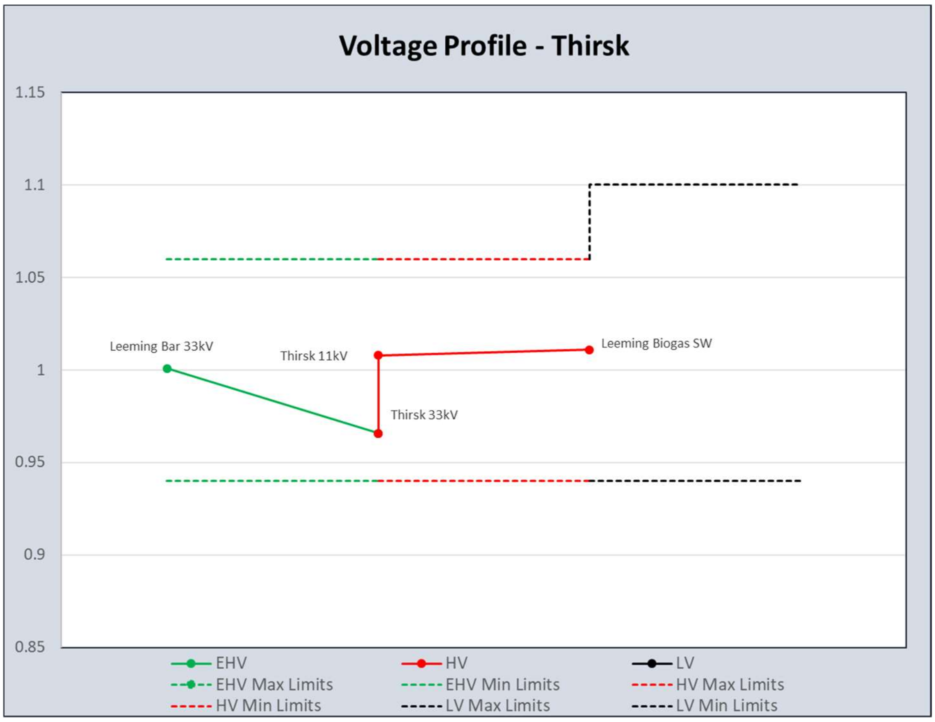


Figure 27 Voltage profile for minimum demand / peak generation - Bedale Station circuit outage, Leeming biogas maximum export



A voltage rise can be observed during this scenario, along the Bedale Station – Carlton Miniott interconnected HV feeders due to the Leeming Biogas SW generation. This is well within statutory voltage limits.

4.3.2.3 Scenario B2, EHV N - 1

Figure 28 illustrates the network topology where one of the 33kV circuits from the Leeming Bar BSP to Thirsk primary is switched out of service, similar to the contingency in Scenario B1.

Figure 28 Thirsk network – Leeming Bar circuit outage

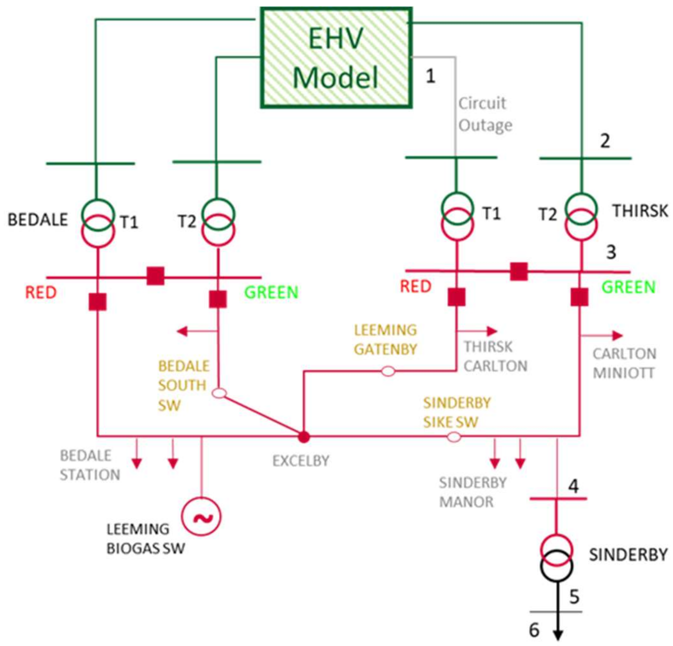
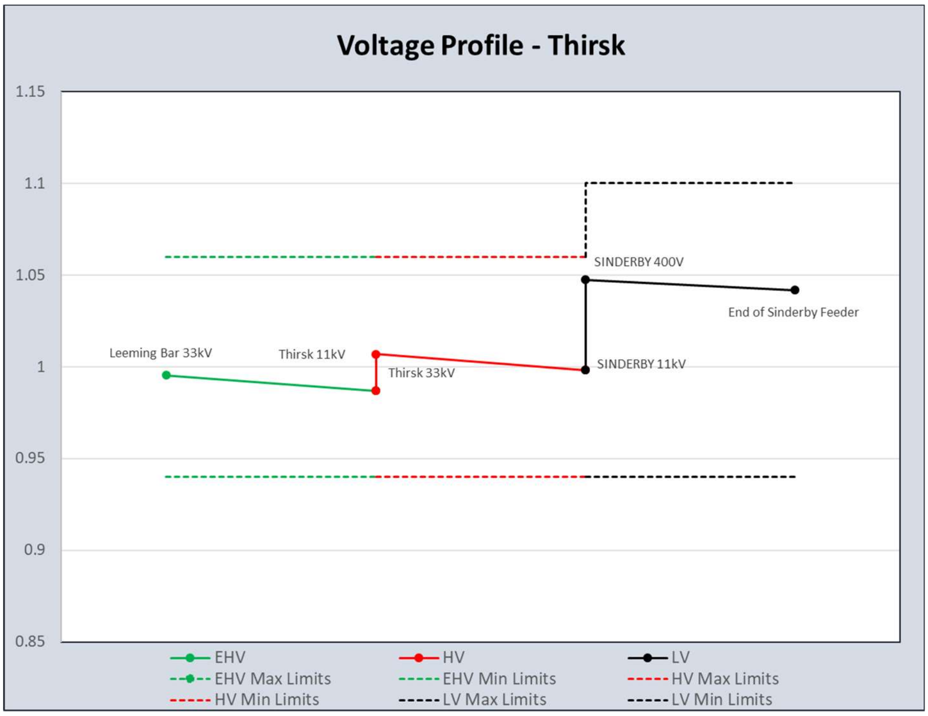


Figure 29 Voltage profile for Leeming Bar circuit outage



Voltage remains within limits during the outage on the Leeming Bar – Thirsk circuit. The existing levels of generation connected to the Thirsk HV network at Thirsk HV busbars is not high enough to trigger voltage issues.

4.3.2.4 Scenario D1, New PV at LV

Figure 30 illustrates the network topology for Scenario D where the network is intact, similar to the base case. In this scenario, 50% of the 66 customers connected to the Sinderby secondary substation are assumed to have a PV connection of 4kW each, exporting a total of 132kW. Since the minimum demand at Sinderby is 62.8kW, there is a total export of 69.2kW to the HV network from the Sinderby secondary substation.

Figure 30 Thirsk network - no contingency

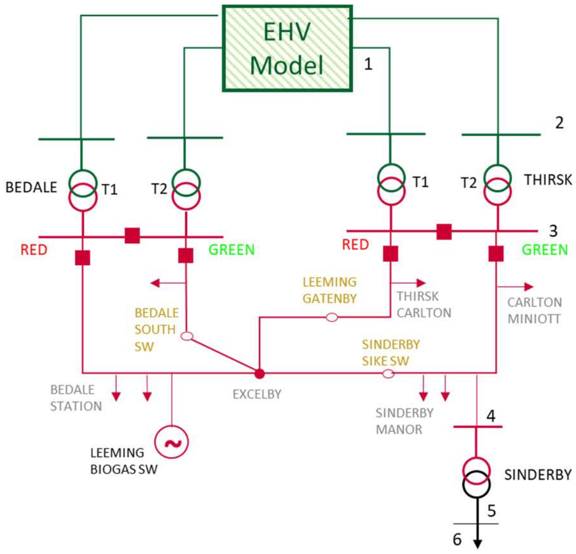
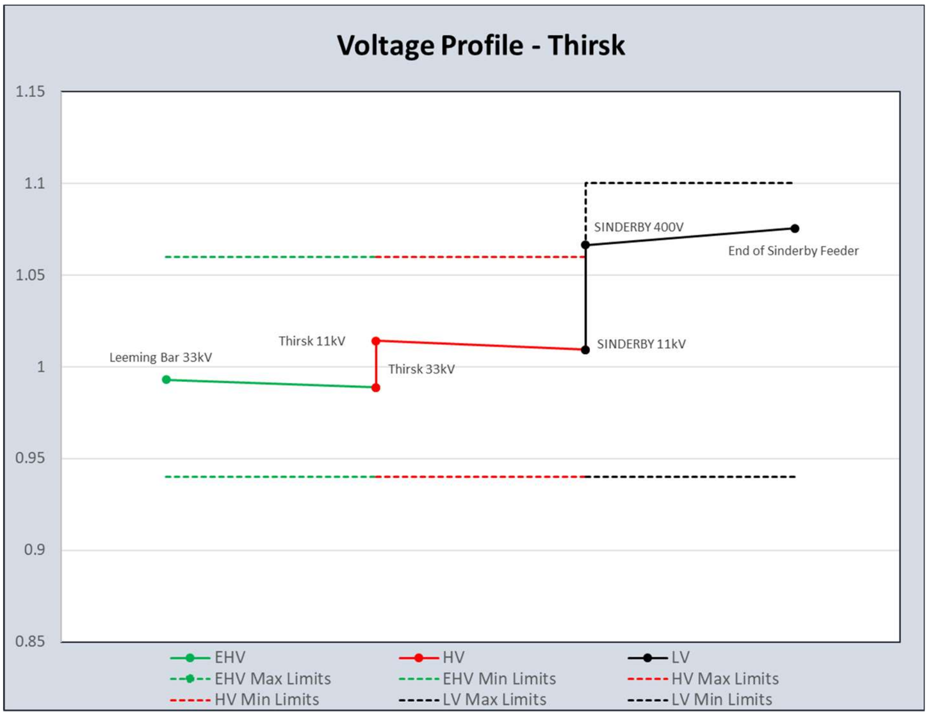


Figure 31 Voltage profile for minimum demand / peak generation – New PV at LV



It can be observed from Figure 31 that the addition of relatively large amounts of embedded PV to the Sinderby LV network leads to a voltage rise. However, due to the high voltage headroom, voltage remains within limits.

4.3.2.5 Scenario D2, New PV at LV HV N-1

This Scenario is a combination of Scenario A5 and Scenario D1.

Figure 32 Thirsk network – Bedale Station circuit outage

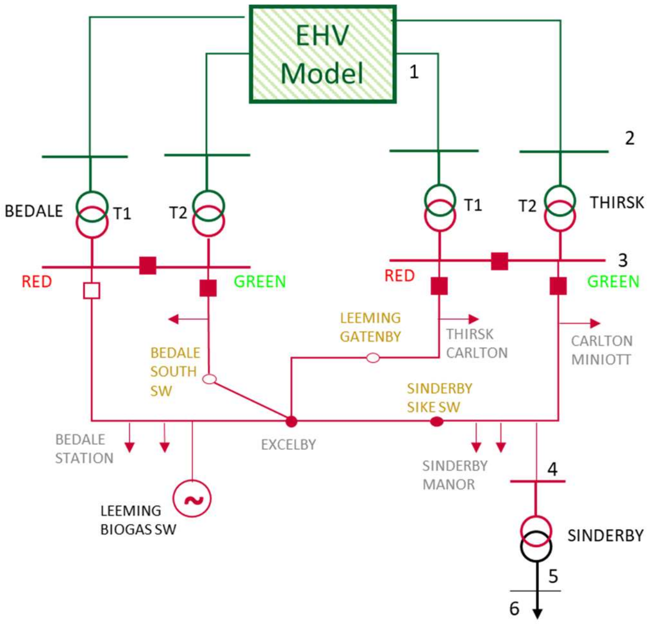
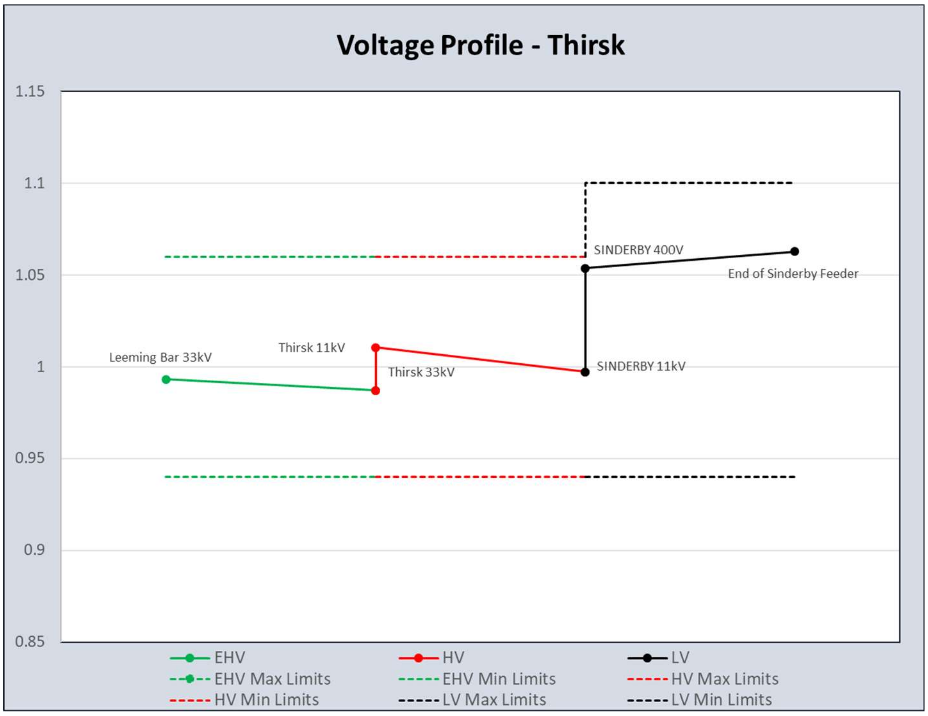


Figure 33 Voltage profile minimum demand / peak generation - New PV at LV, Bedale Station circuit outage



It can be observed from Figure 33 that the addition of significant embedded PV to the Sinderby LV network leads to a voltage rise. However, due to voltage headroom, voltage remains within limits.

4.3.2.6 Scenario E1, New Generation at HV

Figure 34 illustrates the network topology for this scenario, similar to the base case but with the addition of HV generation. A new generator with an export of 2.5MVA and a pf of 0.95 is connected to the Sinderby Manor SW site, close to the Sinderby secondary substation.

Figure 34 Thirsk Network – no contingency

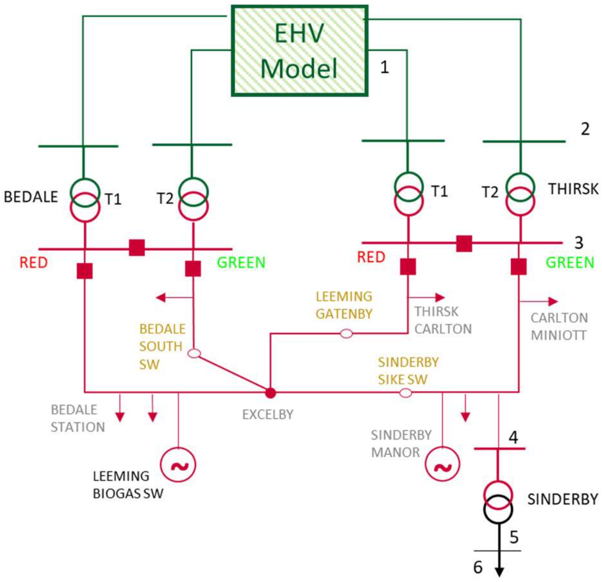
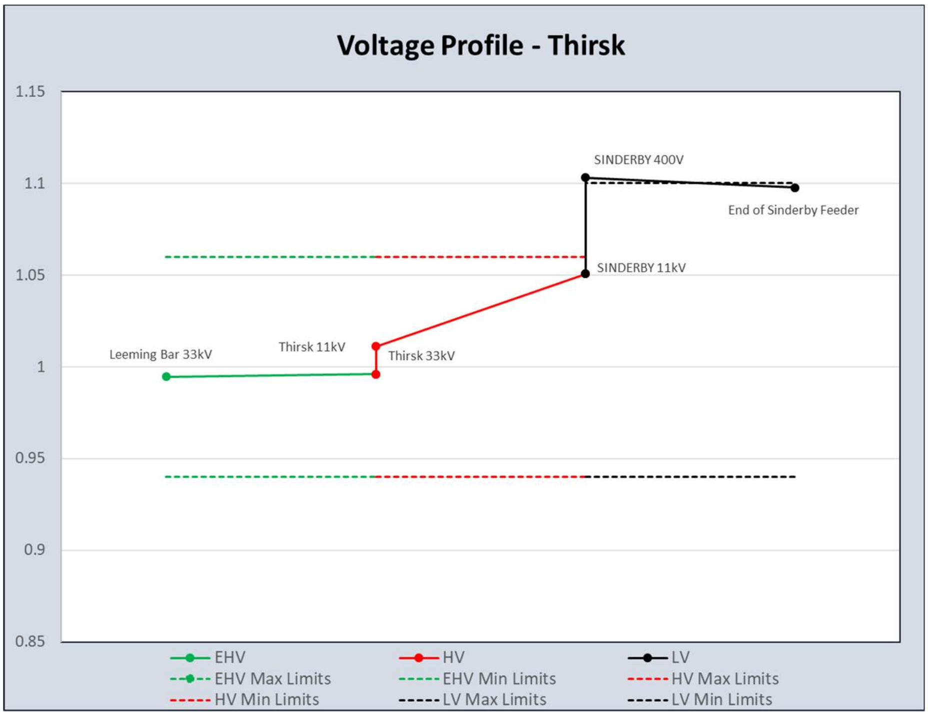


Figure 35 Voltage profile minimum demand / peak generation - New generation at HV

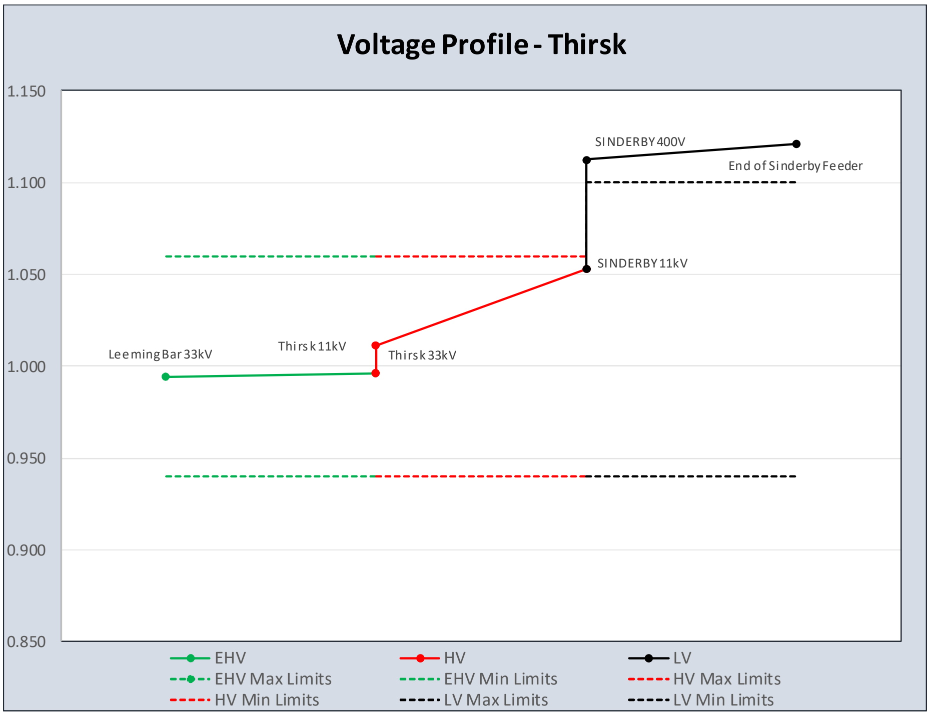


The connection of new HV generation to the Carlton Miniott HV feeder results in a significant voltage rise. With the inherent voltage boost and tap settings for the Sinderby secondary transformer, this results in over-voltages at LV.

4.3.2.7 Scenario E2, New PV at LV & New Generation at HV

This scenario combines both Scenario D1 & Scenario E1, under intact network conditions for Thirsk.

Figure 36 Voltage profile minimum demand / peak generation - New PV at LV & new generation at HV



The addition of substantial domestic PV on the LV network and connection of HV generation on the HV feeder adjacent to the LV network results in over-voltages on the LV network.

4.3.3 Assessment of P10 Requirements

The requirements of Engineering Recommendation P10 were assessed using the MVL model for Leeming Bar BSP. The results below indicate that it is possible for the supply voltage of the 33kV Leeming Bar busbars to be 5% above the nominal voltage under peak load conditions at the BSP i.e. 130% of firm capacity. With only one transformer in service and peak loading, it is also possible to maintain the nominal voltage at the 33kV busbars. Leeming Bar BSP has two transformers with a rating of 45MVA ONAN and 90 MVA ONAF. In practice however for a transformer outage at Leeming Bar BSP, due to the 33kV network being interconnected to Darlington North BSP and Skeeby BSP some power is supplied via that route, resulting in Leeming Bar BSP providing 119% of the demand during the outage. To demonstrate compliance with P10, the interconnection has been switched out such that the load on the remaining transformer is ~130% of 90MVA.

