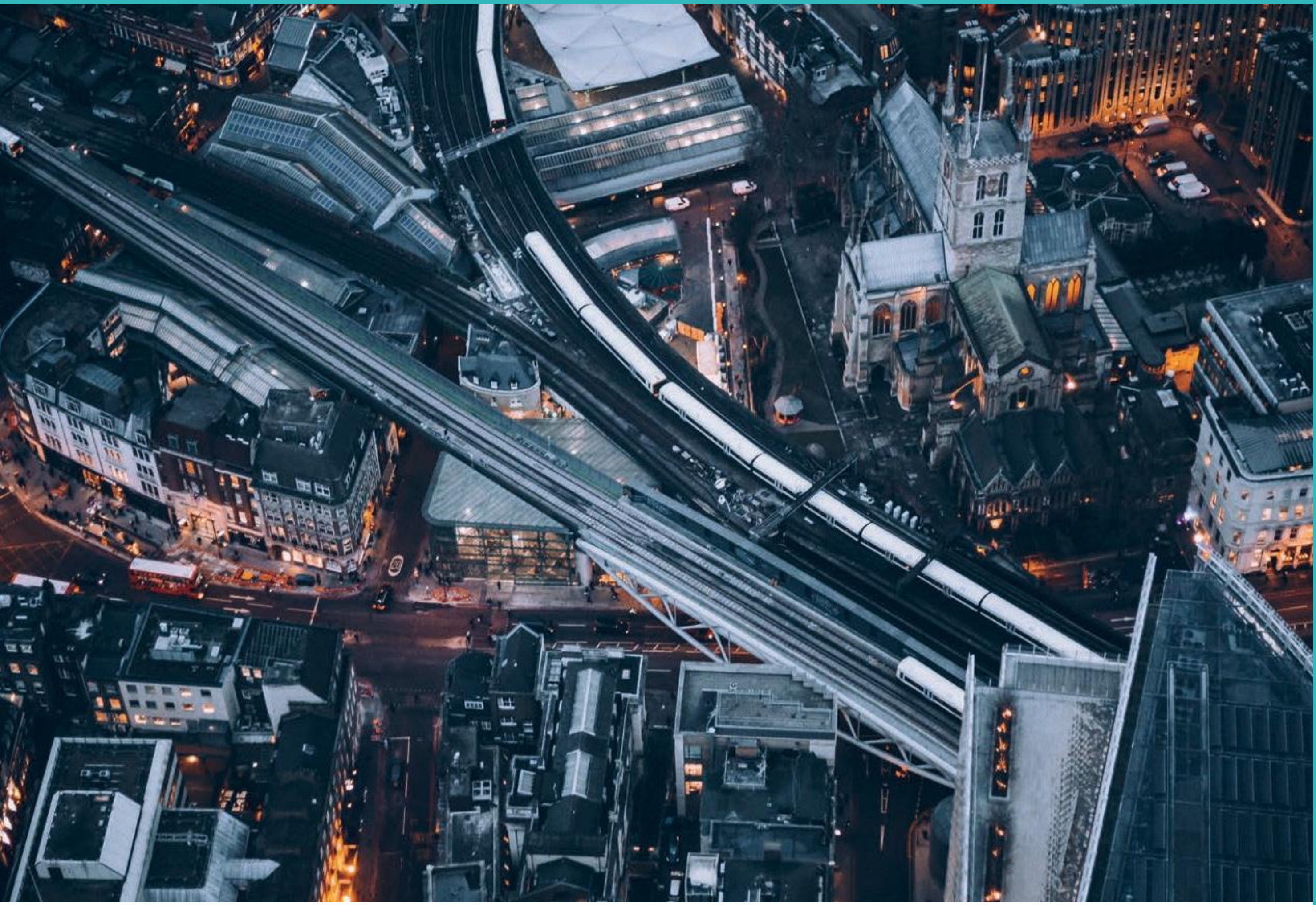

REPORT

SILVERSMITH - PowerFactory Network Study Results

Prepared for: National Grid

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EA Technology Limited, Capenhurst Technology Park, Capenhurst, Chester, CH1 6ES;
Tel: 0151 339 4181 Fax: 0151 347 2404

http://www.eatechnology.com

Registered in England number 2566313

Executive Summary

Background to the Project

Great Britain is undergoing a transition to a system where Low Carbon Technologies (LCTs) are becoming increasingly prevalent. Across National Grid's[1] four distribution licence areas (East Midlands, West Midlands, South West and South Wales) many energy customers are becoming increasingly involved in the energy system, transitioning from being simply energy consumers to instead becoming energy prosumers by installing distributed generation (DG), most commonly solar photovoltaics (PV). Other LCTs such as heat pumps, Electric Vehicles (EVs) and Battery Energy Storage Systems (BESSs) are also forecast to witness vast uptake rates over the next few decades. The uptake of LCTs will have a profound effect on the electricity network; it being carefully managed to facilitate the uptake of LCTs by resolving network constraints in the most cost-effective manner.

To efficiently manage the evolution of the network, it is important to extract as much value as possible from the existing assets. This report presents analysis carried out using DIgSILENT PowerFactory to investigate in detail the impact of LCT uptake on 3 different network archetypes:

- Dense Urban – Representing networks in densely populated areas including multi-occupancy buildings
- Urban – Representing networks on the outskirts of a town or city, containing a mixture of terraced, semi-detached, and detached properties.
- Rural – Representing a small rural village supply via a mixture of underground cables and overhead lines

The networks were modelled with different levels of LCT uptake based on National Grid's 2021 Distribution Future Energy Scenarios (DEFS) at defined points to cover:

- 48 half-hour demand profiles for a typical winter and summer day
- Steady Progression, National Grid's Best View, and Leading the Way scenarios
- Uptake levels in 2028, 2033, 2040 and 2050

This analysis has identified the different challenges around voltage constraints as a result of increasing levels of PV generation along with electrification of heat and transport. Alongside this there are also several thermal circuit issues as a result of increasing demand. The next phase of this project will then investigate the impact different novel solutions can have to reduce or mitigate the constraints and increase LCT uptake along with additional benefits they may bring and to which network type the greatest benefits are realised.

Conclusions

The following conclusions have been made during the delivery of these studies and associated report.

C1. The Dense Urban network is more likely to experience breaches in thermal capacity significantly before statutory voltage limits are breached.

C2. Solutions which may become necessary for the Dense Urban network will favour those which can reduce circuit loading, particularly during the winter evening peak periods.

C3. In the Urban Network, higher levels of PV generation and longer feeders than the Dense Urban network shows that statutory upper voltage limits (+10%) could begin to be breached from 2033.

[1] National Grid Electricity Distribution, part of the National Grid group, were previously known as Western Power Distribution and renamed in September 2022.

C4. In the Urban Network, thermal loadings begin to become overloaded during winter peak from 2033 (Leading the Way) and 2040 (Best View) at which point some intervention would be necessary to continue supporting LCT uptake.

C5. For the Urban Network, interventions which reduce the thermal loading during the winter whilst also improving voltage management in the summer will be necessary.

C6. For the Rural Network, some customers will experience high voltages breaching the upper statutory voltage limits during peak PV export from 2040 onwards.

C7. For the Rural Network, although circuit loadings remain well below their 100% rating the total loading on the supply transformer will begin to be exceeded for the highest LCT uptake scenarios (Leading the Way).

C8. In some situations, circuit loading remains within thermal limits but in Rural networks voltage issues may begin to occur at different points along the feeder.

Recommendations

During the delivery of this study, there are several recommendations which National Grid and other distribution networks may wish to consider with regards to the impact of increasing LCT uptake levels.

R1. Investigate the load profiles associated with heat pumps, their diversity and potentially impact surrounding cyclic rating assumptions of transformers, cables, and overhead lines.

R2. Investigate technology and software solutions to measure or estimate the voltages at customers terminals along a feeder.

Contents

1. Definitions

Term	Definition
EV	Electric Vehicle
pu	Per unit
LCT	Low Carbon Technology
LV	Low Voltage
DFES	Distribution Future Energy Scenarios
HV	High Voltage
PV	Solar Photovoltaics

2. Background and Introduction

Great Britain is undergoing a transition to renewable and distributed energy. Many energy customers are becoming more involved in the energy system, transitioning from simply being electricity consumers to electricity prosumers. This is being led through the electrification of transport (i.e. electric vehicles) and heating (i.e. heat pumps) along with the continued growth in distributed generation, most commonly solar photovoltaics (PV). LCTs such as Electric Vehicles (EVs) and heat pumps are forecast to witness vast uptake rates over the next few decades. The combined effect of these technologies will have a profound effect on the electricity network. Large numbers of these technologies will be deployed on the Low Voltage (LV) networks, which will place significant additional demand on it, in many cases beyond which the network was designed for. National Grid[2] manage the LV network across their licence areas in the East Midlands, West Midlands, South West, and South Wales, and have commissioned this study to help increase their understanding of the challenges and opportunities for new technologies across their LV network.

As National Grid transitions towards management of an active LV network, this must be achieved in a manner which enables customers to install LCTs at the foreseeable uptake rates. This has to be achieved while minimising costs to consumers resulting from network augmentation but continuing to provide a safe and reliable supply of electricity. Additionally, network management should be fair to all electricity consumers, regardless of whether they own LCTs or not. It is therefore important to maximise value extracted from the existing LV network in order to minimise network costs arising from network reinforcement.

The purpose of this report is to present power system analysis carried out on 3 LV networks selected in National Grid's license areas. These networks were selected to represent rural, urban, and dense-urban environments to understand the impact LCT uptake will have on these areas. This first report identifies the challenges each network is likely to face as a result of LCT uptake onto which further analysis will be carried out in subsequent reports to detail the potential benefits new technologies could bring to the network.

This report focusses in detail on the constraints experienced on the selected networks and is focussed on providing the detailed analysis based on an actual network to support the findings of the whole network parametric based on analysis of the EA Technology, Transform Model® [1]. To ensure consistency between reports, assumptions with regards to LCT uptake scenarios and demand/generation profiles were based on the same National Grid, DFES 2021 scenarios [2].

[2] National Grid Electricity Distribution, part of the National Grid group, were previously known as Western Power Distribution and renamed in September 2022.

3. Network Selection and Modelling Assumptions

3.1 Network Selection

Models were produced in PowerFactory to represent three different types of network to understand the impact different LCT uptake, network design and capacity has on constraints. It is envisaged that following this, when then considering different innovative solutions there may be differences in the benefit and value they can bring to different network types.

3.1.1 Dense Urban

The Dense Urban archetype was selected to include feeders where the customers include a number of multi-occupancy buildings. In the case selected there is a 15 storey tower block which has 90 individual dwellings within and a number of small flats/maisonettes where there are two storeys with one address on the ground floor and the second address on the first floor, other properties within the model include buildings with a number of shops on the ground floor with residential properties above, the residential properties being accessed via staircases at the rear of the building. The network model is shown in Table 3Figure 1 below. The lengths of main and branch conductors and the number of customers per feeder are shown in Table 1below.

Table 1 Dense Urban – Circuit length and customer numbers by circuit

Circuit number	Main Length (m)	Branch Length (m)	Customers
-3	75	45	12
10	94	77	100
3	408	174	60
7	74	-	Varies with EV take-up

3.1.2 Urban

The Urban archetype was selected to include a housing estate in the outskirts of a town or city. The properties in the network selected are a mixture of terraced, semi-detached, and detached properties. There are no commercial or industrial properties included within the network selected. There are 4 feeders associated with the substation and around 300 customers associated with these 4 feeders. The network model is shown in Table 3Figure 2 below. The lengths of main and branch conductors and the number of customers per feeder are shown in Table 2 below

Table 2 Urban – Circuit length and customer numbers by circuit

Circuit number	Main Length (m)	Branch Length (m)	Customers
2	269	71	30
3	395	655	132
4	430	254	74
5	367	379	70

3.1.3 Rural

The Rural archetype was selected to represent a small rural village supply. The substation has a smaller capacity ground mounted transformer fed from 11kV overhead lines. The network has a mixture of underground and overhead lines. There is a mixture of commercial and residential properties within the village. The network model is shown in Table 3Figure 3 below. The lengths of main and branch conductors and the number of customers per feeder are shown in Table 3 below.

Table 3 Rural – Circuit length and customer numbers by circuit

Circuit number	Main Length (m)	Branch Length (m)	Customers
-1	181	-	11
-2	140	-	20
2	261	38	19
4	152	-	1
5	204	185	13

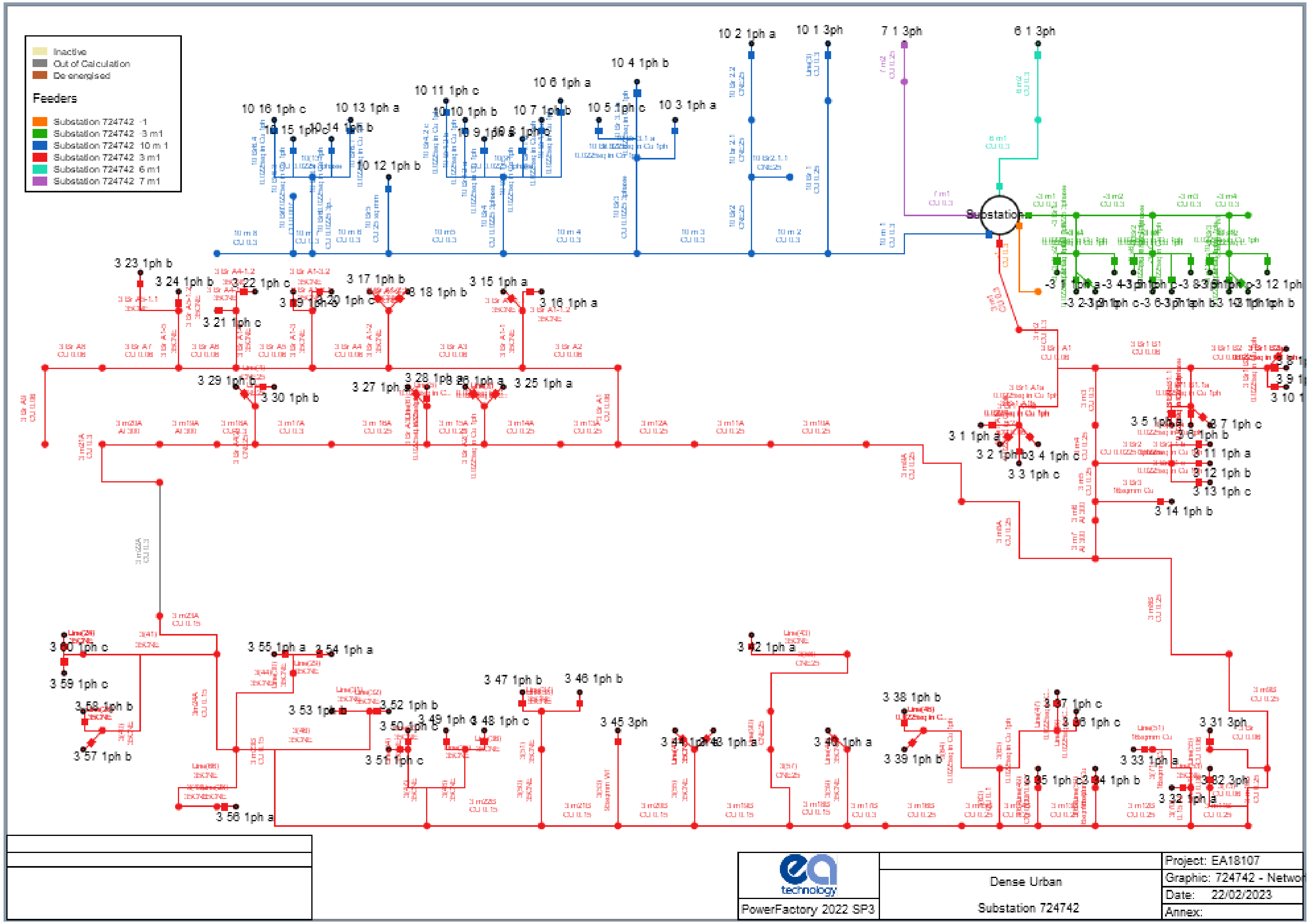

Figure 1 Dense Urban Network Model

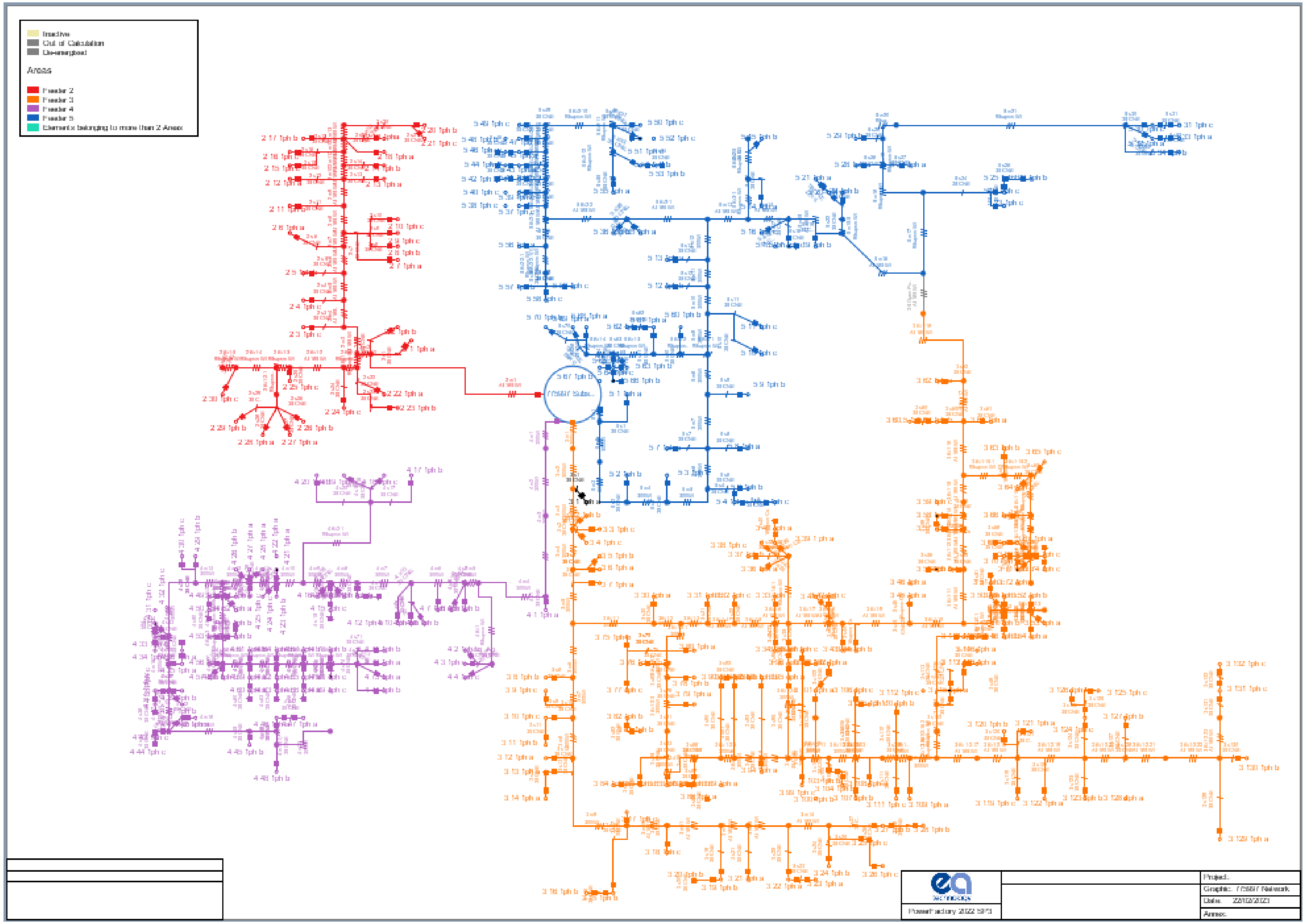

Figure 2 Urban Network Model

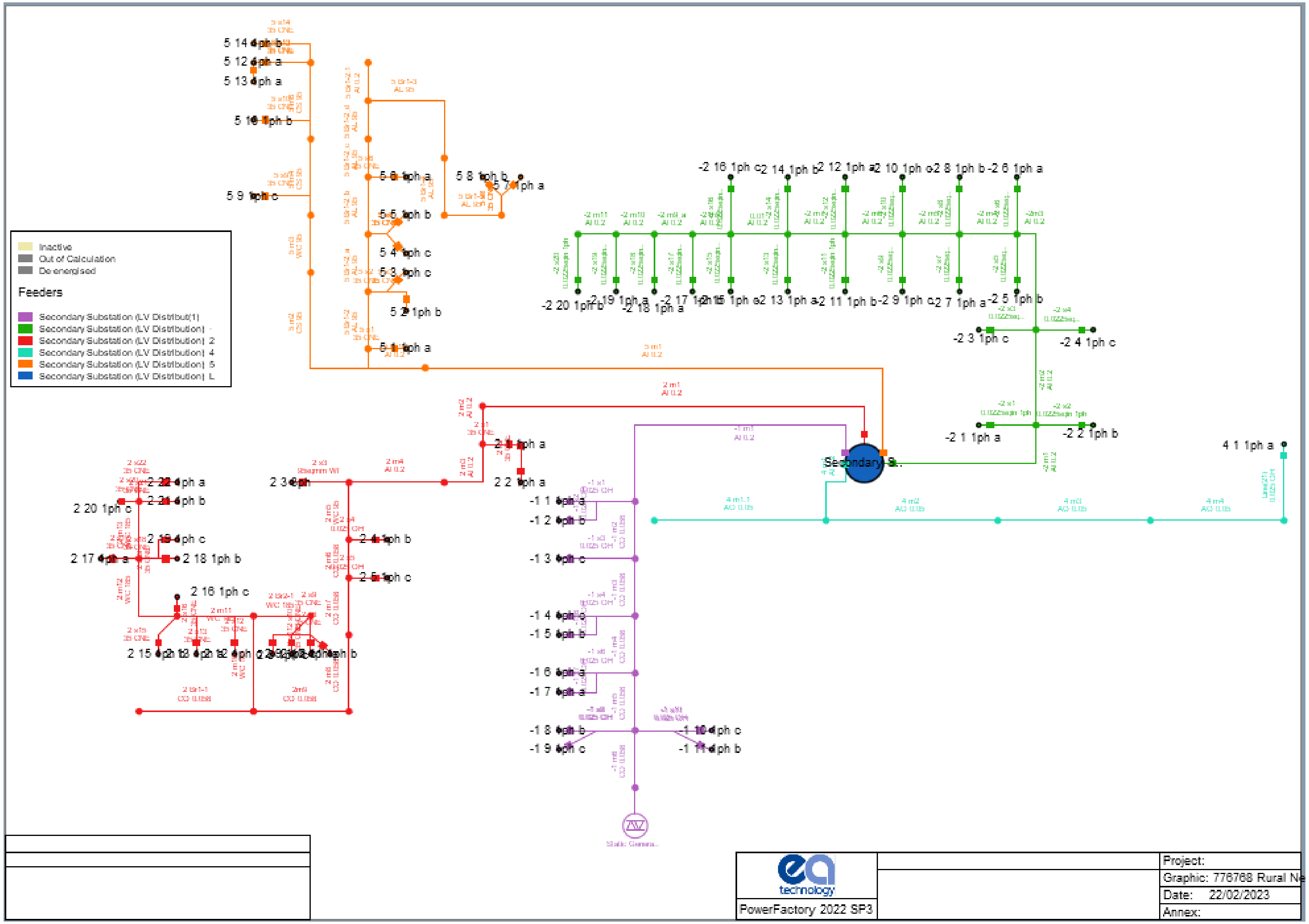

Figure 3 Rural Network Model

3.2 Modelling Assumptions

The following assumptions were made when building and carrying out analysis on the selected LV networks:

3.2.1 Initial Assumptions

- Data and network details associated with selected networks were obtained from National Grid's ConnectLV data models. Where there were gaps or missing data this was augmented with alternative sources or appropriate assumptions.
- The HV side of the transformer was connected to an 11kV grid infeed which acted as the slack busbar. This provides power to the loads or absorbs exported generation output whilst maintaining the voltage at the defined level.
- The 11kV network operating at 1.0pu
- The HV/LV transformers were based on 11kV/433V nominal transformer ratio
- Transformers have off-load tap changers covering -5% to +5% in 2.5% steps and default tap positions were +2.5%
- Steady state statutory voltage limits are +10% and -6% of nominal, 230V
- Circuit loading must remain below 100% and ratings are assumed to already take into consideration cyclic rating allowances.
- The profiles for the non-LCT loads and the individual LCTs are based on the data provided in the DFES, both winter and summer profiles were employed [2].
- For the PV generators the winter output has been assumed to begin and end at around sunrise and sunset on the winter solstice being the shortest day of the year and has been assumed to peak at 10% of the value assumed for the summer peak output.
- Studies are run using quasi-dynamic studies covering a single day through 48 half hour steps. Load flow studies can converge with a range of different conditions and therefore if not carefully controlled can reflect non-realistic consecutive half hour periods. To avoid this, convergence tolerances were set to be iterative and closely managed to ensure the extreme operating points were captured and representative.

3.2.2 Further Model Refinement

Initial load flow studies with only the non-LCT loads applied to the networks showed that the voltage operated at a level which exceeded the statutory minimum. This is in part a result of the reduction in the level of demand both at peak and minimum expected under the DFES profiles compared to demands historically used in the design of LV networks. With a standard distribution transformer having a nominal ratio of 11kV/433V for the phase-to-phase voltage. The typical installation has traditionally been set to operate with these transformers at +2.5% tap position boosting the LV no load voltage to 256.25V (+11.4%) for a HV input voltage of 11.0kV.

Such a voltage is not necessarily sufficient to cause PV generators to shut down, but it does mean that any export will drive the voltage still higher outside of the statutory limits. The overvoltage setting applied to PV installations is 264V which is 230V +15%. The location of the inverter relative to the point of connection to the distribution network can affect when an overvoltage protection operation, there is an expectation of a permissible voltage drop/rise within a customer's installation of up to 3%. With the inverter installed remote from the point of connection the permissible voltage rise within the installation pushes the voltage towards the operation of the overvoltage protection.

For this reason, the transformer tap position was lowered to nominal at the beginning of the scenario studies.

3.3 DFES Scenarios

The studies examine the differences between 3 different scenarios (Steady Progression, Leading the Way, National Grid's Best View) at 4 different points; 2028, 2033, 2040 and 2050. One of the key issues regarding the deployment of LCTs within the network is how their adoption increases over time and where this occurs. To avoid making assumptions which are either too pessimistic, that they all connect at the remote end of a single feeder, or too optimistic that they all connect evenly spread across the phases and the feeders and over the length of the feeders, the following assumptions have been made for the way in which individual LCT will deploy to the network with time.