Table 13 Assessment of ER P10 for Leeming Bar BSP

	% Firm Capacity	BSP 33kV busbar % V above nominal	BSP Tap Position %	GSP 132kV busbar V (pu)
Leeming Bar T1	133%	5%	-18.33	0.946
Leeming Bar T2	133%	5%	-18.33	0.946
Leeming Bar T1	135%	7%	-20%	0.946
Leeming Bar T2	135%	7%	-20%	0.946
Leeming Bar T2 (N-1)	131%	0%	-20%	0.959

4.3.4 Observations

Based on our analysis of holistic voltage behaviour for this multi-voltage level network under a range of scenarios, we can make the following observations:

- This network generally complies with NPg HV and LV design principles as-is, however in some cases (C1) the voltage at Sinderby 400V busbar is less than the NPg HV and LV design principles to be at least 1.0pu, although the voltage at the end of the Sinderby feeder is within limits.
- The MVL modelling approach enables the voltage across the network to be better characterised under different loading conditions including with new generation (D1, D2, E1, E2) or load (A2, C1) connected at both HV and LV and under a range of network topologies, without reverting to assumptions relating to the allocation of the permissible voltage drop / rise to the HV and LV network. For example, implications for LV network voltage with new generation or demand on HV feeders can be observed.
- Whilst there is some existing voltage headroom and legroom on the Thirsk and Sinderby networks under the credible operational regimes and loading conditions tested, these will be depleted with increasing demand for example from low carbon technology and increasing embedded generation.

This could eventually lead to voltage issues at both HV and LV. Long rural feeders are more susceptible to larger voltage drops.

- The primary substation transformer tapping range seems to be able to cope with a range of expected demand and generation conditions however it generally operates between tap 5 and 13 for the scenarios analysed, indicating that the tap range may not be optimal for the future range of loading conditions.
- The target voltage at Leeming Bar 33kV busbar is 32.7kV, this is to enable more embedded generation to connect at 33kV. However, for high demand loading conditions, this target voltage may need to be increased. This could be automated for seasonal conditions or using LDC depending on correlation between generation output and demand and correlation of various feeder loading patterns.
- The Sinderby HV/LV transformer tap setting is -2.5%, managing the risk of high voltage at times of low load. However, this may limit the connection of generation at LV.
- Generation may have more impact on voltage under intact conditions rather than N-1 conditions, depending on the generation connected to the network and the backfeeds, as seen in scenarios D1 and D2.

4.4 Scenario Results - First Avenue

Voltage results for First Avenue are given in Table 14 for various scenarios under peak demand and minimum demand / peak generation conditions.

Table 14 Voltage results for peak demand and minimum demand / peak generation scenarios

Scenario – Peak Demand		Contingency Description	Voltage at First Avenue or Endike Lane substations EHV/HV (pu)	Minimum Substation voltage along HV Feeders (pu)	Voltage at Cranwood Substation (pu)	Cranwood LV Minimum V (pu)	Primary Tap Position Tap Range: Endike Lane: 1(-18.7%) to 15(0.4%) at 1.366% First Avenue: 1(-13.9%) to 21(5.2%) at 0.956%	Scaling
	Base Case (Peak Demand)	None	0.979 / 1.014 (First Avenue)	1.014	1.014 / 1.079	1.05	First Avenue: 10 (-5.30%) Endike Lane: 12 (-3.67%)	1
A1	HV N-1	Outage of Cranwood HV feeder at First Avenue Primary (Oldstead North HV feeder picks up Cranwood HV feeder)	0.982 / 1.009 (Endike Lane)	1.006	1.006 / 1.071	1.041	Endike Lane: 12 (-3.67%)	1
A2	HV N-1	Outage of Cranwood HV feeder at First Avenue Primary (Oldstead North HV feeder picks up Cranwood HV feeder)	0.995 / 1.017 (Endike Lane)	1.016	1.016 / 1.094	1.084	Endike Lane: 10 (-6.39%)	2.2
A3	HV N-1	Outage of First Avenue T2 busbar (5 circuits back-fed by Endike Lane)	0.979 / 1.015 (Endike Lane)	1.012	1.012 / 1.078	1.048	Endike Lane: 11 (-5.03%)	1
B1	EHV N-1	Outage of the 33kV circuit between Beverley & First Avenue T2/Endike Lane T2	0.98 / 1.005 (First Avenue)	1.005	1.005 / 1.070	1.040	First Avenue: 9 (-6.26%) Endike Lane: 12 (-3.67%)	1
C1	New demand at HV N-1	Addition of a 2.5 MVA demand between Cranwood & Crandyke in the Scenario A1 network.	0.993 / 1.005 (Endike Lane)	0.996	0.996 / 1.070	1.054	Endike Lane: 13 (-2.29%)	1

Scenario – Minimum Demand / Peak Generation		Contingency Description	Voltage at First Avenue or Endike Lane substations EHV/HV (pu)	Maximum Substation voltage along HV Feeders (pu)	Voltage at Cranwood Substation (pu)	Cranwood LV Maximum V (pu)	Primary Tap Position Tap Range: Endike Lane: 1(-18.7%) to 15(0.4%) at 1.366% First Avenue: 1(-13.9%) to 21(5.2%) at 0.956%	Scaling
	Base Case (Min Demand)	None	0.994 / 1.006 (First Avenue)	1.006	1.006 / 1.08	1.064	First Avenue: 13 (-2.43%) Endike Lane: 13 (-2.29%)	1
A4	HV N-1	Outage of Cranwood HV feeder at First Avenue Primary (Oldstead North HV feeder picks up Cranwood HV feeder)	0.992 / 1.012 (Endike Lane)	1.01	1.01 / 1.085	1.069	Endike Lane: 13 (-2.29%)	1
B2	EHV N-1	Outage of 33kV circuit between Beverley and First Avenue/Norwood tee point	1.069 / 1.000 (First Avenue)	1.01	1.01 / 1.084	1.069	First Avenue: 17 (1.39%)	1
D1	New PV at LV	50% of Cranwood Loads are assumed to have 4kW PV connected onsite	0.995 / 1.007 (First Avenue)	1.007	1.007 / 1.075	1.127	First Avenue: 13 (-2.43%)	1
D2	HV N-1 New PV at LV	Combination of A4 & D1	0.993 / 1.018 (Endike Lane)	1.018	1.012 / 1.08	1.133	Endike Lane: 13 (-2.29%)	1
E1	New generation at HV	A new generation of 2.5MVA with a PF of 0.95 is introduced between Cranwood & Crandyke	0.997 / 1.013 (First Avenue)	1.014	1.014 / 1.089	1.089	First Avenue: 13 (-2.43%)	1
E2	New PV to LV & New generation at HV	New generation of 2.5MVA with a PF of 0.95 connected at HV with 25% of Cranwood Loads assumed to have 4kW PV connected onsite	0.997 / 1.014 (First Avenue)	1.016 (New HV generator)	1.015 / 1.089	1.109	First Avenue: 13 (-2.43%)	1

4.5 Voltage Profile – First Avenue

Voltage results are plotted to show the voltage profile (defined as voltage change with electrical circuit length, rather than with time) across the EHV, HV & LV networks of the representative Yorkshire network including First Avenue primary, along a connected electrical path. The voltage profile is based on six key nodes as listed below. Figure 11 illustrates the First Avenue primary network topology along with numbers that indicate the location of the busbars referred to in Figure 37. Other key switching points are also shown.

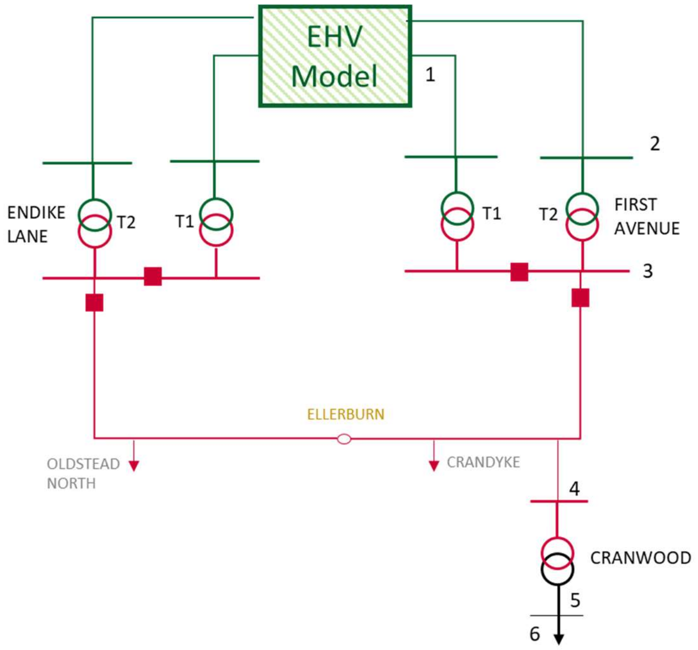
Table 15 Voltage nodes for First Avenue

No.	Node Name	Voltage Level	Colour (Plot)
1	Beverley 33kV	33kV (EHV)	Green
2	First Avenue/Endike Lane 33kV - 1	33kV (EHV)	Green
3	First Avenue/Endike Lane 11kV - 1	11kV (HV)	Red
4	Cranwood 11kV	11kV (HV)	Red
5	Cranwood 400V	400V (LV)	Black
6	Cranwood Feeder End	400V (LV)	Black

The voltage step-ups observed in the profile plots are due to the voltage management capabilities of the transformers.

Figure 11 shows the normal running arrangement of the feeders between the First Avenue and Endike Lane primary substations. Consistent voltage colours have been used in Figure 37 and the voltage result graphs – Green (EHV), Red (HV) & Black (LV). The gold coloured text indicates the location of the normal open points whereas the grey text indicates the first substation along that particular feeder.

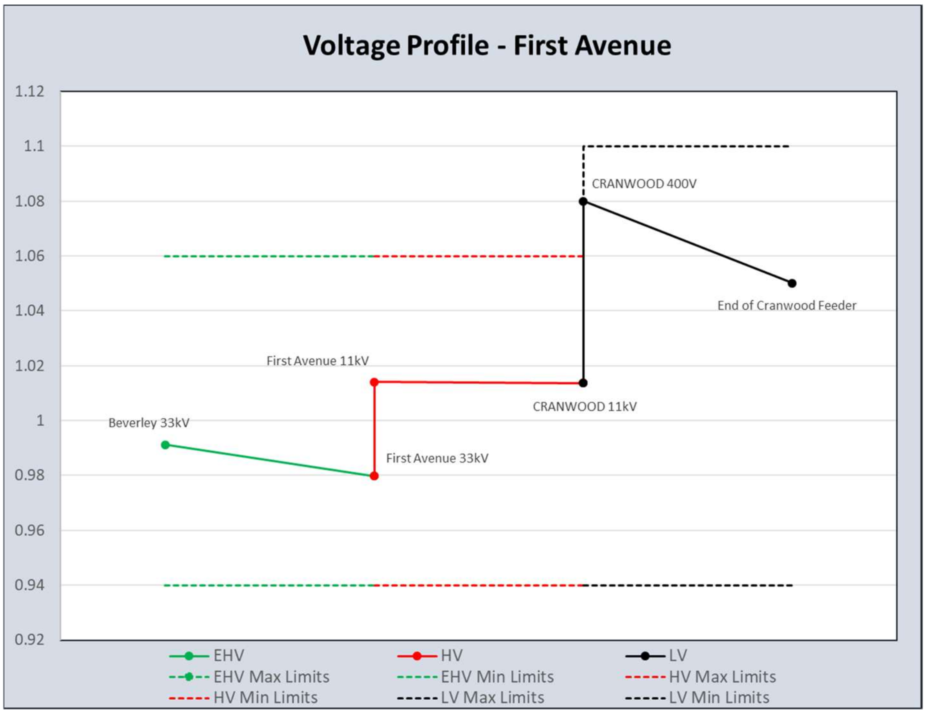
Figure 37 First Avenue network – no contingency



4.5.1 Peak Demand

4.5.1.1 Base Case

Figure 38 Voltage profile for peak demand – Base Case



The voltage profile for the First Avenue base case indicates little voltage drop at HV compared to the Thirsk base case, although there is somewhat more voltage drop at LV. There are only four secondary substations on the Cranwood HV feeder, and it is relatively short compared to the Carlton Miniott HV feeder, with the Cranwood secondary substation being located very close to the First Avenue primary substation. Cranwood is an urban LV network and has 629 customers connected.

4.5.1.2 Scenario A1, HV N-1

Figure 39 illustrates the network topology when there is an outage on the circuit between First Avenue primary and the Cranwood secondary substation, the Ellerburn NOP is closed and the Oldstead North HV feeder from Endike Lane primary substation picks up load on the Cranwood feeder.

Figure 39 First Avenue network – Cranwood circuit outage

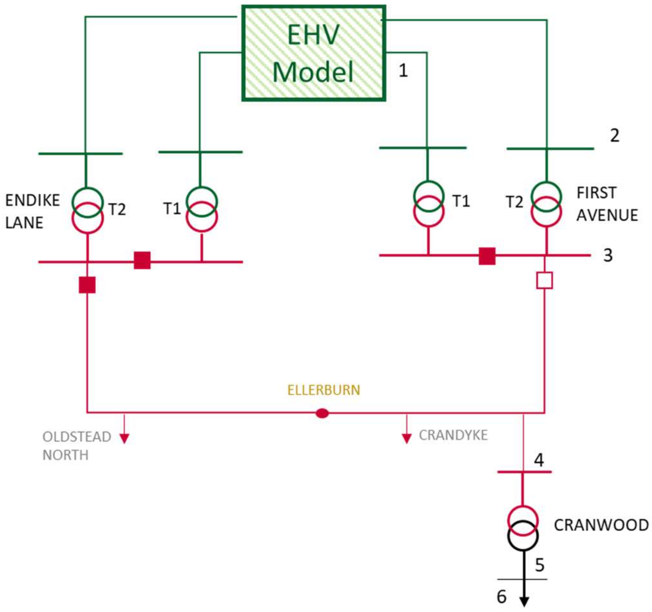
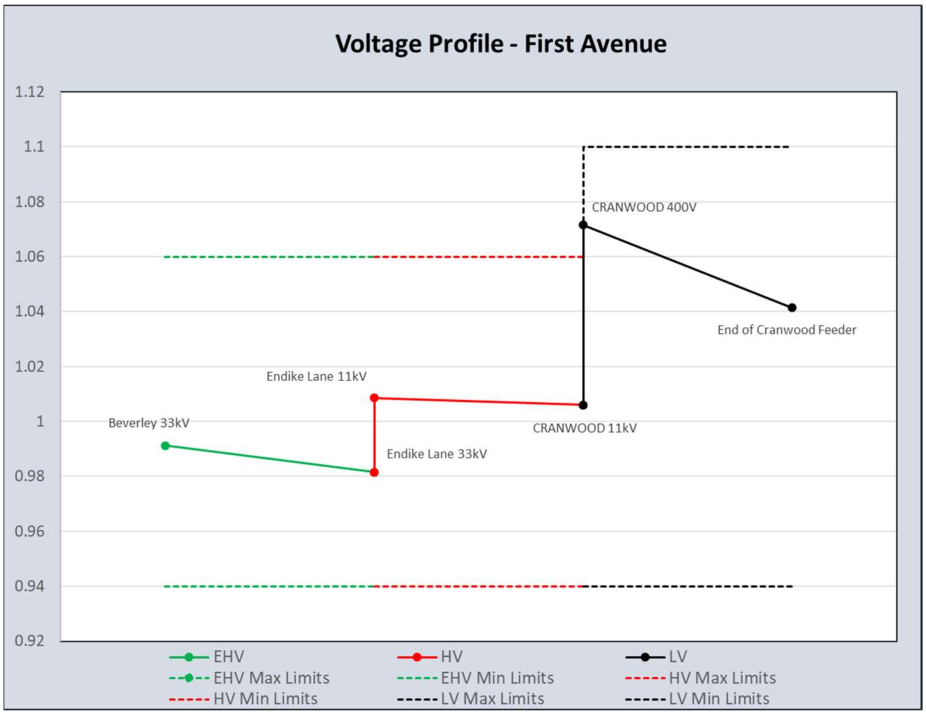


Figure 40 Voltage profile for peak demand – Cranwood circuit outage

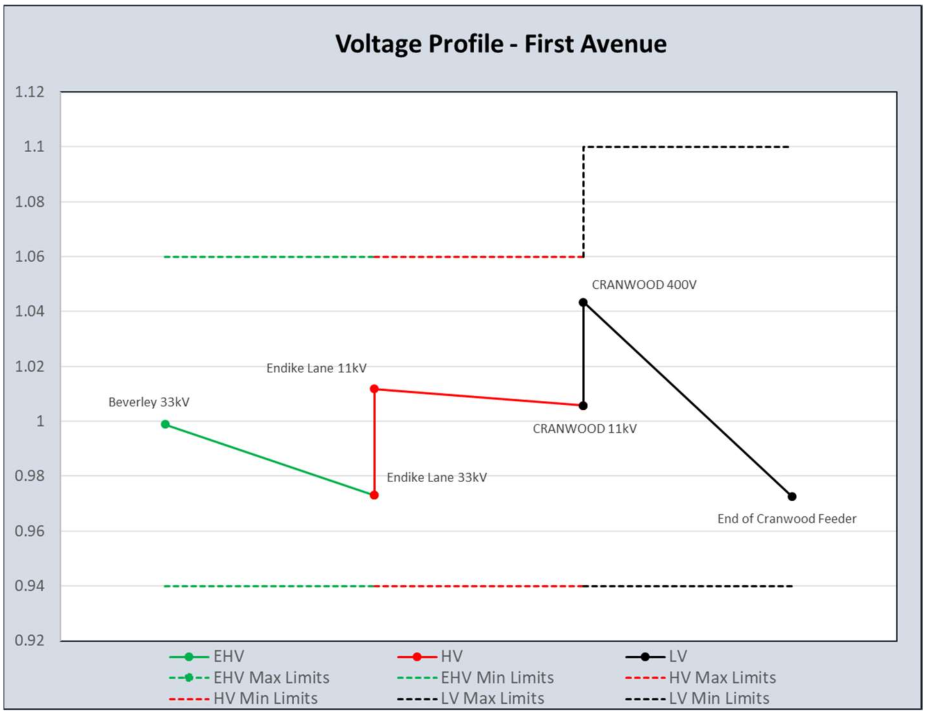


The voltage profile in Figure 40 indicates that the Oldstead North HV feeder is capable of picking up the loads along the Cranwood HV feeder in an outage scenario. The voltage drop observed when compared to the base case scenario is fairly minimal. As the Cranwood LV network is connected close to the First Avenue substation, there is little voltage drop when an outage is modelled on the Oldstead North HV feeder from Endike Lane and First Avenue picks up the Oldstead North feeder.

4.5.1.3 Scenario A2, HV N-1

A scenario was also explored where the loads in the network were increased by 220% under the same contingency conditions as Scenario A1 in order to observe any voltage violations at LV. However, even at such an extreme loading condition, the voltages remained within the statutory limits. The load flow calculations failed to converge when the network load was increased beyond 220%. This loading level is quite unrealistic as the thermal capacity of the network will be exceeded at a much lower loading.

Figure 41 Voltage profile for peak demand – Cranwood circuit outage at 2.2x loading

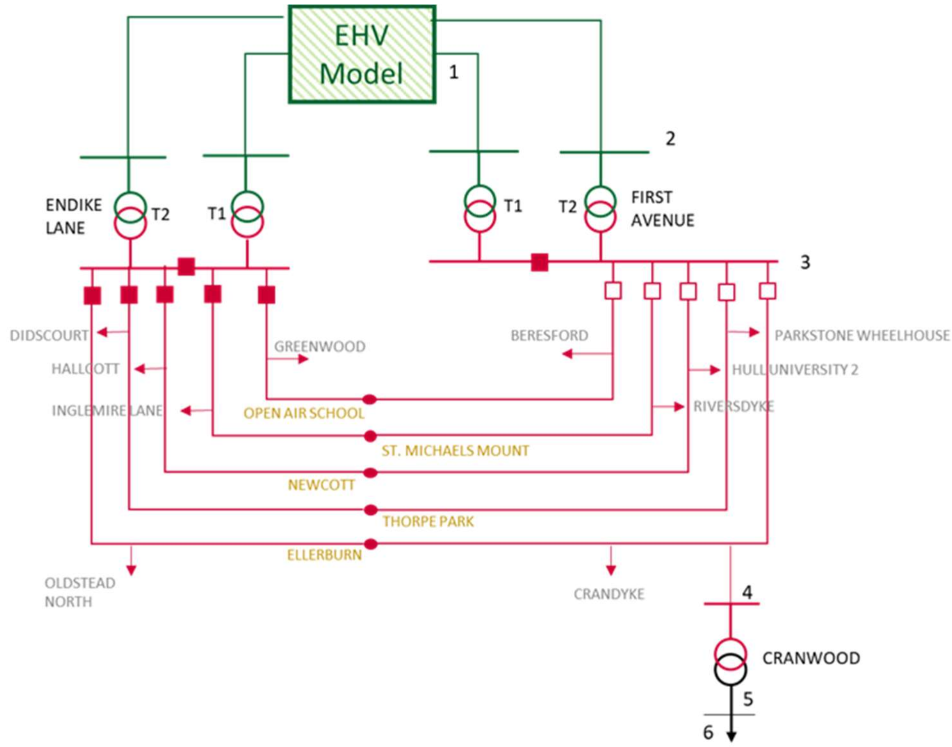


These results indicate that the Cranwood HV feeder can accommodate more secondary substations and customers with minimal impact on voltage however thermal impacts should also be assessed.

4.5.1.4 Scenario A3, HV N-1

Figure 42 illustrates the network topology where there is an outage on the First Avenue T2 11kV busbar and some of the First Avenue HV feeders on this busbar are backfed from Endike Lane primary substation.

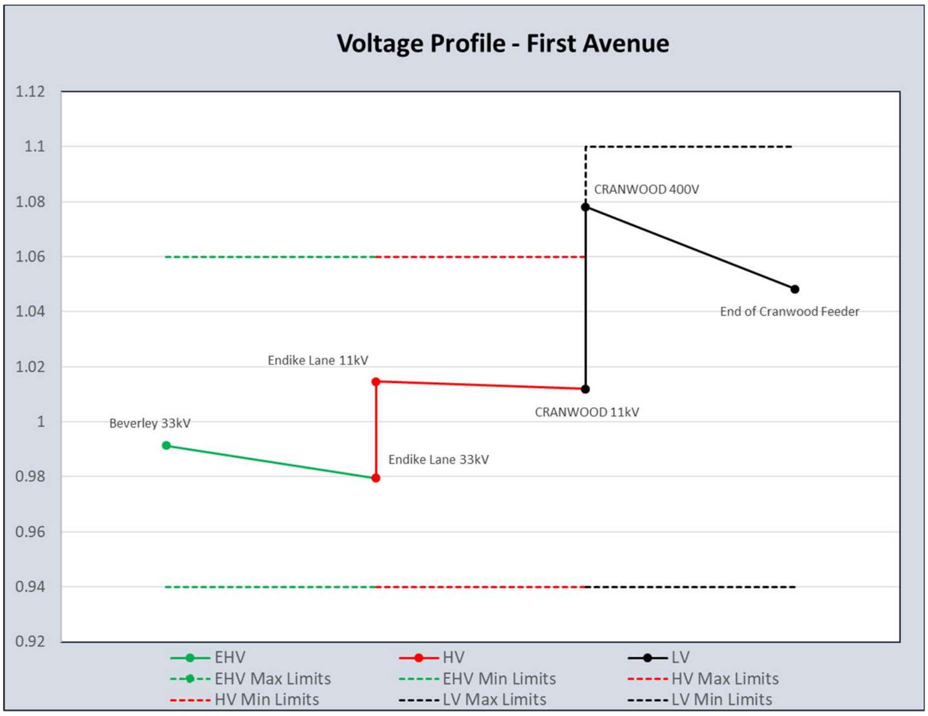
Figure 42 First Avenue network - First Avenue T2 Busbar outage



The following running arrangements have been considered for this scenario:

- Oldstead North feeder picks up the Cranwood feeder - Close Ellerburn switch at Crandyke
- Hallcott feeder picks up the Hull University 2 feeder – Close Newcott switch at New University
- Inglemire Lane feeder picks up the Riversdyke feeder – Close Auckland switch at St Michaels Mount
- Didscourt feeder picks up the Parkstone Wheelhouse feeder – Close Ilthorpe switch at Thorpe Park
- Greenwood feeder picks up the Beresford feeder – Close Open Air School switch at Campus North

Figure 43 Voltage profile for peak demand - First Avenue T2 Busbar outage



The voltage profile indicates that Endike Lane is capable of supplying all five interconnected First Avenue HV feeders during this contingency scenario. There is change in voltage drop from Scenario A1, HV N-1 where only one feeder was fed by Endike Lane and this scenario where five feeders are being fed by Endike Lane. Note that the tap setting has changed at Endike Lane to maintain the target voltage.

4.5.1.5 Scenario B1, EHV N-1

Figure 44 shows the network topology where there is an outage on the Beverley – First Avenue T2/ Endike Lane T2 circuit. The First Avenue and Endike Lane primary networks are both fed by their corresponding T1 transformers.

Figure 44 First Avenue network – Beverley – First Avenue T2/Endike Lane T2 circuit outage

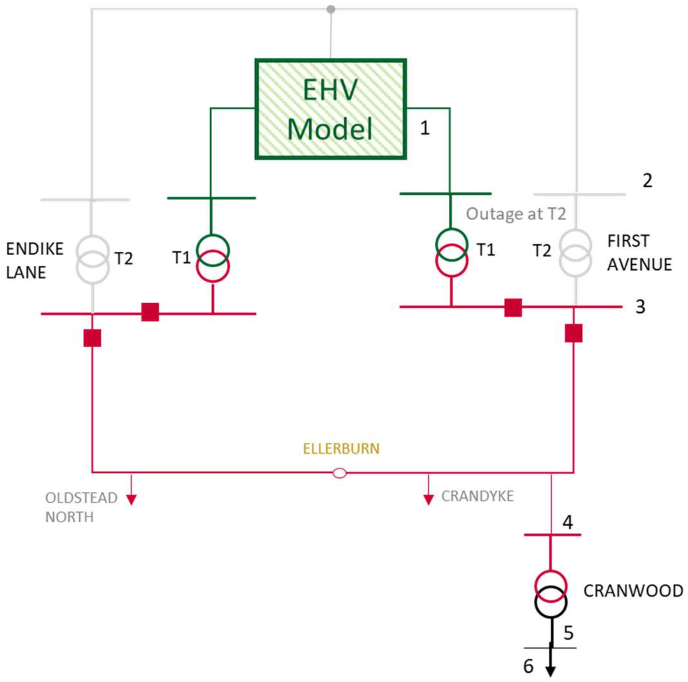
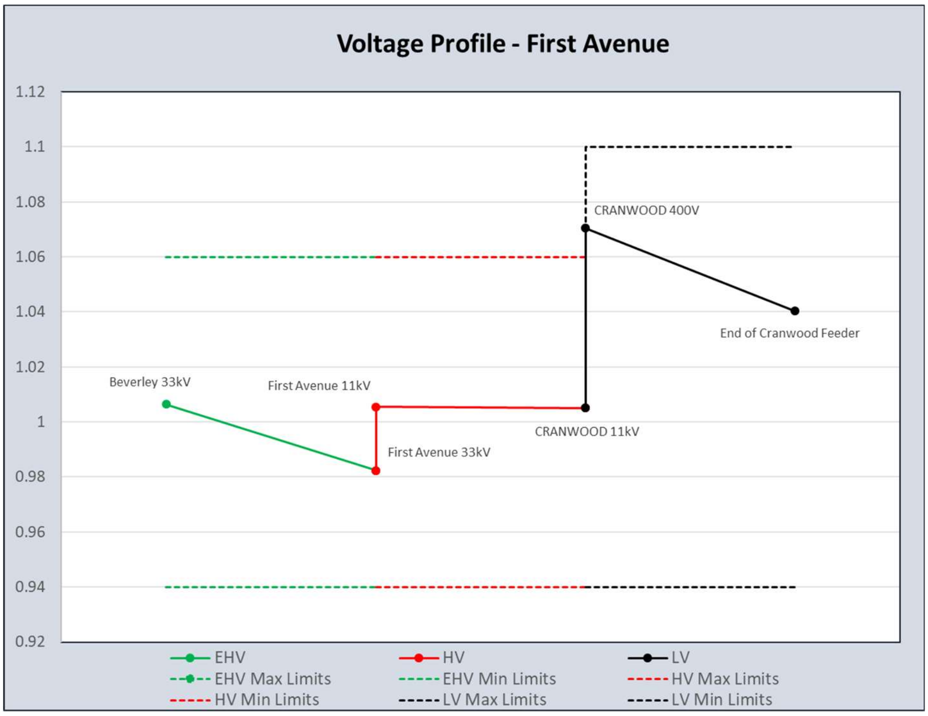


Figure 45 Voltage profile for peak demand - Beverley – First Avenue T2/Endike Lane T2 circuit outage



The voltage profile indicates that voltage remains well within limits under this contingency scenario. The tap settings at both Endike Lane and First Avenue primaries change slightly to maintain target voltage.

4.5.1.6 Scenario C1, New Demand at HV, HV N-1

Figure 46 indicates the network topology where a new HV demand is connected between Cranwood and Crandyke secondary substations and where there is an outage of Cranwood HV feeder between the First Avenue 11kV green busbar and the Cranwood secondary substation. A 2.5MVA demand was added in this case which only results in slightly reduced voltages. A 26MVA load was tested in order to trigger voltage issues in this network, shown in Figure 46, although we recognise that this is not a feasible demand connection at HV and would result in significant thermal issues. However, this provides an insight into how much of demand must be added to the First Avenue network in order to observe a voltage violation.

Figure 46 First Avenue Network - New demand at HV, Cranwood HV circuit outage

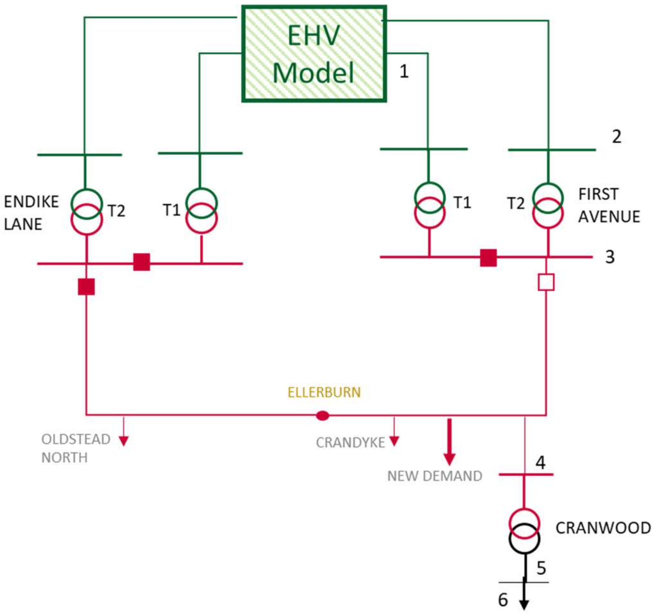


Figure 47 Voltage profile for peak demand – New 2.5MVA demand at HV, Cranwood HV circuit outage

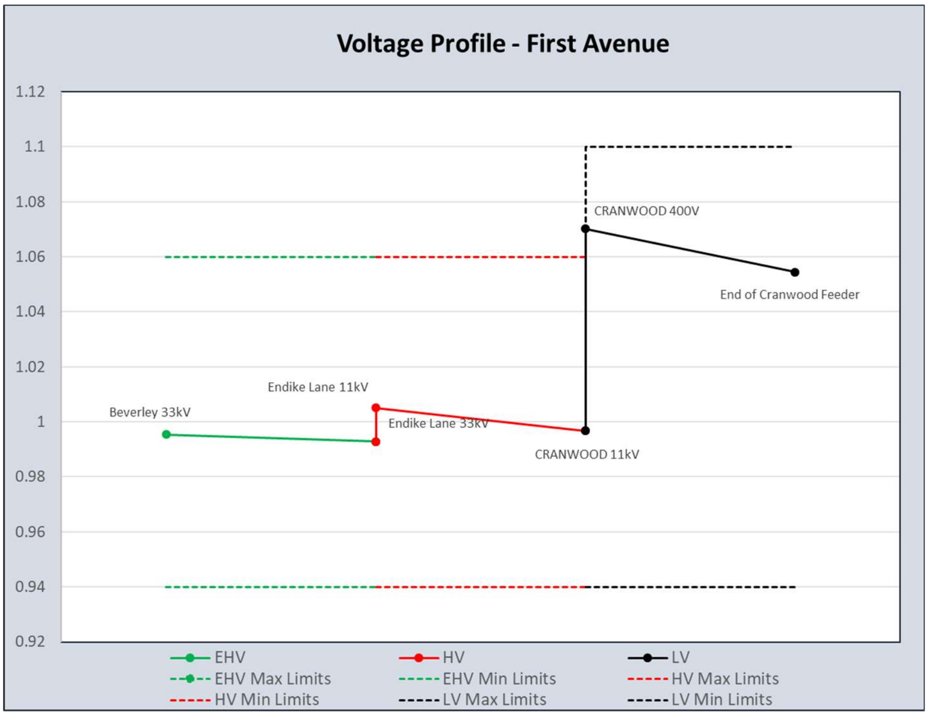
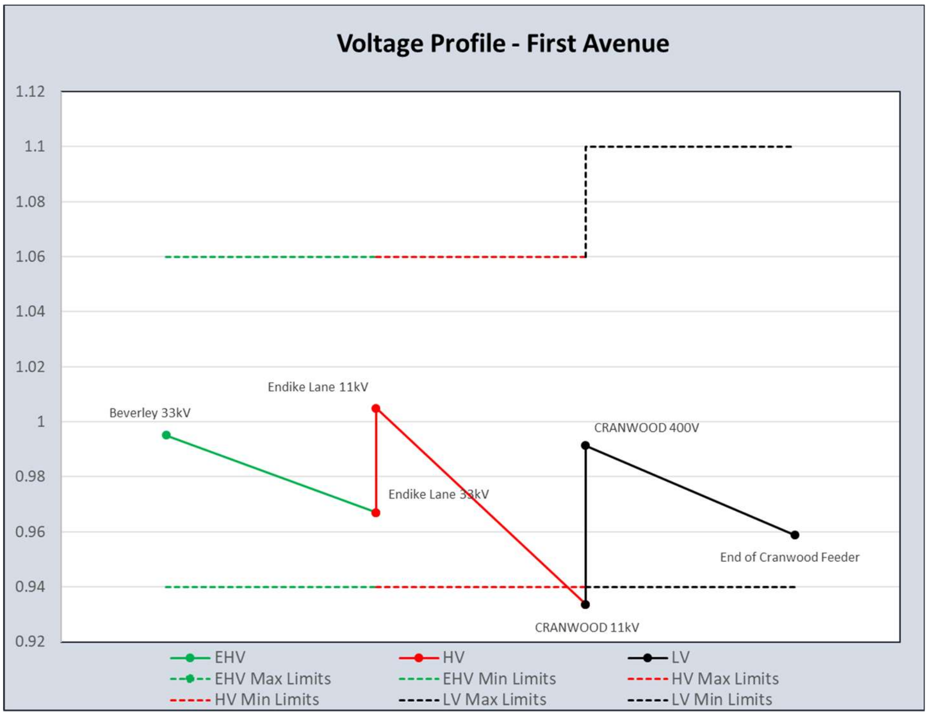


Figure 48 Voltage profile for peak demand – New 26MVA demand at HV, Cranwood HV circuit outage



The voltage profile indicates that the voltage on the HV feeder is outside statutory limits due to the addition of such a large load, however the voltage at LV is within limits.

4.5.2 Minimum Demand / Peak Generation

4.5.2.1 Base Case

The network topology for the minimum demand / peak generation base case can be observed in Figure 37 and is the same as the peak demand base case, in intact conditions. In the First Avenue network model, there is one embedded generator at HV – Croda Chemical Wind Turbine, on the Universal HV feeder (which is not shown as it's not connected to the HV circuits analysed in detail). At EHV, there are two wind farms, Routh and Sober Hill. These have been set to maximum export capacity in the minimum demand / peak generation scenarios.

Figure 49 Voltage profile for minimum demand / peak generation - base case

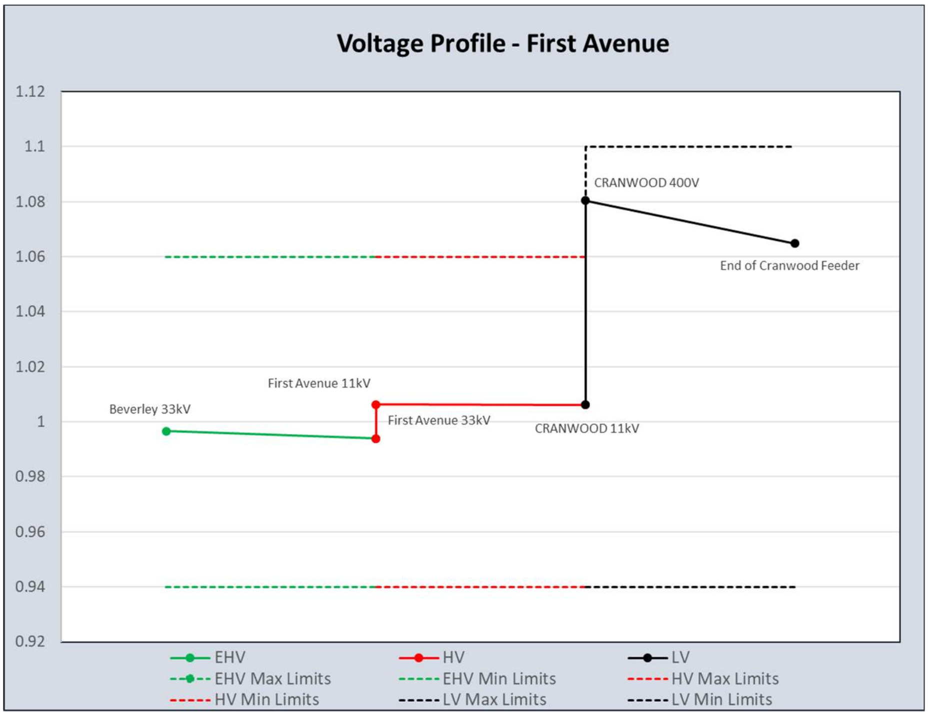
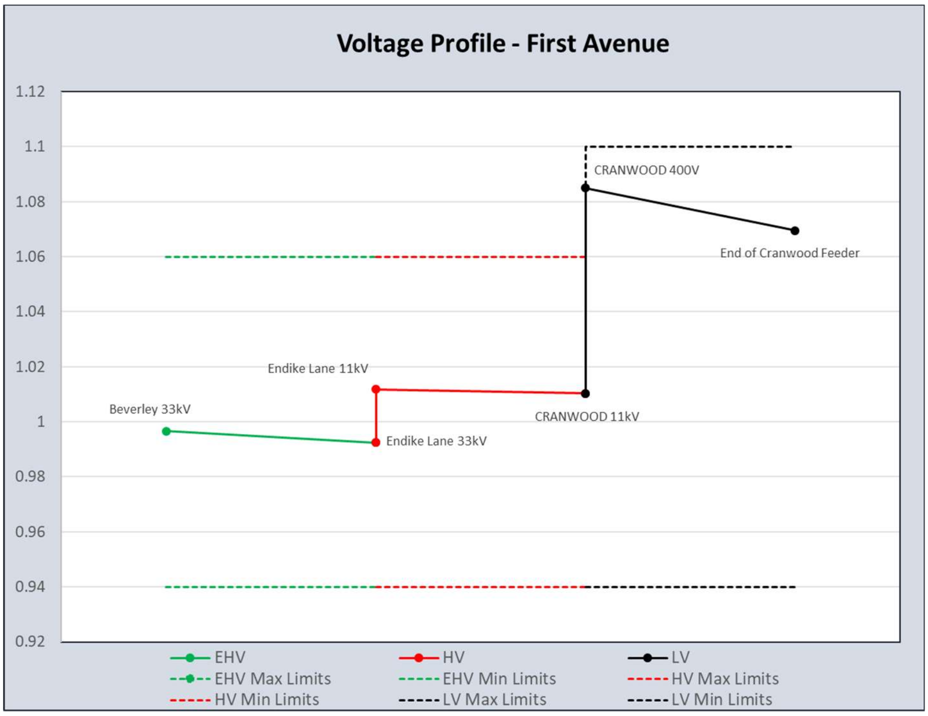


Figure 49 indicates that the voltage profile under light loading conditions is well within limits.

4.5.2.2 Scenario A4, HV N-1

The First Avenue network topology for Scenario A4 is the same as Scenario A1, HV N-1 under minimum demand / peak generation conditions. However, in this case the network is lightly loaded and there is no generation connected on the Cranwood HV feeder or the interconnecting Oldstead North HV feeder. The voltage profile of this scenario indicates that there are no voltage violations as can be seen in Figure 50.

Figure 50 Voltage profile for minimum demand / peak generation - Cranwood feeder circuit outage



4.5.2.3 Scenario B2, EHV N-1

In this scenario, shown in Figure 51, there is a circuit outage between Beverley and the tee point in First Avenue T1 / Norwood T1 / Routh Wind Farm circuit. The Routh wind farm, which is exporting at its maximum capacity, supplies the First Avenue T1 transformer. However, as per NPg's operating arrangements, the outage of the circuit would lead to the wind farm being switched off completely due to lack of an earth point on the 33kV network so this scenario is hypothetical. This will be discussed further in the solutions section.