- The numbers of a LCT for each study stage for individual substation modelled are determined from the anticipated percentage penetration calculated from the number of installations detailed in the DFES. To ensure consistency, these were derived from the LV2, LV6,and LV10 archetypes used in the Transform analysis and scaled based on the numbers of customers in these models [1].
- The number of LCTs applied at each stage are based on the relative numbers of customers per circuit so each circuit gets approximately the same proportional deployment.
- The LCTs deployed on each circuit are clustered at the ends of the main and/or the ends of branches. Placing customers towards the end of the feeders or at the end of branches has no adverse effects on the assessment of thermal capacity of the overall feeder but would likely indicate when voltage issues may develop with increased penetration. However, by not placing them all at the same location the very worst case (most pessimistic view) would not be fully examined.
- As the time series for each scenario progresses the numbers of each LCT increase at different rates for each scenario. It has been assumed that the early adopters of one LCT are more likely to be the early adopters of other LCTs. For example, in the 2033 stage where additional EVs are adopted they will be applied to a customer that only had a PV in the 2028 stage a new heat pump connection will be applied to a customer that had both PV and EV connections in 2028. Similar approaches are adopted at each stage of the study.

The subsections below show the expected number of LCT installations across the example networks for each of the DFES explored.

3.3.1 Dense Urban LCT Uptake

The Dense Urban network consists of multi-occupancy buildings both in terms of the 15-storey tower block and the smaller flats and maisonettes. The uptake of LCTs has been focussed on those customers not in the tower block where individual uptake is potentially more readily achievable. That said the individual uptake of PV in these kinds of properties will be limited as not every individual customer has roof directly above their dwelling. For this reason, the potential uptake under the more optimistic scenarios in later years is limited to a number below the target uptake and Figure 7 shows the uptake applied to this model.

In the case of the tower block individual LCT development is impractical. PV has been considered as a single installation on the roof of the building, heat pumps have not been considered and the development of EV charging has been implemented as a separate supply to the car park area whose magnitude of demand increases with time.

The following figures show the LCT uptake for the Dense Urban network covering PV, EV, and HP uptake over the modelling years (2028, 2033, 2040 and 2050).

Steady Progress

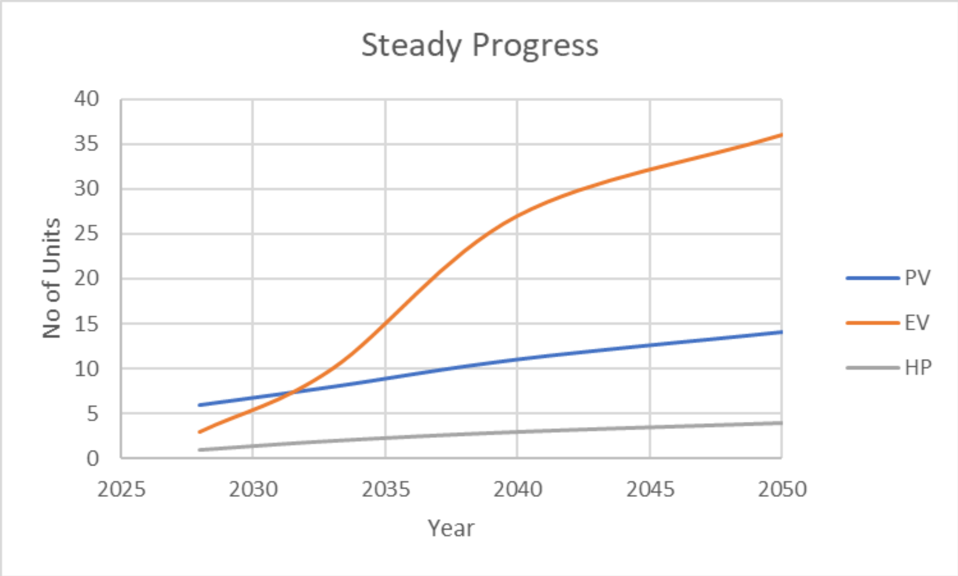

Figure 4 Dense Urban DFES 2021 LCT uptake applied – Steady Progress

Best View

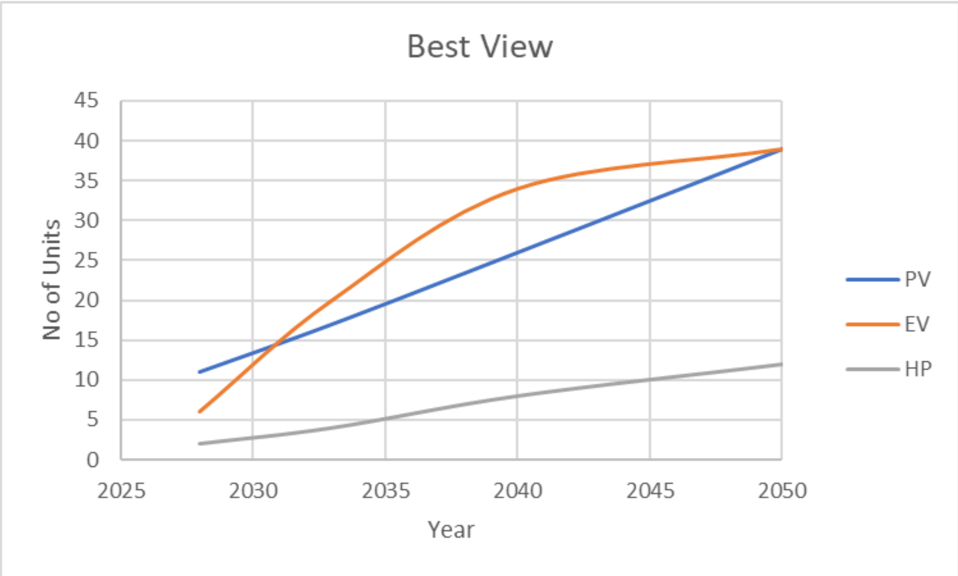

Figure 5 Dense Urban DFES 2021 LCT uptake applied – Best View

Leading the Way

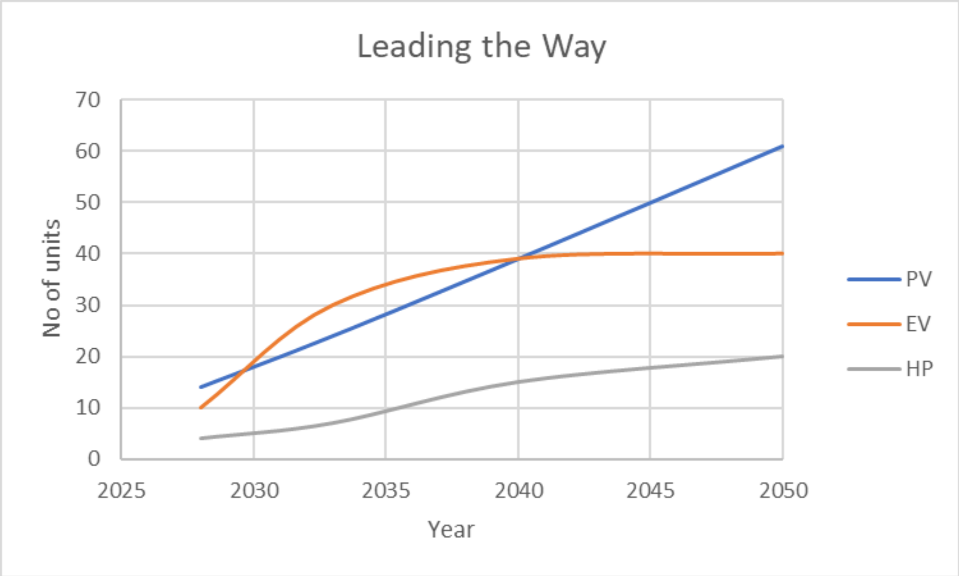

Figure 6 Dense Urban DFES 2021 LCT uptake applied – Leading the Way

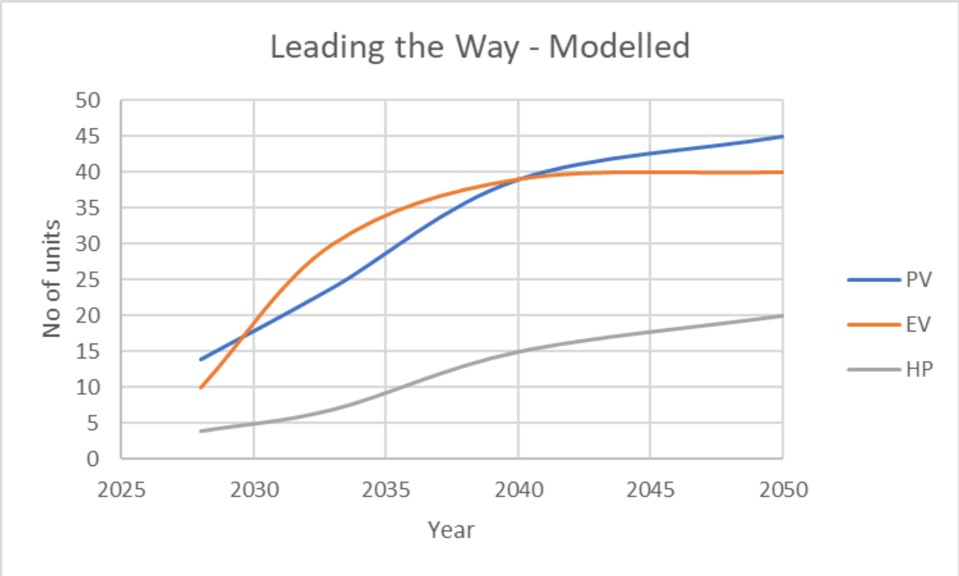

Figure 7 Dense Urban DFES 2021 LCT uptake applied – Leading the Way as modelled

3.3.2 Urban LCT Uptake

The Urban network includes a mixture of terraced, semi-detached, and detached properties covering a total of 300 customers across 4 feeders. There are no commercial or industrial properties captured within the network model.

The following figures show the LCT uptake for the Urban network covering PV, EV, and HP uptake over the modelling years (2028, 2033, 2040 and 2050). It is clear that in this network region, PV uptake particularly in the case of Best View and Leading the Way dominates with coverage of more than 50% of the properties by 2050.

Steady Progress

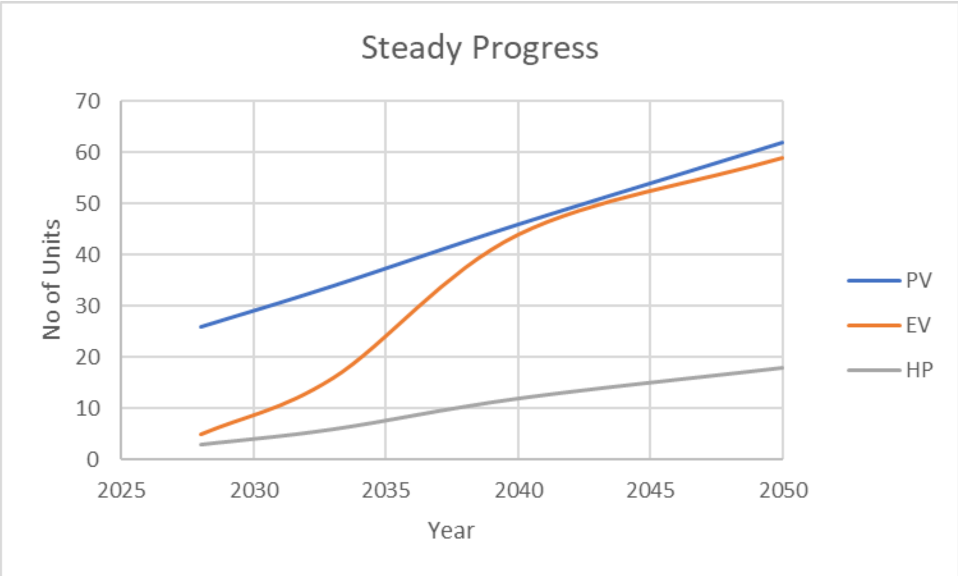

Figure 8 Urban DFES 2021 LCT uptake applied – Steady Progress

Best View

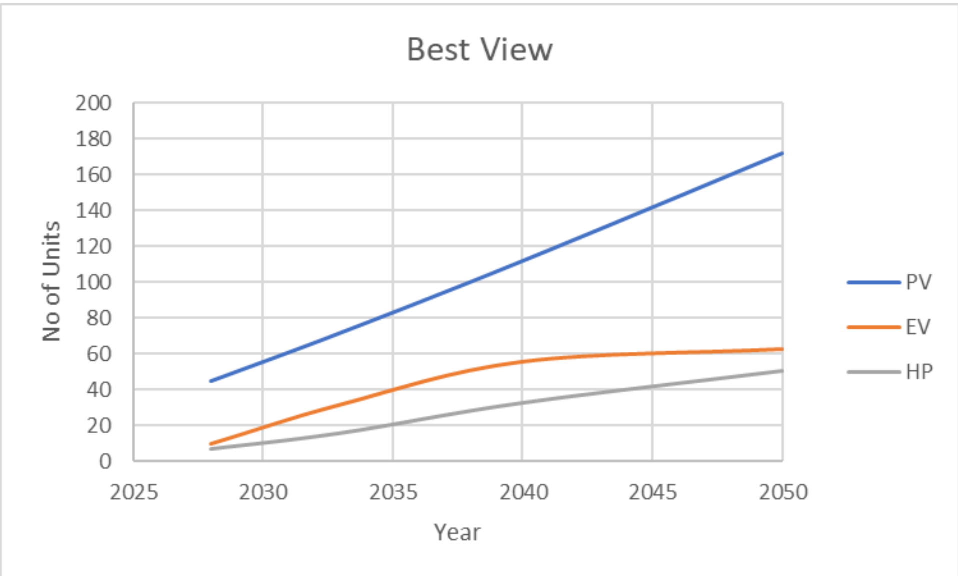

Figure 9 Urban DFES 2021 LCT uptake applied – Best View

Leading the Way

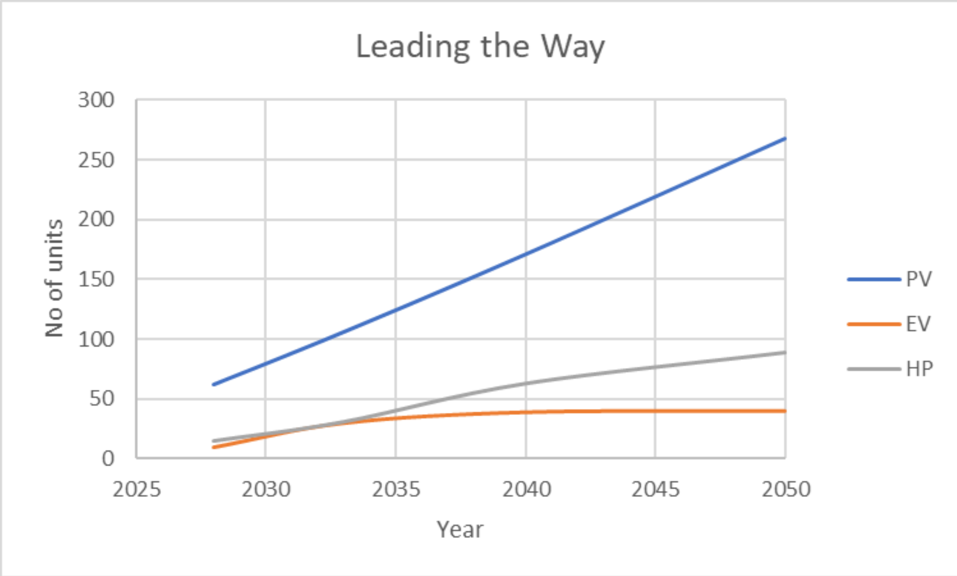

Figure 10 Urban DFES 2021 LCT uptake applied – Leading the Way

3.3.3 Rural LCT Uptake

The Rural network represents a small rural village supplying a mixture of commercial and residential properties within a village. These are supplied from a small capacity ground mounted transformer via a mixture of underground and overhead lines.

The following figures show the LCT uptake for the Rural network covering PV, EV, and HP uptake over the modelling years (2028, 2033, 2040 and 2050). In this case, EV dominates in all scenarios except Leading the Way but with similarly high levels of PV uptake.

Steady Progress

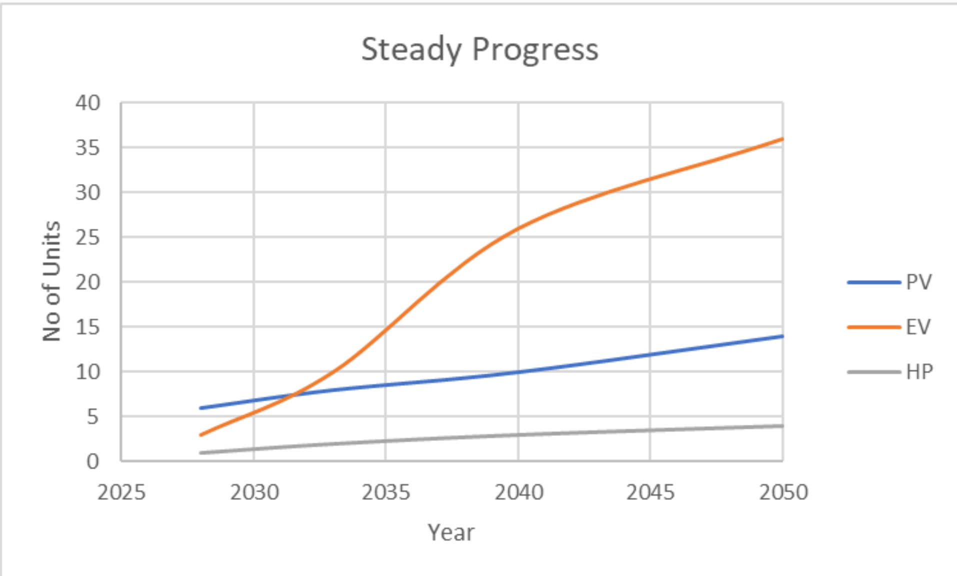

Figure 11 Rural DFES 2021 LCT uptake applied – Steady Progress

Best View

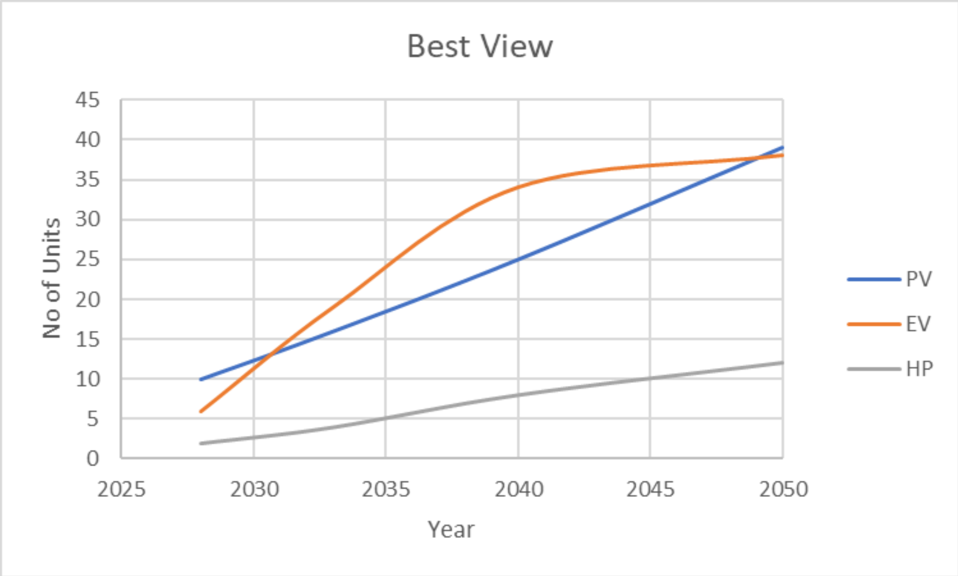

Figure 12 Rural DFES 2021 LCT uptake applied – Best View

Leading the Way

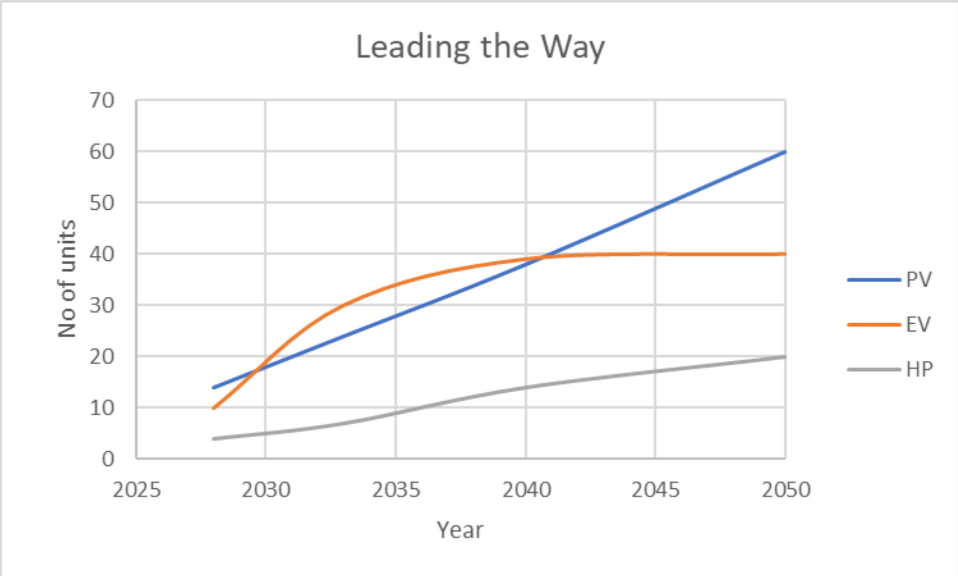

Figure 13 Rural DFES 2021 LCT uptake applied – Leading the Way

4. Dense Urban Results

This section presents the results for the Dense Urban network, to avoid repetition of the same results analysis is focussed on the Best View scenario and then results for the other scenarios (Leading the Way and Steady Progression) only included where these deviate.

The voltage profile plots show the voltage at each customer's point of connection during the 24 hour study window. The statutory requirements are for these voltages to remain below 1.1pu and above 0.94pu for all steady state operating conditions. The loading profile plots show the loading on each of the feeders supplied from the HV / LV substation and must remain below 100% of their rating.

4.1 2028

4.1.1 National Grid's Best View

Summer

Figure 14 shows the summer 2028 voltage profile in the Best View scenario. Voltage limits within a tight band, rising to just over 1.08p.u. in the middle of the day when solar PV generation is highest, and falling to approximately 1.07p.u. in the evening when consumer load is highest. At all times therefore voltages at customer sites are well within statutory limits.

Figure 15 shows the summer 2028 thermal profile in the Best View scenario. Loading remains well within thermal limits at all times, peaking on feeder 10 at 18:00 at approximately 30% of the thermal limit.

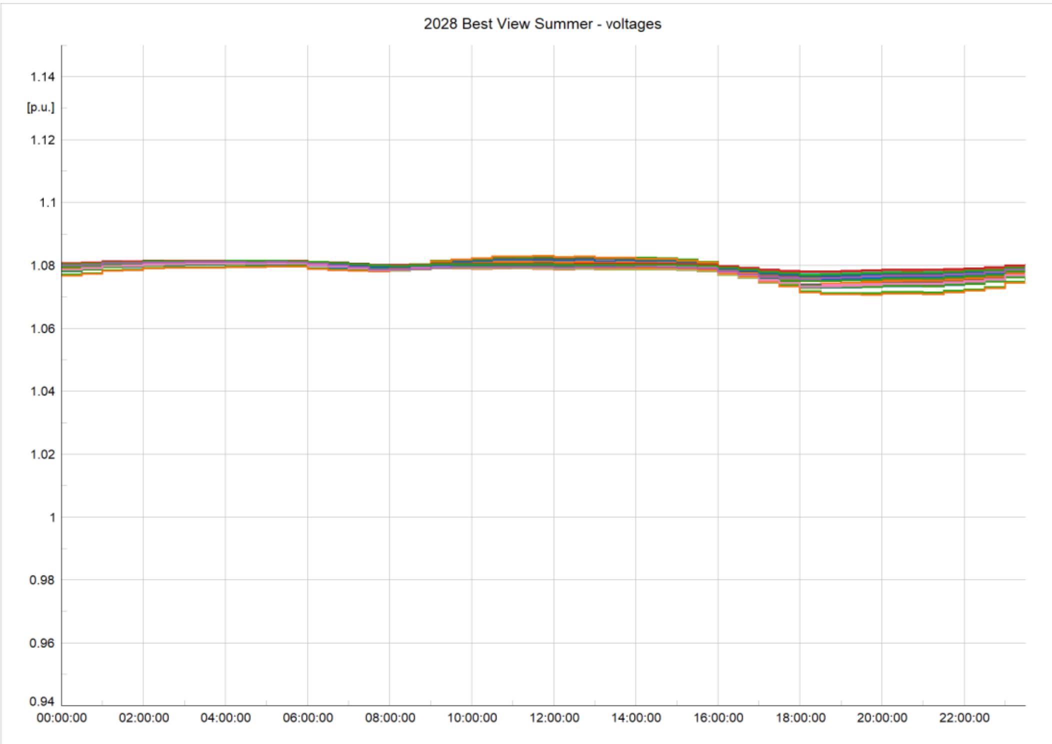

Figure 14 2028 Dense Urban Network Best View summer voltage profiles

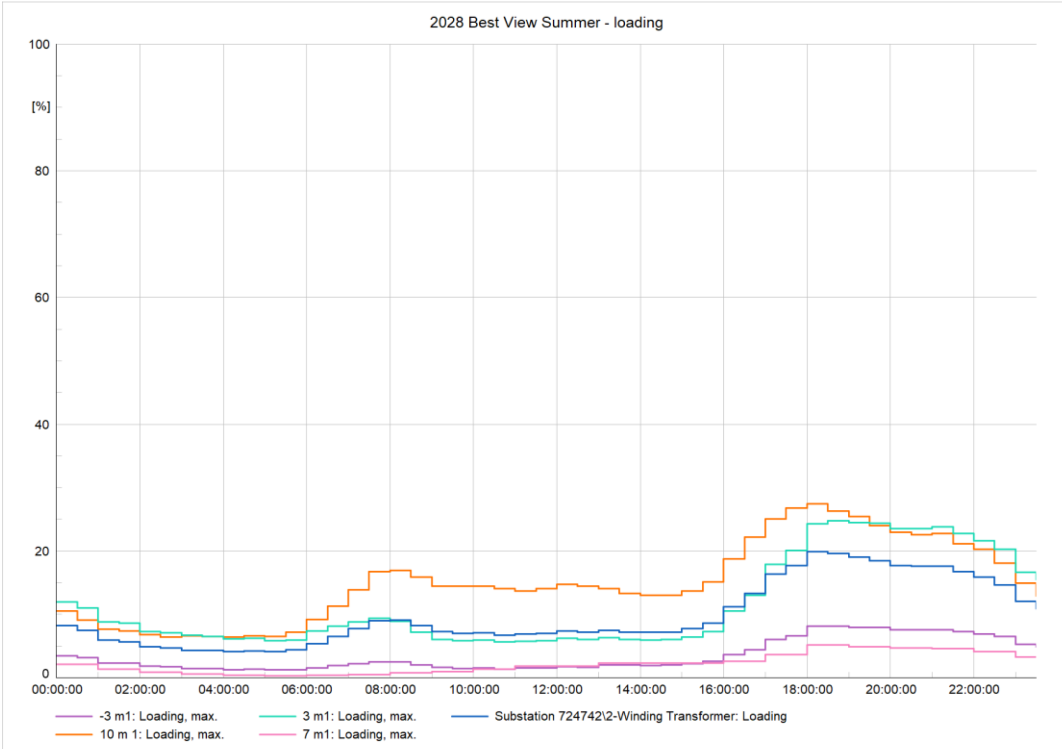

Figure 15 2028 Dense Urban Network Best View summer loading profiles

Winter

Figure 16 shows the winter 2028 voltage profile under the Best View scenario. Voltages at all customer sites remain well within statutory limits at all times, ranging between approximately 1.06p.u. to 1.08p.u.