Figure 51 First Avenue network – Beverley - First Avenue T1 / Norwood T1 Circuit Outage

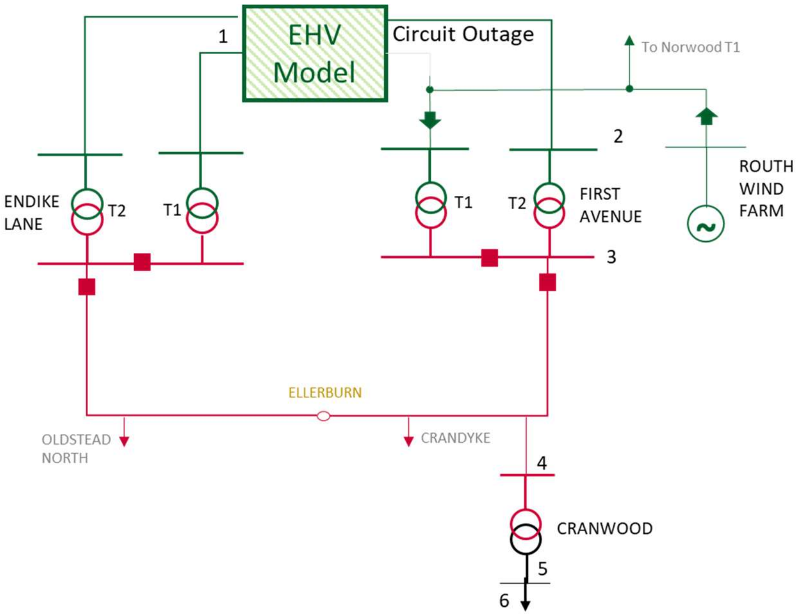
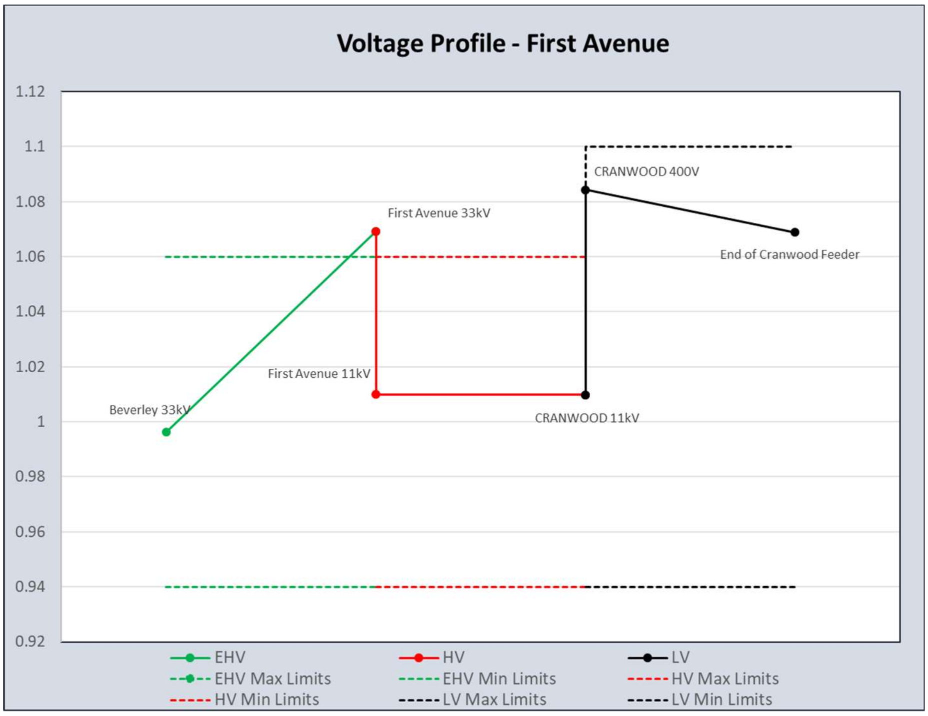


Figure 52 Voltage profile for minimum demand / peak generation - Beverley - First Avenue T1 / Norwood T1 Circuit Outage

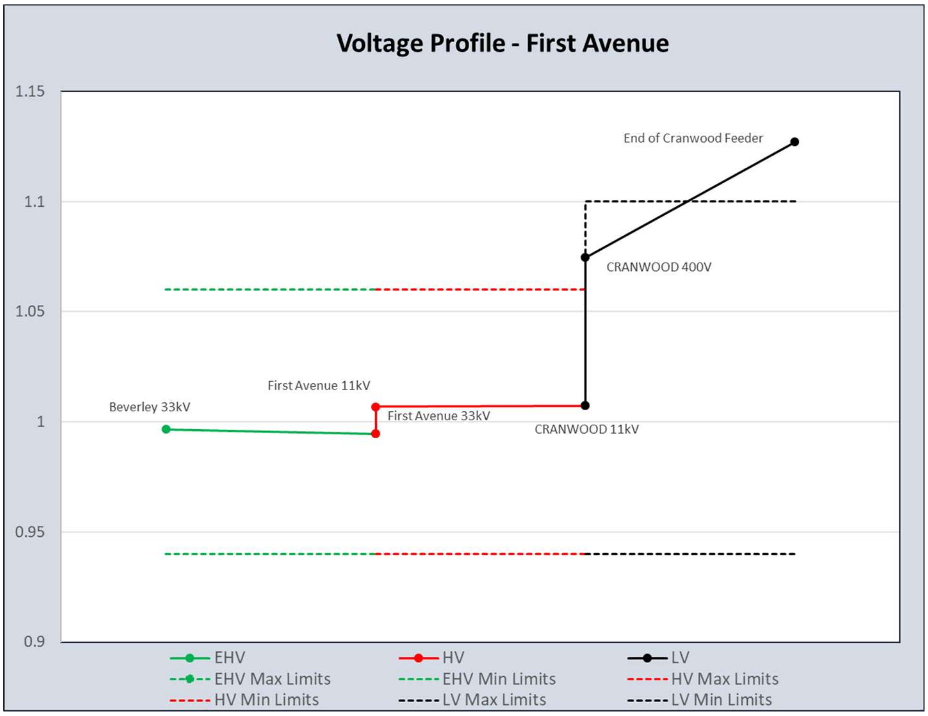


The voltage profile indicates that the outage results in over-voltages at the First Avenue 33kV busbar, where the voltage would rises up to 35.3kV if the Routh Windfarm is not disconnected. This would have no direct impact on any customers as there are no customers connected along this length of 33kV circuit or directly to this 33kV busbar and the transformers maintain the target 11kV voltage. However, it should be noted that 33kV equipment is rated up to 36kV.

4.5.2.4 Scenario D1, New PV at LV

Figure 37 illustrates the base network topology which is applied in this scenario. For Scenario D1, 50% of the customers connected to the Cranwood LV network are assumed to have a 4kW PV generator connected and generating at maximum capacity.

Figure 53 Voltage profile for minimum demand / peak generation – New PV at LV

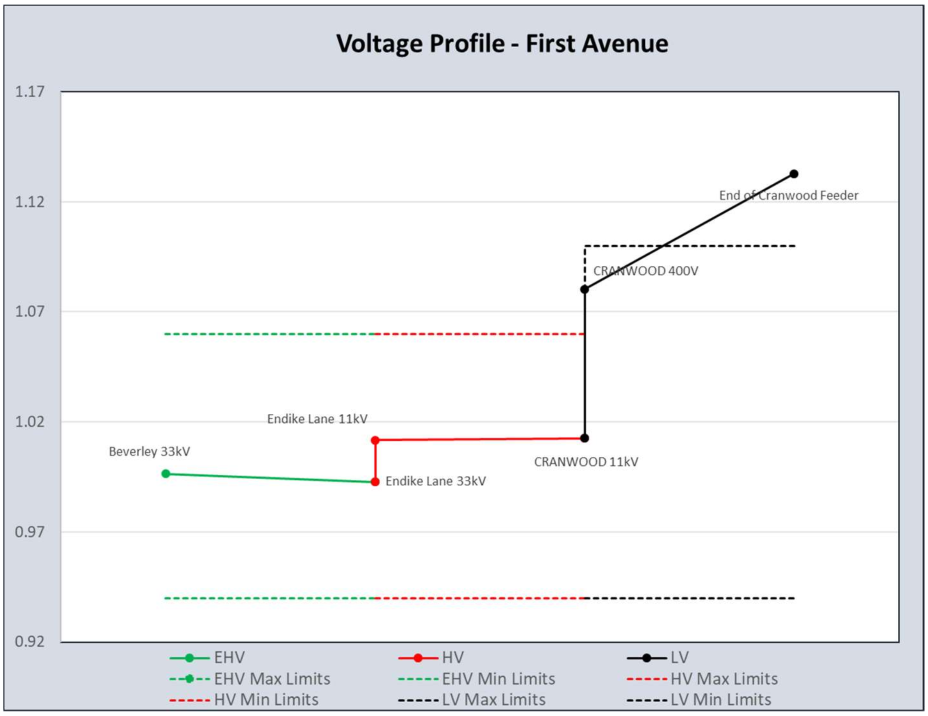


The voltage profile shows the rise in voltage along the Cranwood feeder due to the increase in generation under minimum load conditions, leading to voltages exceeding the limits.

4.5.2.5 Scenario D2, New PV at LV, HV N-1

This scenario combines Scenario A4 and Scenario D1 by adding domestic PV and an HV N-1 condition.**Error! Reference source not found.** Figure 39 illustrates the network topology used in this scenario while the voltage profile can be observed in Figure 54.

Figure 54 Voltage profile minimum demand / peak generation - New PV at LV, HV N-1



The voltage profile indicates that even though more demand is picked up by the HV feeder, slightly reducing the voltage on Cranwood HV busbar, there is still a considerable voltage rise in the Cranwood LV network due to the embedded generation (as per Scenario D1) leading to voltages exceeding the limits.

4.5.2.6 Scenario E1, New Generation at HV

Figure 55 illustrates the addition of a 2.5 MVA generation operating at 0.95 power factor connected at HV between Cranwood and Crandyke substations. We also explored how much generation can be connected to the HV network in order to exceed the voltage limits and it was possible to connect 28.5MVA with no voltage issues however this is a highly unrealistic scenario due to operational and thermal constraints.

Figure 55 First Avenue network –New Generation at HV

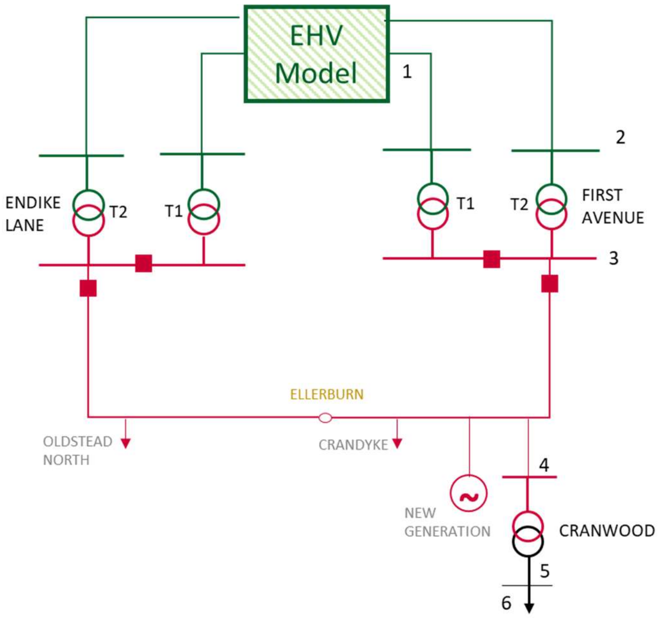
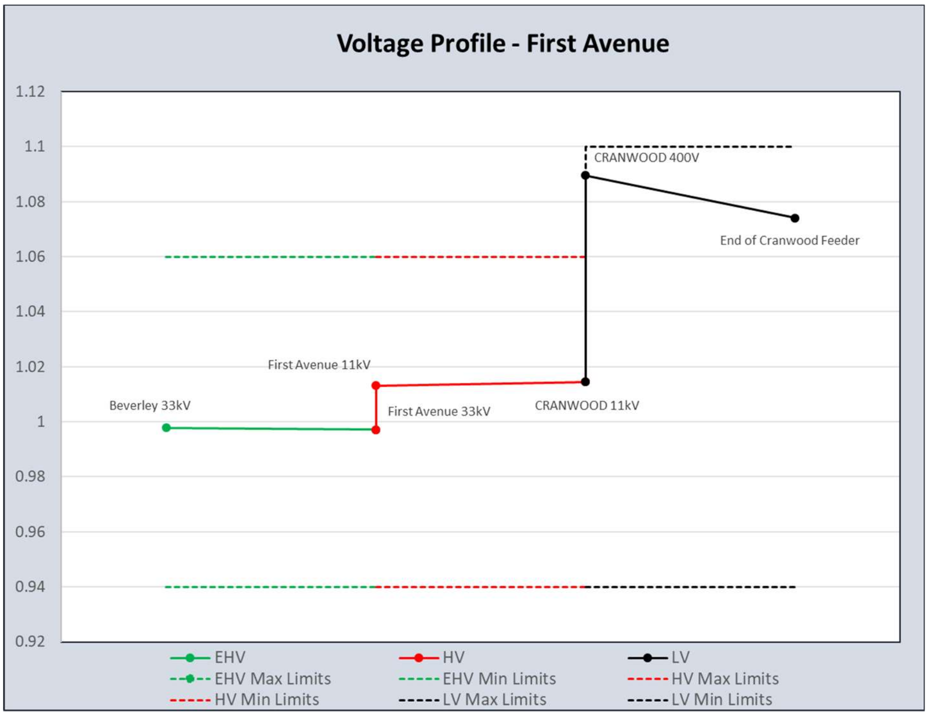


Figure 56 Voltage profile for minimum demand / peak generation - New 2.5MVA Generation at HV

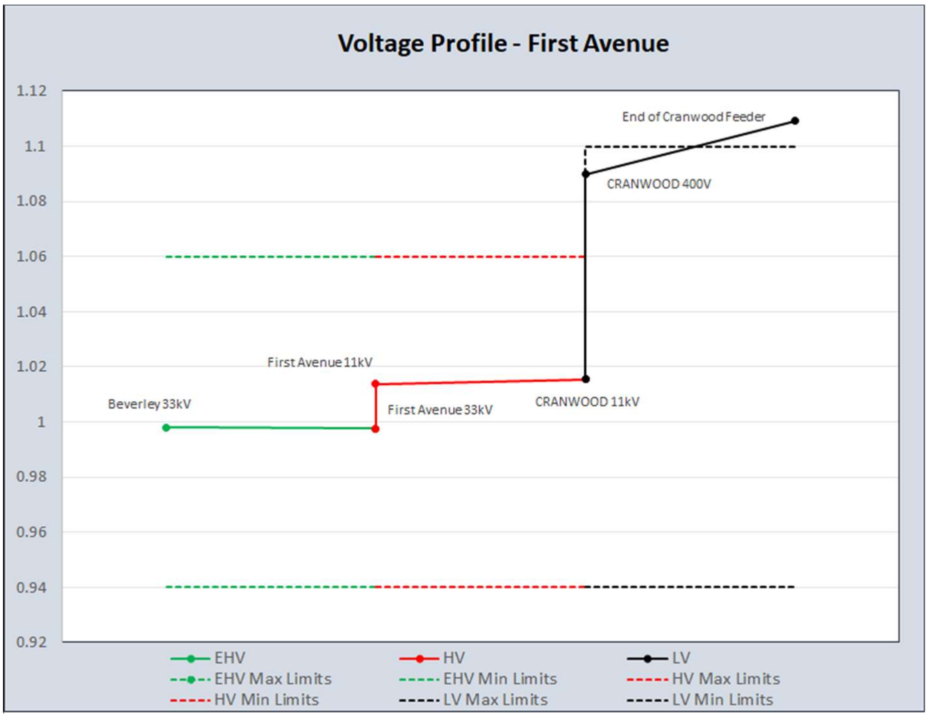


The voltage profile indicates that though there is generation connected to the HV network, it is still not enough to create any voltage violations in the network being studies. This indicates that the feeder has enough capability from a voltage rise perspective to connect a significant volume of generation.

4.5.2.7 Scenario E2, New PV at LV, New Generation at HV

In this scenario, using the same network topology as shown in Figure 55, new generation of 2.5MVA export capacity is connected to the HV network between Cranwood and Crandyke substations. At the same time, it is assumed that 25% of the LV customers fed by the Cranwood substation have 4kW of PV generation connected, a reduction from the 50% PV penetration assumed in Scenario D1 as 25% penetration still results in over-voltages in this scenario. Figure 57 shows the voltage profile indicating voltages in excess of the limits at LV with the addition of generation to the HV network and the increase in PV at LV.

Figure 57 Voltage profile for minimum demand / peak generation - New PV at LV, new generation at HV



4.5.3 Assessment of P10 Requirements

The requirements of Engineering Recommendation P10 were assessed using the MVL model for Beverley BSP. The results below indicate that it is possible for the supply voltage of the 33kV Beverley busbars to be 5% above the nominal voltage under peak load conditions at the BSP i.e. 130% of firm capacity. With only one transformer in service and peak loading, it is also possible to maintain the nominal voltage at the 33kV busbars. Beverley BSP has two transformers with a rating of 45MVA ONAN and 90 MVA ONAF.

Table 16 Assessment of ER P10 for Leeming Bar BSP

	% Firm Capacity	BSP 33kV busbar % V above nominal	BSP Tap Position %	GSP 132kV busbar V (pu)
Beverley T1	131%	12%	-20%	0.94
Beverley T2	132%	12%	-20%	0.94
Beverley T1	132%	5%	-15%	0.94
Beverley T2	132%	5%	-15%	0.94
Beverley T1	131%	7%	-20%	0.90
Beverley T2	132%	7%	-20%	0.90
Beverley T2 (N-1)	133%	4%	-20%	0.94

4.5.4 Observations

Based on our analysis of holistic voltage behaviour for the First Avenue multi-voltage level network under a range of scenarios, we can make the following observations in relation to First Avenue as well as the modelling of voltage using this approach:

- The First Avenue network complies with NPg HV and LV design principles as-is under credible operational regimes and loading conditions.
- Overall, the First Avenue urban network is a strong network with plenty of voltage legroom and headroom, although this is depleted with increasing demand from low carbon technology and increasing embedded generation.
- The Cranwood LV transformer tap setting is 0%, balancing voltage legroom and headroom. This could be changed to +2.5%, lowering the target voltage, to provide more voltage headroom for connection of generation at HV and LV and/or managed through techniques to lower HV voltage.
- The First Avenue and Endike Lane primary substation transformer tapping range seems to be able to cope with a range of expected demand and generation conditions however they generally operate between tap 9 and 13 for the scenarios analysed, indicating that the tap range may not be optimal for the future range of loading conditions.
- Routh Windfarm is tripped off when the Beverley-First Avenue T1 /Norwood T1 circuit has an outage (B2). This is to avoid operation of an unearthed system as the earth would be provided by the LV windings of the 132/33kV transformer. Understanding voltage profile better and implementing some demand and/or voltage management techniques (e.g. interconnection) could enable a reduction in curtailment under outage conditions although the lack of a system earth would still need to be addressed.

5 Testing of Voltage Management Solutions

A number of voltage solutions have been tested on the Thirsk and First Avenue multi-voltage networks to assess the improvement to the voltage profile under the range of scenarios described previously and from this set of results, voltage policy recommendations can be made. This includes a strategic assessment of existing transformer specifications, focussing on primary transformers.

5.1 Voltage Solution Prioritisation

Based on the voltage control solutions presented in Table 9, a list of prioritised solutions was developed as shown in Table 17 for addressing LV and HV voltage issues. This was based on which solutions would currently be technically least challenging to implement, and low cost to implement in an NPg context.

Table 17 Prioritisation of voltage management solutions at LV and HV

Solution Priority	Solution for Voltage Issues at LV	Solution Considerations
1	Change tap position on HV/LV transformer	Adverse implications for customers whilst making the change.
2	Change of HV target voltage at EHV/HV primary substation	

Solution Priority	Solution for Voltage Issues at LV	Solution Considerations
3	Deploy Load Drop Compensation at EHV/HV substation	
4	Introducing OLTC on HV/LV transformers	OLTCs on HV/LV transformers are an expensive solution which must be justified.
5	Interconnection with adjacent networks at LV	Interconnection needs to be available (i.e. if there is a means for implementing load shifting) and load pattern is suitably different for load shifting. Remote operation of LV equipment and the associated comms required.
	Solutions for Voltage issues at HV	
1	Change of HV target voltage at EHV/HV substation	
2	Deploy Load Drop Compensation at EHV/HV substation	Requires a reasonable degree of similarity between the loading on each HV circuit.
3	Inline HV voltage regulator	
4	Change generator voltage / reactive power control characteristics	
5	Interconnection with adjacent network at HV	Interconnection needs to be available and load pattern is suitably different for load shifting
6	Changing the tap range on transformers at EHV/HV primary substation	Would require a new transformer

Voltage management solutions to address specific identified issues can be applied individually or in combination with other solutions, however where voltage issues have already occurred, or may materialise in the future, implementation of a more holistic solution may be more appropriate.

1) A solution to a specific problem using a voltage management technique (e.g. installing an HV voltage regulator or changing a specific AVC target voltage);
2) A solution to a specific problem which incorporates a combination of voltage management techniques; or
3) As a strategic approach that changes the voltage management system design philosophy (see IMP/001/915) e.g. changing a transformer plant specification such as the tapping range or step size or changing the way voltage drops are allocated at each 132kV/EHV/HV/LV voltage level.

Currently designers tend to work within a silo at each voltage level and a more holistic approach to voltage management across the voltage levels could bring improvements.

5.2 Solutions - Thirsk

The following voltage solutions have been modelled on the Thirsk network.

Table 18 Voltage management solutions modelled on the Thirsk network

Scenarios – Peak Demand		Contingency Description (take worst-case for each scenario)	Solution	Thirsk/ Bedale EHV/HV (pu)	HV Substation Max V along the Feeder (pu)	Sinderby HV/LV (pu)	Sinderby LV feeder Min (pu)	Primary Tap Position Tap Settings: 1 (-18.7) to 14(-0.04) at 1.435% - Thirsk 1 (-13.91) to 16(5.22) at 1.33% - Bedale
A3	HV N-1	Outage of Carlton Miniott HV feeder at Thirsk Primary Substation (Bedale Station HV feeder picks up Carlton Miniott HV feeder)	None	0.987 / 1.006 (Bedale T2)	0.887 (Carlton Miniott)	0.893/0.930	0.918	9 (-3.71) Bedale
A3.S1			Voltage change at Bedale primary EHV/HV from 11.1kV to 11.3kV	0.986 / 1.031 (Bedale T2)	0.916 (Carlton Miniott)	0.922/0.960	0.948	7 (-6.26) Bedale
A3.S2			Tap setting on Sinderby HV/LV transformer changed from -2.5% to -5%	0.987 / 1.006 (Bedale T2)	0.887 (Carlton Miniott)	0.893/0.957	0.944	9 (-3.71) Bedale

A3.S3			Combination of solutions S1 & S2	0.986 / 1.031 (Bedale T2)	0.911 (Carlton Miniott)	0.917/0.979	0.968	10 (-5.779) Bedale
B1	EHV N-1	Outage of 33kV circuit Leeming Bar-Thirsk-Leeming RAF	None	0.858 / 1.011 (Thirsk T2)	0.995 (Sinderby Sike SW)	0.995/1.038	1.028	4 (-14.389) Thirsk
B1.S1			Voltage change at Leeming Bar EHV/EHV from 32.7kV to 34kV	0.905 / 1.016 (Thirsk T2)	0.999 (Sinderby Sike SW)	0.999/1.043	1.033	7 (-10.084) Thirsk
C1	New demand at HV	Addition of a 0.4 MVA demand near Sinderby in the Scenario A1 network.	None	0.953 / 1.005 (Thirsk T2)	0.872 (Bedale Station)	0.935/0.974	0.962	9 (-7.215) Thirsk
C1.S1		HV Voltage Regulator Settings – -10% to +10% with step size of 0.625% with current tap at -5%	HV Voltage Regulator – located along Carlton Miniott HV feeder	0.956 / 1.009 (Thirsk T2)	0.928 (Bedale Station)	0.986/1.029	1.018	9 (-7.215) Thirsk
C1.S2			Voltage change at EHV/HV from 11.1kV to 11.3kV	0.956 / 1.027 (Thirsk T2)	0.893 (Bedale Station)	0.954/0.994	0.983	8 (-8.649) Thirsk

Scenarios – Min Demand		Contingency Description (take worst-case for each scenario)	Solution	Thirsk/ Bedale EHV/HV (pu)	HV Substation Max V along the Feeder (pu)	Sinderby HV/LV (pu)	Sinderby LV feeder Max (pu)	Primary Tap Position Tap Settings: 1 (-18.7) to 14(-0.04) at 1.435% - Thirsk 1 (-13.91) to 16(5.22) at 1.33% - Bedale
A5	HV N-1	Outage of Bedale Station HV feeder (Carlton Miniott HV feeder picks up Bedale Station HV feeder))	None	0.964 / 1.009 (Thirsk T2)	1.012 (Leeming Biogas SW)	0.984 / 1.026	1.026	11 (-4.344)
A5.S1			Voltage change at EHV/HV from 11.1kV to 10.9kV	0.964 / 0.992 (Thirsk T2)	0.995 (Leeming Biogas SW)	0.967 / 1.008	1.008	10 (-5.779)
D1	New PV at LV	50% of Sinderby loads are assumed to have connected 4kW PV with Leeming Biogas SW exporting 1.5MW generation	None	0.989 / 1.014 (Thirsk T2)	1.013 (Carlton Miniott)	1.009 / 1.066	1.075	12 (-2.909)
D1.S1			Tap setting on Sinderby HV/LV transformer changed from -2.5% to 0%	0.989 / 1.014 (Thirsk T2)	1.013 (Carlton Miniott)	1.009 / 1.041	1.0050	12 (-2.909)

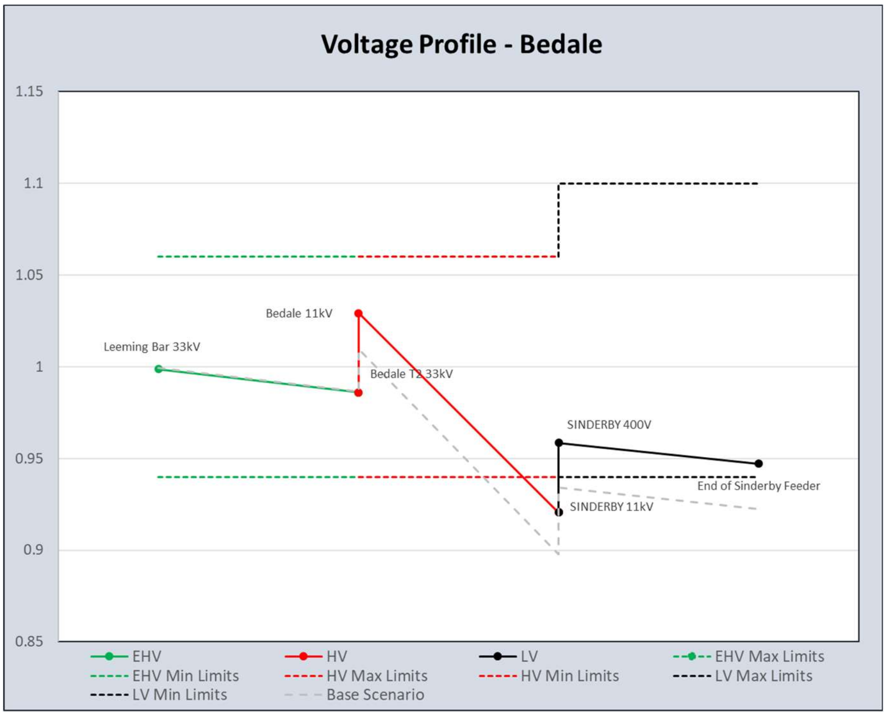
E1	New generation at HV	A new generation of 2.5MVA with a PF of 0.95 is introduced at Sinderby Manor SW with Leeming Biogas SW exporting 1.5MW generation	None	0.996 / 1.011 (Thirsk T2)	1.053 (Sinderby Manor SW)	1.051 / 1.103	1.103	13 (-1.475)
E1.S1			Voltage change at EHV/HV from 11.1kV to 11kV	0.996 / 0.996 (Thirsk T2)	1.039 (Sinderby Manor SW)	1.036 / 1.087	1.087	14 (-0.04) Tap Limit Reached
E1.S2			Change the PF of new generation from 0.95 to 0.99 i.e. exporting less reactive power	0.994 / 1.007 (Thirsk T2)	1.048 (Sinderby Manor SW)	1.045 / 1.098	1.098	13 (-1.475)
E2	New PV at LV & New HV generation	The scenarios D1 & E1 are combined in this particular case.	None	0.995 / 1.011 (Thirsk T2)	1.056 (Sinderby Manor SW)	1.053 / 1.113	1.121	13 (-1.475)
E2.S1			Tap setting on Sinderby HV/LV transformer changed from -2.5% to 0%	0.995 / 1.011 (Thirsk T2)	1.056 (Sinderby Manor SW)	1.041 / 1.075	1.084	13 (-1.475)

5.2.1 Peak Demand

5.2.1.1 Solution A3.S1, Voltage change at EHV/HV

Scenario A3, HV N-1 is a contingency scenario where there is a circuit outage at the Carlton Miniott HV feeder at Thirsk which is now fed from Bedale via the Bedale Station HV feeder. The plot for this scenario is indicated in Figure 58 as a 'grey dotted line'. In this solution, the voltage at the Bedale primary substation is increased to 11.3kV from 11.1kV. This could be implemented as a target voltage change, either as a permanent change or in conjunction with Load Drop Compensation. However, for implementation in conjunction with LDC, there would be a need to ensure that there were no adverse implications for other feeders.

Figure 58 Voltage profile for solution A3.S1

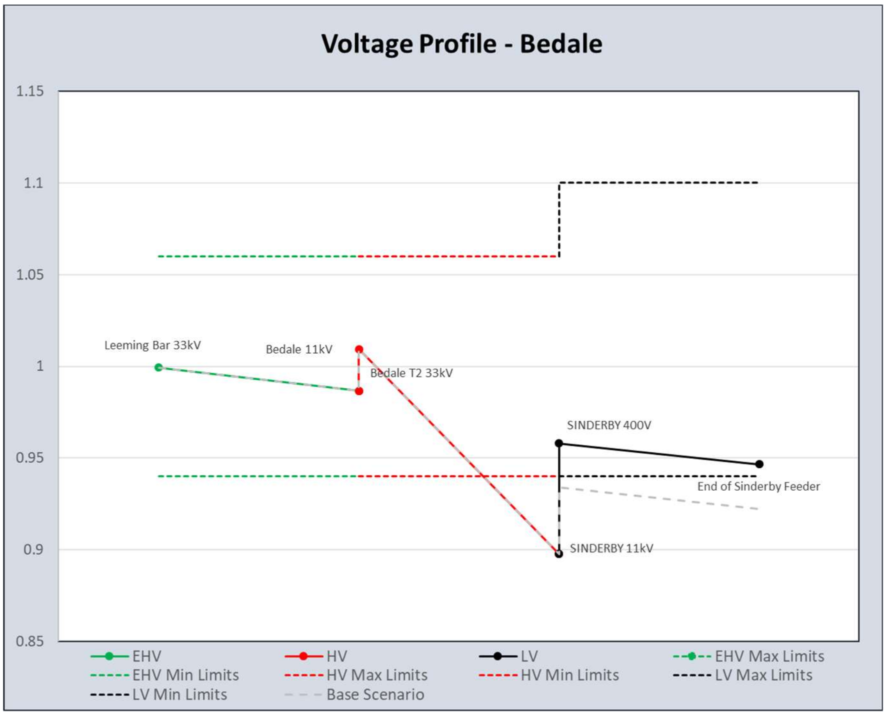


Changing the voltage at the primary improves the voltage profile and mitigates the under-voltage at Sinderby. However, there is still a voltage violation along the HV feeder which may result in under-voltages at LV, for secondary substations located further along the HV feeder. The existing policy suggests that the voltage on the 11kV busbar side of the primary should not be increased beyond 11.3kV, without further investigation, to avoid over voltages during low demand and high generation conditions.

5.2.1.2 Solution A3.S2, Voltage change at HV/LV

In this solution, the taps are changed at the Sinderby HV/LV transformer from the initial setting of -2.5% to -5%. This could be implemented through a manual change or through the replacement of the existing transformer with an OLTC transformer.

Figure 59 Voltage profile for solution A3.S2



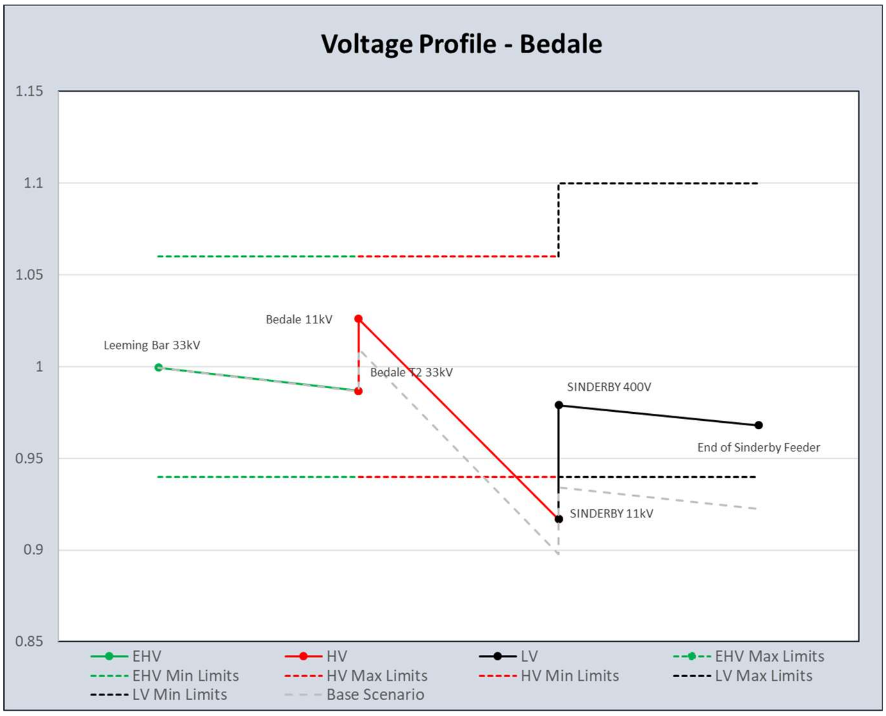
On changing the taps of the HV/LV transformer, the under-voltages on the Sinderby LV network are resolved. However, there are other secondary substations further along the interconnected HV feeder where LV voltages may be outside the limits due to the HV voltage drop, which is not addressed by this localised solution. In practice, there could be other HV/LV transformers to tap as well and it would be important to ensure that this would not result in over voltages during times of low demand and high generation conditions.

If there is increasing embedded generation connected at LV, and variable operation of the demand and generation, an engineer may need to return to site on a seasonal basis to reset taps manually which is not practical as a BAU solution due to the significant volumes of secondary substations that might need to be tapped and the need to interrupt customer supplies to change the tap position. Whilst this would not be the case with an OLTC HV/LV transformer, capital costs to replace the transformer would be incurred.

5.2.1.3 Solution A3.S3, Combination of A2.S1 & A2.S2

In this solution, Solution A3.S1 & Solution A3.S2 are combined, the resulting voltage profile can be observed in Figure 60.

Figure 60 Voltage profile for solution A3.S3

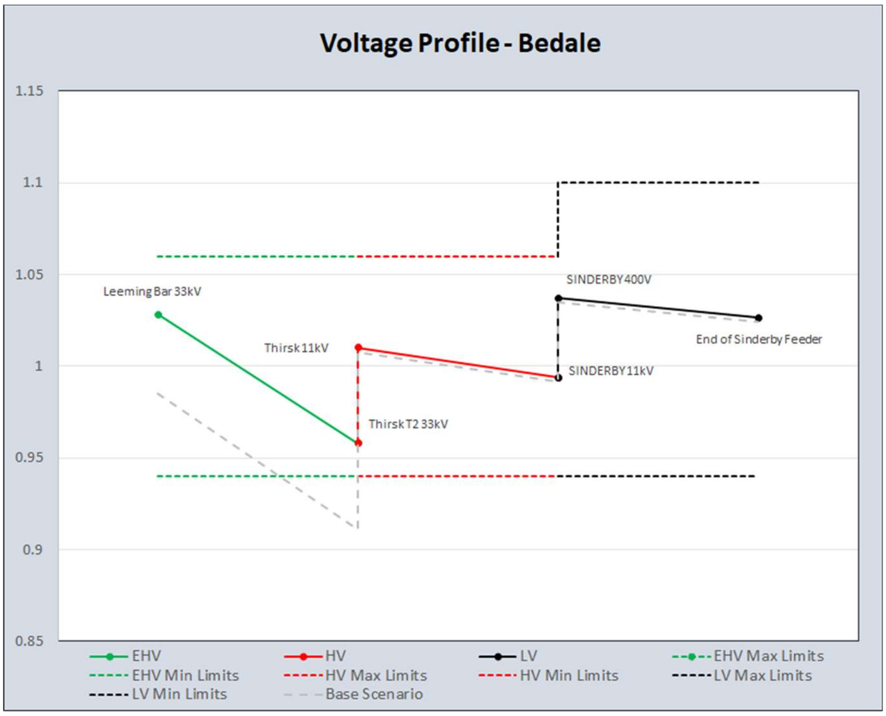


The combined solution provides increased voltage legroom for the Sinderby LV network. However, the voltage issues on the HV Feeder remains unresolved. This could potentially be resolved by increasing the secondary voltage at Bedale primary further although this wouldn't align with NPg voltage policy which advises that the voltage should not exceed to 11.3kV, without further assessment. Alternative interconnections were tested however, long rural circuit lengths resulted in similarly limiting voltage drops. A bi-directional HV in-line voltage regulator could potentially be deployed along the interconnected HV feeder, this is explored later.

5.2.1.4 Solution B1.S1, Voltage Change at EHV/EHV

Scenario B1, EHV N-1 is a contingency scenario where there is a 33kV circuit outage on the Leeming Bar-Thirsk-Leeming RAF circuit. The plot for this scenario is indicated in the Figure 61 as 'grey dotted line'. In this solution B1.S1, the target voltage at Leeming Bar is increased from 32.7kV to 34kV.

Figure 61 Voltage Profile for Solution B1.S1



It can be observed that the voltage violations at the EHV voltage level are resolved without affecting the HV or the LV voltage levels. Changes to the voltage at EHV have limited effect on the HV or LV networks if the primary transformer is within its tap range. This could provide a solution in the event that there was a 33kV customer connecting at Thirsk.

5.2.1.5 Solution C1.S1, HV Voltage Regulator

Scenario C1, New Demand at HV, HV N-1 is a contingency scenario where a new 0.4MVA demand is connected along the feeder close to where Sinderby secondary substation is located and the Carlton Miniott HV feeder is picking up the Bedale Station HV feeder due to an outage between Bedale primary and Bedale Station substation. The plot for this scenario is shown in Figure 62. In this solution C1.S1, an HV voltage regulator is introduced near the Holme Switching Station on the Carlton Miniott feeder with tap settings of -10% to 10% at a step size of 0.625%, with the tap fixed at -5%.

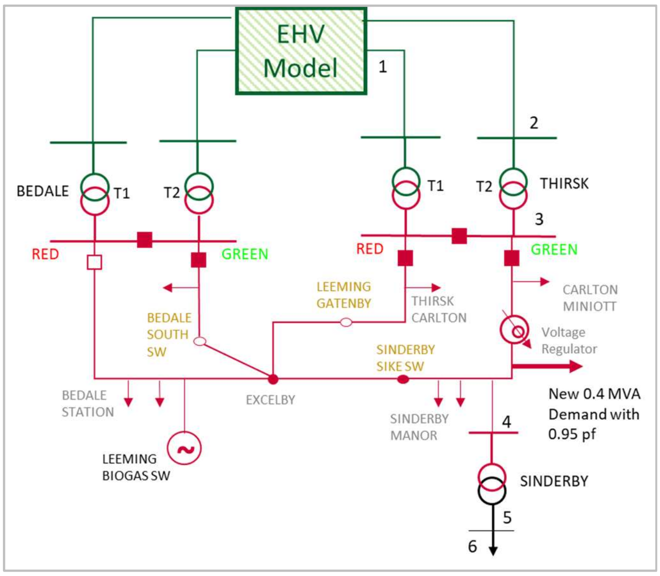
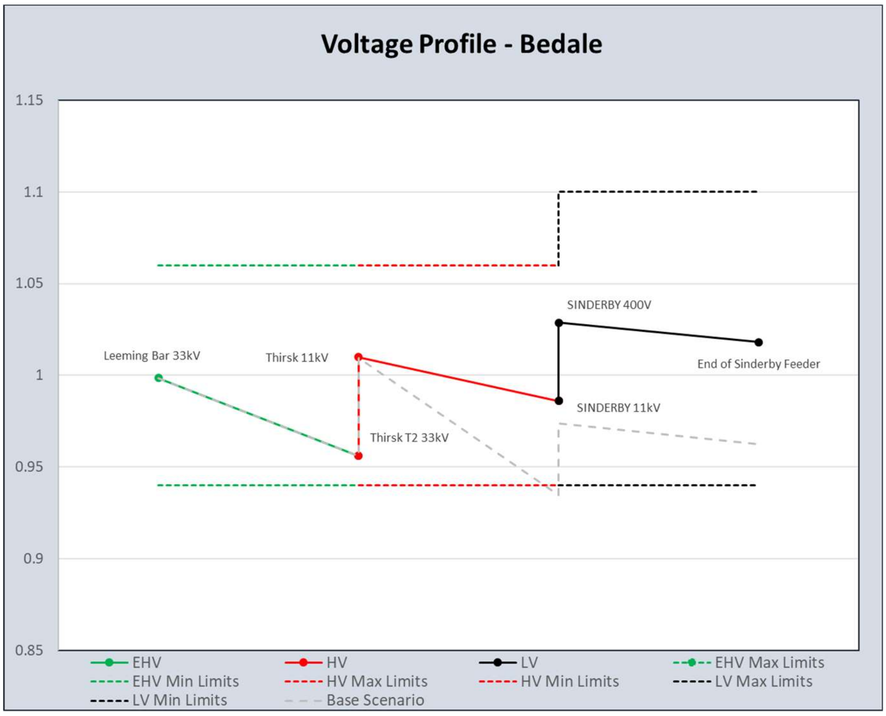


Figure 62 Voltage profile for Solution C1.S1

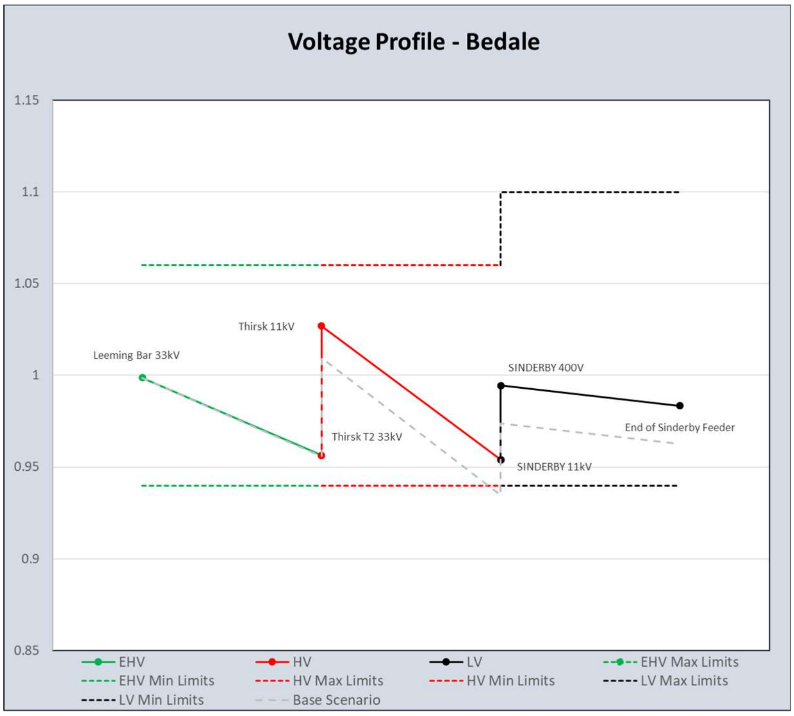


The introduction of an in-line voltage regulator along the HV feeder considerably improves the voltage profile. This could also be utilised for the previous 'A' scenarios to improve the voltage profile if limits were exceeded at LV. Although regulators are relatively expensive, they may address issues on all the LV feeders supplied from a HV feeder.