Figure 17 shows the winter 2028 loading profile under the Best View scenario. Thermal loading stays well under the thermal limit across all feeders at all times, peaking at 40% of the thermal limits for feeders 10 and 3 at 18:00 in the evening peak.

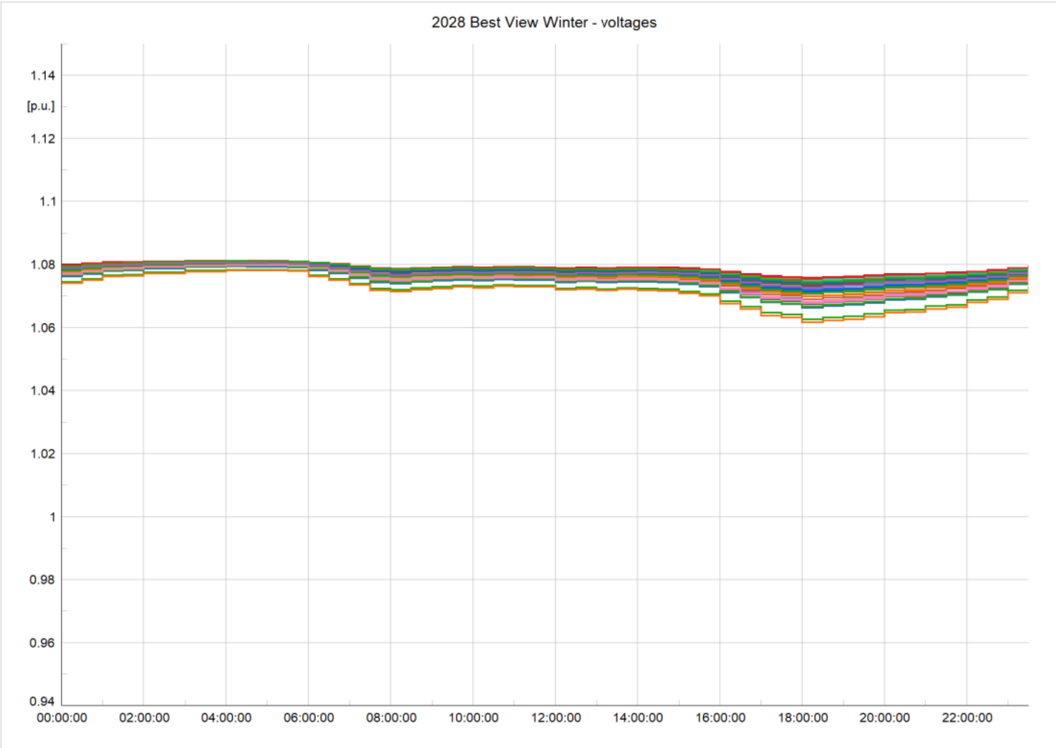

Figure 16 2028 Dense Urban Network Best View winter voltage profiles

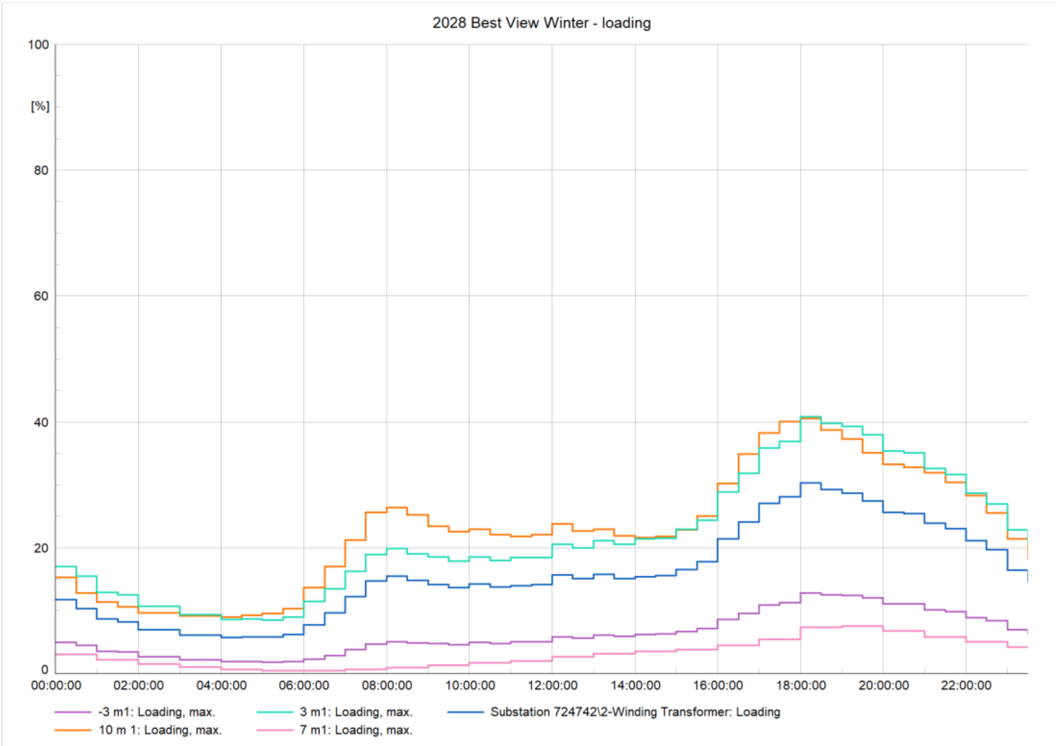

Figure 17 2028 Dense Urban Network Best View winter loading profiles

4.1.2 Steady Progression

Summer

As with the Best View scenario, voltages remain within a tight banding and do not breech statutory limits in the Steady Progress scenario. Similarly, the loading also does not approach thermal limits.

Winter

As in the Best View scenario voltages remain within a tight banding and do not breech statutory limits in the Leading the Way scenario. Similarly, the loading does not approach thermal limits, peaking at a slightly lower level than in the Best View case due to a lower uptake of LCTs (specifically heat pumps and EVs) in the Steady Progress scenario compared to the Best View scenario.

4.1.3 Leading the Way

Summer

As with the Best View and Steady Progress scenarios, voltages remain within a tight banding and do not breech statutory limits. Similar to the Best View and Steady Progress scenarios, thermal loading does not approach thermal limits. However, comparing Figure 18 to Figure 15 reveals a noticeably higher level of loading in the middle of the day when solar generation is highest, reflecting the higher uptake rates of solar PV compared with the Best View scenario.

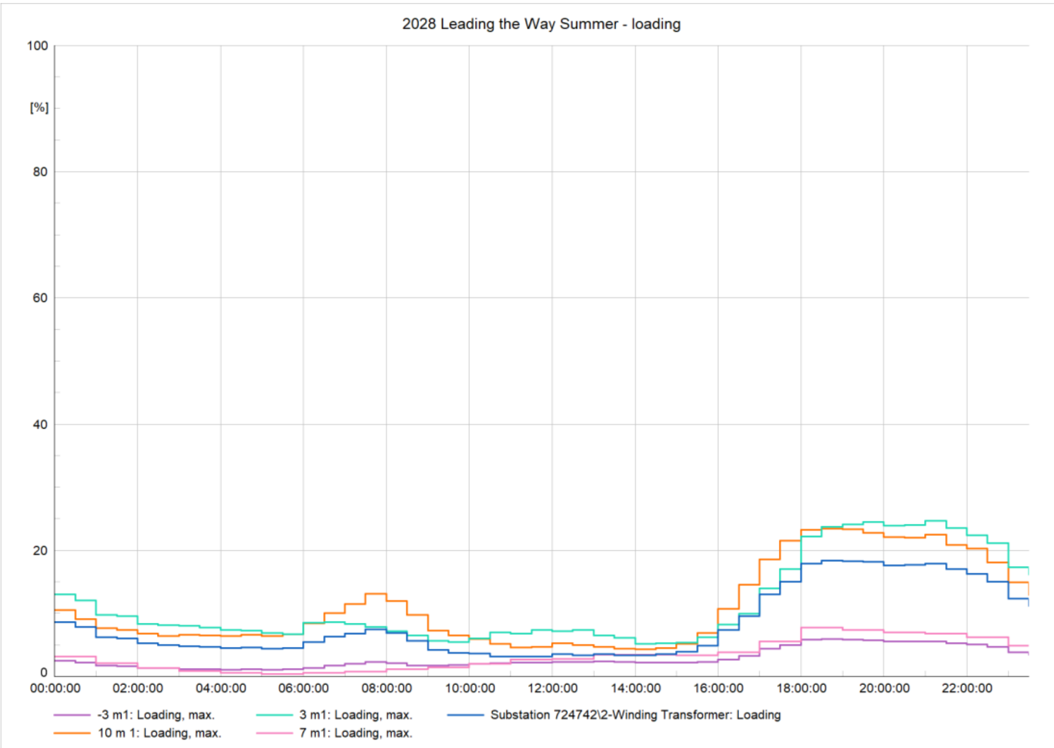

Figure 18 2028 Dense Urban Network Leading the Way summer loading profiles

Winter

As in the Best View and Steady Progress scenarios, voltages remain within a tight banding and do not breech statutory limits in the Leading the Way scenario. Similarly, the loading does not approach thermal limits, peaking on feeder 3 at approximately 42% of the thermal limit, a slightly higher level than in the Best View scenario due to a slightly higher level of LCT deployment.

4.2 2033

4.2.1 National Grid's Best View

Summer

Figure 19 shows the summer 2033 voltage profile under the Best View scenario. It shows that voltages at all customer sites remain well within statutory voltage limits, rising only slightly in the middle of the day when PV generation is at its highest. Plenty of voltage drop capacity is still available, with the network only dropping to approximately 1.07p.u.

Figure 20 shows the summer 2033 loading profile under the Best View scenario. Loading peaks at around 30% on feeder 3 in the evening when the domestic load, and LCT loads peak.

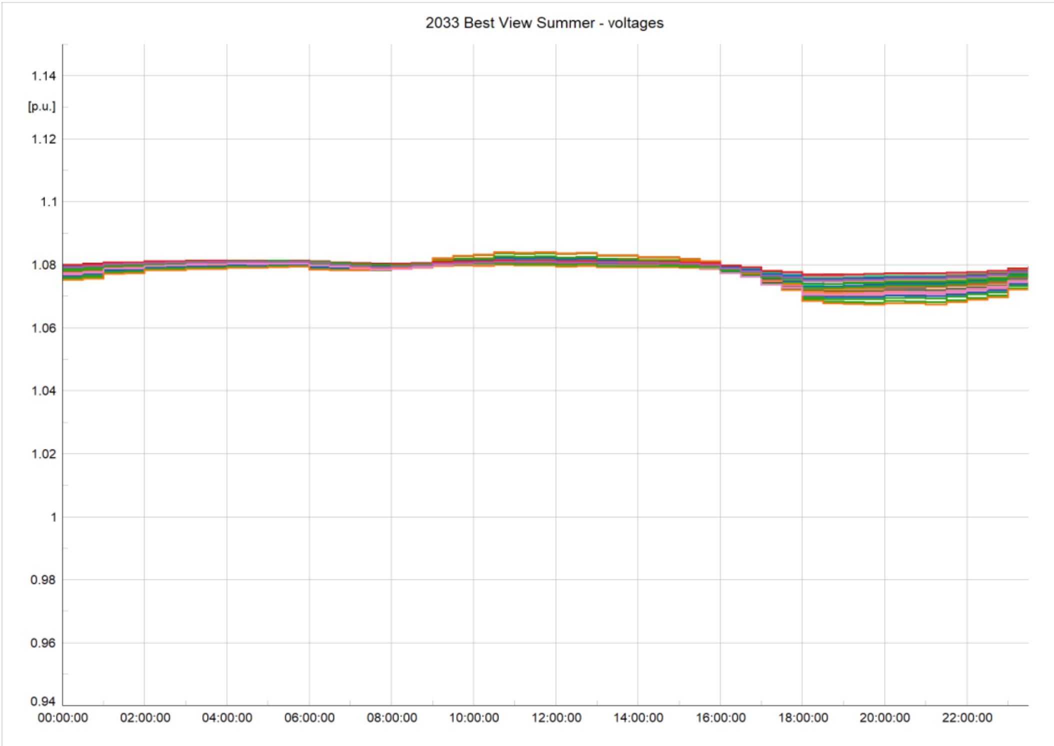

Figure 19 2033 Dense Urban Network Best View summer voltage profiles

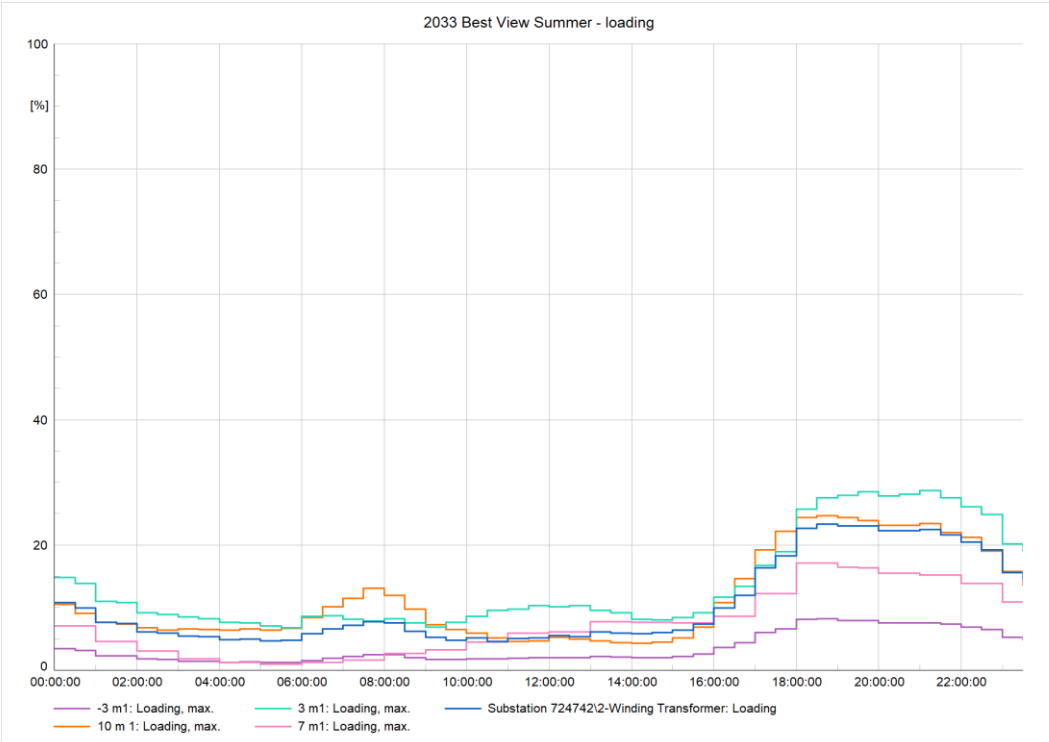

Figure 20 2033 Dense Urban Network Best View summer loading profiles

Winter

Figure 21 shows that similarly, the winter voltage and loading (Figure 22) results show the limits remain below voltage statutory and loading limits for all conditions. The voltages remaining tightly banded between 1.05 and 1.08p.u. The loading is also below the maximum loading condition.

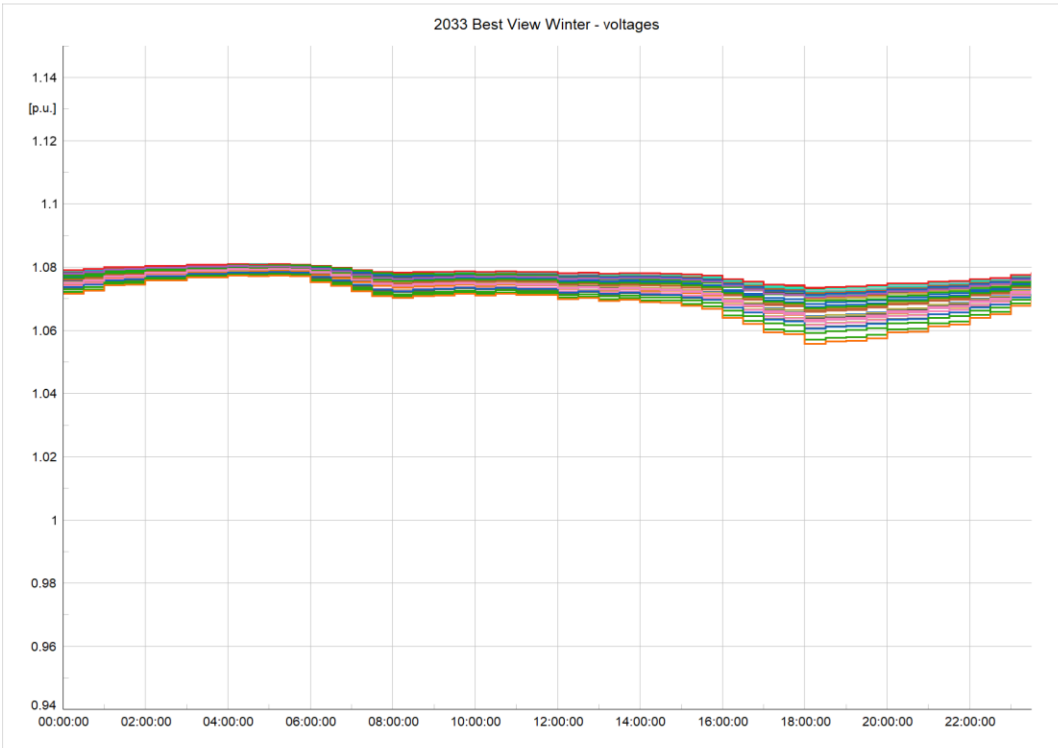

Figure 21 2033 Dense Urban Network Best View winter voltage profiles

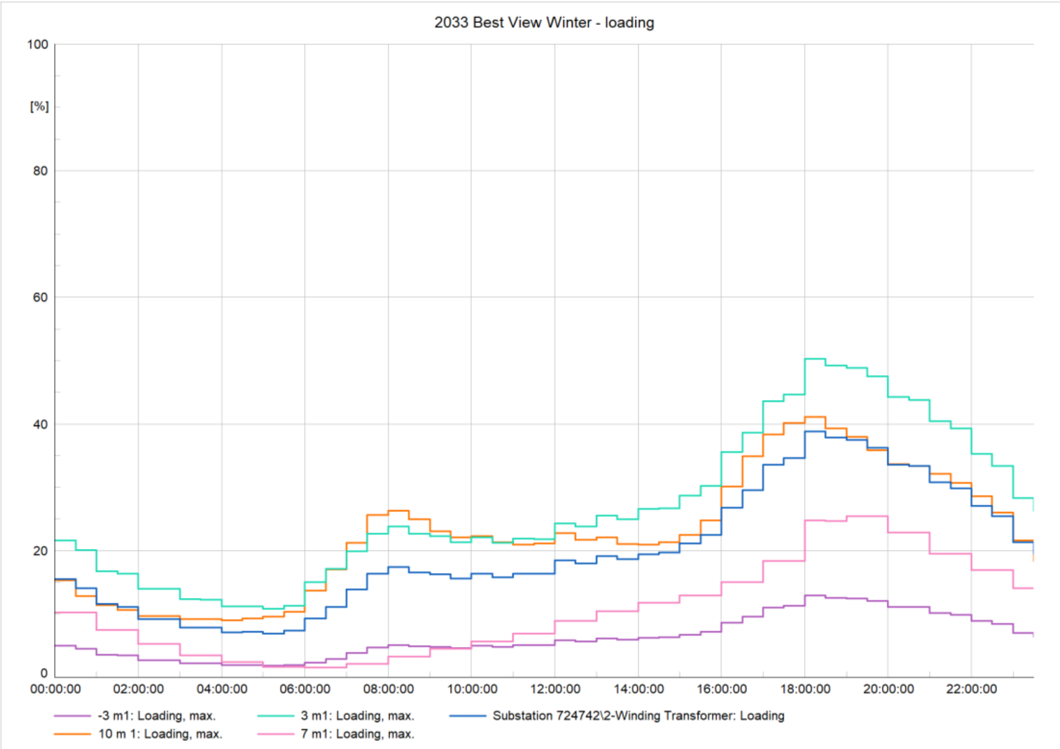

Figure 22 2033 Dense Urban Network Best View winter load profiles

4.2.2 Steady Progression

Summer

As with the Best View scenario, in the Steady Progress scenario voltages at all customer sites remain within statutory limits.

Loading in summer 2033 remains far below the thermal limit. Peak loading occurs on feeder 10 at 18:00 at approximately 30% of the thermal limit.

Winter

Voltage profiles in the Steady Progression scenario during 2033(Figure 23) show the voltages remain tightly banded around 1.05p.u. to 1.08p.u., still well within statutory limits as LCT uptake increases. Figure 24 shows the loading results during winter which remains low, peaking at around 40% on feeders 10 during the evening peak (17:00 to 19:00).