5.2.1.6 Solution C1.S2, Voltage Change at EHV/HV

The plot for this scenario is shown in the Figure 63 . In this solution, the 11kV target voltage of the Thirsk transformers is increased from 11.1kV to 11.3kV. This could be implemented as a target voltage change, either as a permanent change or in conjunction with Load Drop Compensation. However, for implementation in conjunction with LDC, there would be a need to ensure that there were no adverse implications for other feeders.

Figure 63 Voltage profile for Solution C1.S2



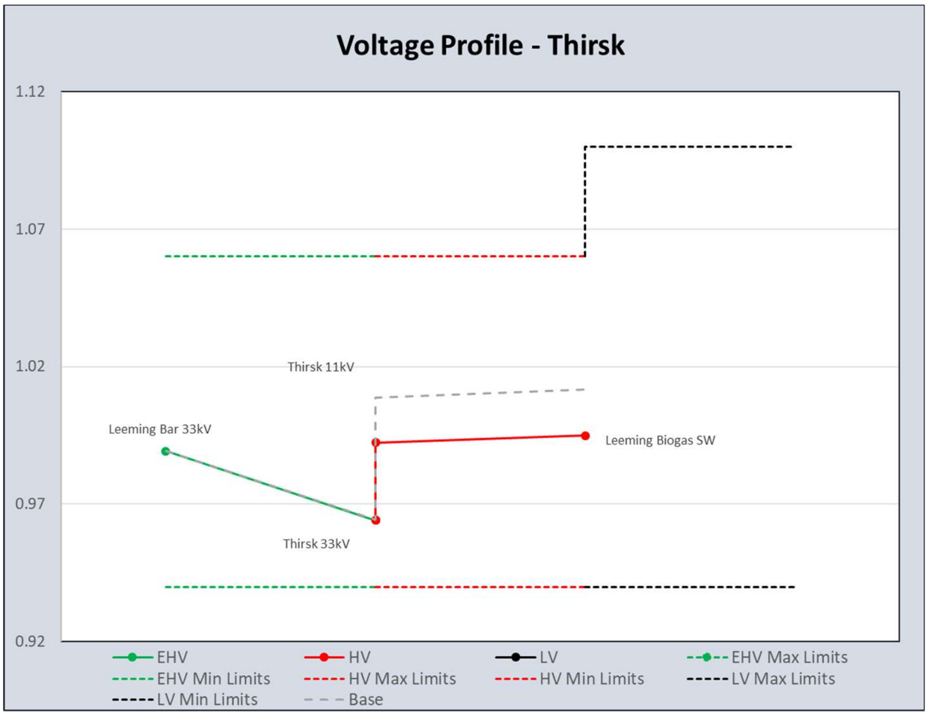
The change in target voltage at the primary substation resolves the voltage violations along the HV feeder and improves the voltage legroom along the LV feeder, subject to there being no high voltage concerns on the other feeders.

5.2.2 Minimum Demand / Peak Generation

5.2.2.1 Solution A5.S1, Voltage Change at EHV/HV

Scenario A5, HV N-1 is a contingency scenario where there is a circuit outage between the Bedale Station HV feeder and Bedale primary substation so the Bedale Station feeder is now supplied from Thirsk primary via the Carlton Miniott HV feeder. Leeming Biogas generator is exporting 1.5MW. In this solution A5.S1, the secondary voltage at the Thirsk Primary is decreased from 11.1kV to 10.9kV. This could be implemented to avoid potential over-voltages on the LV network if material embedded PV generation is connected (although the LV networks in the vicinity of Leeming Biogas SW are not modelled here and hence are not shown in Figure 64). This could be through a target voltage change alone or in conjunction with LDC if this creates issues in high demand scenarios.

Figure 64 Voltage profile for Solution A5.S1

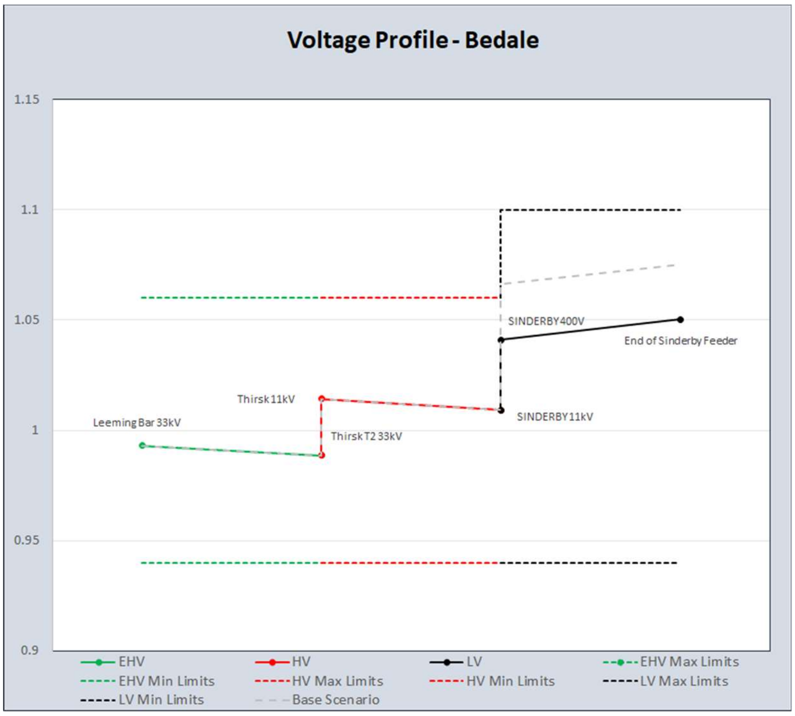


In Solution A3.S2 it was observed how the increase in voltage affects the network during a peak demand scenario. In this solution A5.S1, the voltage is reduced during a minimum demand, maximum generation scenario. Though, there were no existing voltage violations at HV, this solution can be considered when multiple generators or PVs are installed the network at HV or LV.

5.2.2.2 Solution D1.S1, Tap Change at HV/LV

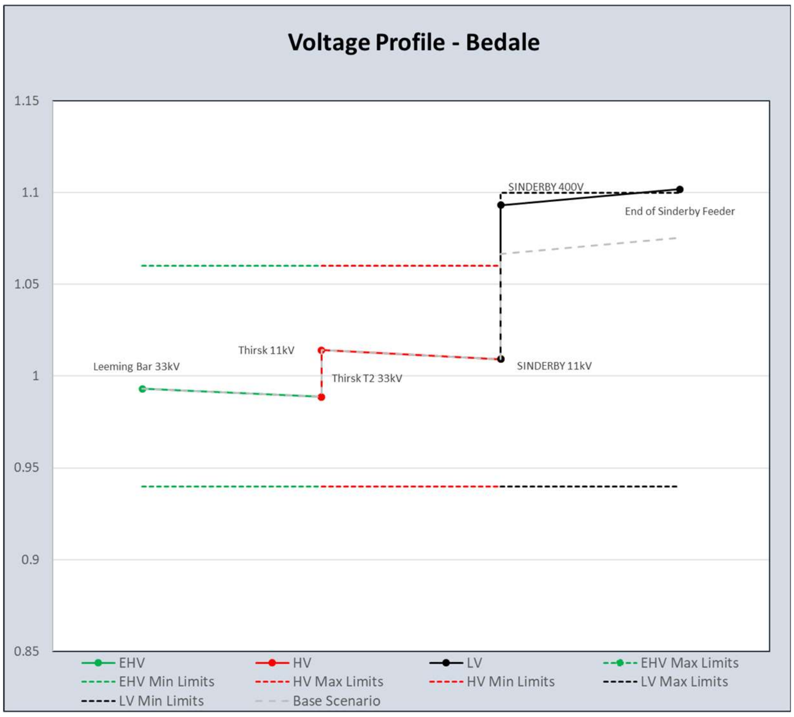
In this solution D1.S1, there is change of the tap setting (to +5%) at the Sinderby transformer to reduce the LV voltage substantially. This could be implemented either through a manual tap change or deployment of an OLTC, providing localised improvements at LV.

Figure 65 Voltage profile for Solution D1.S1



If the tap setting applied in Solution A3.S3 (-5%) was already implemented, in this scenario, it would result in significant over-voltage as shown in Figure 66. If tap settings are changed for a peak demand scenario, settings would then need to be readjusted seasonally if there was a moderate to high uptake of PV. This may not be a very practical solution and would have some cost implications given the high volumes of HV/LV substations, and the installation of a transformer equipped with an OLTC could be more effective solution.

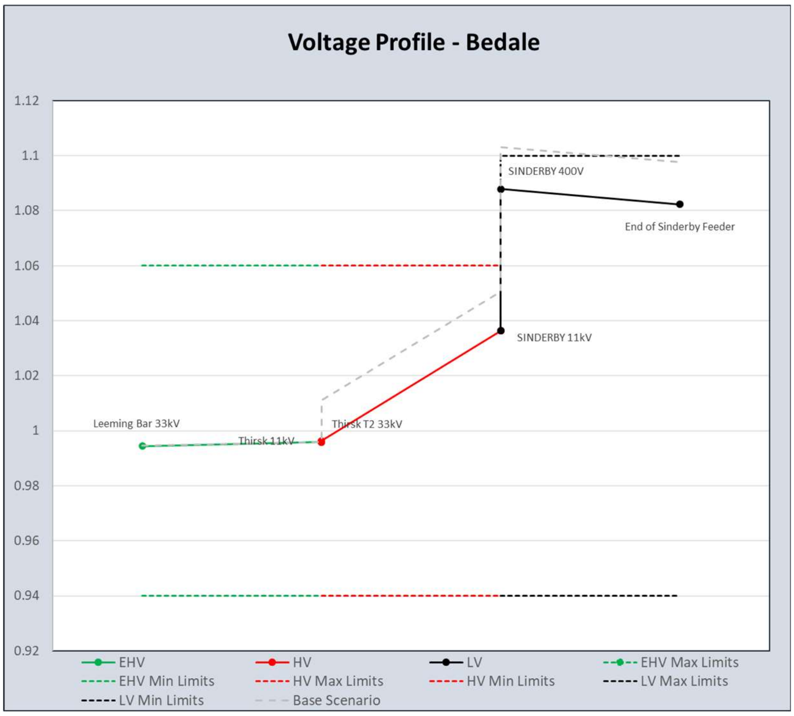
Figure 66 Voltage profile for A3.S3 under minimum demand / peak generation conditions



5.2.2.3 Solution E1.S1, Voltage Change at EHV/HV

In solution E1.S1, the target voltage at Thirsk is reduced from the 11.1kV to 11kV, resolving voltage issues at LV. This could be implemented as a target voltage change, either as a permanent change or in conjunction with Load Drop Compensation. However, for implementation in conjunction with LDC, there would be a need to ensure that there were no adverse implications for other feeders. However, it should be noted that in Solution C1.S2, the voltage was increased to 11.3kV to mitigate voltage drop issues from increasing demand. As LDC has a boost range of up to 3%, it may be feasible to reduce the target voltage (to implement solution E1.S1) then apply LDC to increase the voltage at times of high load / low generation (to implement solutionC1.S1).

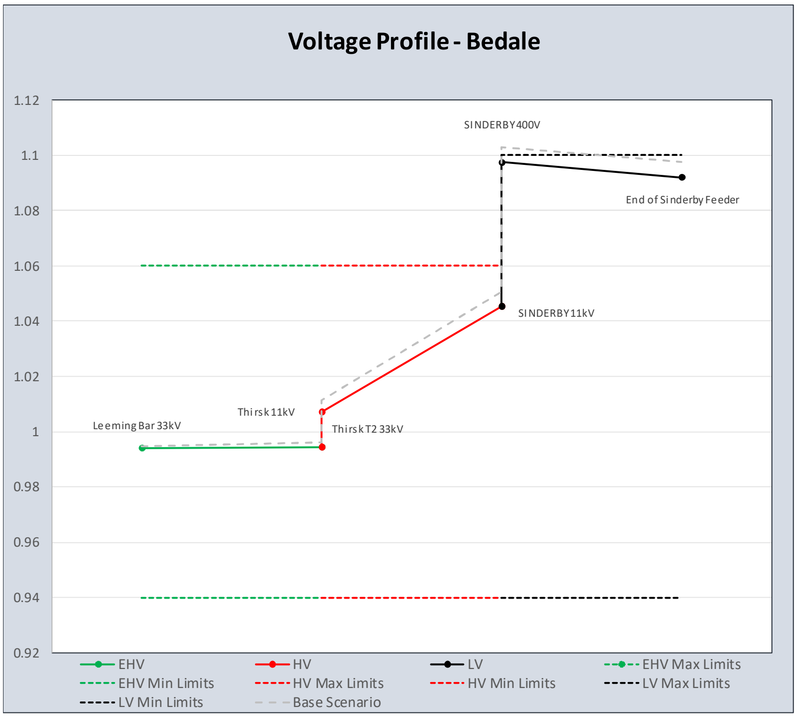
Figure 67 Voltage profile for Solution E1.S1



5.2.2.4 Solution E1.S2, Change Generator Power Factor

In Solution E1.S2, the power factor of the export from the new generation is changed from 0.95 to 0.99, to reduce the reactive power export and improve voltage profile.

Figure 68 Voltage profile for Solution E1.S2

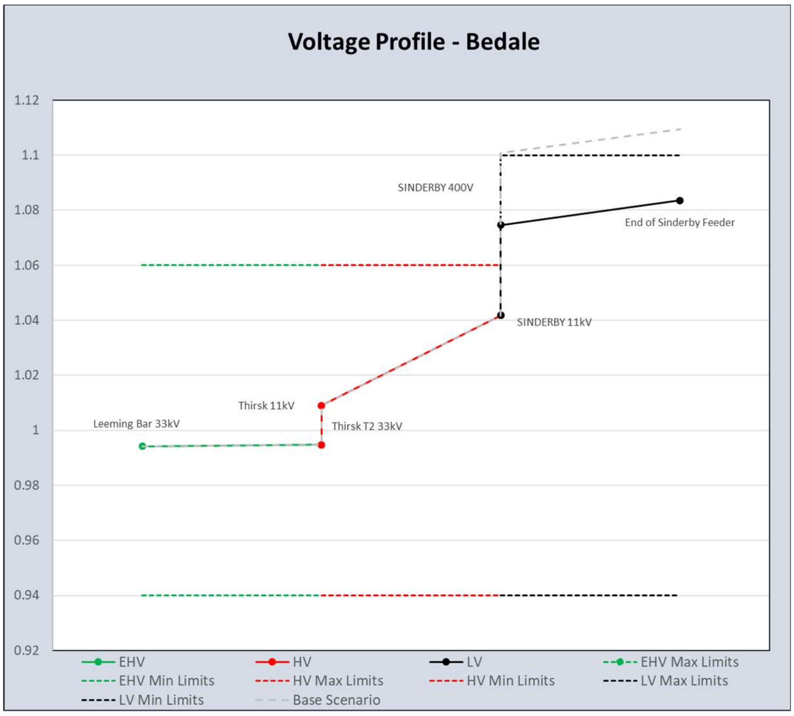


It can be observed that the change in power factor brings the voltage at Sinderby back to within the statutory limits in this scenario. The voltage headroom can be further increased by curtailing the Leeming Biogas generation, or altering its operational power factor. Whilst the assumption of 0.95 exporting power factor is worst case, this illustrates the material improvements to voltage headroom with changes to generator reactive power output.

5.2.2.5 Solution E2.S1, Tap Change at HV/LV

In this solution E3.S3, there is change of the tap setting at the Sinderby transformer to reduce the LV voltage substantially. This could be implemented either through a manual tap change or deployment of an OLTC. This provides localised voltage improvements to the voltage profile on the Sinderby LV feeder, however with the new generator connected at HV, the implications are that this solution would need to be applied at many secondary substations in the Thirsk network.

Figure 69 Voltage profile for Solution E2.S1



5.3 Solutions – First Avenue

The following voltage solutions have been modelled on the First Avenue network. A reduced solution set was studied as there were less voltage issues observed on the First Avenue network.

Table 19 Voltage Management Solutions modelled on the First Avenue network

Scenarios – Min Demand		Contingency Description (take worst-case for each scenario)	Solution	Voltage at First Avenue or Endike Lane substations EHV/HV (pu)	Minimum Substation voltage along HV Feeders (pu)	Voltage at Cranwood Substation (pu)	Cranwood LV Minimum V (pu)	Primary Tap Position Tap Settings: Endike Lane: 1(-18.7%) to 15(0.4%) at 1.366% First Avenue: 1(-13.9%) to 21(5.2%) at 0.956%
B2	EHV N-1	Outage of 33kV circuit between Beverley and First Avenue/Norwood t-point.	None	1.069 / 1.000 (First Avenue)	1.01	1.01 / 1.084	1.069	First Avenue: 17 (1.39%)
B2.S1			Curtailing Routh Wind Farm Generation to 10 MW	1.032 / 1.013 (First Avenue)	1.012	1.012 / 1.087	1.072	First Avenue: 15 (-0.522%)
D2	New PV at LV HV N-1	Combination of A4 & D1	None	0.993 / 1.018 (Endike Lane)	1.012 (Cranwood)	1.012 / 1.080	1.133	Endike Lane: 13 (-2.29%)
D2.S1			Tap setting on Cranwood HV/LV transformer changed from --0% to 5%	0.993 / 1.018 (Endike Lane)	1.012 (Cranwood)	1.012 / 1.027	1.081	Endike Lane: 13 (-2.29%)
E2	New PV at LV & New generation at HV	A new generation of 2.5MVA with a PF of 0.95 with 25% of Cranwood loads are assumed to	None	0.997 / 1.014 (First Avenue)	1.016 (New HV generator)	1.015 / 1.089	1.109	First Avenue: 13 (-2.43%)

		have 4kW PV connected onsite.						
E2.S1			Change PF of the new added generation from +0.95 to -0.95	0.994 / 1.004 (First Avenue)	1.006 (New HV generator)	1.006 / 1.079	1.098	First Avenue: 13 (-2.43%)

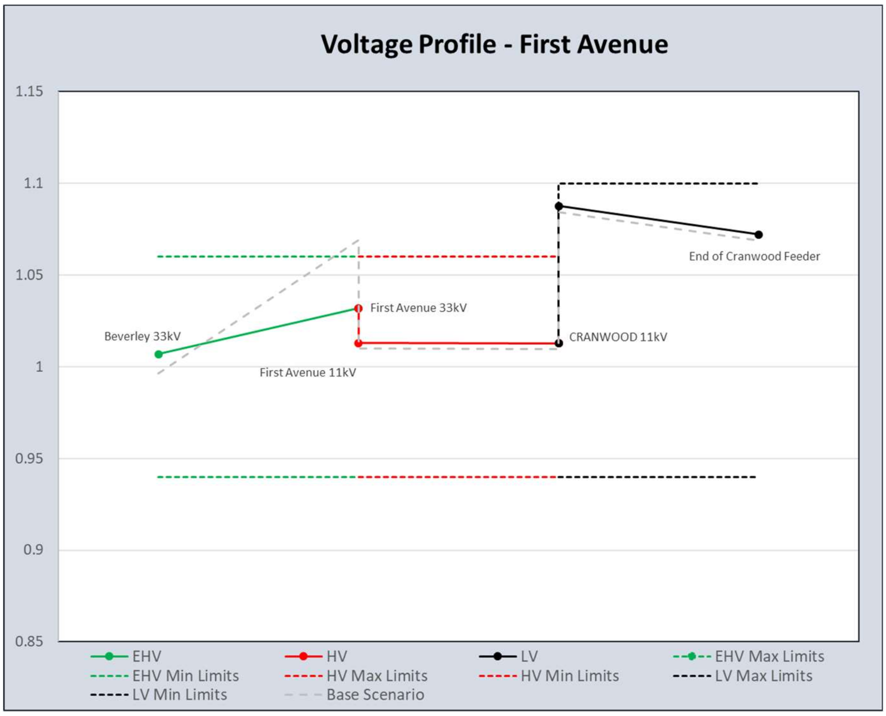
5.3.1 Minimum Demand / Peak Generation

5.3.1.1 Solution B2.S1, Curtailing the EHV Generation

Scenario B2 for First Avenue explores the scenario where there is a circuit outage between Beverley and the tee point in First Avenue T1 / Norwood T1 / Routh Wind Farm circuit. The Routh Wind Farm generation is curtailed to 10MW from 25MW in this solution. As per NPg's operating arrangements, an outage of the circuit would lead to the wind farm being switched off completely due to lack of an earth point on the 33kV network, so this scenario is hypothetical.

If the earthing problem was resolved, the solution would provide the potential to curtail, rather than disconnect, the generation at Routh Wind Farm and supply Norwood and First Avenue whilst avoiding over-voltages.

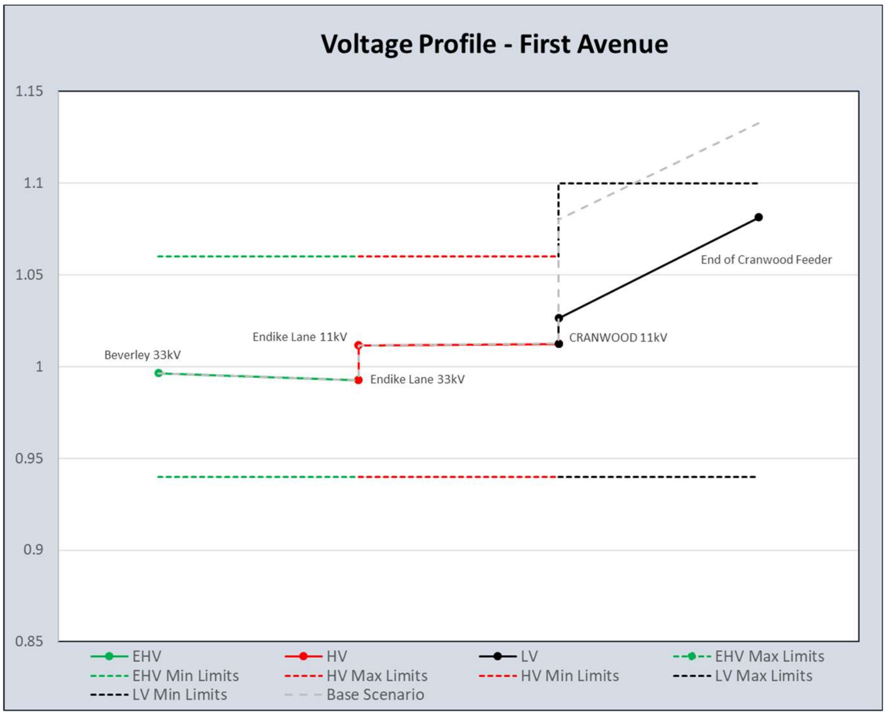
Figure 70 Voltage profile for Solution A2.S2



The voltage profile shows how the curtailment of the Routh Generation alleviates the voltage rise on the 33kV network due to reduced generation during the circuit outage. It may be beneficial to explore different operating conditions for such outage conditions to make the network more flexible.

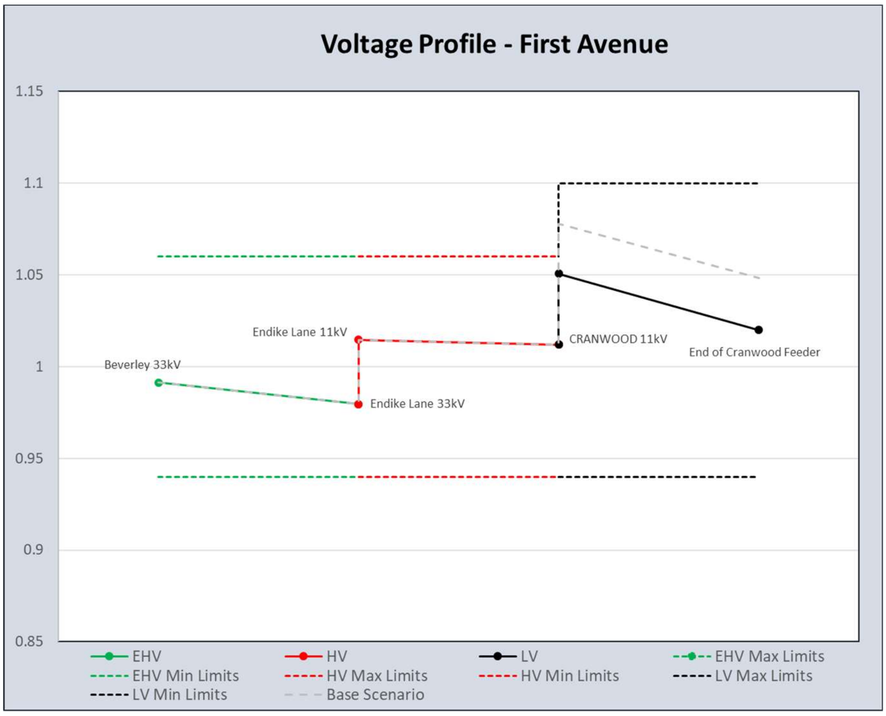
5.3.1.2 Solution D2.S1, Change Tap Setting at HV/LV

In this solution, the tap setting of the HV/LV transformer at Cranwood is changed to 5% from 0% to reduce the target voltage. This could be implemented manually or with an OLTC transformer.



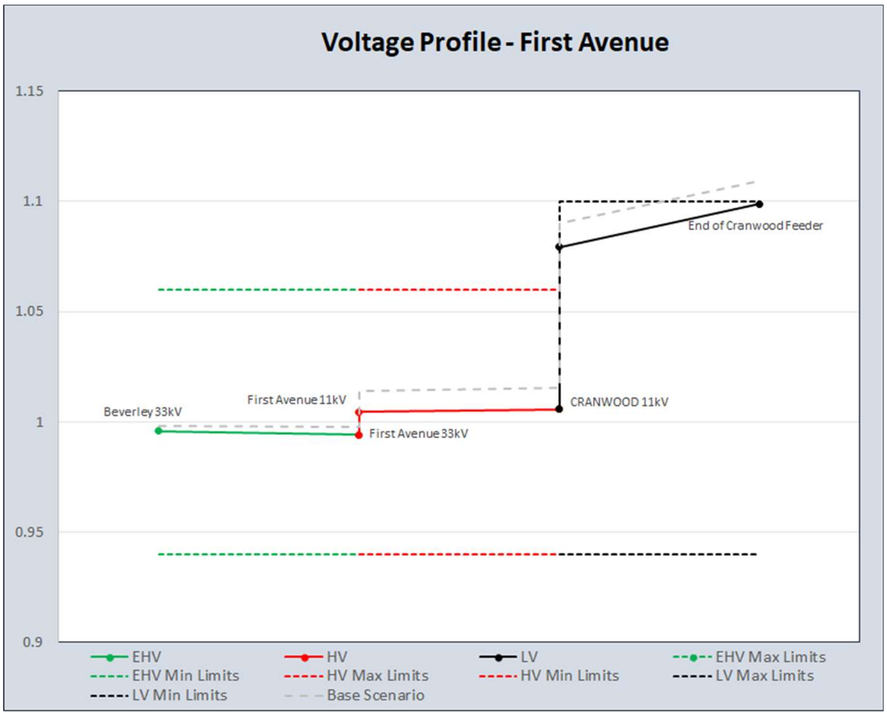
The voltage profile indicates how the change in the tap setting resolves the voltage issues caused by the increase in the PVs connected to the Cranwood LV network. Whilst this would reduce voltage legroom, the reduction is not material as shown in for the peak demand scenario A3, suggesting that a permanent change to the Cranwood transformer tap position could be made.

Figure 71 Voltage profile for Solution A3.S2



5.3.1.3 Solution E2.S1, Change Tap Setting at HV/LV

In this solution, the power factor of the new HV connected generation is changed from +0.95 lagging to -0.95 leading such that the generator would import, rather than export reactive power.



The voltage profile indicates how the voltage can be managed by changing the power factor of generation in the HV (or LV) networks. A small voltage dip can even be observed on the 33kV network as the generation on the 11kV feeder is now importing reactive power.

6 Learning Outcomes and Recommendations

Based on analysis of the representative multi-voltage networks under a range of scenarios and voltage management solutions, we can provide the following broad learning outcomes and recommendations:

6.1 Learning Outcomes

- The rural Thirsk network has comparatively has less voltage headroom and legroom as feeders are much longer, consistent with rural network topology. The relatively urban First Avenue network is more resilient to the impact of connecting new demand and generation on the network in terms of voltage; thermal constraints are likely to occur first. With heat and transport electrification, rural networks are likely to be more affected by voltage issues.
- A number of existing and novel solutions can be implemented to unlock network voltage capacity on both the First Avenue and Thirsk networks under increasing demand and generation scenarios. Solution analysis was focussed on the Thirsk network where voltage issues were found to be more material and solutions which are business ready with proven benefits were assessed.
- The present NPg voltage policy appears to be suitable for existing and future loading conditions under credible operational regimes. The allocation of voltage drop across the HV and LV voltage levels appears to be broadly appropriate for both urban and rural networks. However, our analysis has illustrated that in some cases the voltage at the 400V busbar is less than 1pu and is not aligned with the HV and LV design principles, yet voltages at the end of the LV feeder are within limits. Our findings support the recent NPg policy to purchase new transformers with taps settings of -2.5% (voltage boost) to 7.5% (voltage buck) as it enables an improved balance of voltage headroom and legroom.
- Changes to the target voltage at EHV substations makes very little difference to downstream voltage as the primary substations are set to manage the voltage to a target set point, with sufficient tap range to generally accommodate a wide range of loading conditions. For the representative networks analysed, the primary transformer tap changers are lying towards the higher end of the tapping range, potentially reducing the amount of generation headroom.
- Assessment of the two representative networks indicates that transformers installed in both rural and urban networks should be able to meet the requirements set out in Engineering Recommendation P10.
- A voltage reduction solution in conjunction with a LDC appears to be the most suitable to implement at primary substation level if high voltage constraints occur. LDC can help manage voltages in various future demand and generation conditions at HV and LV although this will vary from network to network and the loading patterns of feeders connected to those networks would need to be fairly similar, including under various contingency conditions, in order for LDC to be applied successfully. Inline voltage regulators can be implemented to address feeder specific voltage issues.
- Alternatively, target voltage settings on new AVC relays fitted with remote communications could be changed remotely on a seasonal basis, for example, by Network Operations, resulting in a similar voltage change to LDC.
- Solutions may also enable new outage topologies to be considered. For example, in the Thirsk network, backfeeding the Thirsk circuits from Bedale can potentially be considered with the deployment of an in-line voltage regulator. This would provide the operational engineers with more

options when there is an outage as well as enabling the connection of some further demand or generation.

- For localised LV voltage issues, manually changing the HV/LV substation tap settings may be a suitable short-term solution for demand increase. However, settings would then need to be readjusted seasonally if there was a moderate to high uptake of PV; in this scenario the solution would not be a feasible long-term solution. In addition to the resources required to change the tap position, as the transformers would need to be switched off, there would be an increase in Customer Interruptions and Customer Minutes Lost. A wider scale rollout of OLTCs may provide a more flexible future proof solution however, this has implications for capital expenditure.
- The MVL modelling approach enables cross-network voltage issues to be better studied and solutions tested to resolve issues with specific networks as well as provide strategic guidance on voltage policy. For example, the connection of generation at HV combined with high uptake of PV at LV. The implications of a voltage management solution applied at primary substation, to connected generation or an in-line voltage regulator along a feeder can also be assessed across a range of voltage levels. By bounding the model to a thin slice and relevant voltage levels, it is possible to build quickly and efficiently. Most value is delivered for HV and LV multi-voltage level models, the addition of EHV models does not provide significant additional value.

6.2 Recommendations

Our recommendations on network modelling and application of voltage control solutions and management techniques, both at design and strategic level, are provided below.

- This innovative and efficient MVL modelling approach developed here should be applied to NPg networks where voltage is specifically an issue across HV and LV networks. This could occur due to connection of material generation and/or demand both at HV and on LV feeders supplied from the HV feeder for example. It should also be used to advise policy on strategic voltage solutions, for example on the use of target voltage changes, on their own or in conjunction with LDC across a wider range of network types beyond the two networks studied here.
- The modelling of NPg networks could be improved to better capture voltage behaviour e.g. by including susceptance values for network models.
- Rural networks are more likely to suffer from voltage issues and should be considered for a more detailed assessment where there is significant embedded generation or high electric vehicle/heat pump uptake. There is potentially a case for treating rural and urban networks differently in voltage policy however, this can lead to lack of clarity for networks that are difficult to classify. This should be explored further.
- The present NPg voltage policy should be retained for now but review as loading conditions change materially. Transformer tap ranges and specifications, for example, appear to be broadly suitable for urban and rural network types based on the two representative networks studied, with transformers generally not reaching the end of their tapping range. However, the two networks studied are not likely to be fully representative of the wide and varied range of network characteristics across NPg so we would recommend further verification of these recommendations on other networks. This can be efficiently carried out based on the methodology developed and presented here.
- The tap change step and range should be sufficient to enable future connection of demand and generation, as low carbon technology uptake increases and distributed energy resources are increasingly deployed. For the representative networks analysed, the primary transformer tap

changers are lying towards the higher end of the tapping range, potentially reducing the amount of generation headroom.

- In some cases, it may be found that NPg HV and LV design principles are overly limiting and compliance with voltage statutory limits can still be achieved although the design principles are not. These cases should be tracked to support assessment of wider applicability and thresholds to ensure that the balance of HV and LV voltage drop is appropriate. The risk associated with the treatment of AVC deadband to voltage non-compliance should also be considered in more detail.
- Use of revised target voltage, with LDC at primary substations to manage the impact of new demand and generation on voltage can be quite flexible. However, the application depends on the loading patterns of HV feeders being relatively similar including under various contingency conditions. Alternatively, target voltages could potentially be broadly set for rural and urban networks and adjusted seasonally. Strategic application of LDC across a range of network types should be explored further, which could be achieved using this modelling framework. An improved understanding of when to deploy target voltage changes and/or LDC, how these might interact including during contingency conditions, and how this could best be reflected in both the planning and design process and voltage policy is required.
- Change of generator voltage / reactive power characteristics can provide some material voltage support when the generator is in service. This solution should be studied in more detail under a wider range of conditions to understand the behaviour of generation operating in different modes e.g. PV, PQ, QV, (as defined in EREC G99) and how the benefits could be realised in practice.
- Where there is a requirement to replace a HV/LV transformer due to asset condition or load, the deployment of an OLTC transformer should be considered to both provide future proof voltage support.
- There is expected to be an increase in the volume of devices that are connected to the network as the penetration of LCTs increases. Some of these devices, e.g. a primary transformer AVC and a secondary transformer AVC, are DNO assets and others will be customer assets e.g. V2G and domestic batteries which may be able to provide reactive power and voltage control services. Further work should be done to understand the potential interactions, implications and complexities.
- Any design or strategic voltage management solution should also consider the impact on network losses.

7 Annex A – MVL Network Models

7.1 Generators in Northeast (Thirsk) Model

Table 20 Generation connections in Thirsk MVL model

Generation Name	Supply Point	Primary	Voltage	Type	Installed Capacity	Contracted Capacity	Feeder
Sand Hutton Solar Farm	Leeming Bar	Thirsk	HV (11)	Solar	5MW	5MW	Sand Hutton Solar Farm Feeder
East Appleton Generation SW	Leeming Bar	East Appleton North	EHV (33)	Solar	4.5MW	4.5MW	Leeming Bar- Catterick Camp
R and R Ice Cream*	Leeming Bar	Bedale	HV (11)	CHP	4MW	0MW	Leeming Richmond
Clapham Lodge Biogas	Leeming Bar	Bedale	HV (11)	Biogas	1.5MW	1.5MW	Bedale Station (known as Leeming Biogas)
WE Jameson & Son Ltd	Leeming Bar	Bedale	LV (0.4)	Solar	unknown	0.842MW	Bedale Trees

*Note: R and R Ice Cream is a non-export type generation.

7.2 Generators in Yorkshire (First Avenue) Model

Table 21 Generation connections in First Avenue model

Generation Name	Supply Point	Primary	Voltage	Type	Installed Capacity	Contracted Capacity	Feeder
Routh Wind Farm	Beverley	Routh Windfarm	EHV (33)	Wind	24.6MW	25.361MVA	Beverley - Norwood
Croda Chemical Wind Turbine	Beverley	First Avenue	HV (11)	Wind	2.1MW	2.2MVA	First Avenue – Universal substation (embedded generation)
Sober hill Wind Farm	Beverley	Sober Hill	EHV (33)	Wind	12.3MW	12.68MVA	Beverley Busbar 33kV

7.3 Data Sources and Conversion

Table 22 Data sources, conversion and assumptions for NPg MVL models

	Data source	Units	Conversion	Assumptions
EHV/HV transformers	SCADA	MW, MVAr	None	Uses actual MVAr
EHV feeders	SCADA	MW, MVAr	None	Uses actual MVAr
EHV customers	SCADA	MW, MVAr	None	Uses actual MVAr
EHV/HV transformers	SCADA	MW, MVAr	None	Uses actual MVAr
HV feeders	SCADA	Amps and Voltage	MW, MVAr	Uses actual MVAr
HV customers	SCADA	MW, MVAr	None	Uses actual MVAr
HV/LV substations	EEDM	MVA	MW, MVAr	Uses actual MVAr

*Please note that the power factor value can be altered in the script.

8 Annex B – Susceptance Results

Busbar Names	Initial Voltage pu	New Voltage pu	Actual Difference	% Difference
Creyke Beck 132kV	1	1	0	0.00%
Beverley 33kV-2	0.999131	0.993487	-0.005644	0.56%
Endike Lane 33kV-2	0.989809	0.98263	-0.007179	0.73%
Endike Lane 11kV-2	1.01708	1.00847	-0.00861	0.85%
First Avenue 33kV-2	0.985963	0.978395	-0.007568	0.77%
First Avenue 11kV-2	1.01826	1.00699	-0.01127	1.11%
Norwood 33kV-1	0.993625	0.987187	-0.006438	0.65%
Norwood 11kV-1	1.00682	1.00056	-0.00626	0.62%
Spark Mill Lane 33kV-2	0.991109	0.98513	-0.005979	0.60%
Spark Mill Lane 11kV-2	1.01462	1.00826	-0.00636	0.63%
Southwood Road 33kV-1	0.979426	0.972907	-0.006519	0.67%
Southwood Road 11kV-1	1.00394	1.01315	0.00921	0.92%
tPoint	0.997316	0.991362	-0.005954	0.60%
Ross Farm	0.995393	0.989113	-0.00628	0.63%
Routh Windfarm	0.994787	0.988364	-0.006423	0.65%
Routh Wind Farm	0.994831	0.988322	-0.006509	0.65%
tPoint(2)	0.992367	0.98547	-0.006897	0.70%
Dunswell Lane	0.991018	0.983902	-0.007116	0.72%
01_Beverley 33kV-1	0.999131	0.993487	-0.005644	0.56%
02_First Avenue 33kV-1	0.987748	0.980441	-0.007307	0.74%
03_First Avenue 11kV-1	1.01826	1.00699	-0.01127	1.11%
Spark Mill Lane 33kV-1	0.995357	0.989673	-0.005684	0.57%
Spark Mill Lane 11kV-1	1.01462	1.00826	-0.00636	0.63%
Norwood 33kV-2	0.993133	0.987129	-0.006004	0.60%
Norwood 11kV-2	1.00682	1.00056	-0.00626	0.62%
tPoint(3)	0.994427	0.988472	-0.005955	0.60%
Endike Lane 33kV-1	0.984837	0.978087	-0.00675	0.69%
Endike Lane 11kV-1	1.01708	1.00847	-0.00861	0.85%
tPoint(4)	0.986614	0.980122	-0.006492	0.66%
Southwood Road 33kV-2	0.976362	0.970177	-0.006185	0.63%
Southwood Road 11kV-2	1.00394	1.01315	0.00921	0.92%
Eppleworth Bottom	0.983158	0.977132	-0.006026	0.61%
tPoint(5)	0.983896	0.977888	-0.006008	0.61%
Sculcoates B 132kV-2	0.999879	0.999735	-0.000144	0.01%
Sculcoates B 132kV-1	1.00034	0.999835	-0.000505	0.05%
Cornwall Street 132kV-2	0.99986	0.999711	-0.000149	0.01%
Cornwall Street 11kV-2	0.998964	0.998532	-0.000432	0.04%
Cornwall Street 132kV-1	1.00038	0.999796	-0.000584	0.06%
Cornwall Street 11kV-1	0.998964	0.998532	-0.000432	0.04%

Sculcoates A 132kV-2	0.999872	0.999725	-0.000147	0.01%
Sculcoates A 11kV-2	1.01392	1.01243	-0.00149	0.15%
Sculcoates A 132kV-1	1.00033	0.999831	-0.000499	0.05%
Sculcoates A 11kV-1	1.01392	1.01243	-0.00149	0.15%
Driffield 132kV-2	0.986556	0.986108	-0.000448	0.05%
Driffield 66kV-2	0.997088	0.996735	-0.000353	0.04%
Driffield 132kV-1	0.992814	0.992572	-0.000242	0.02%
Driffield 66kV-1	0.997088	0.996735	-0.000353	0.04%
Bransholme 132kV-2	0.996839	0.996474	-0.000365	0.04%
Bransholme 33kV-2	0.994273	0.990459	-0.003814	0.38%
Bransholme 132kV-1	0.994604	0.994303	-0.000301	0.03%
Bransholme 33kV-1	0.994273	0.990459	-0.003814	0.38%
tPoint(6)	0.996939	0.996651	-0.000288	0.03%
tPoint(7)	0.99464	0.994408	-0.000232	0.02%
Tiverton Road 33kV-2	0.993196	0.989193	-0.004003	0.40%
Tiverton Road 11kV-2	1.00459	0.999929	-0.004661	0.46%
Tiverton Road 33kV-1	0.994033	0.99015	-0.003883	0.39%
Tiverton Road 11kV-1	1.00459	0.999929	-0.004661	0.46%
Wawne Road 33kV-2	0.992677	0.988644	-0.004033	0.41%
Wawne Road 11kV-2	1.00316	1.0119	0.00874	0.87%
Wawne Road 33kV-1	0.992052	0.987998	-0.004054	0.41%
Wawne Road 11kV-1	1.00316	1.0119	0.00874	0.87%
Beverley 132kV-2	1	1	0	0.00%
Beverley 132kV-1	1	1	0	0.00%
Beverley 132kV-3	1	1	0	0.00%
Beverley 66kV-2	0.9996	0.9996	0	0.00%
EDYO005N1V 11	1.0166	1.00794	-0.00866	0.85%
EDYO005N1Z 11	1.01046	1.00174	-0.00872	0.86%
EDYO005N2N 11	1.01167	1.00022	-0.01145	1.13%
EDYO005N2U 11	1.0121	1.00067	-0.01143	1.13%
EDYO005N34 11	1.01489	1.0035	-0.01139	1.12%
EDYO005N3M 11	1.00462	1.00304	-0.00158	0.16%
EDYO005N3Q 11	1.01329	1.00182	-0.01147	1.13%
EDYO005N46 11	1.0177	1.00639	-0.01131	1.11%
EDYO005N4A 11	1.01436	1.00285	-0.01151	1.13%
EDYO005N4G 11	1.00624	1.00465	-0.00159	0.16%
EDYO005N4R 11	1.00828	1.00672	-0.00156	0.15%
STOCKHOLME ROAD MAURI EQUIV FAULT INFEED 11	1.00191	1.00021	-0.0017	0.17%
INGS BRIDGE SOUTH 11	1.01441	1.003	-0.01141	1.12%
INGS BRIDGE SOUTH	1.00835	0.996871	-0.011479	1.14%
PARKSTONE WHEELHOUSE 11	1.01748	1.00619	-0.01129	1.11%
PARKSTONE WHEELHOUSE	1.01178	1.00041	-0.01137	1.12%