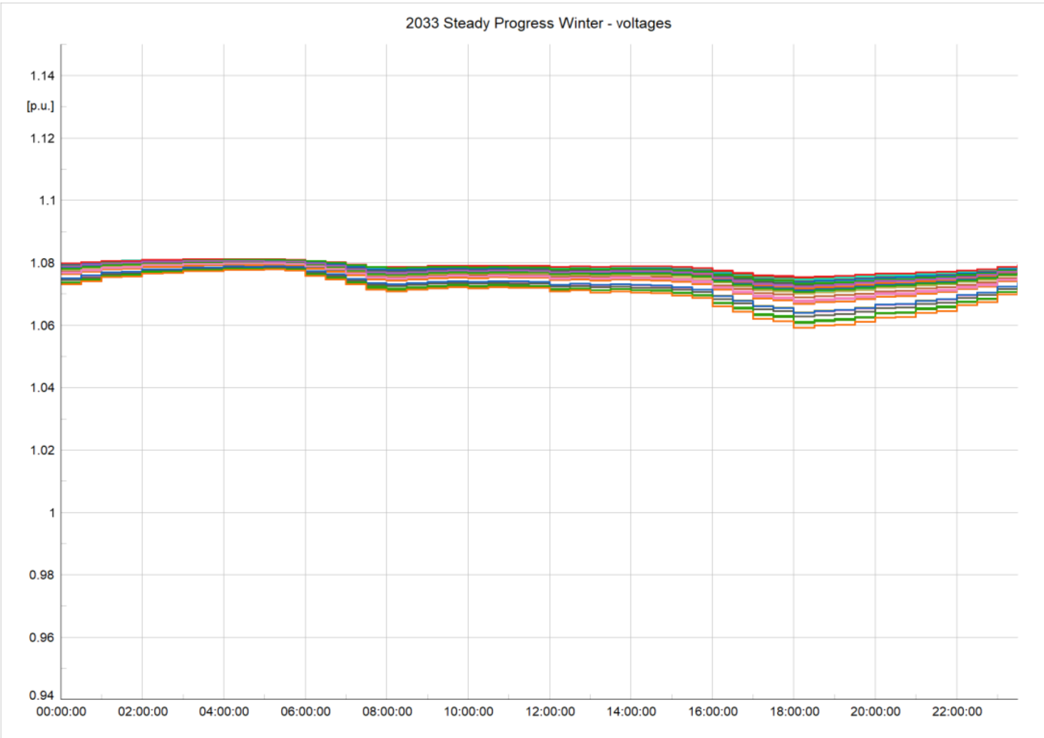

Figure 23 2033 Dense Urban Network Steady Progression winter voltage profiles

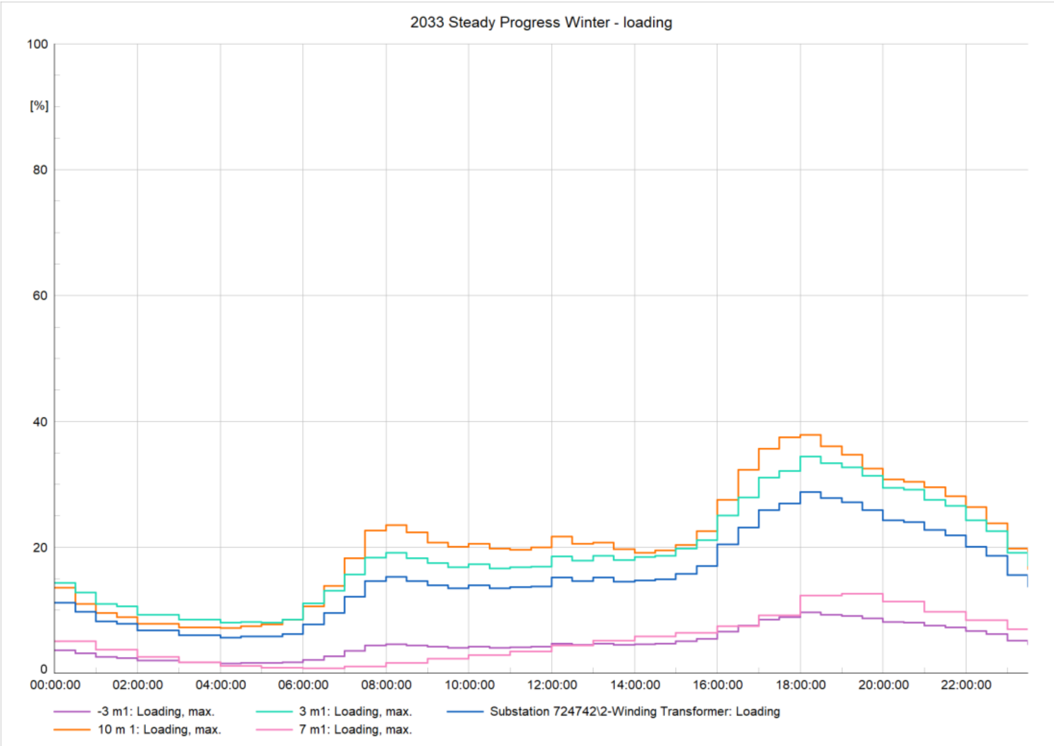

Figure 24 2033 Dense Urban Network Steady Progression winter loading profiles

4.2.3 Leading the Way

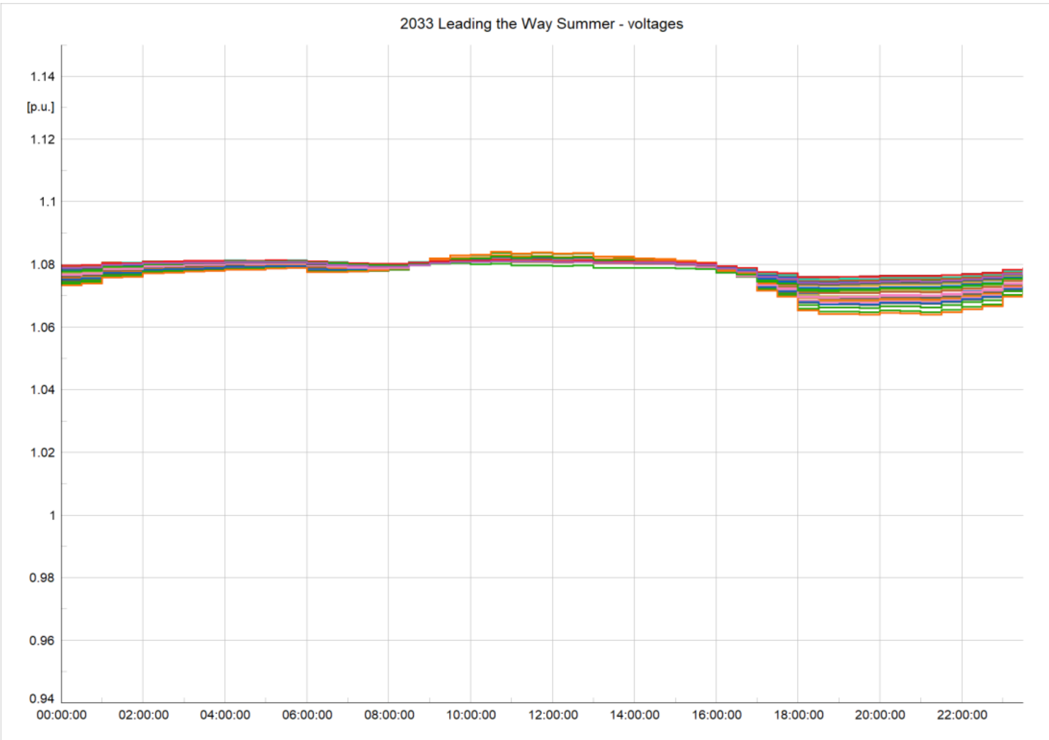

Figure 25 2033 Dense Urban Network Leading the Way Summer voltage profiles

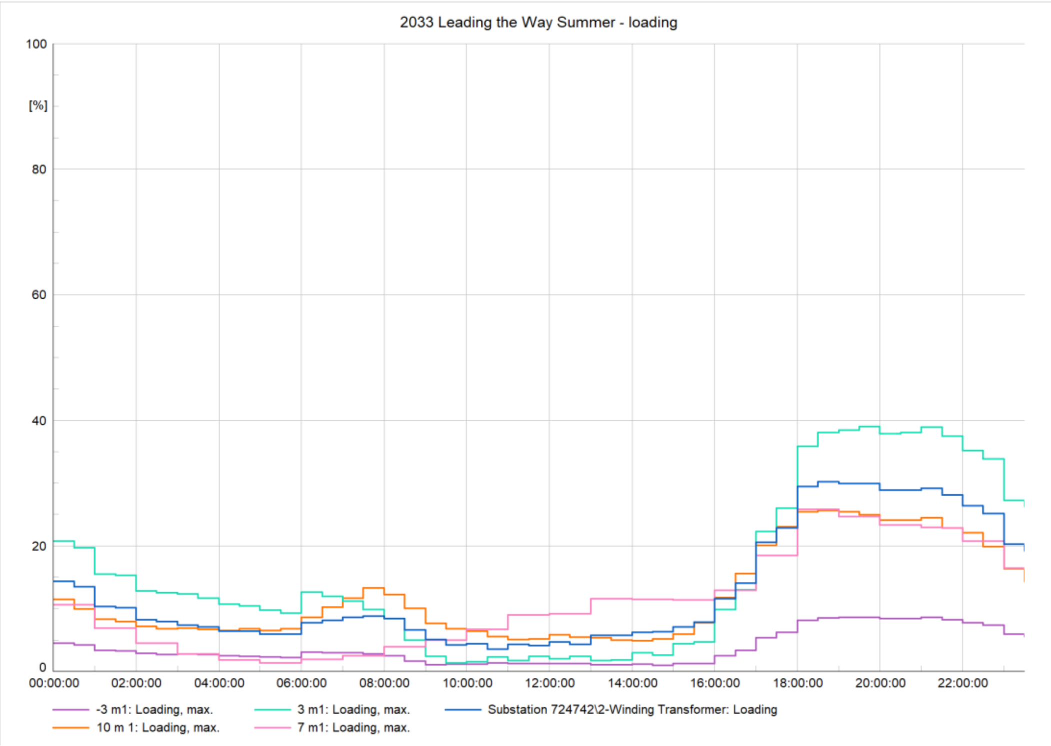

Figure 26 2033 Dense Urban Network Leading the Way Summer load profiles

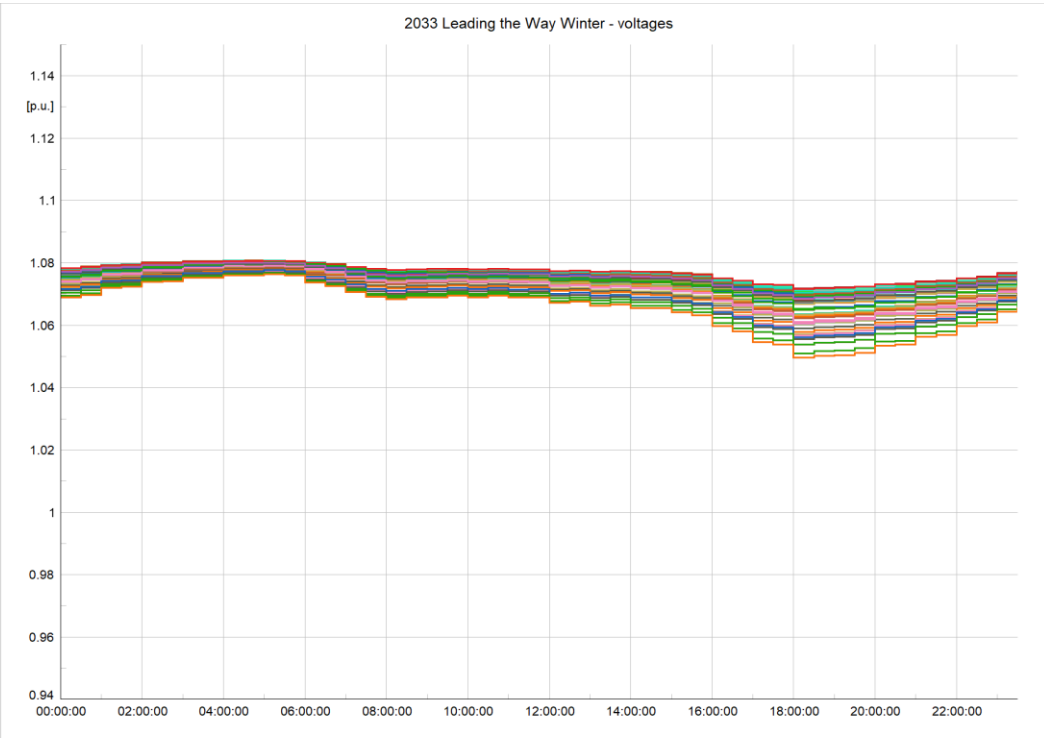

Figure 27 2033 Dense Urban Network Leading the Way Winter voltage profiles

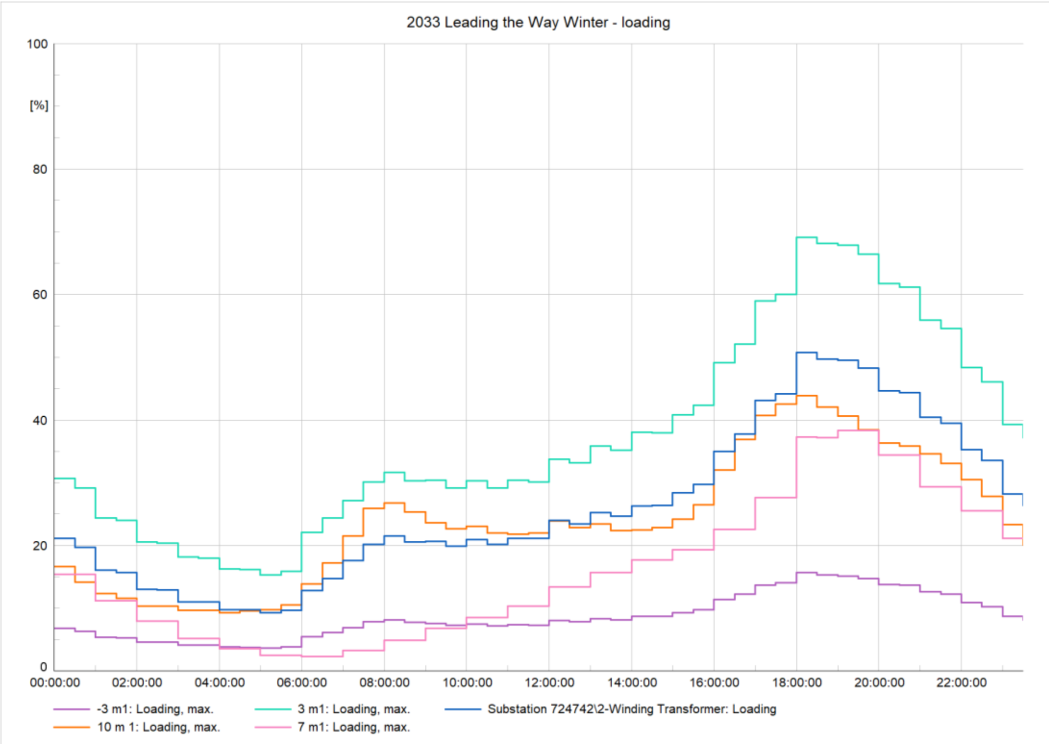

Figure 28 2033 Dense Urban Network Leading the Way Winter load profiles

4.3 2040

4.3.1 National Grid's Best View

Summer

The summer voltage profiles in Figure 26 below show a slight level of voltage rise during the daytime peak output. There is an increased level of voltage drop along the feeders in the evening compared to the voltage rise seen during the day under export from the PV installations. This is of course reflective of the increased loading within the feeders compared to the day-time net loading of these feeders.

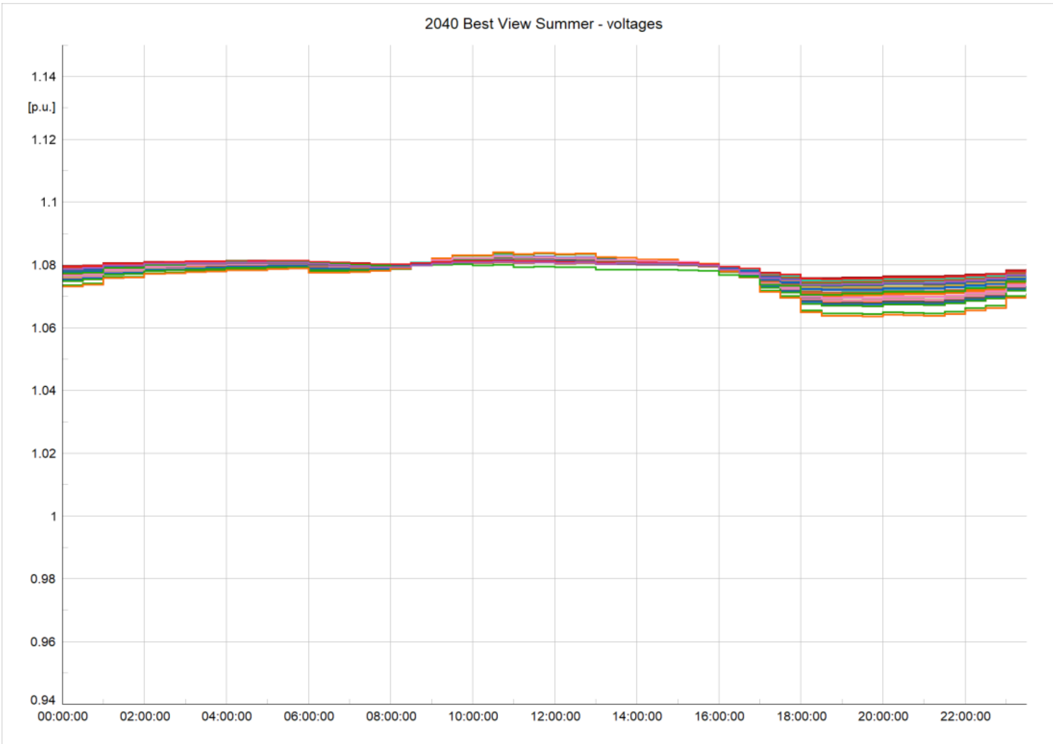

Figure 29 2040 Dense Urban Network Best View Summer voltage profiles

The loading profiles shown in Figure 27 below reflect the loading variations suggested by the variation in voltage profile noted above. The loadings are well within the capacity of the network feeders and the transformer.

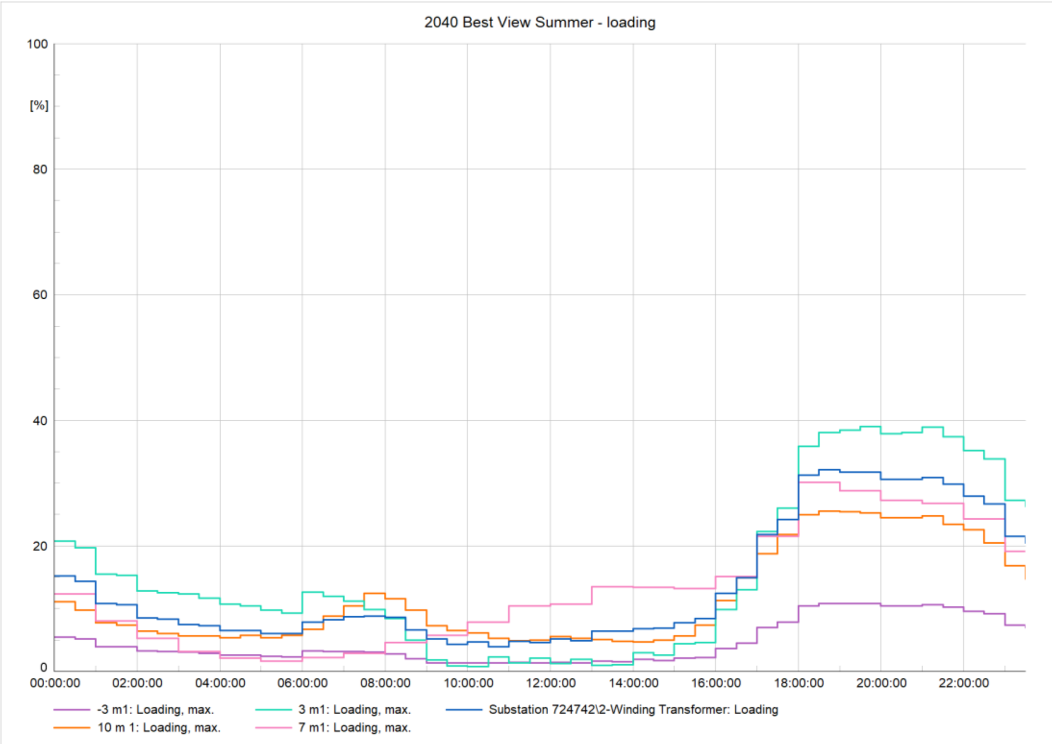

Figure 30 2040 Dense Urban Network Best View Summer load profiles

Winter

The following figures show the results for the Dense Urban network under the 2040 Best View scenario and show the voltages remain well within statutory limits. The circuit loading however (Figure 32) shows that feeder 3 approaches 70% of its rating at the peak.

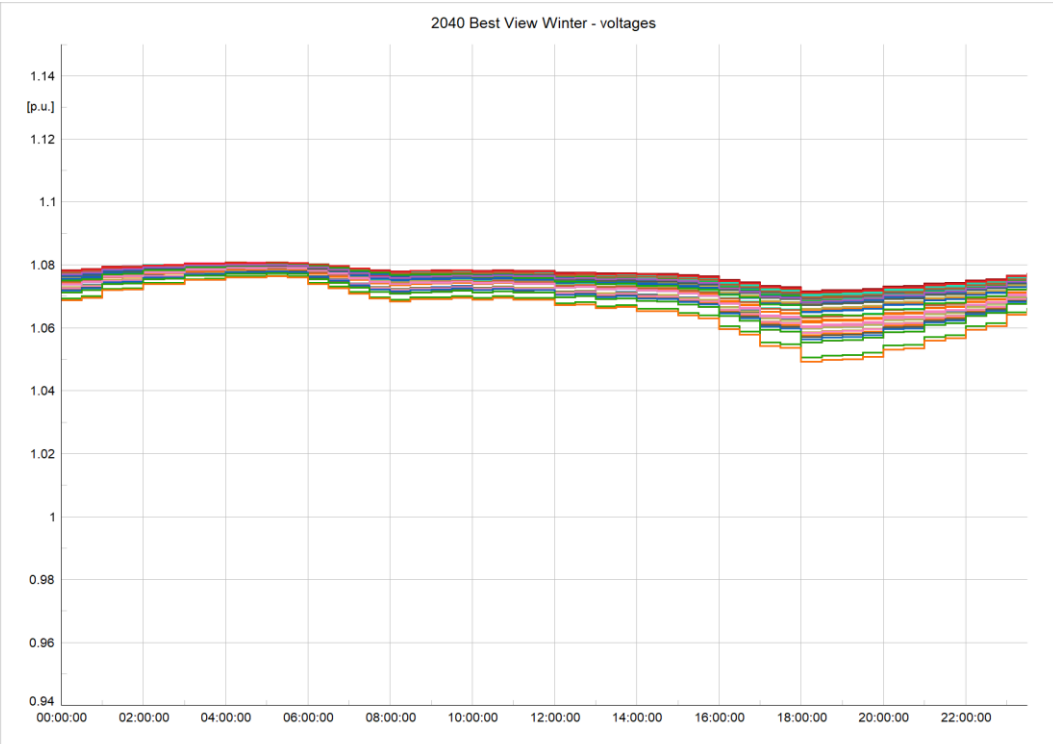

Figure 31 2040 Dense Urban Network Best View winter voltage profiles

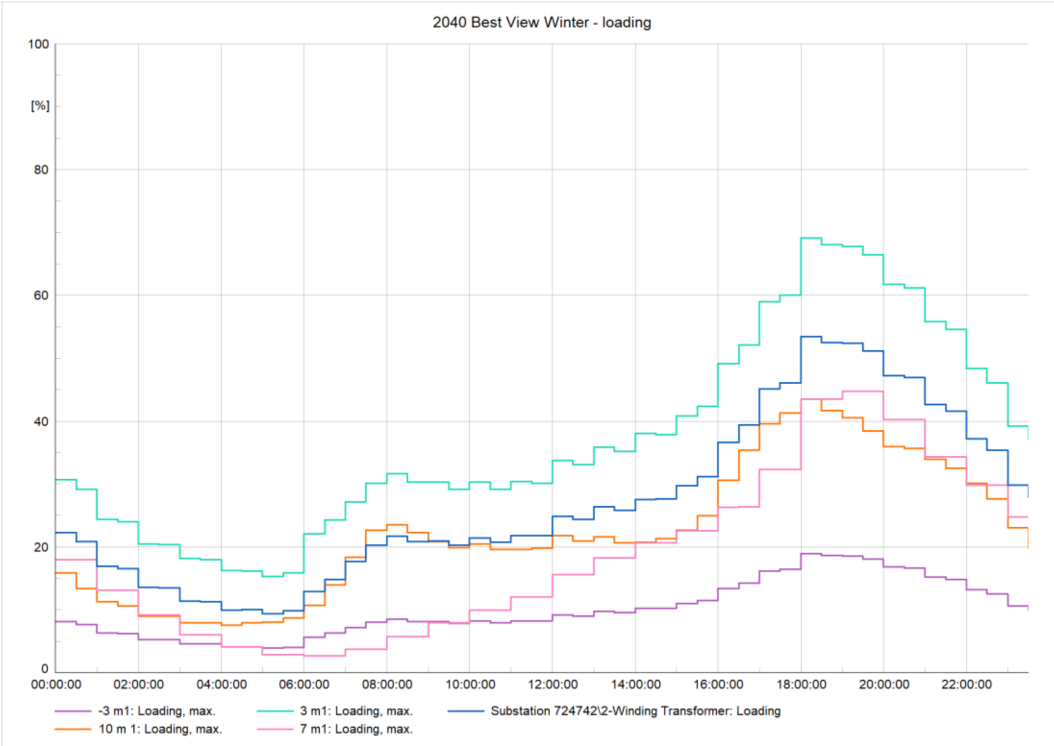

Figure 32 2040 Dense Urban Network Best View winter loading profiles

4.3.2 Steady Progression

Summer

During 2040, under the Steady Progression scenario voltages and loading remain well within limits for the summer condition and voltages remain tightly within a 1.06 to 1.08p.u. banding.

Winter

During winter, voltages at the remote customer feeders reach as low as 1.05p.u. and still remain well within statutory limits.

4.3.3 Leading the Way

Summer

The summer voltage profiles show a slightly increased voltage peak during times of PV export compared to the Best View the overall profile remains well within the statutory voltage limits. Peak loading increases slightly compared to the Best View scenario but remain well within the circuit ratings.

Winter

During the winter evening peak in 2040 under the Leading the Way scenario, feeder loading, and supply transformer loading will significantly exceed peak capability (Figure 34). However, as shown in Figure 33 this does not suggest there will be issue with low voltages outside of statutory limits with the lowest voltage seen being 1.05p.u.

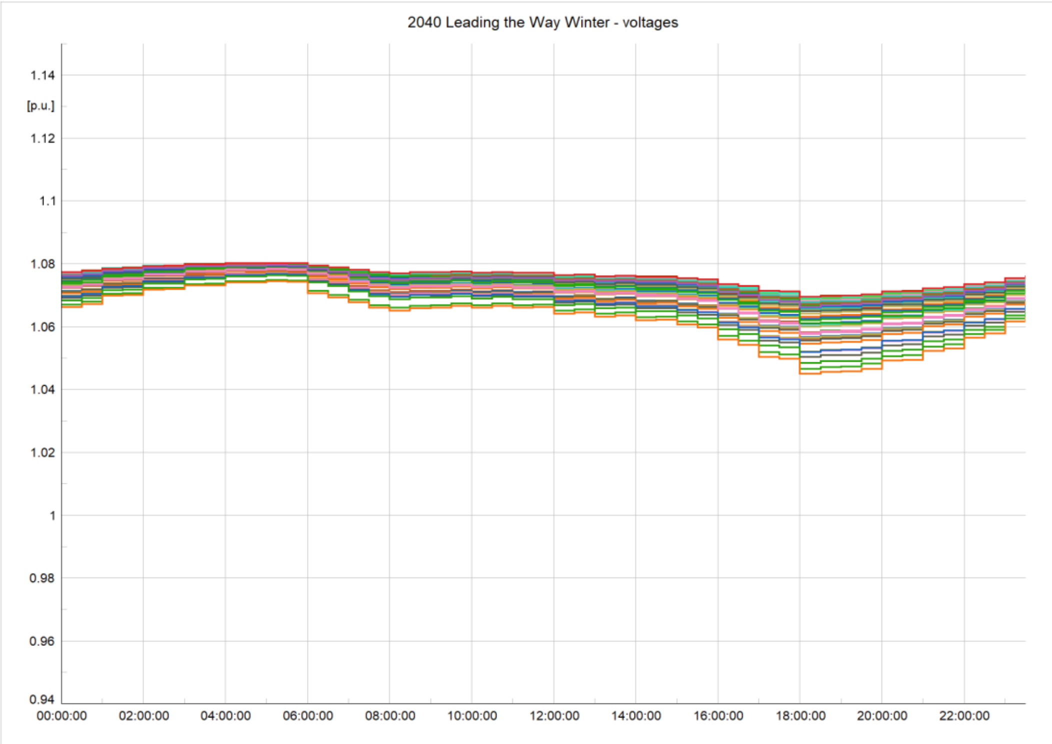

Figure 33 2040 Dense Urban Network Leading the Way winter voltage profiles

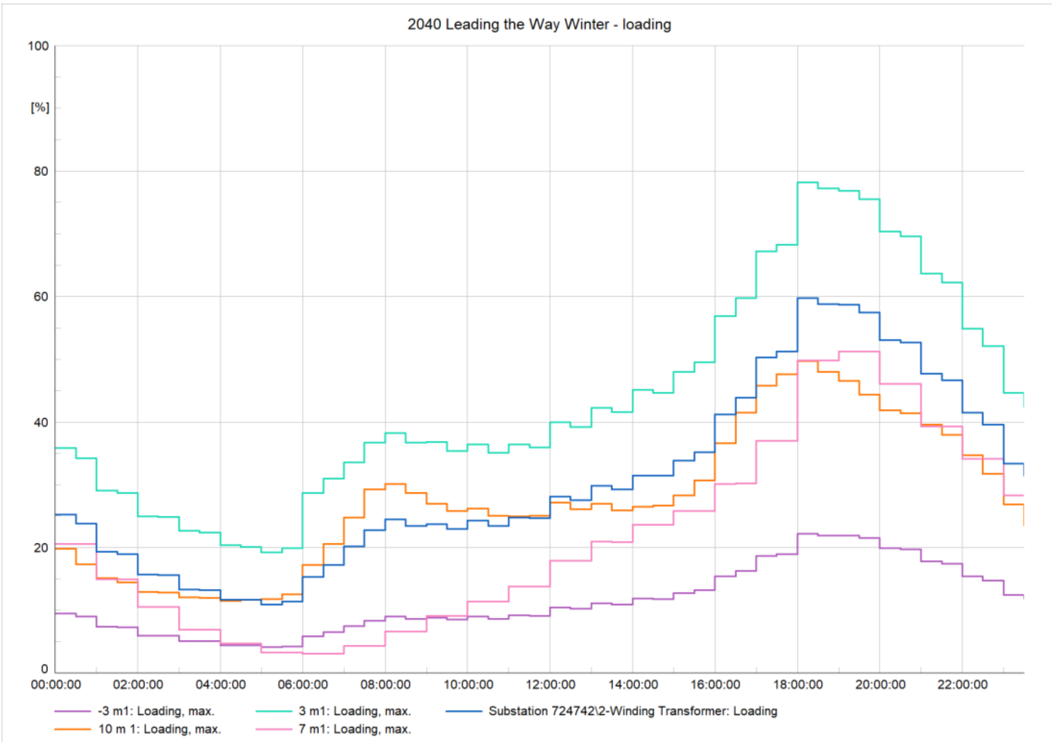

Figure 34 2040 Dense Urban Network Leading the Way winter loading profiles

4.4 2050

4.4.1 National Grid's Best View

Summer

The voltage profiles remain within the statutory limits the increased PV penetration leading to a small increase in the peak voltage compared to the 2040 Best View scenario. Loading for the summer remains well within the ratings of the circuits with the peak loading on feeder 2 only slightly exceeding 40% of rating.

Winter

Figure 35 shows the voltage profile in winter 2050 in the Best View scenario. The voltage at the customer sites remain well within statutory limits at all times. The lowest the voltage falls to at a customer site is just below 1.05 p.u. during the evening peak.

Figure 36 shows that the loading on the network in winter 2050 is within the thermal limit, peaking at 18:00 on feeder 3 with approximately 75% of the thermal limit.

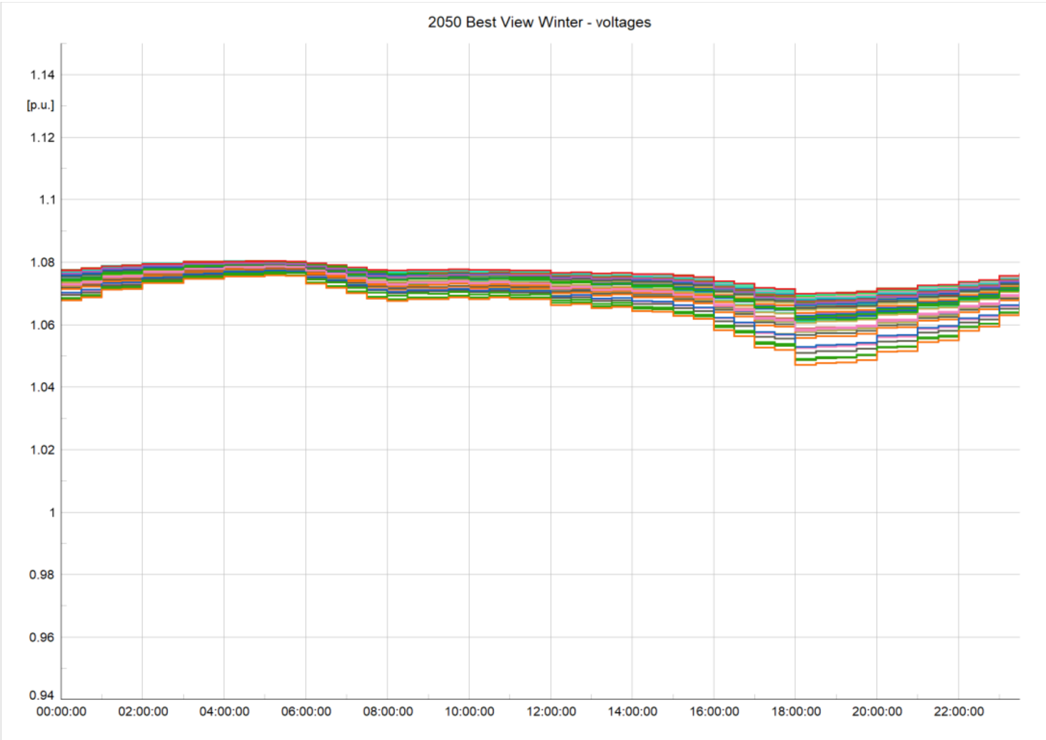

Figure 35 2050 Dense Urban Network Best View winter voltage profiles

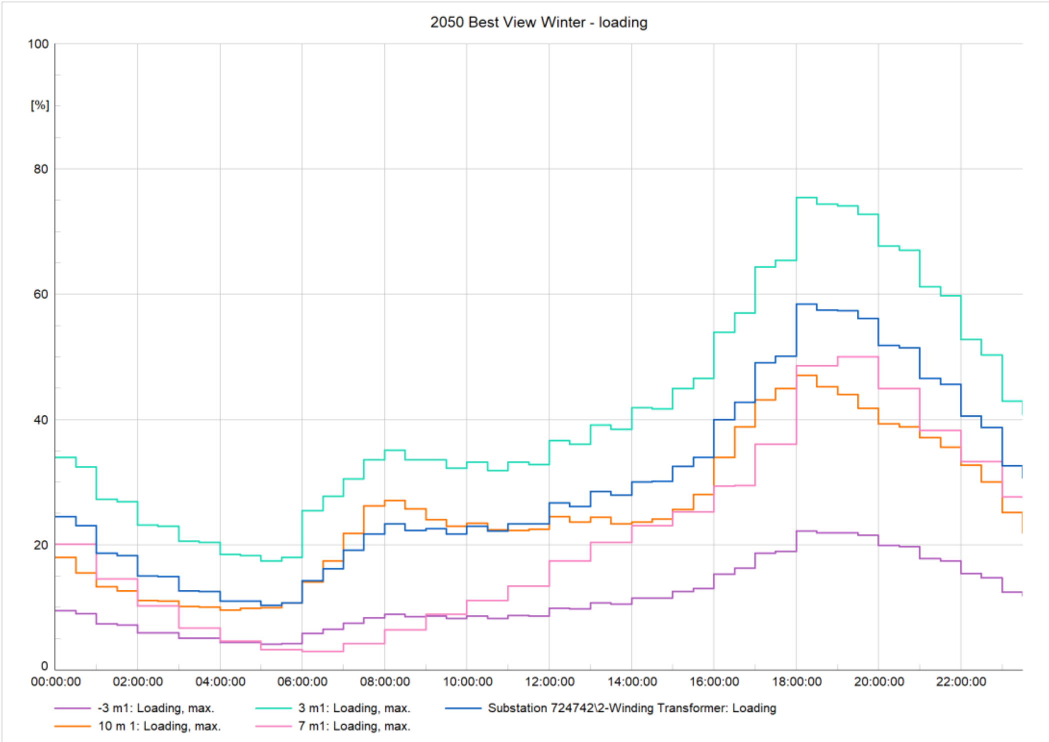

Figure 36 2050 Dense Urban Network Best View winter loading profiles

4.4.2 Steady Progression

Summer

The Summer 2050, Steady Progression scenario shows that customers voltages all remain tightly banded around 1.06 to 1.08p.u. along with no significant issues surrounding system export

Winter

In Winter 2050, similarly to the Best View scenario, voltages at customer sites remain well within statutory limits at all times. Minimum voltage is approximately in the Steady Progress scenario is 1.05p.u.

4.4.3 Leading the Way

Summer

The summer voltage profiles shown in Figure 34 below exhibit increased voltage rise during the day due to the export from the higher penetration of PV installations expected in this scenario. Nevertheless, the voltages remain within statutory limits.

The trace for feeder 3 shows an increase in loading on the first segment of the feeder during the day resulting from a net export from the feeder PV installations.

Summer

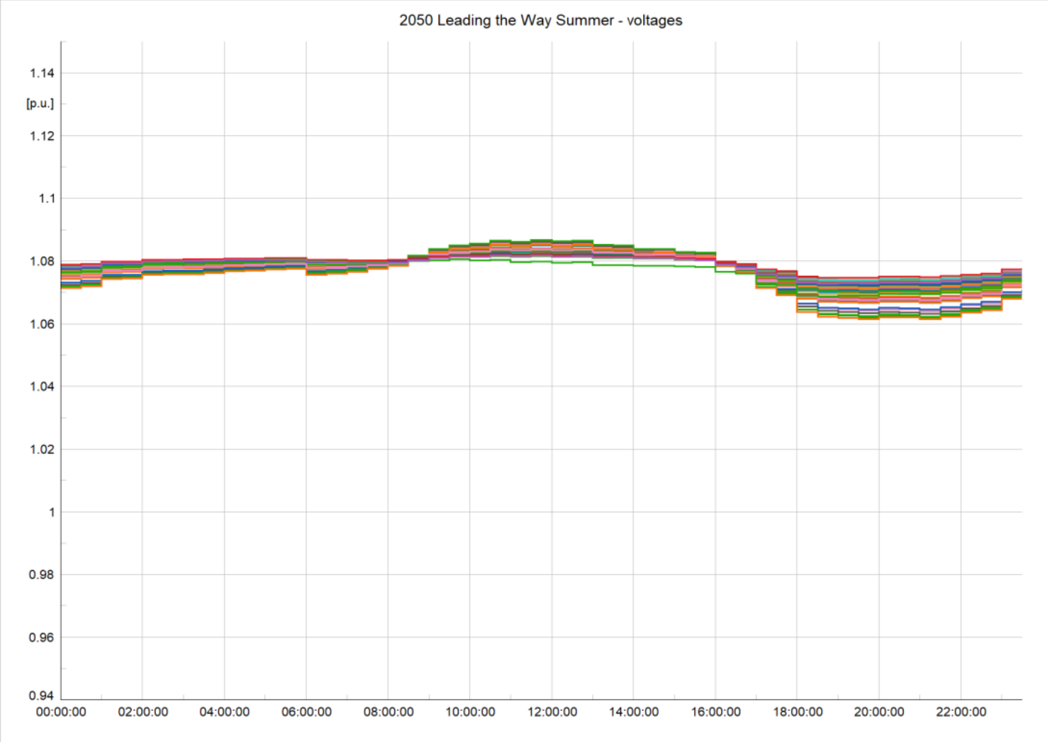

Figure 37 2050 Dense Urban Network Leading the Way summer voltage profiles

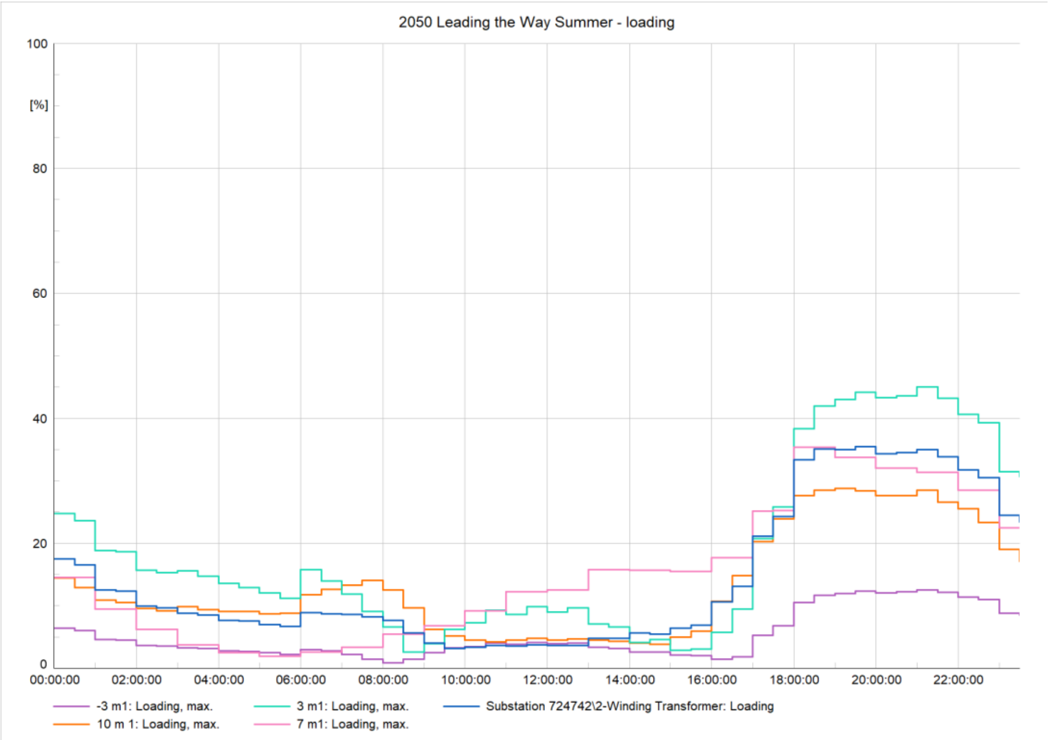

Figure 38 2050 Dense Urban Network Leading the Way summer loading profiles

Winter

Figure 39 and Figure 40 show the Leading the Way scenario voltage and loading profile results during 2050. After 18:00 the loading on the network from unconstrained loading increases with feeder 3 exceeding 80%. However, the voltages at customer terminals are only marginally below 1.05p.u. suggesting that low voltages as a result of LCT uptake will not be a challenge for the Dense Urban network.

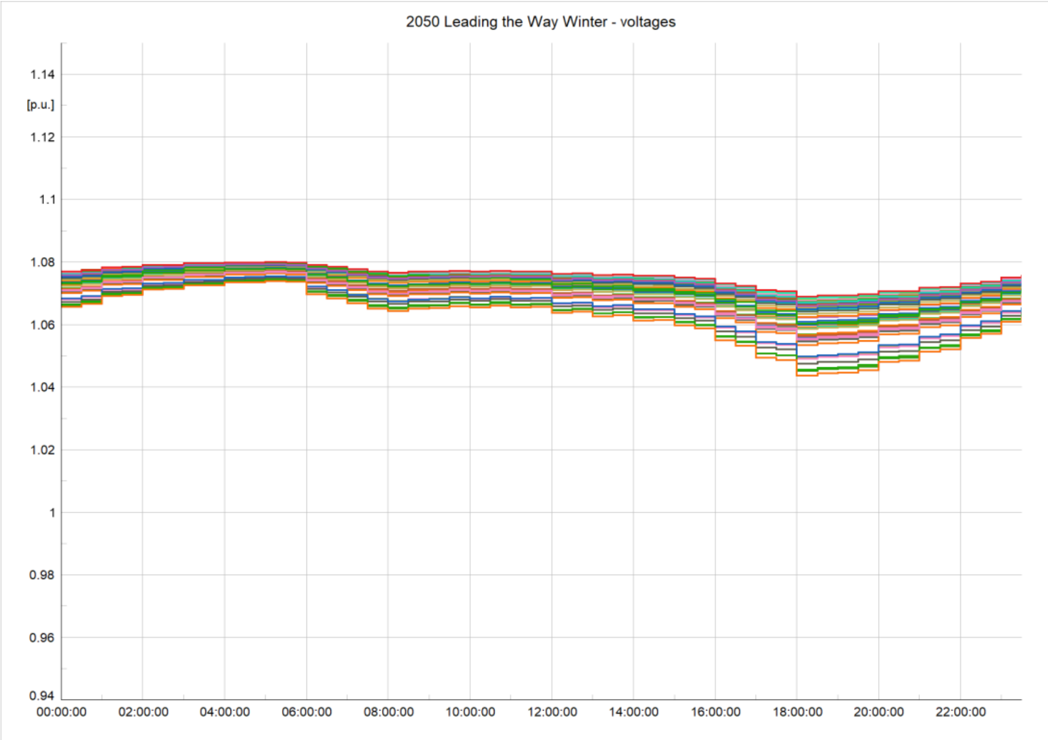

Figure 39 2050 Dense Urban Network Leading the Way winter voltage profiles

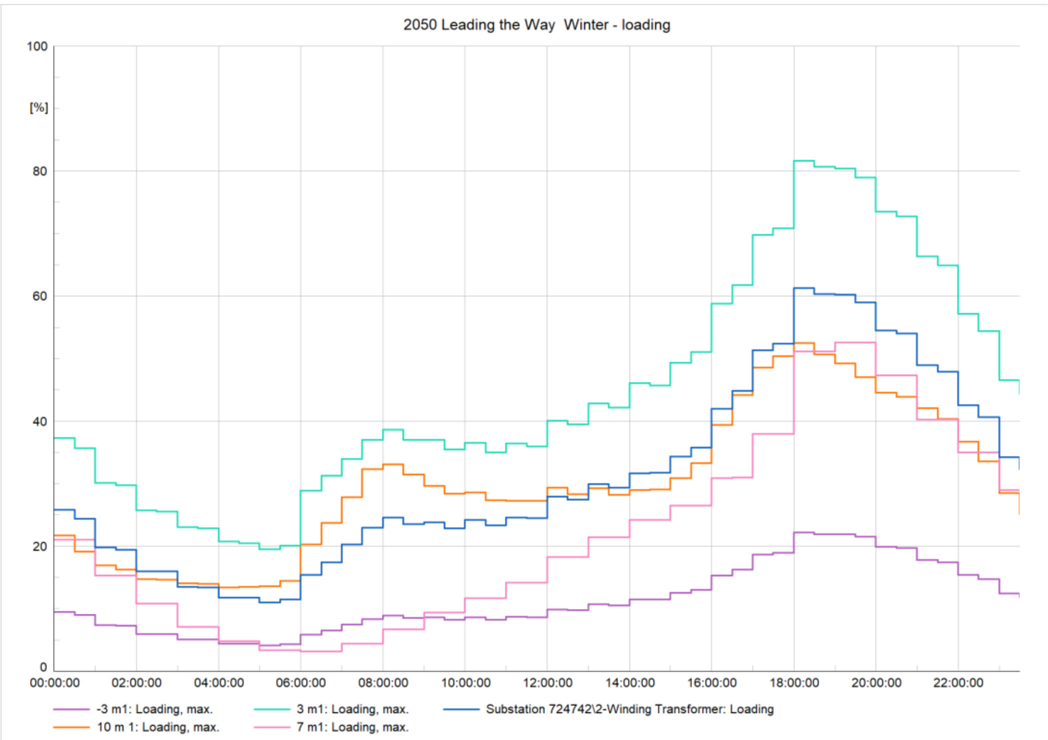

Figure 40 2050 Dense Urban Network Leading the Way winter loading profiles

5. Urban Results

This section presents the results for the Urban network, to avoid repetition of the same results analysis is focussed on the Best View scenario and then results for the other scenarios (Leading the Way and Steady Progression) only included where they deviate.

The voltage profile plots show the voltage at each customer's point of connection during the 24-hour study window. The statutory requirements are for these voltages to remain below 1.1pu and above 0.94pu for all steady state operating conditions. The loading profile plots show the loading on each of the feeders supplied from the HV / LV substation and must remain below 100% of their rating.

5.1 Base Case Conditions

The following plot shows the voltage profile for the base case study, prior to increasing numbers of LCT uptake and at the nominal tap position. This plot shows that even prior to increases in LCT uptake there is already a significant variation in the voltage at customers terminals when compared with the Dense Urban network results presented previously.

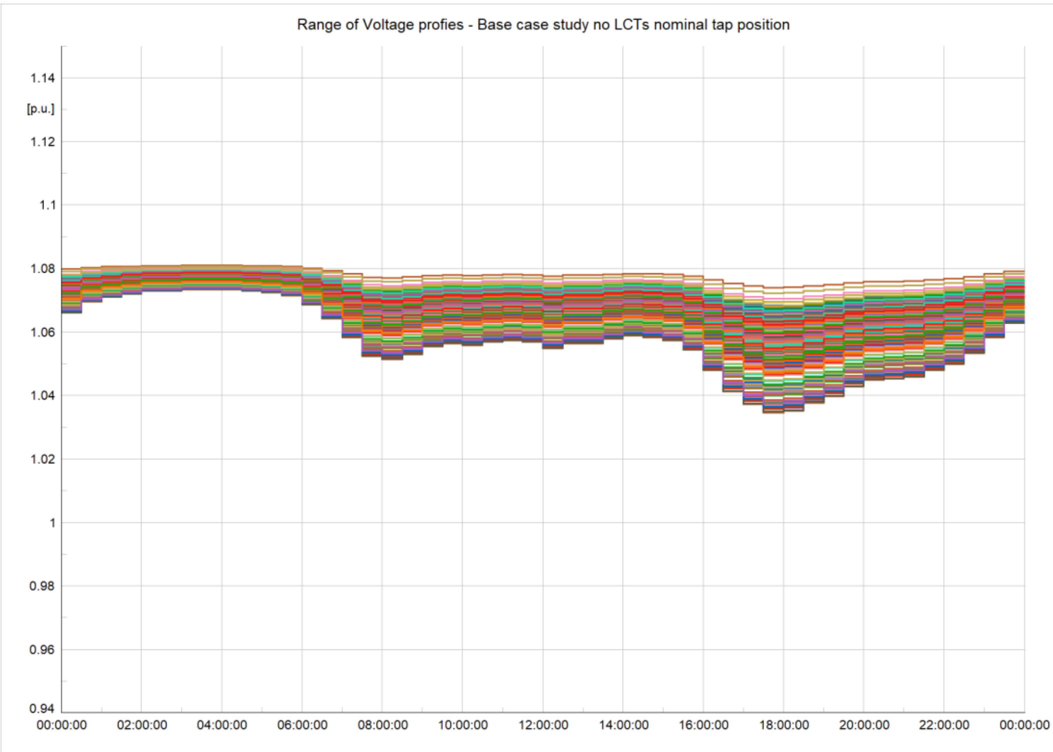

Figure 41 Urban Network - Base Case voltage profiles (winter)

Figure 42 shows the circuit loading for the Urban Network prior to the increase in LCT levels and shows that all feeders are significantly below the 100% loading limit.

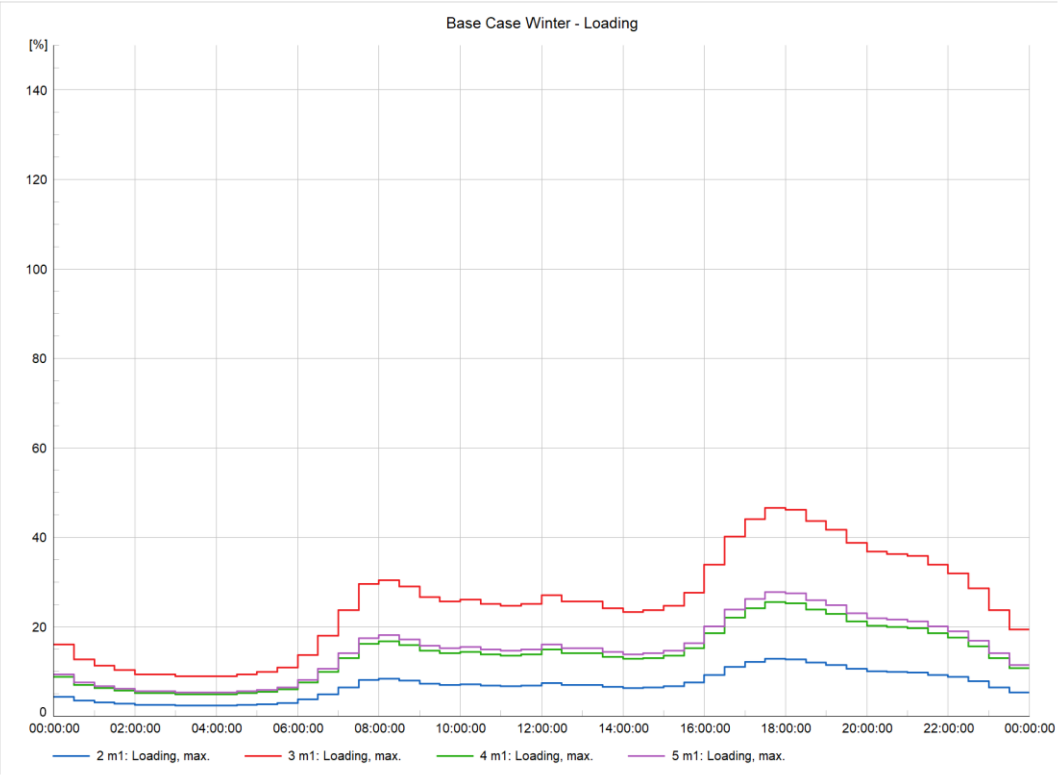

Figure 42 Urban network - Base Case load profiles (winter)

5.2 2028

5.2.1 National Grid's Best View

Summer

Figure 43 shows the voltage profile on the urban feeder in 2028 under the Best View scenario. Voltages remain within a narrow range. Neither the upper voltage (1.1 p.u.) or lower voltage (0.94 p.u.) statutory limits are breeched. However, in 2028 it is already clear that the PV generation is pushing up the voltage and approaching the 1.1p.u. limit, leaving little additional voltage headroom.

Figure 44 shows the thermal loading curve in the summer. The thermal loading doesn't approach the limits, remaining below 40% of the thermal limits on all feeders at all times.

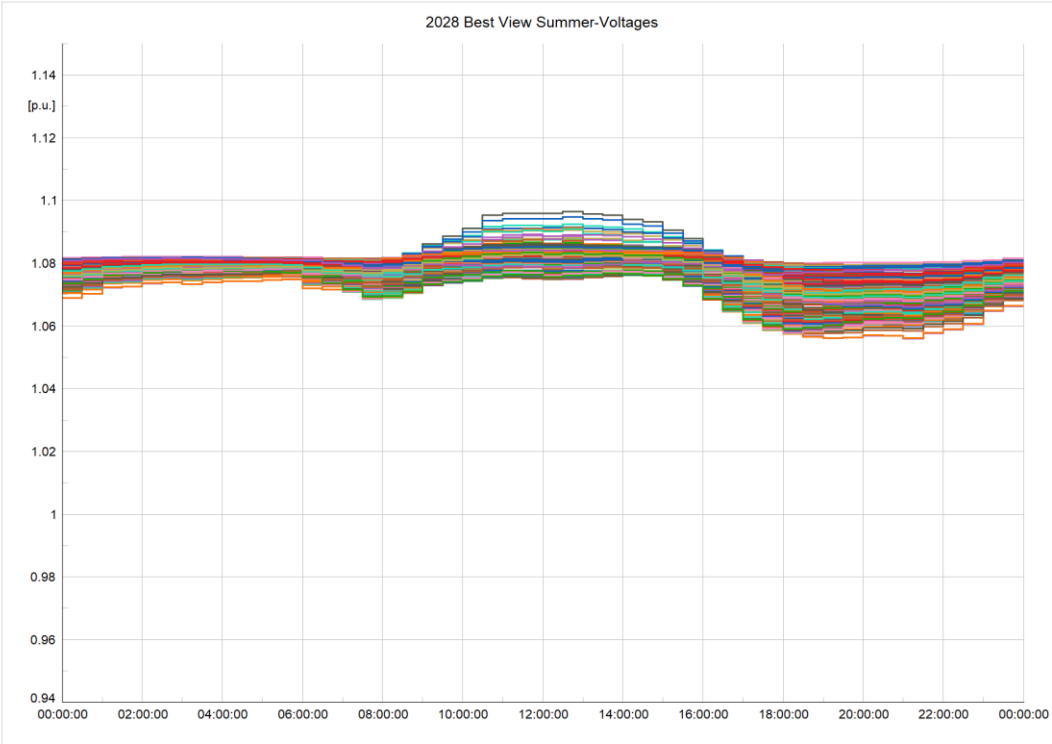

Figure 43 2028 Urban Network Best View summer voltage profiles

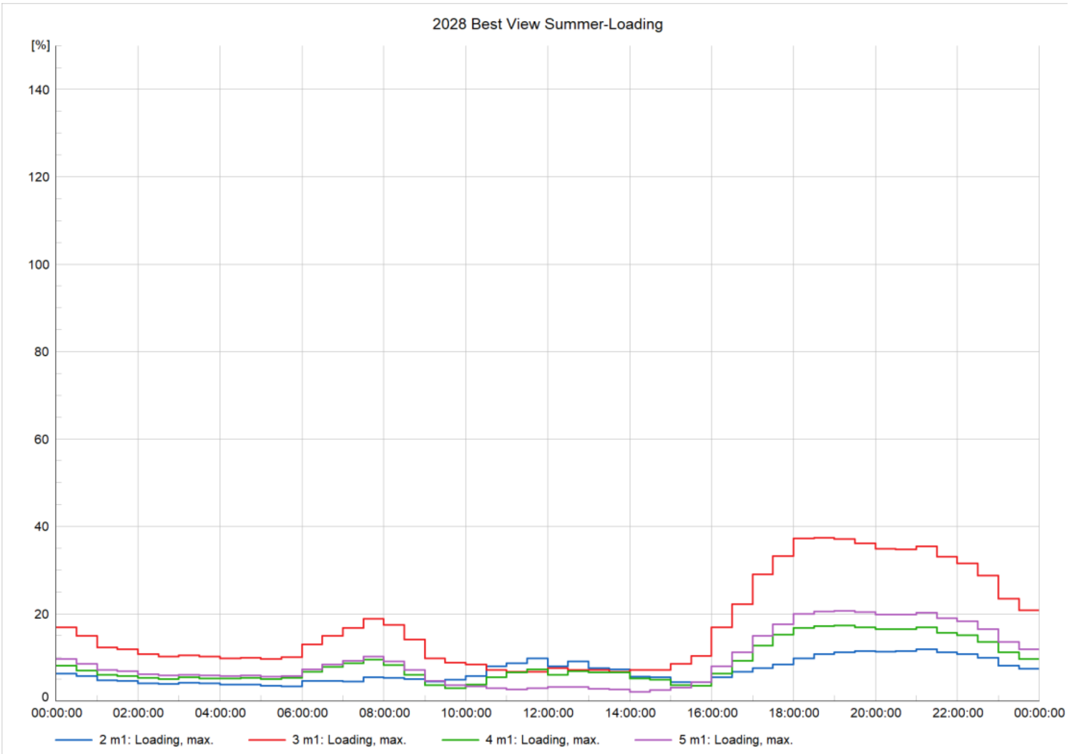

Figure 44 2028 Urban Network Best view summer load profiles

Winter

Figure 45 shows the voltage profile in 2028 for the Best View scenario. The voltage remains within both the upper and statutory voltage limits. Voltage rise is not considered a likely issue in the winter due to low levels or PV generation but higher loads making voltage drop issues to be more likely. The analysis presented here shows that there is still plenty of voltage drop capacity on the network.