BLYTHORPE 11	1.01638	1.00771	-0.00867	0.85%
BLYTHORPE	1.01459	1.0059	-0.00869	0.86%
DIDSCOURT 11	1.01682	1.00819	-0.00863	0.85%
DIDSCOURT	1.01519	1.00655	-0.00864	0.85%
INGLEMIRE 11	1.01204	1.00334	-0.0087	0.86%
INGLEMIRE	0.999373	0.99055	-0.008823	0.88%
ILTHORPE 11	1.01593	1.00723	-0.0087	0.86%
ILTHORPE	1.01312	1.00439	-0.00873	0.86%
EASETHORPE 11	1.01636	1.00769	-0.00867	0.85%
EASETHORPE	1.01513	1.00645	-0.00868	0.86%
KINTHORPE 11	1.01592	1.00721	-0.00871	0.86%
KINTHORPE	1.01518	1.00647	-0.00871	0.86%
LAXTHORPE 11	1.01228	1.00086	-0.01142	1.13%
LAXTHORPE	1.01156	1.00012	-0.01144	1.13%
THORPE PARK 11	1.01431	1.0029	-0.01141	1.12%
THORPE PARK	1.01277	1.00134	-0.01143	1.13%
CLADSHAW 11	1.01651	1.00784	-0.00867	0.85%
CLADSHAW	1.01566	1.00699	-0.00867	0.85%
ELLERBURN WELFARE CENTRE 11	1.01605	1.00736	-0.00869	0.86%
ELLERBURN WELFARE CENTRE	1.01402	1.00531	-0.00871	0.86%
BARDSHAW 11	1.0166	1.00794	-0.00866	0.85%
BARDSHAW	1.01431	1.00563	-0.00868	0.86%
QUILLCOURT 11	1.01642	1.00776	-0.00866	0.85%
QUILLCOURT	1.01388	1.00519	-0.00869	0.86%
SYLVIA 11	1.01077	1.00205	-0.00872	0.86%
SYLVIA	0.998219	0.989377	-0.008842	0.89%
OLDSTEAD 11	1.01032	1.00159	-0.00873	0.86%
OLDSTEAD	0.999486	0.990655	-0.008831	0.88%
OLDSTEAD NORTH 11	1.0163	1.00766	-0.00864	0.85%
OLDSTEAD NORTH	1.00911	1.00041	-0.0087	0.86%
GREENWOOD 11	1.01434	1.00568	-0.00866	0.85%
GREENWOOD	1.00849	0.999778	-0.008712	0.86%
HALLCOTT 11	1.01557	1.00691	-0.00866	0.85%
HALLCOTT	1.00909	1.00037	-0.00872	0.86%
COTTINGS 11	1.01543	1.00676	-0.00867	0.85%
COTTINGS	1.01099	1.00228	-0.00871	0.86%
QUADRANT 11	1.01012	1.00139	-0.00873	0.86%
QUADRANT	1.0131	1.0039	-0.0092	0.91%
ALDERIDGE 11	1.01327	1.00447	-0.0088	0.87%
ALDERIDGE	1.01196	1.00315	-0.00881	0.87%
NEWLAND PARK 11	1.01294	1.00145	-0.01149	1.13%
NEWLAND PARK	1.01081	0.999297	-0.011513	1.14%

NEWPARK 11	1.01331	1.00451	-0.0088	0.87%
NEWPARK	1.01242	1.00362	-0.0088	0.87%
COTTINGHAM ROAD 11	1.01319	1.00171	-0.01148	1.13%
COTTINGHAM ROAD	1.00929	0.997768	-0.011522	1.14%
UNIVERSITY NO 1 11	1.01305	1.00156	-0.01149	1.13%
UNIVERSITY NO 1	1.00916	0.997626	-0.011534	1.14%
NEWCOTT 11	1.01529	1.0066	-0.00869	0.86%
NEWCOTT	1.01169	1.00297	-0.00872	0.86%
OPEN AIR SCHOOL 11	1.01021	1.00148	-0.00873	0.86%
OPEN AIR SCHOOL	1.00644	0.997679	-0.008761	0.87%
INGLEMIRE CENTRAL 11	1.01419	1.00544	-0.00875	0.86%
INGLEMIRE CENTRAL	1.00987	1.00108	-0.00879	0.87%
CRANDYKE 11	1.01792	1.00665	-0.01127	1.11%
04_CRANWOOD 11	1.01792	1.00665	-0.01127	1.11%
ELLERBURN 11	1.01605	1.0074	-0.00865	0.85%
ELLERBURN	1.00724	0.998507	-0.008733	0.87%
SIXTEENTH AVENUE 11	1.01387	1.00249	-0.01138	1.12%
SIXTEENTH AVENUE	1.0025	0.990972	-0.011528	1.15%
TENTH AVENUE 11	1.01519	1.00384	-0.01135	1.12%
TENTH AVENUE	1.01218	1.00079	-0.01139	1.13%
SEXTANT 11	1.01423	1.00279	-0.01144	1.13%
SEXTANT	1.00811	0.996598	-0.011512	1.14%
CAPSTAN 11	1.01418	1.00275	-0.01143	1.13%
CAPSTAN	1.01133	0.999858	-0.011472	1.13%
COMPASS 11	1.01478	1.00339	-0.01139	1.12%
COMPASS	1.01337	1.00196	-0.01141	1.13%
MIZZEN 11	1.01482	1.00343	-0.01139	1.12%
MIZZEN	1.00849	0.997015	-0.011475	1.14%
PARKSTONE SCHOOL 11	1.01477	1.00335	-0.01142	1.13%
PARKSTONE SCHOOL	1.00874	0.997253	-0.011487	1.14%
WELWYN 11	1.01547	1.00408	-0.01139	1.12%
WELWYN	1.01004	0.998588	-0.011452	1.13%
STRATHMORE 11	1.0167	1.00537	-0.01133	1.11%
STRATHMORE	1.01214	1.00076	-0.01138	1.12%
RIVERSDYKE 11	1.01674	1.00545	-0.01129	1.11%
RIVERSDYKE	1.00635	0.994926	-0.011424	1.14%
ENDSLEIGH HOSTEL 11	1.01576	1.00444	-0.01132	1.11%
ENDSLEIGH HOSTEL	1.01092	0.999546	-0.011374	1.13%
AUCKLAND 11	1.01396	1.0052	-0.00876	0.86%
AUCKLAND	1.01297	1.0042	-0.00877	0.87%
ST MICHAELS MOUNT 11	1.01513	1.0038	-0.01133	1.12%
ST MICHAELS MOUNT	1.01261	1.00125	-0.01136	1.12%

CRANBROOK 96 11	1.01368	1.00491	-0.00877	0.87%
CRANBROOK 96	1.01114	1.00234	-0.0088	0.87%
SALMON GROVE 11	1.01344	1.00466	-0.00878	0.87%
SALMON GROVE	1.01139	1.00258	-0.00881	0.87%
CRANBROOK 13 11	1.01353	1.00475	-0.00878	0.87%
CRANBROOK 13	1.01271	1.00392	-0.00879	0.87%
AUCKLAND 26 11	1.01337	1.00459	-0.00878	0.87%
AUCKLAND 26	1.01102	1.00221	-0.00881	0.87%
BROOKLYN 11	1.00462	1.00304	-0.00158	0.16%
BROOKLYN	0.994207	0.992607	-0.0016	0.16%
CONVENT 11	1.01518	1.00385	-0.01133	1.12%
CONVENT	1.00707	0.995639	-0.011431	1.14%
INGLEMIRE EAST 11	1.01517	1.00384	-0.01133	1.12%
INGLEMIRE EAST	1.01243	1.00107	-0.01136	1.12%
BERESFORD 11	1.01535	1.00396	-0.01139	1.12%
BERESFORD	1.00946	0.997999	-0.011461	1.14%
BEVERLEY ROAD BLIND 11	1.00372	1.00213	-0.00159	0.16%
BEVERLEY ROAD BLIND	0.995736	0.994136	-0.0016	0.16%
ALEXANDRA ROAD 11	1.00324	1.00166	-0.00158	0.16%
ALEXANDRA ROAD	1.01703	1.01538	-0.00165	0.16%
MELBOURNE 11	1.00215	1.00056	-0.00159	0.16%
MELBOURNE	1.01018	1.00851	-0.00167	0.17%
LANGTREE 11	1.00429	0.999622	-0.004668	0.46%
LANGTREE	1.00338	0.998707	-0.004673	0.47%
BUDE ROAD 11	1.00402	0.999347	-0.004673	0.47%
BUDE ROAD	1.00169	0.997002	-0.004688	0.47%
GORSDALE 11	1.00319	0.998496	-0.004694	0.47%
GORSDALE	0.99824	0.993518	-0.004722	0.47%
CLARONDALE 11	1.00374	0.99905	-0.00469	0.47%
CLARONDALE	1.00156	0.996858	-0.004702	0.47%
PAXDALE 11	1.0036	0.99891	-0.00469	0.47%
PAXDALE	1.0029	0.99821	-0.00469	0.47%
THORNDALE 11	1.00344	0.998749	-0.004691	0.47%
THORNDALE	1.00211	0.997407	-0.004703	0.47%
BERGEN WAY 11	1.01458	1.00315	-0.01143	1.13%
BERGEN WAY	1.00779	0.996282	-0.011508	1.14%
STOCKHOLME ROAD NORTH 11	1.01774	1.00644	-0.0113	1.11%
STOCKHOLME ROAD NORTH	1.01345	1.00209	-0.01136	1.12%
STOCKHOLME LETTER OFFICE 11	0.999343	0.99456	-0.004783	0.48%
STOCKHOLME LETTER OFFICE	0.992967	0.988152	-0.004815	0.48%
STOCKHOLME FOUNDRY 11	1.01756	1.00623	-0.01133	1.11%
STOCKHOLME FOUNDRY	1.0164	1.00506	-0.01134	1.12%

COPENHAGEN 11	0.98698	0.986377	-0.000603	0.06%
COPENHAGEN	1.00651	1.00589	-0.00062	0.06%
HELSINKI ROAD NORTH 11	1.01531	1.00385	-0.01146	1.13%
HELSINKI ROAD NORTH	1.01427	1.0028	-0.01147	1.13%
HELSINKI ROAD SOUTH 11	1.01503	1.00355	-0.01148	1.13%
HELSINKI ROAD SOUTH	1.01452	1.00304	-0.01148	1.13%
LENINGRAD 11	1.01426	1.00274	-0.01152	1.14%
LENINGRAD	1.01256	1.00103	-0.01153	1.14%
STOCKHOLME ROAD 11	1.00399	1.00232	-0.00167	0.17%
STOCKHOLME ROAD	1.003	1.00132	-0.00168	0.17%
CLOUGH WATER 11	1.00625	1.00466	-0.00159	0.16%
CLOUGH WATER	1.00431	1.00271	-0.0016	0.16%
CLOUGH ROAD SOUTH 11	1.00816	1.0066	-0.00156	0.15%
CLOUGH ROAD SOUTH	1.00588	1.00432	-0.00156	0.16%
VULCAN 11	1.00614	1.00454	-0.0016	0.16%
VULCAN	1.00411	1.00251	-0.0016	0.16%
THIRTIETH AVENUE 11	1.01197	1.00054	-0.01143	1.13%
THIRTIETH AVENUE	0.999422	0.98783	-0.011592	1.16%
COTTINGHAM ROAD FLATS 11	1.01386	1.00241	-0.01145	1.13%
COTTINGHAM ROAD FLATS	1.00551	0.993955	-0.011555	1.15%
OSLO ROAD 11	1.0157	1.00426	-0.01144	1.13%
OSLO ROAD	1.01528	1.00383	-0.01145	1.13%
ENNERDALE WEST 11	1.01451	1.00307	-0.01144	1.13%
ENNERDALE WEST	1.00759	0.996066	-0.011524	1.14%
NORTH HOUSE (1) 11	1.01166	1.00022	-0.01144	1.13%
NORTH HOUSE	1.00465	0.993124	-0.011526	1.15%
NORTH HOUSE 11	1.01167	1.00023	-0.01144	1.13%
NORTH HOUSE (3)	1.00465	0.993124	-0.011526	1.15%
BEVERLEY ROAD NORTH	1.01473	1.00333	-0.0114	1.12%
STOCKHOLME VAN LEER	1.01469	1.00326	-0.01143	1.13%
STOCKHOLME FREEBOOTER	1.01645	1.00505	-0.0114	1.12%
STOCKHOLME ROAD MAURI	1.00191	1.00021	-0.0017	0.17%
STOCKHOLME HOLLICELL	1.00222	1.00053	-0.00169	0.17%
STOCKHOLME ROAD BOOTHS	1.00311	1.00143	-0.00168	0.17%
OSLO ROAD HUMBER KITCHENS	1.01438	1.00288	-0.0115	1.13%
STOCKHOLME MCBRIDE	1.00393	1.00225	-0.00168	0.17%
CLOUGH GAS	1.00642	1.00484	-0.00158	0.16%
UNIVERSAL	1.01387	1.00252	-0.01135	1.12%
COLD HARBOUR 11	1.01246	1.00104	-0.01142	1.13%
COLD HARBOUR	1.00397	0.99245	-0.01152	1.15%
EDYO005PM7 11	1.01455	1.00311	-0.01144	1.13%
GOTHENBURG WAY 11	1.0001	0.99533	-0.00477	0.48%

GOTHENBURG WAY	0.999641	0.994865	-0.004776	0.48%
STOCKHOLME COUNCIL 11	1.00269	1.001	-0.00169	0.17%
STOCKHOLME COUNCIL	1.00253	1.00084	-0.00169	0.17%
OSLO ROAD EAST 11	1.01585	1.00442	-0.01143	1.13%
OSLO ROAD EAST	1.01585	1.00442	-0.01143	1.13%
EDYO00CIS1 11	1.00121	0.996457	-0.004753	0.47%
NOP 8	1	1	0	0.00%
NOP 1	1.01829	1.00699	-0.0113	1.11%
HULL UNIVERSITY	1.01144	1.00005	-0.01139	1.13%
ALEXANDRA ROAD CENTRAL 11	1.00253	1.00094	-0.00159	0.16%
ALEXANDRA ROAD CENTRAL	0.99407	0.992463	-0.001607	0.16%
MALMO ROAD 11	1.01763	1.0063	-0.01133	1.11%
MALMO ROAD	1.01716	1.00583	-0.01133	1.11%
OAKFIELD COURT 11	1.01547	1.0068	-0.00867	0.85%
OAKFIELD COURT	1.01488	1.00621	-0.00867	0.85%
ORCHARD PARK MEDICAL 11	1.01237	1.00094	-0.01143	1.13%
ORCHARD PARK MEDICAL	1.0121	1.00068	-0.01142	1.13%
NEWLAND GROVE 11	1.01308	1.0016	-0.01148	1.13%
NEWLAND GROVE	1.00555	0.993974	-0.011576	1.15%
NORTHERN ACADEMY 11	1.01612	1.00477	-0.01135	1.12%
NORTHERN ACADEMY	1.01522	1.00386	-0.01136	1.12%
STOCKHOLME CENTRAL	0.999271	0.994488	-0.004783	0.48%
CLOUGH POLICE	1.00677	1.00519	-0.00158	0.16%
TARCOM 11	1.01474	1.00334	-0.0114	1.12%
TARCOM	1.01134	0.999905	-0.011435	1.13%
PEARSON WAY	1.01509	1.00374	-0.01135	1.12%
ST MARYS IDNO	1.01388	1.00512	-0.00876	0.86%
ELLERBURN RETAIL 11	1.01231	1.00088	-0.01143	1.13%
ELLERBURN RETAIL	1.00916	0.997701	-0.011459	1.14%
INGLEMIRE LANE 11	1.01441	1.00567	-0.00874	0.86%
INGLEMIRE LANE	1.01432	1.00558	-0.00874	0.86%
CAMPUS SOUTH 11	1.01303	1.00153	-0.0115	1.14%
CAMPUS SOUTH	1.01289	1.00139	-0.0115	1.14%
CAMPUS NORTH 11	1.01303	1.00153	-0.0115	1.14%
CAMPUS NORTH	1.01289	1.00139	-0.0115	1.14%
EDYO005Y0G 11	0.989949	0.989364	-0.000585	0.06%
EDYO005Y0Q 11	0.993347	0.992813	-0.000534	0.05%
EDYO005Y0S 11	0.993347	0.992813	-0.000534	0.05%
EDYO005Y1J 11	0.988965	0.988364	-0.000601	0.06%
EDYO005Y2C 11	1.01398	1.00241	-0.01157	1.14%
EDYO005Y7P 11	0.988965	0.988364	-0.000601	0.06%
WORDSWORTH 11	1.01113	1.01073	-0.0004	0.04%

WORDSWORTH	1.00572	1.00531	-0.00041	0.04%
LEADS ROAD CENTRAL 11	0.989304	0.988707	-0.000597	0.06%
LEADS ROAD CENTRAL	1.0119	1.01128	-0.00062	0.06%
CULLEN 11	1.00856	1.00807	-0.00049	0.05%
CULLEN	1.00637	1.00587	-0.0005	0.05%
BURLINGTON 11	1.00838	1.00789	-0.00049	0.05%
BURLINGTON	1.00486	1.00436	-0.0005	0.05%
MUNROE 11	1.0087	1.00821	-0.00049	0.05%
MUNROE	1.00622	1.00573	-0.00049	0.05%
LEADS ROAD ASCOL 11	0.988857	0.988255	-0.000602	0.06%
LEADS ROAD ASCOL	0.988857	0.988255	-0.000602	0.06%
FOREDYKE 11	0.989666	0.989076	-0.00059	0.06%
FOREDYKE	0.986942	0.98635	-0.000592	0.06%
ANTWERP 11	0.987155	0.986553	-0.000602	0.06%
ANTWERP	0.985516	0.984914	-0.000602	0.06%
ROTTERDAM 11	0.988479	0.987886	-0.000593	0.06%
ROTTERDAM	0.985568	0.984973	-0.000595	0.06%
AMSTERDAM ROAD 11	1.01399	1.00245	-0.01154	1.14%
AMSTERDAM ROAD	1.008	0.996388	-0.011612	1.15%
LEADS ROAD 11	0.989517	0.98893	-0.000587	0.06%
LEADS ROAD	1.01082	1.01021	-0.00061	0.06%
STONEFERRY 11	0.991973	0.991418	-0.000555	0.06%
STONEFERRY	0.986389	0.98583	-0.000559	0.06%
STONEFERRY SUPERSTORE 11	1.00892	1.00731	-0.00161	0.16%
STONEFERRY SUPERSTORE	1.00733	1.00572	-0.00161	0.16%
LEE ST 11	1.01041	1.00998	-0.00043	0.04%
LEE ST	0.982541	0.982116	-0.000425	0.04%
LEADS ROAD KINGSTOWN	0.988856	0.988255	-0.000601	0.06%
ROTTERDAM EUROCON CONS OWNED	0.987242	0.986641	-0.000601	0.06%
ROTTERDAM ROCKWARE CONS OWNED	0.987784	0.987186	-0.000598	0.06%
ROTTERDAM MARSDENS CONS OWNED	0.987968	0.987372	-0.000596	0.06%
STONEFERRY BRIDGE S/STN	1.00595	1.00436	-0.00159	0.16%
WHITETHORNE WAY 11	1.00923	1.00876	-0.00047	0.05%
WHITETHORNE WAY	1.00569	1.00521	-0.00048	0.05%
ROTTERDAM PARK 11	1.00656	1.00491	-0.00165	0.16%
ROTTERDAM PARK	1.00356	1.00191	-0.00165	0.16%
AMSTERDAM ROAD CARAVANS 11	1.01396	1.00241	-0.01155	1.14%
AMSTERDAM ROAD CARAVANS	1.01331	1.00175	-0.01156	1.14%
AMSTERDAM ROAD CENTRAL 11	1.01396	1.00241	-0.01155	1.14%
AMSTERDAM ROAD CENTRAL	1.01304	1.00148	-0.01156	1.14%

Westcott Street 33kV	1	1	0	0.00%
SWITCH STN 11	1.01529	1.0066	-0.00869	0.86%
NOP 2	1.01606	1.0074	-0.00866	0.85%
NOP 3	1.01592	1.00721	-0.00871	0.86%
NOP 4	1.01434	1.00568	-0.00866	0.85%
NOP 5	1.01418	1.00275	-0.01143	1.13%
NOP 6	1.01636	1.00769	-0.00867	0.85%
NOP 7	1.01593	1.00723	-0.0087	0.86%
KINGSWOOD WATERSIDE	1.01451	1.00307	-0.01144	1.13%
NOP 9	1.01455	1.00311	-0.01144	1.13%
NOP 10	0.999273	0.994488	-0.004785	0.48%
NOP 11	1.0177	1.00639	-0.01131	1.11%
NOP 12	1.00614	1.00454	-0.0016	0.16%
NOP 13	1.01398	1.00241	-0.01157	1.14%
NOP 14	1.01436	1.00285	-0.01151	1.13%
NOP 15	1.01399	1.00241	-0.01158	1.14%
NOP 16	1.01388	1.00512	-0.00876	0.86%
NOP 17	1.0183	1.00699	-0.01131	1.11%
NOP 18	1.01303	1.00153	-0.0115	1.14%
NOP 19	1.01308	1.0016	-0.01148	1.13%
Westcott Street 11kV-1	1.01143	1.01103	-0.0004	0.04%
Westcott Street 11kV-2	1.01143	1.01103	-0.0004	0.04%