Figure 46 shows the thermal profile in 2028 for the Best View scenario with the thermal limits not being breeched on any of the feeders. The peak thermal load is at just over 60% of the thermal capacity on feeder 3 during winter peak.

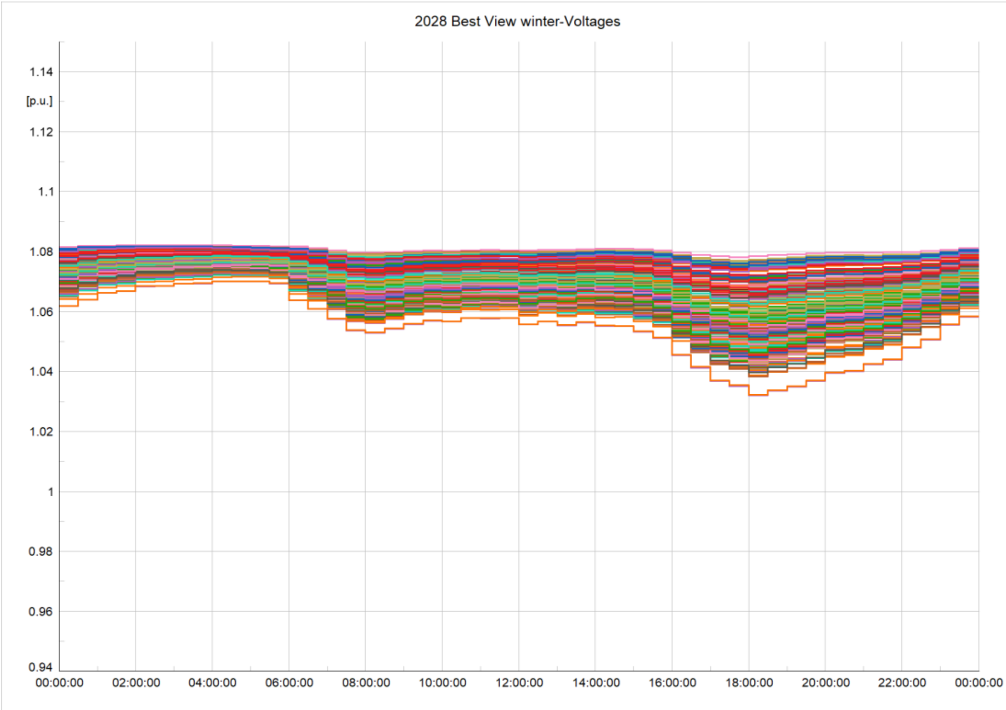

Figure 45 2028 Urban Network Best View winter voltage profiles

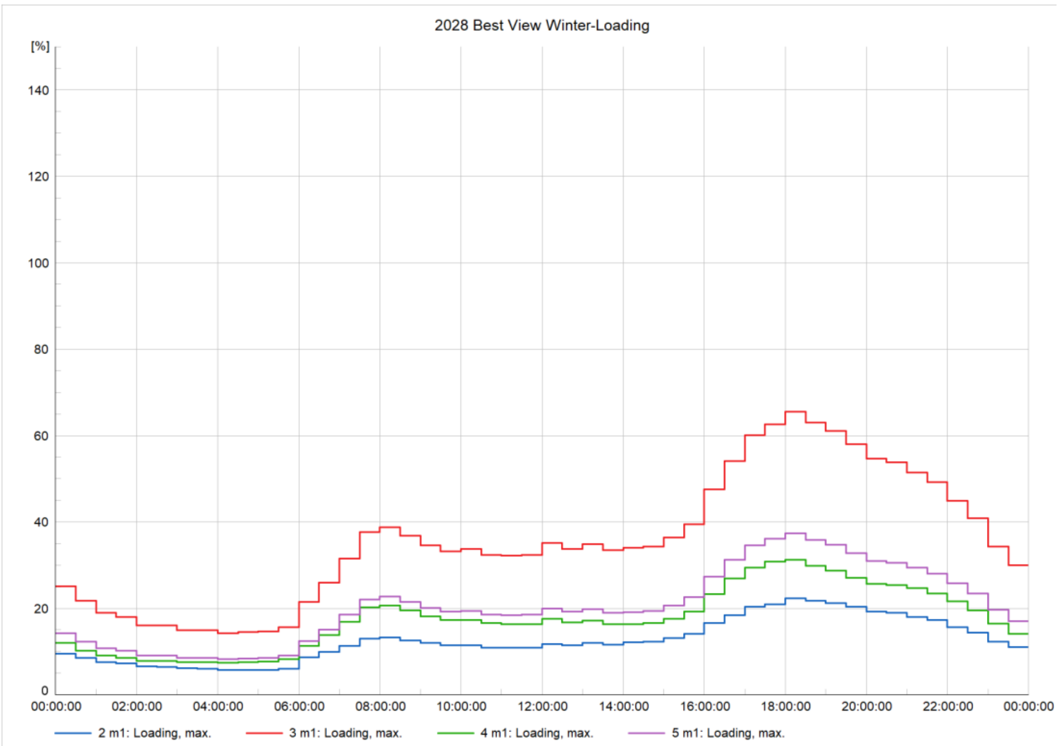

Figure 46 2028 Urban Network Best View winter load profiles

5.2.2 Steady Progress

Similarly, to in the Best View scenario, neither voltage limits or thermal limits are breeched in the Steady Progress scenario in 2028.

5.2.3 Leading the Way

Similarly, to in the Best View and Steady Progress scenarios, neither voltage limits nor thermal limits are breeched in the Leading the Way scenario in 2028.

5.3 2033

5.3.1 National Grid's Best View

Figure 47, Figure 48, Figure 49 and Figure 50 show the summer voltage, summer loading, winter voltage and winter loading plots for Best View scenario in 2033 respectively. Neither voltage or thermal limits are reached in any season in 2033 under this scenario in either winter or summer. There is only a small amount of voltage headroom capacity left available in the summer in the Best View scenario, the voltage remains only slightly below the 1.1 p.u. limit. Peak thermal load reaches approximately 85% of the thermal capacity, for feeder 3 during winter peak.

Summer

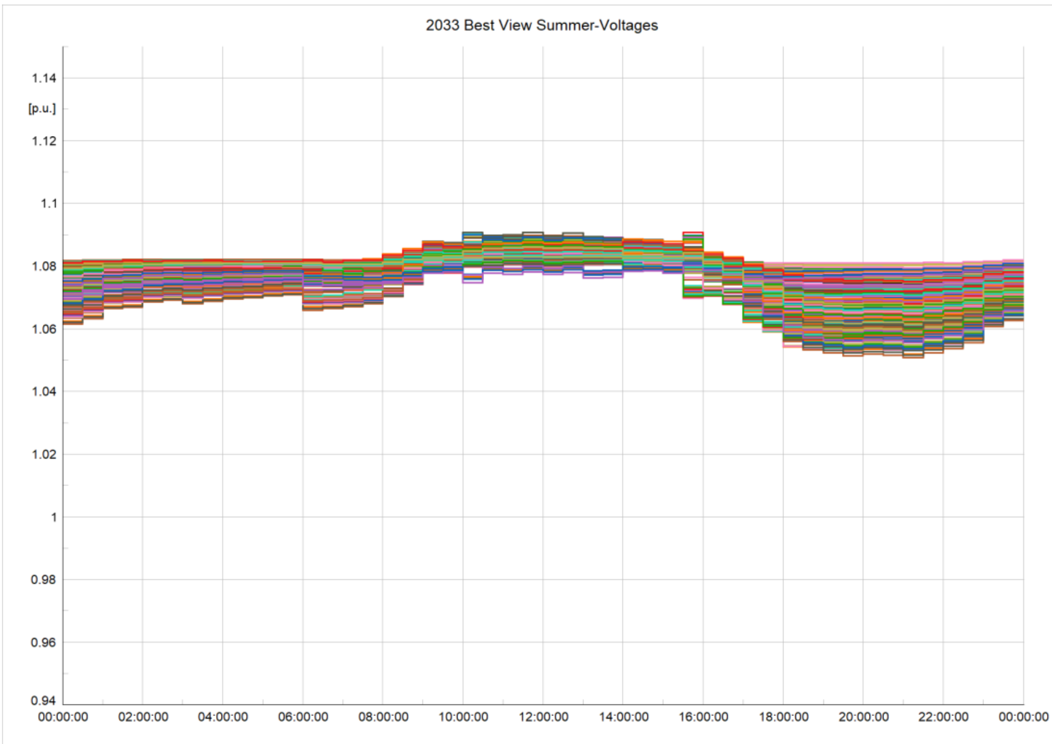

Figure 47 2033 Urban Network Best View summer voltage profiles

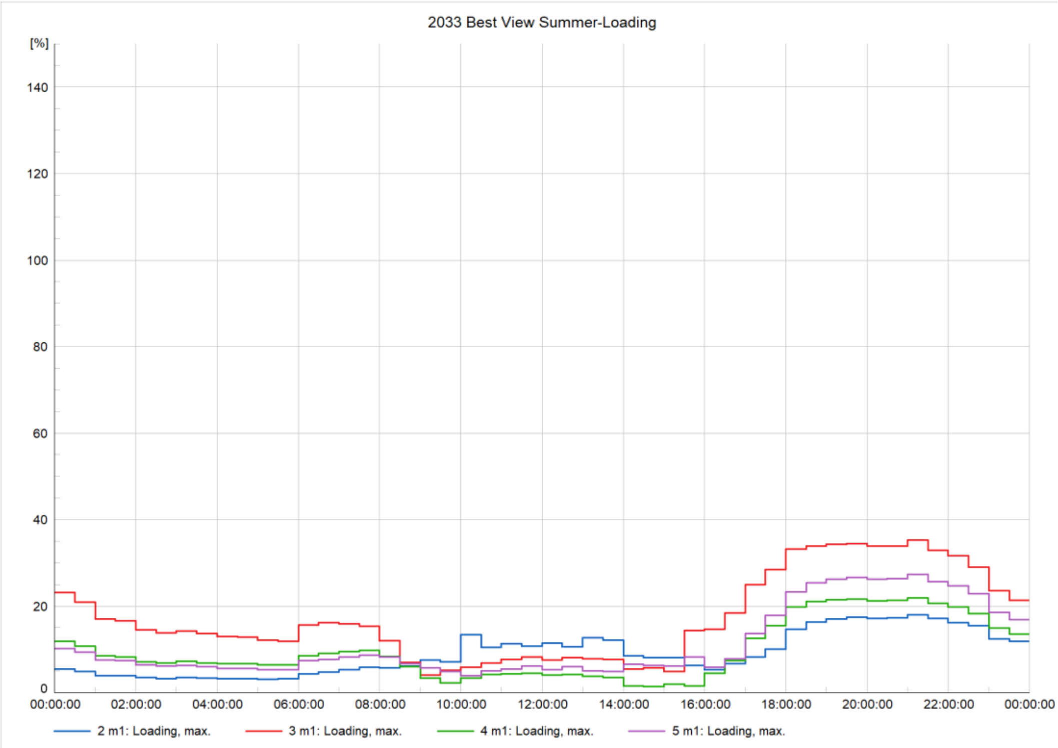

Figure 48 2033 Urban Network Best View summer load profiles

Winter

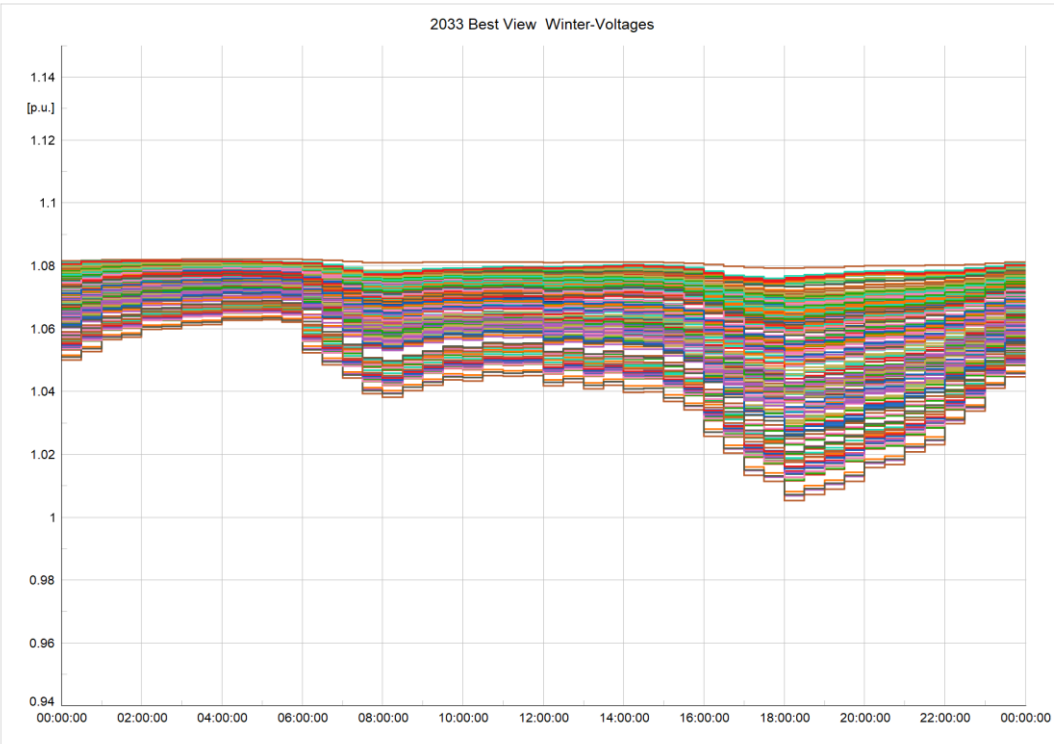

Figure 49 2033 Urban Network Best View winter voltage profiles

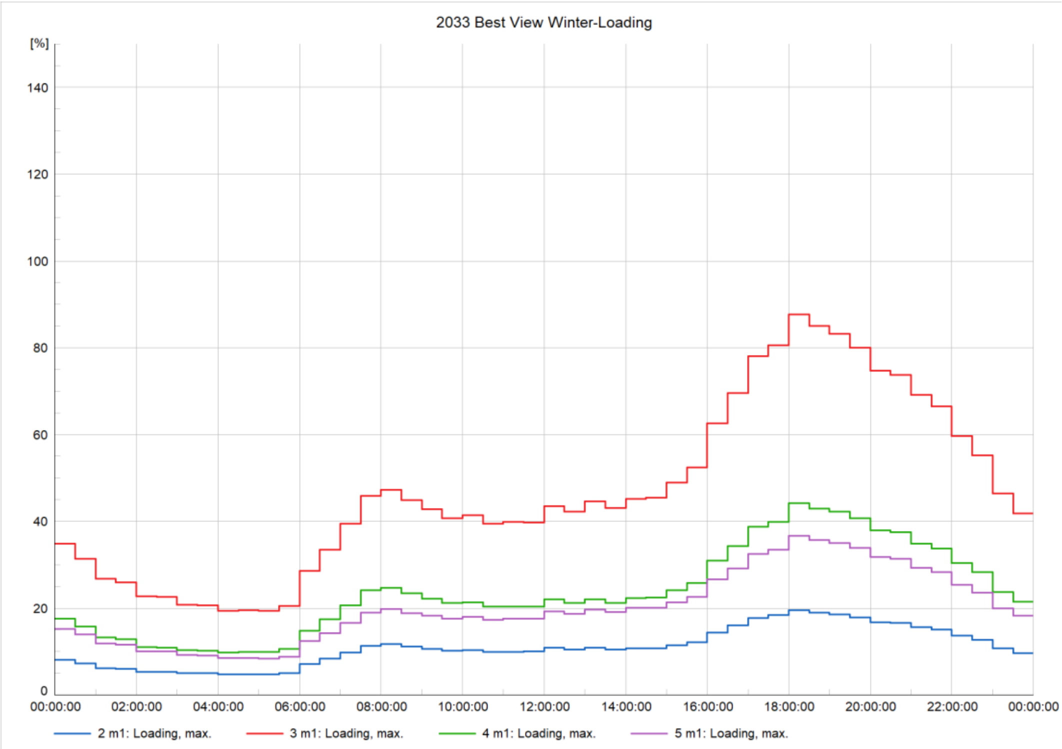

Figure 50 2033 Urban Network Best View winter load profiles

5.3.2 Steady Progress

The Steady Progress scenario results are similar to the Best View results. The peak loadings are lower, and voltage rise reduced in summer and voltage fall reduced in winter, due to the slower uptake rates of LCTs in this scenario. As with the Best View scenario, no thermal or voltage limits are exceeded in 2033 in the Steady Progress scenario.

5.3.3 Leading the Way

Summer

Figure 51 shows that in 2033, in the Leading the Way scenario, during the summer voltage rises above statutory limits for a small number of customers (at the remote end of feeders), due to the higher levels of PV witnessed in this scenario compared to the Best View or Steady Progress scenarios. Thermal issues are not encountered in the summer in this scenario.

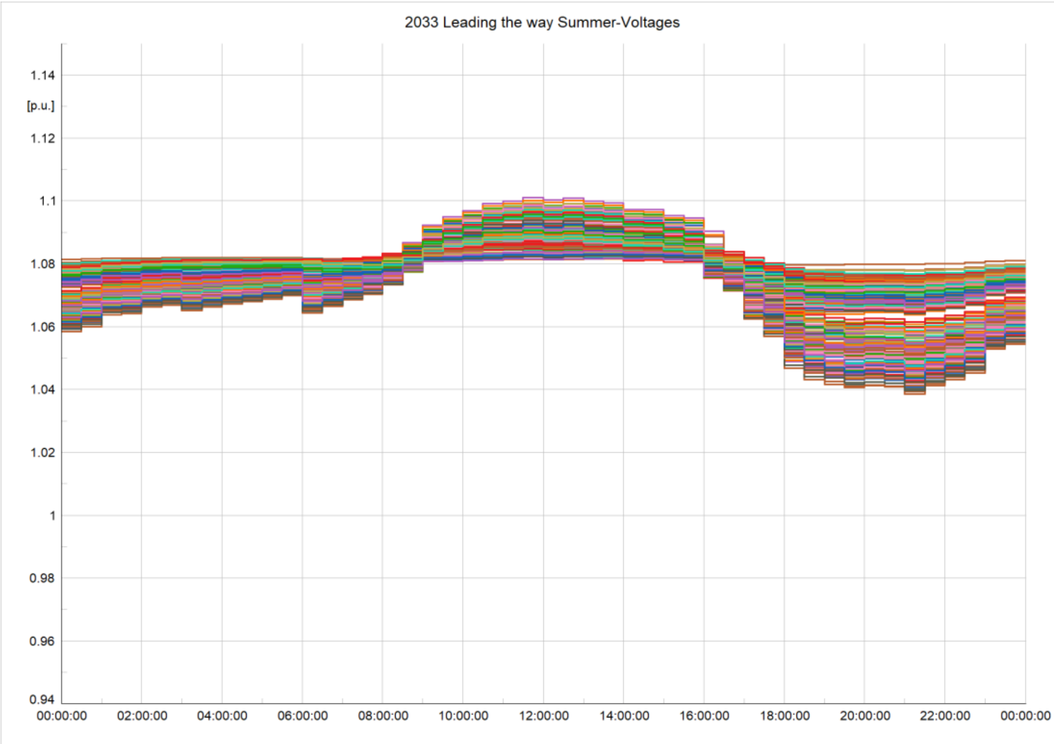

Figure 51 2033 Urban Network Leading the Way summer voltage profiles

Winter

In 2033, in the Leading the Way scenario, thermal limits are exceeded at winter peak. As shown in Figure 52 thermal limits are exceeded between 17:00 and 21:00, rising to a maximum of nearly 120% of the rated thermal capacity on feeder 3. There are no voltage issues encountered in 2033 during the winter peak in this scenario.

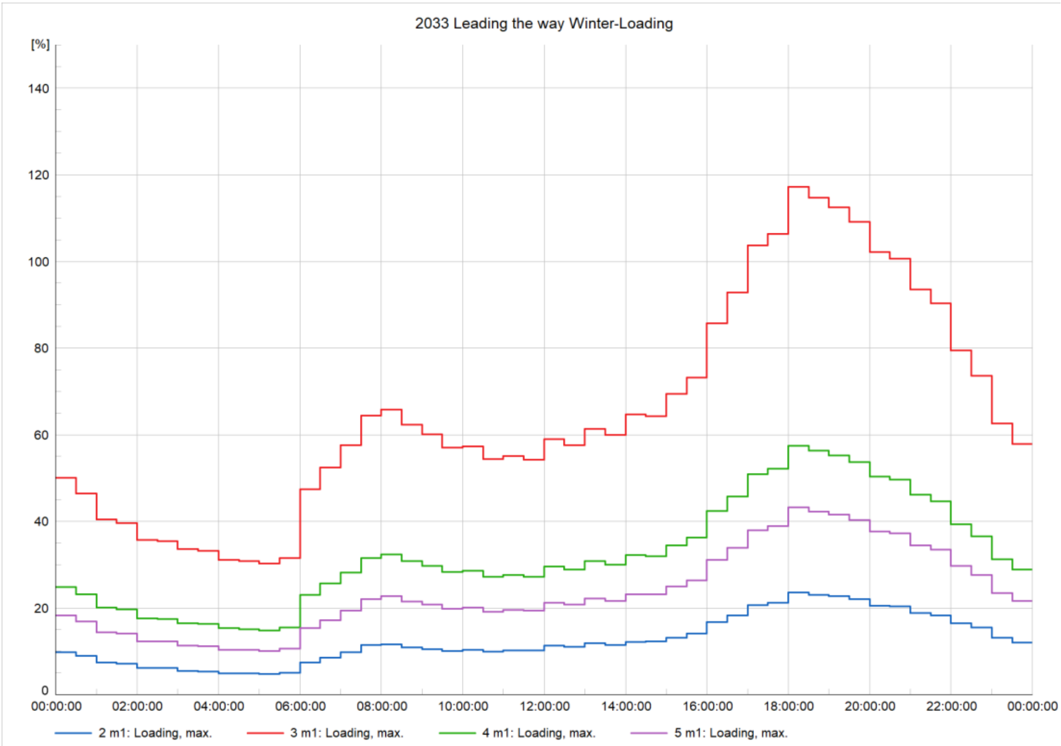

Figure 52 2033 Urban Leading the Way winter load profiles

5.4 2040

5.4.1 National Grid's Best View

Summer

Figure 53 shows the voltage profile in 2040 in summer for the Best View scenario. Voltage limits are not breeched. However, the highest voltage on the network remains below the upper statutory limit by a small margin (less than 0.005p.u.).

Figure 54 shows the loading profile in 2040 for summer in the Best View scenario. The loading in the summer in 2040 remains far below the thermal limit.

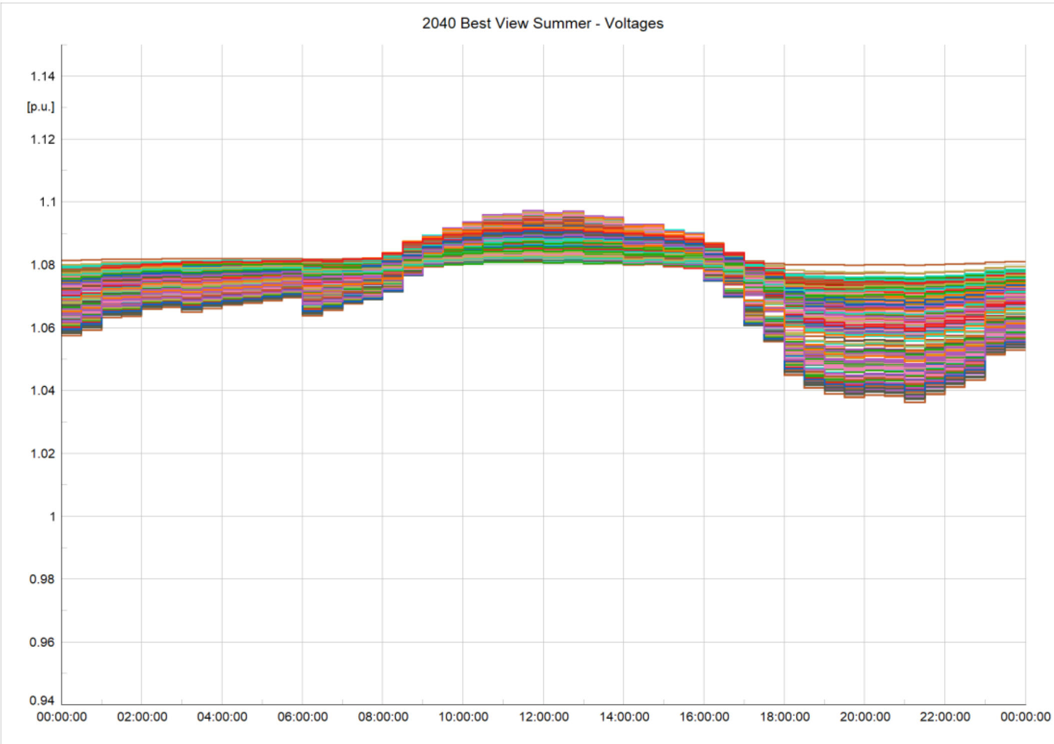

Figure 53 2040 Urban Network Best View summer voltage profiles

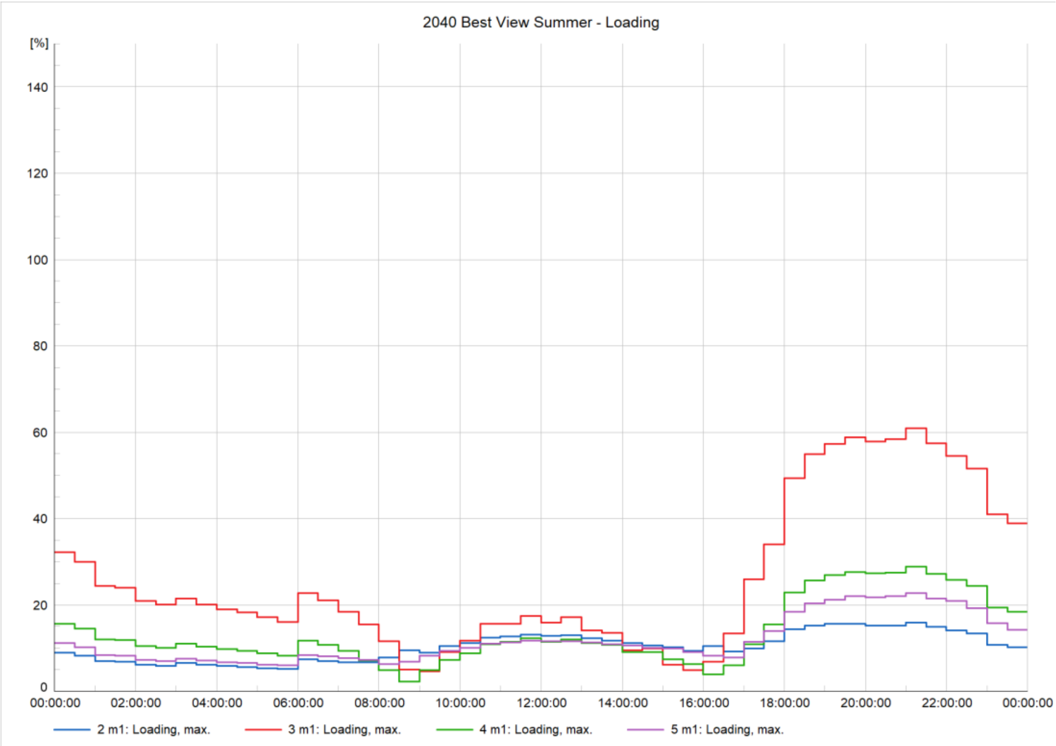

Figure 54 2040 Urban Network Best View summer loading profiles

Winter

Figure 55 shows that in the winter, neither upper or lower voltage limits are breeched, remaining well within both the upper and lower statutory limits.

However, thermal limits are breeched in the Best View scenario in 2040 on feeder 3, as shown in Figure 56. LCT loads cause the load on the network to increase above the thermal limits. The thermal limit is breeched between 17:00 and 21:00, reaching a peak of nearly 120% of the thermal limit of the network.

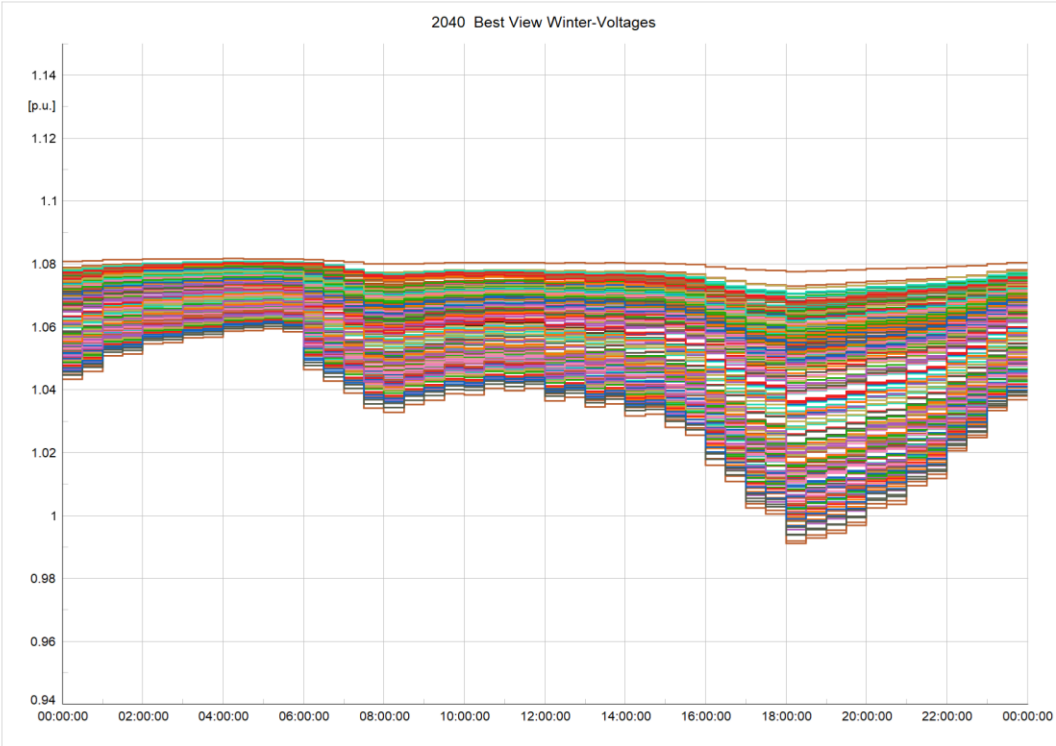

Figure 55 2040 Urban Network Best View winter voltage profiles

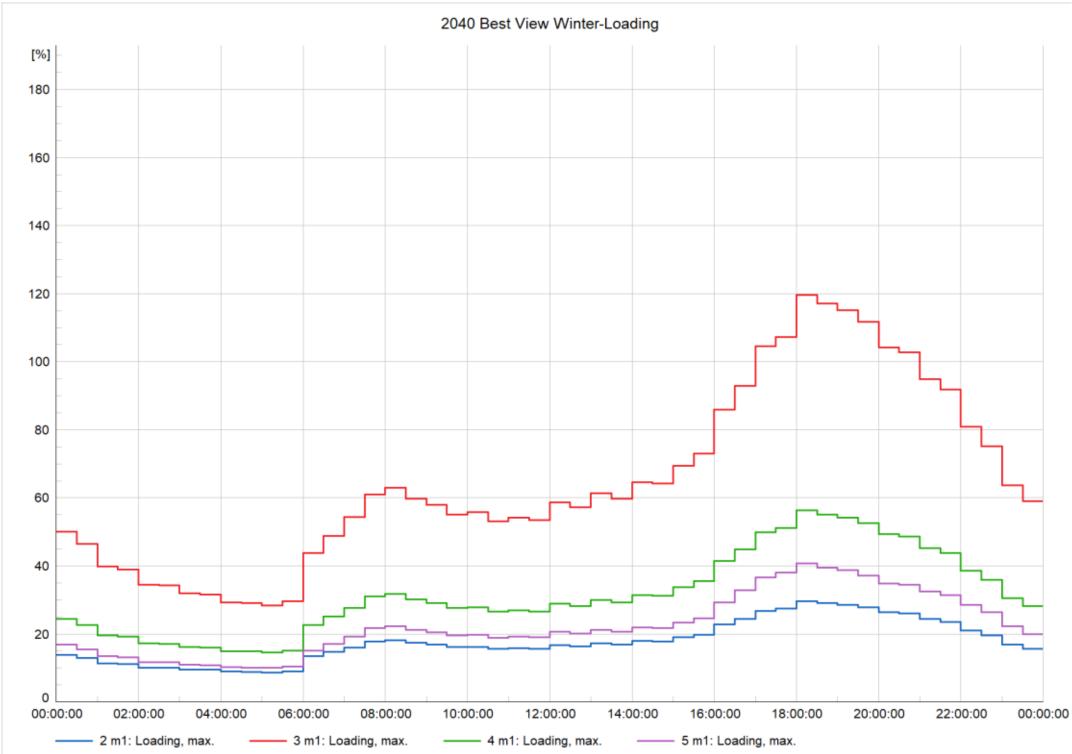

Figure 56 2040 Urban Network Best View winter loading profiles

5.4.2 Steady Progress

In the Steady Progress scenario, as with the Best View scenario, the voltage limits in both summer and winter are not reached. The thermal limits are not breeched in the summer as with the Best View scenario. However, in contrast to the Best View scenario, thermal limits are not breeched in the winter, peaking at around 90%.

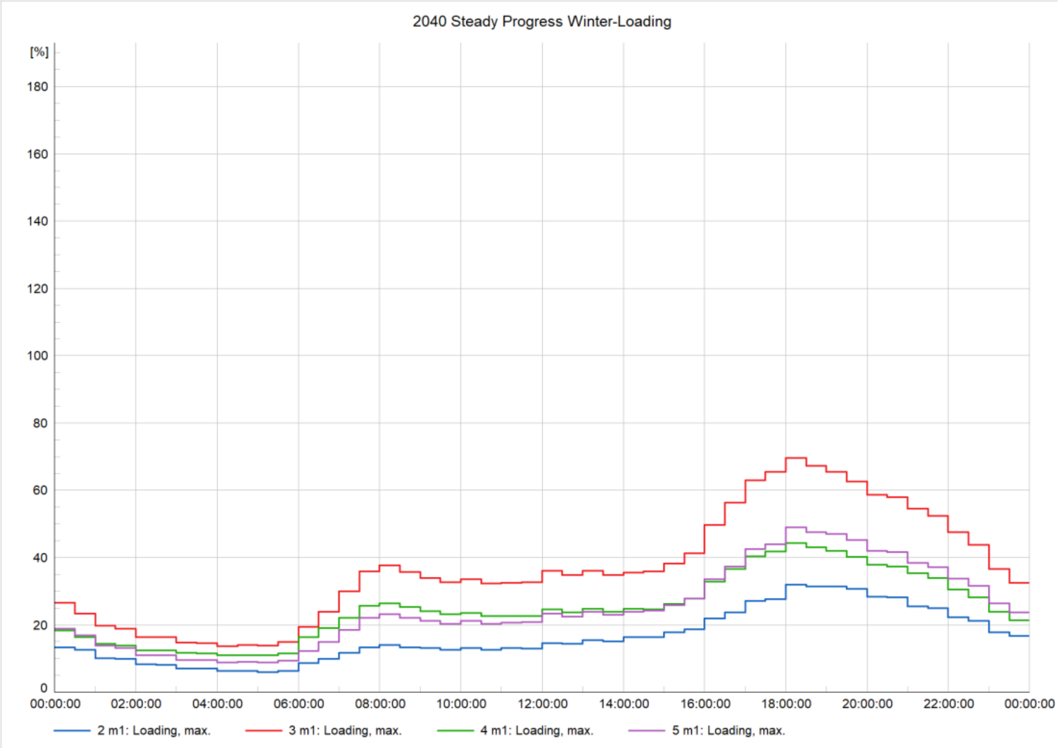

Figure 57 2040 Urban Network Steady Progress winter loading profiles

5.4.3 Leading the Way

In 2040, thermal limits during summer are also not breeched in the Leading the Way scenario.

In contrast to the Best View and Steady Progress, the level of PV deployment on the feeders in the Leading the Way scenario is sufficient to cause voltage to rise above statutory limits, as shown in Figure 58. Comparing Figure 58 to Figure 51 voltage limits at the worst affected customer sites (at the far ends of the feeder) are exceeded by a greater amount than in 2033. Additionally, more customer sites have voltages that exceed the statutory maximum voltage level than in 2033.

Voltage limits in the winter are not breeched in the Leading the Way scenario. As with the Best View scenario, thermal limits are breeched in winter on feeder 3, peaking at nearly 140% of the limit and exceeding the statutory limit from 16:00 to 22:00. Thus, in the Leading the Way scenario, thermal limits are breeched by a larger amount and for a longer time period than in the Best View scenario, due to higher uptake rates of LCTs, specifically EVs and heat pumps.

The transformer load profile (Figure 60) shows that the peak loading exceeds the transformer rating under these conditions.

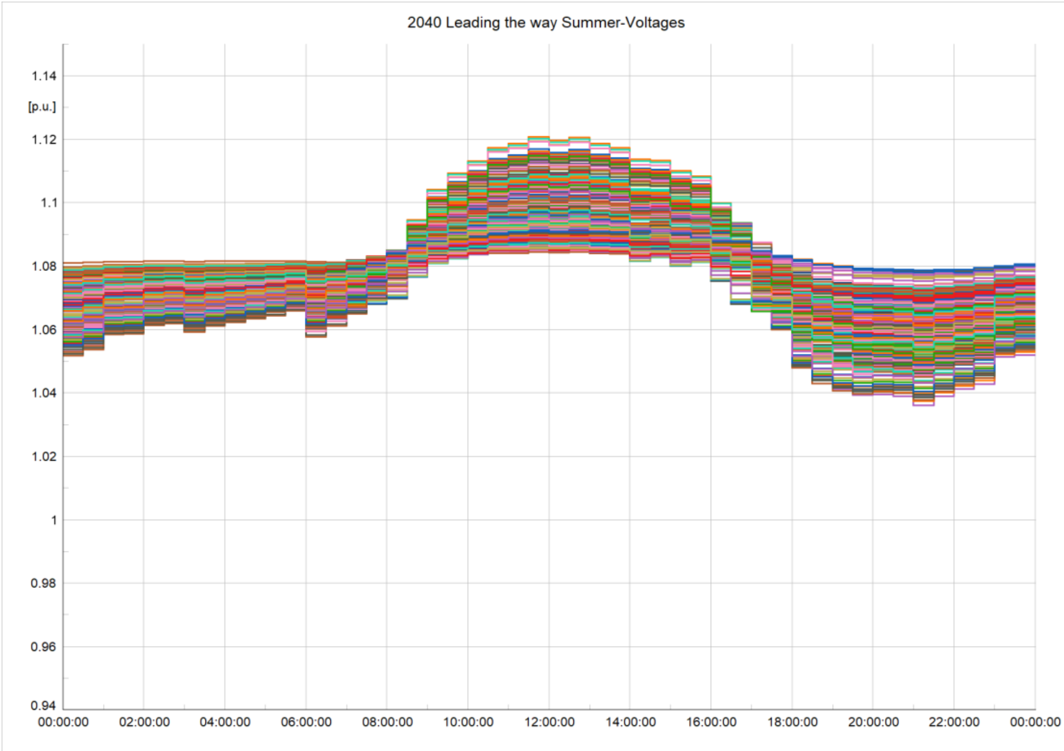

Figure 58 2040 Urban Network Leading the Way summer voltage profiles

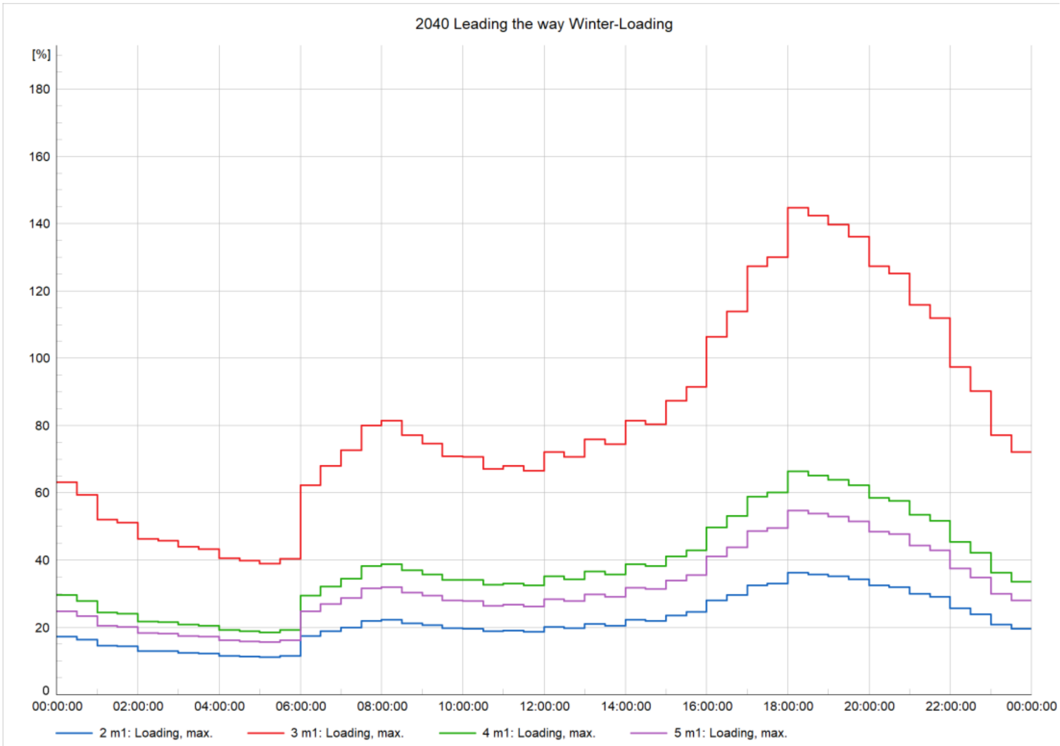

Figure 59 2040 Urban Network Leading the Way Winter loading profiles

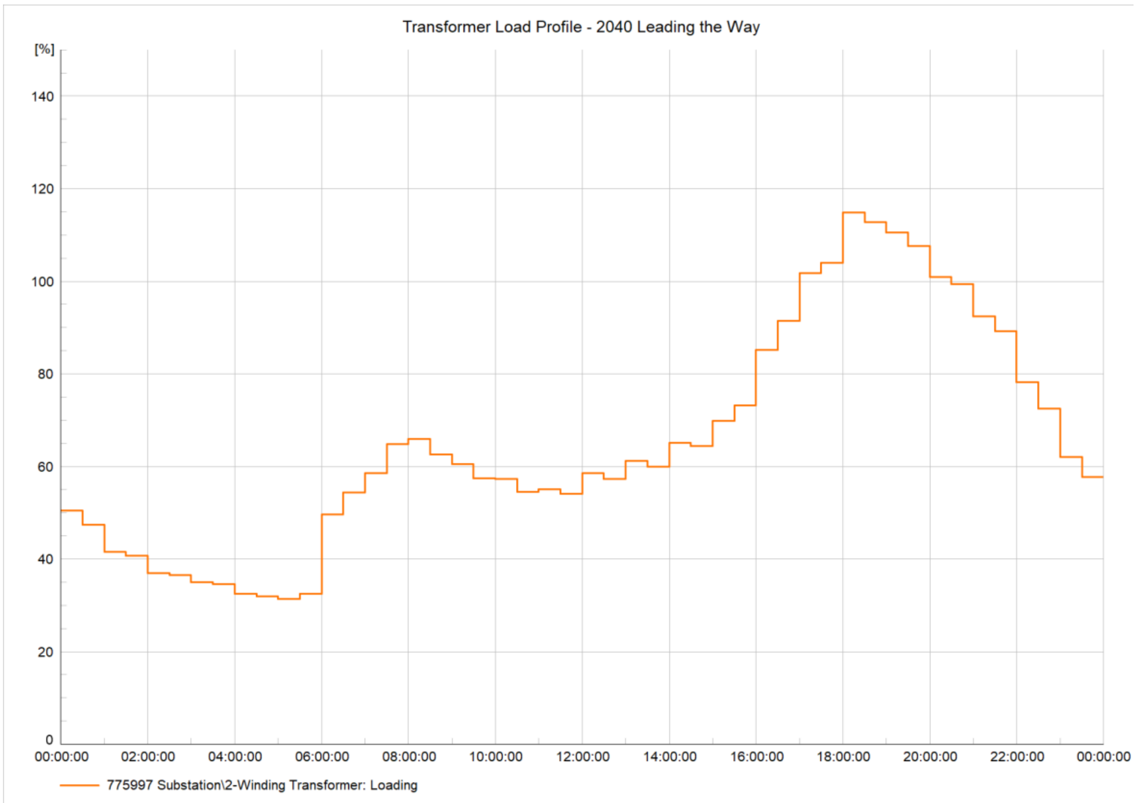

Figure 60 2040 Urban Network Leading the Way transformer loading profiles

5.5 2050

5.5.1 National Grid's Best View

Figure 61 shows the voltage plot in 2050 under the Best View scenario. The statutory voltage limits are exceeded in summer 2050 under the Best View scenario, reaching 1.12 times the nominal voltage in the middle of the day, exceeding 1.1 times the nominal voltage that is statutory limit.

Figure 62 shows that thermal limits are not breeched in summer 2050.

Summer

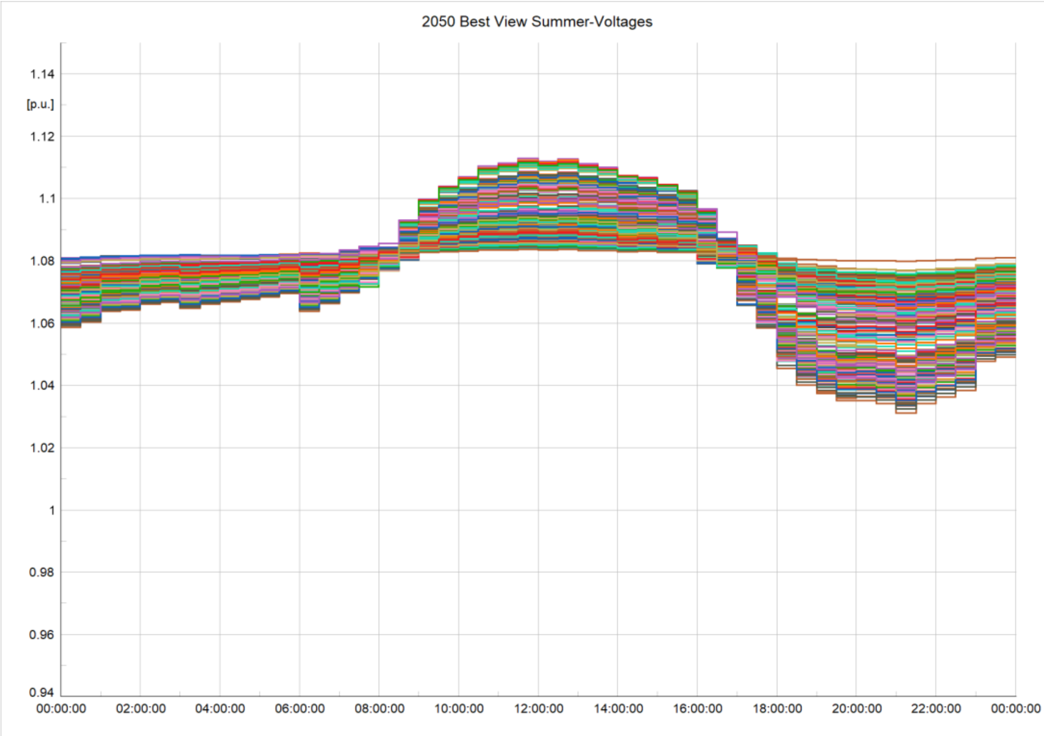

Figure 61 2050 Urban Network Best View summer voltage profiles

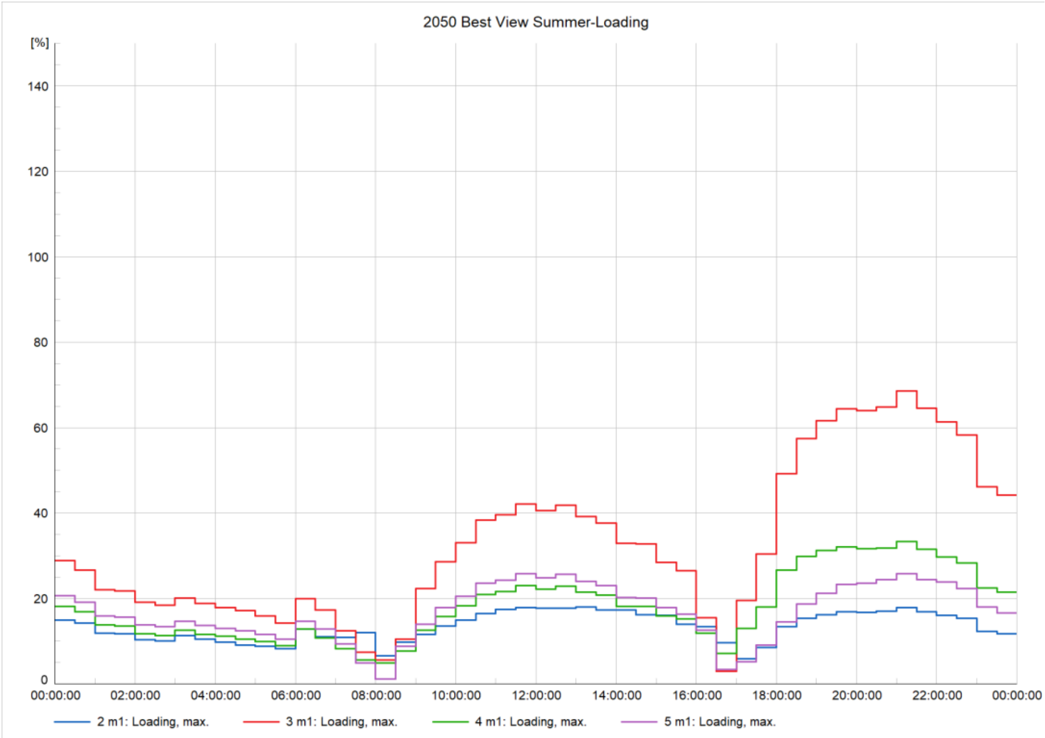

Figure 62 2050 Urban Network Best View summer loading profiles

Winter

Figure 63 shows that voltage limits are not breeched in the winter in 2050 under the Best View scenario. Figure 64 shows that thermal limits are breeched in the winter in 2050 under the Best View scenario. Thermal limits are breeched from 16:00 until 22:00 and the loading reaches a peak at 140% of the thermal limit. The transformer remains just below the rating at peak demand in this scenario.

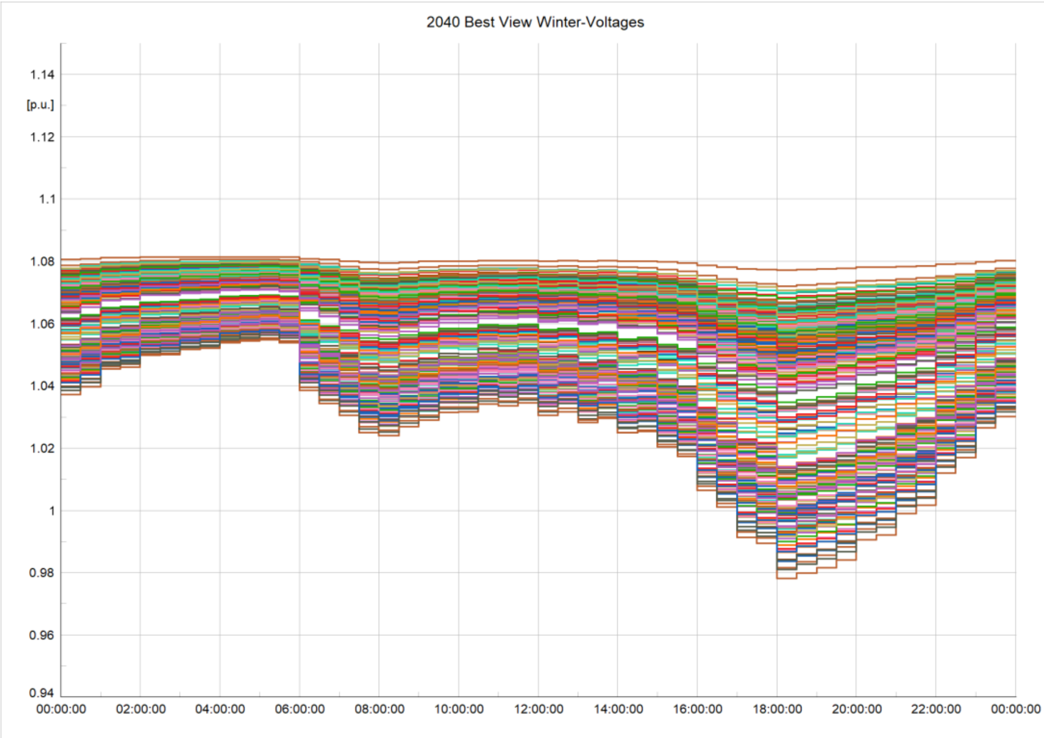

Figure 63 2050 Urban Network Best View winter voltage profiles

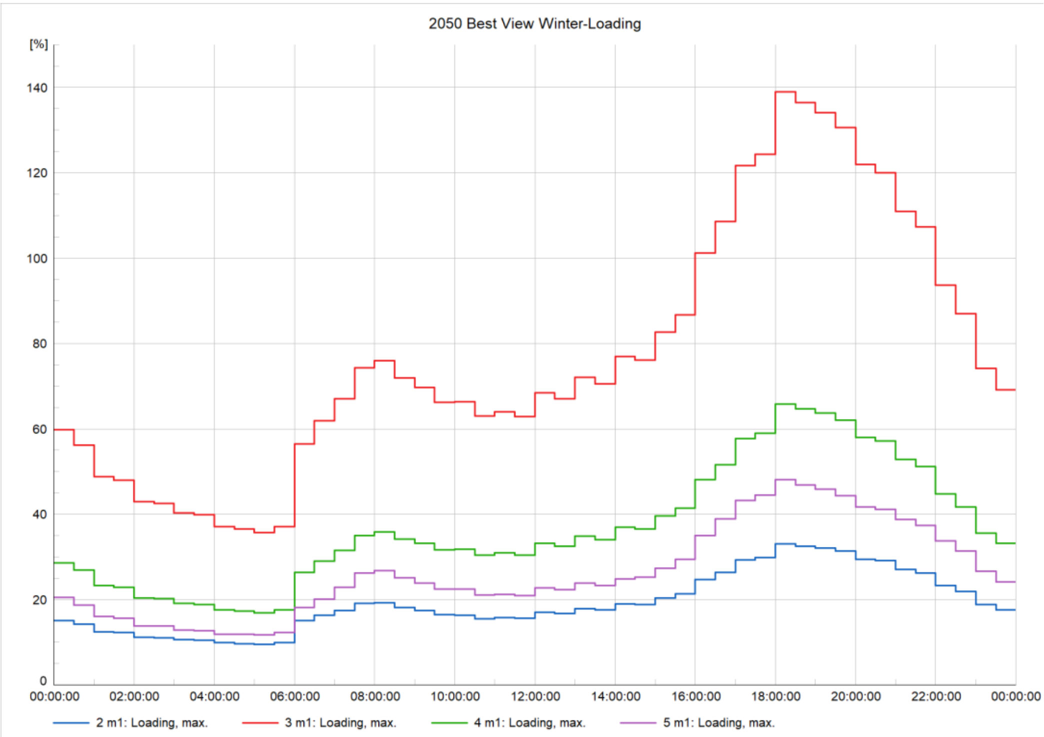

Figure 64 2050 Urban Network Best View winter loading profiles

5.5.2 Steady Progress

In 2050 under the Steady Progress scenario, thermal limits are not breeched, as with the Best View scenario. Figure 65 shows that in contrast to the Best View scenario, during the summer voltage limits are not exceeded in the Steady Progress scenario due to the lower uptake rates of solar PV.

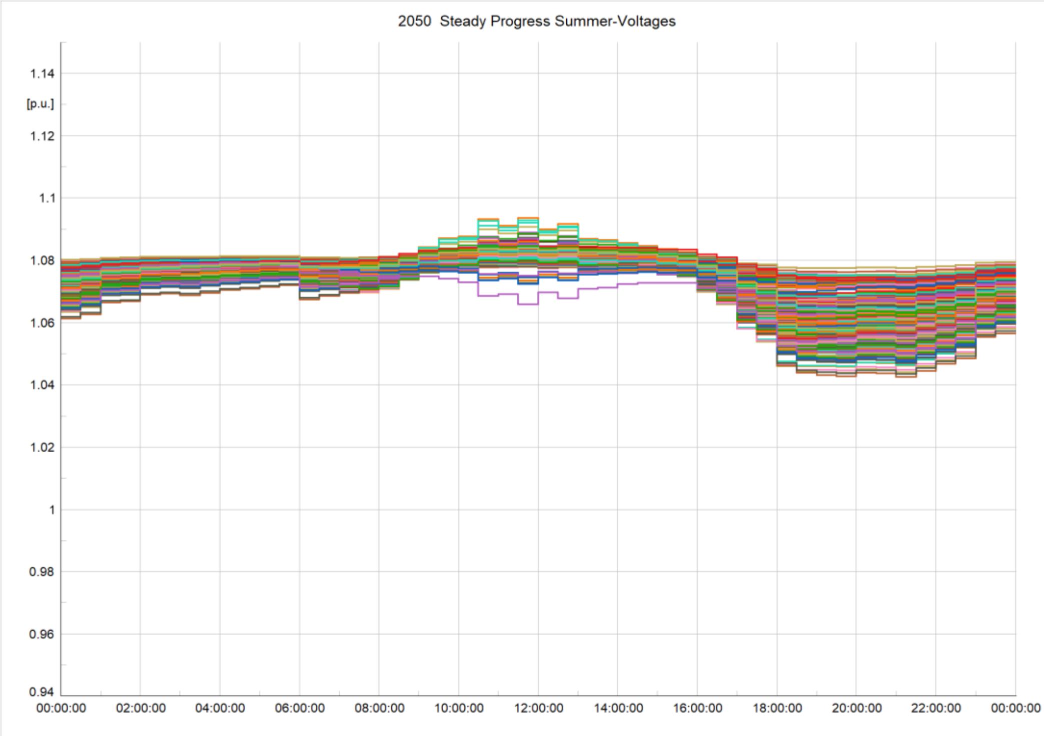

Figure 65 2050 Urban Network Steady Progress summer voltage profiles

In the winter in 2050, thermal limits are not breeched as in the Best View scenario. In contrast to the Best View scenario, thermal limits are not breeched in the winter under the Steady Progress scenario as shown in Figure 66. Instead, the thermal loading reached a peak of 80% of the thermal capacity on feeder 3 in the Steady Progress scenario.

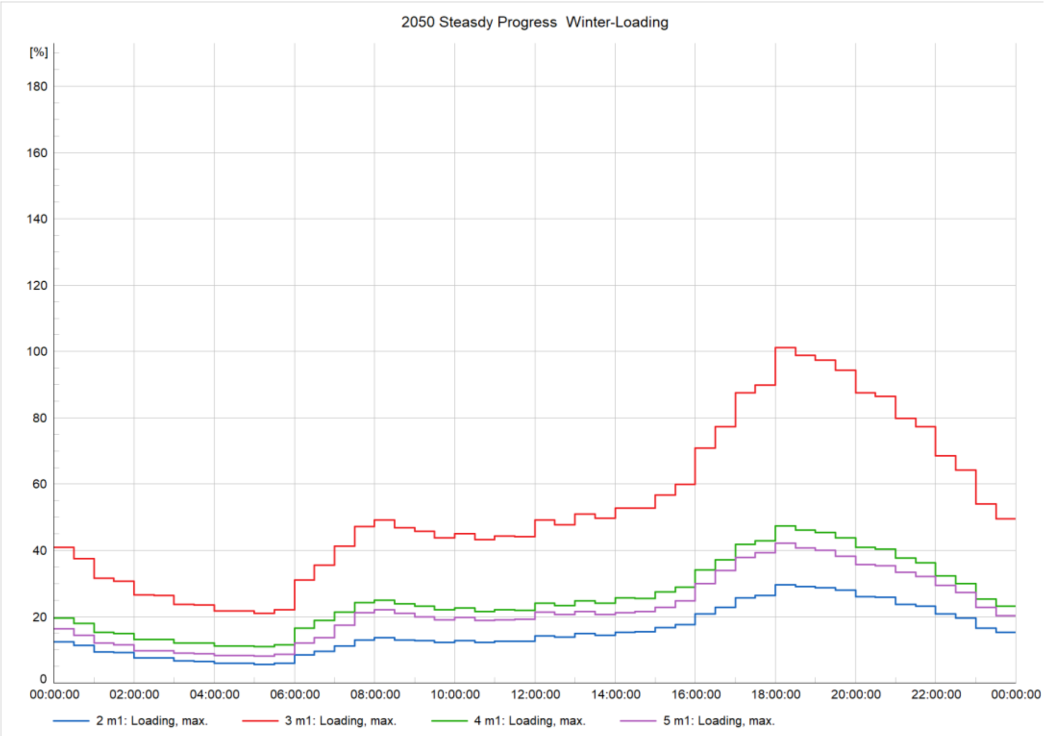

Figure 66 2050 Urban Network Steady Progress winter loading profiles

5.5.3 Leading the Way

As in the Best View scenario, in summer 2050 thermal limits are not breeched.

However, also as with the Best View Scenario, in summer 2050 voltage limits are breeched, with voltage rising above the statutory maximum for a greater number of customers and by a greater amount.

In the winter in the Leading the Way scenario, the voltage stays within statutory limits, again as with the Steady Progress scenario.

Thermal limits are breeched on Feeder 3 and the transformer in the Leading the Way scenario in winter. This is again consistent with the Best View scenario.

6. Rural Results

This section presents the results for the Rural network, to avoid repetition of the same results analysis is focussed on the Best View scenario and then results for the other scenarios (Leading the Way and Steady Progression) only included where they deviate.

The voltage profile plots show the voltage at each customer's point of connection during the 24 hour study window. The statutory requirements are for these voltages to remain below 1.1pu and above 0.94pu for all steady state operating conditions. The loading profile plots show the loading on each of the feeders supplied from the HV / LV substation and must remain below 100% of their rating.

6.1 2028

6.1.1 National Grid's Best View

Summer

The results shown in Figure 67 and Figure 68 show that the although the voltages do rise with the operation of the PV generation they remain below the upper statutory limit during the daytime peak generation and well above statutory minimum during the evening peak load conditions. The circuit loading also remains well below the rated limit, peaking at around 20% of capacity.

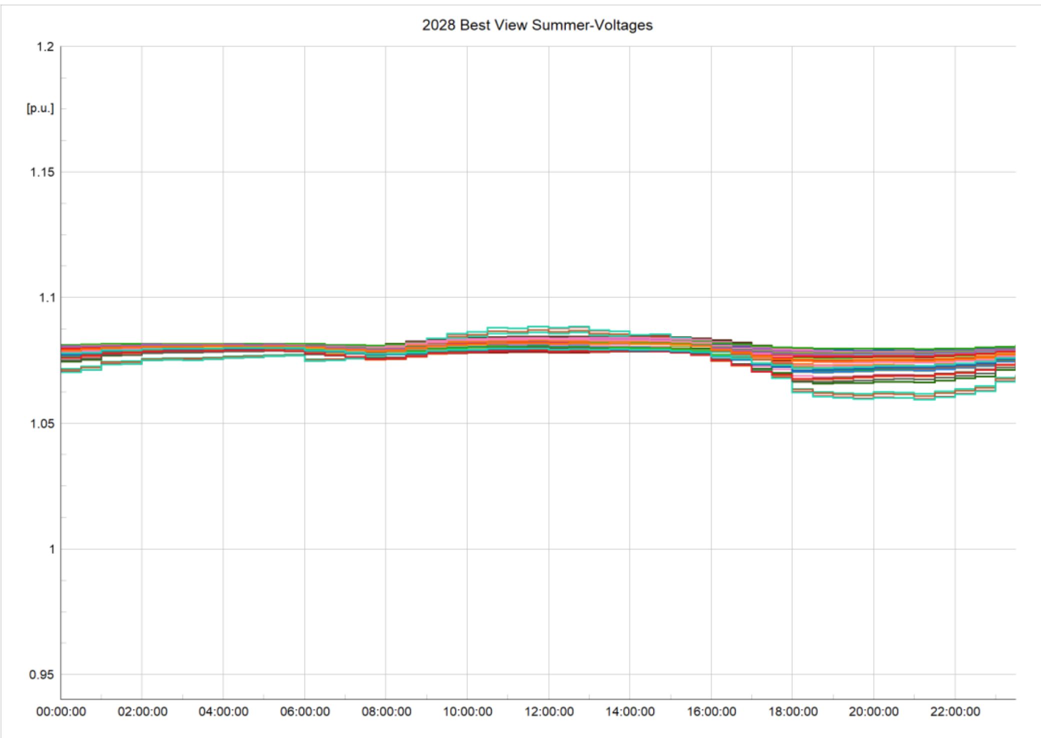

Figure 67 2028 Rural Network Best View summer voltage profiles

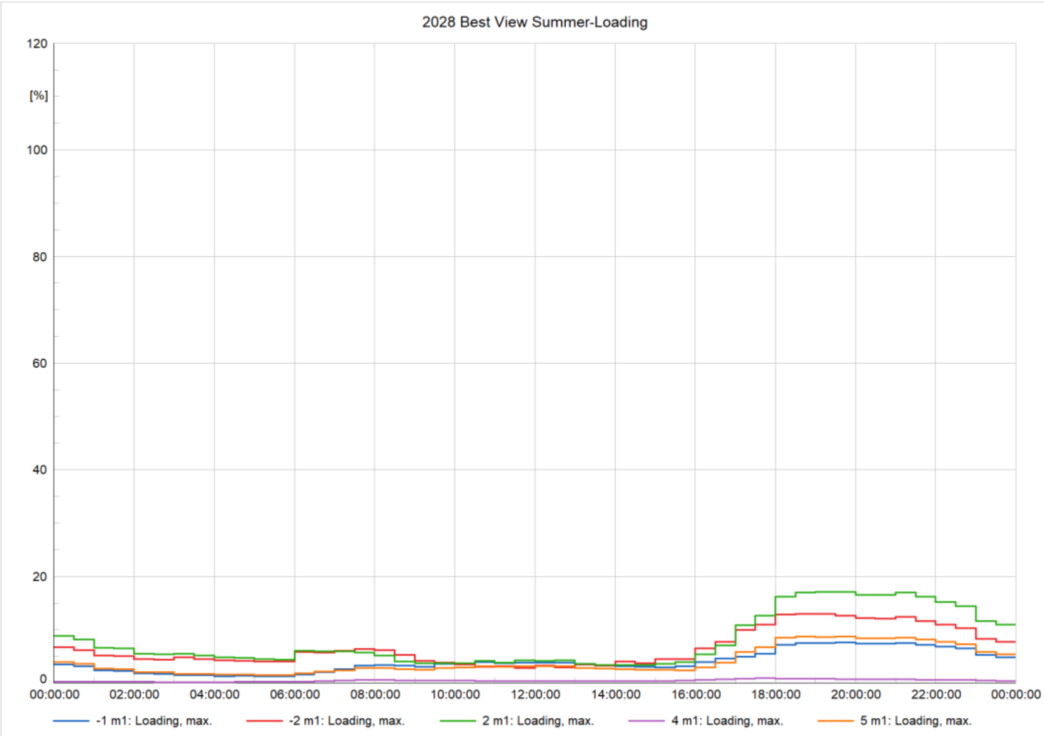

Figure 68 2028 Rural Network Best View summer loading profiles

Winter

The results in Figure 69 and Figure 70 demonstrate that under the 2028 Best View winter peak demand conditions when the PV output will be reduced the minimum, voltages remain well above the statutory minimum. The feeders are only partially loaded with Feeder 2 being the highest as percentage of capacity with just over 30% peak loading.

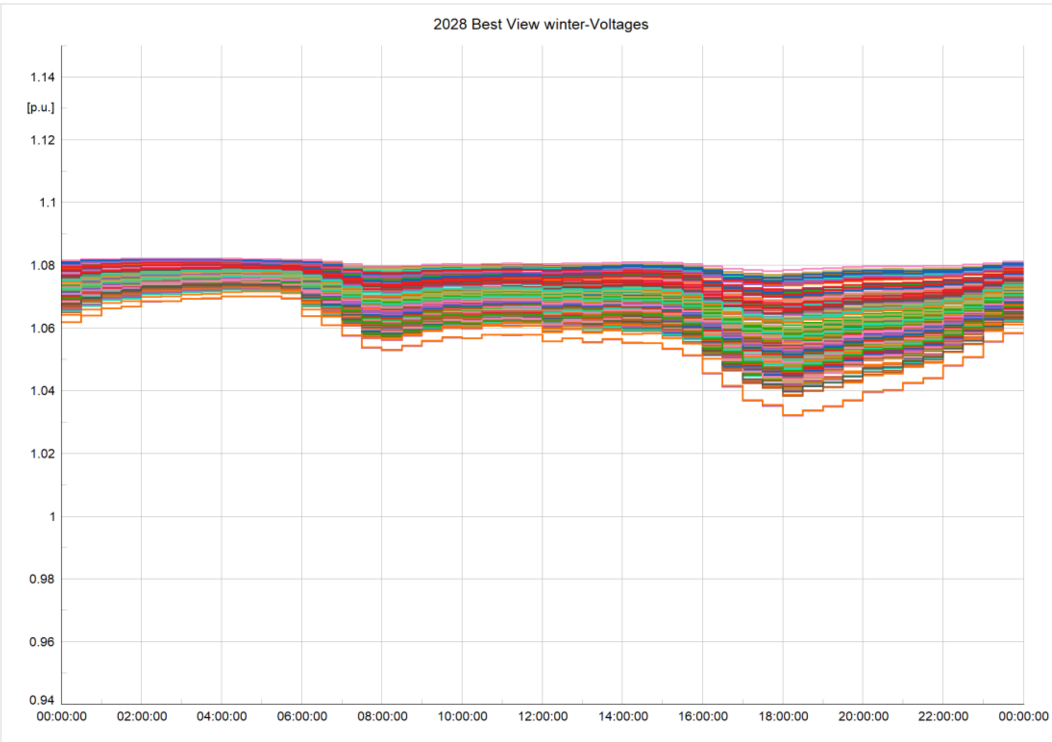

Figure 69 2028 Rural Network Best View winter voltage profiles

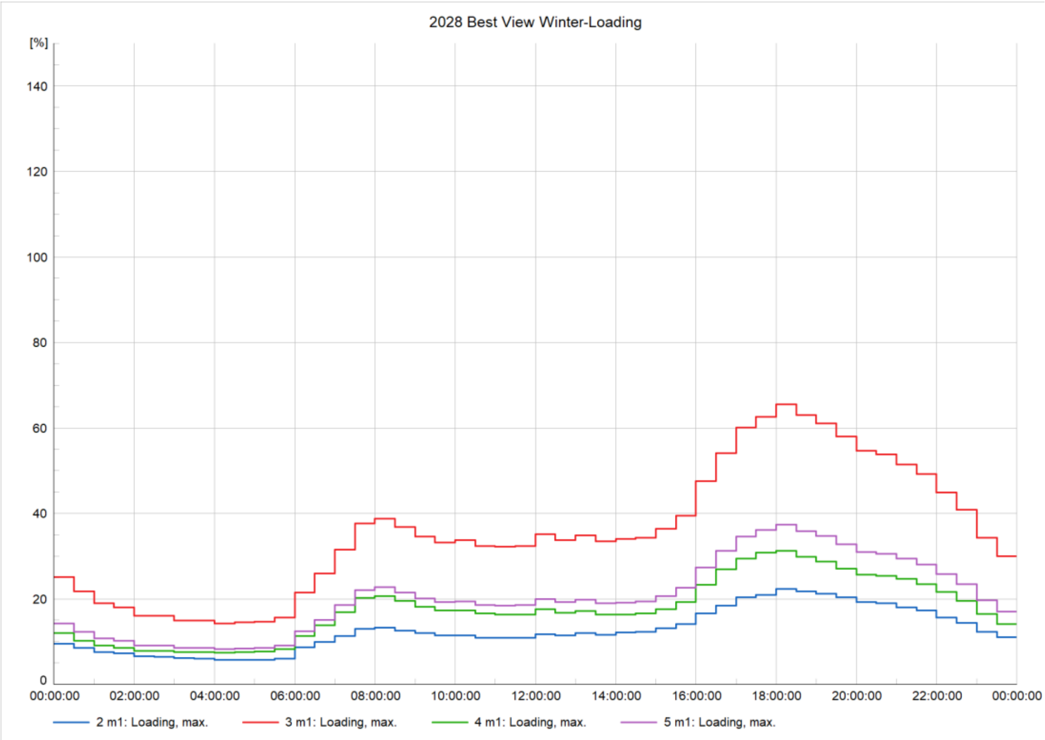

Figure 70 2028 Rural Network Best View winter loading profiles

6.1.2 Steady Progress

Summer

The Steady Progress summer results show a lower peak loading consistent with fewer EV and Heat pump connections. The voltage profile exhibits similar rise during peak PV output but remains well within statutory limits.

Winter

The Steady Progress winter results show the same effects relating to the lower peak loading due to fewer EV and Heat Pump connections.

6.1.3 Leading the Way

Summer

The Leading the way results show increased levels of peak demand during the evening/night-time peaks although these are all still well within the feeder capacities. The voltage profiles also remain well within statutory limits.

Winter

The winter demand profiles show increased levels of peak demand in line with the profiles applied to the EV and heat pump load connections, the feeders remain well within their capacity and the voltage profiles remain well within the statutory envelope.

6.2 2033

6.2.1 National Grid's Best View

Summer

The summer Best View results show some unusual voltage results around the times of peak PV output, this is believed to be an artefact within the model giving strange results as the feeder switches from import to export. More detailed studies have shown that the voltages still remain within statutory limits, but the PV output is clearly pushing up the voltage as the network begins to export.

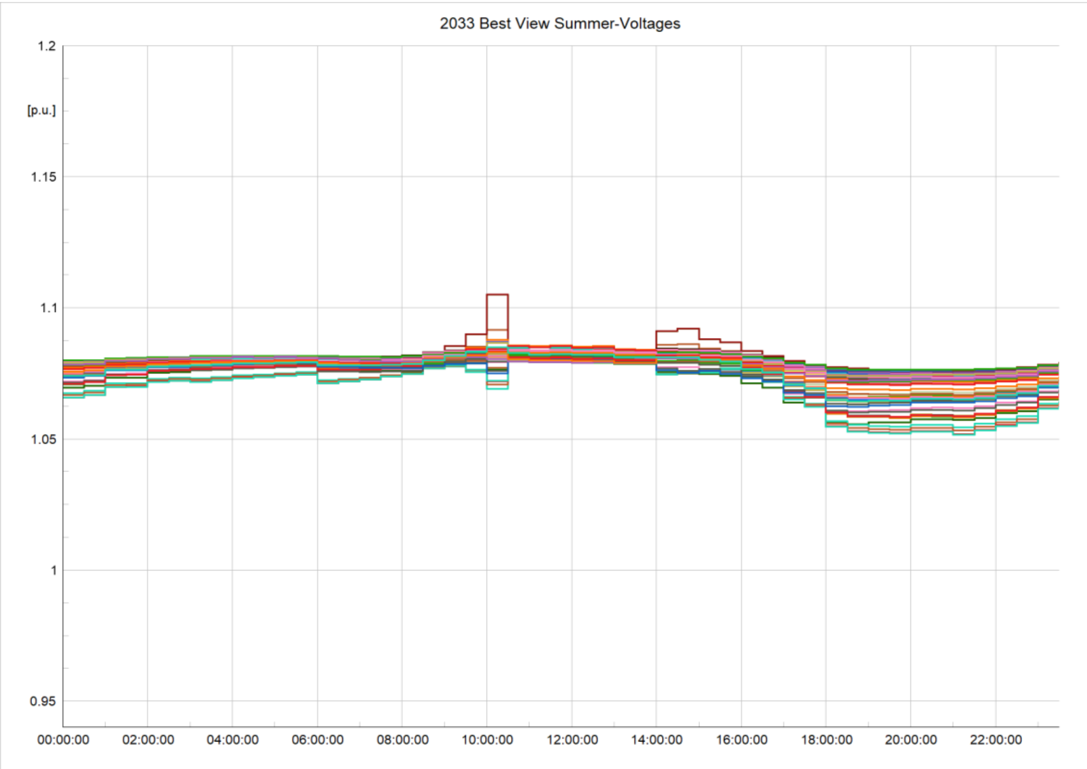

Figure 71 2033 Rural Best View summer voltage profiles

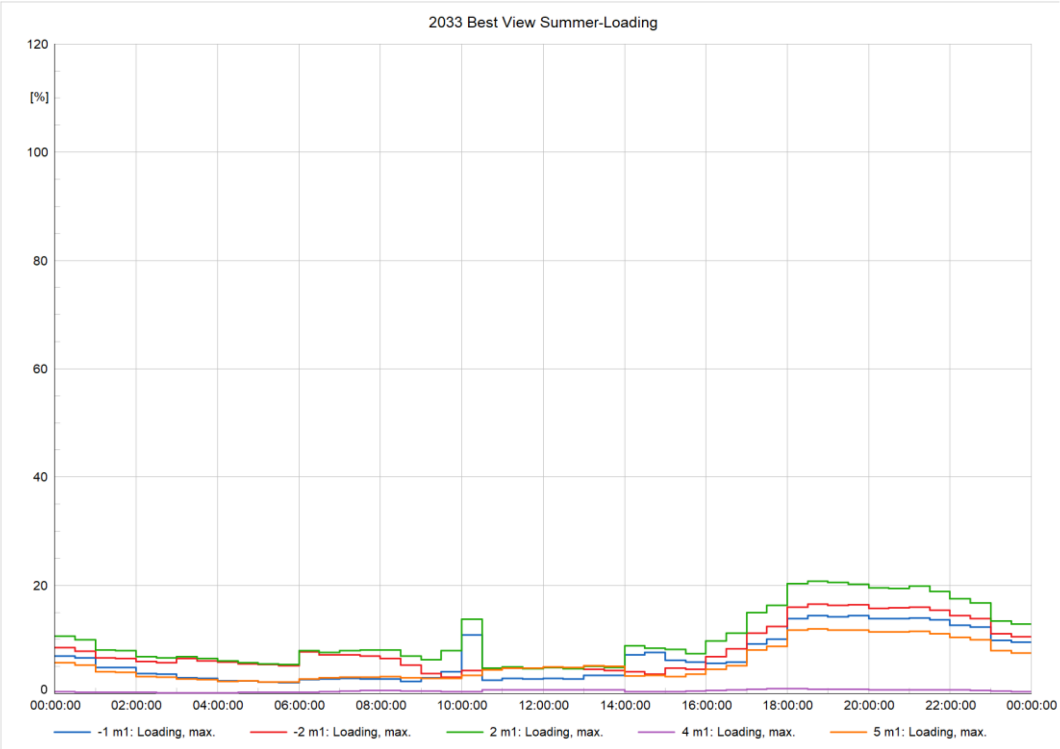

Figure 72 2033 Rural Best View summer loading profiles

Winter

The winter Best View results again show voltage profiles well within the Statutory Limits and peak feeder loading all below 40% of the ratings. The voltage profiles (Figure 73) are beginning to show that customers at the very ends of the feeders are seeing more significant voltage drops but during high demand but still within limits.

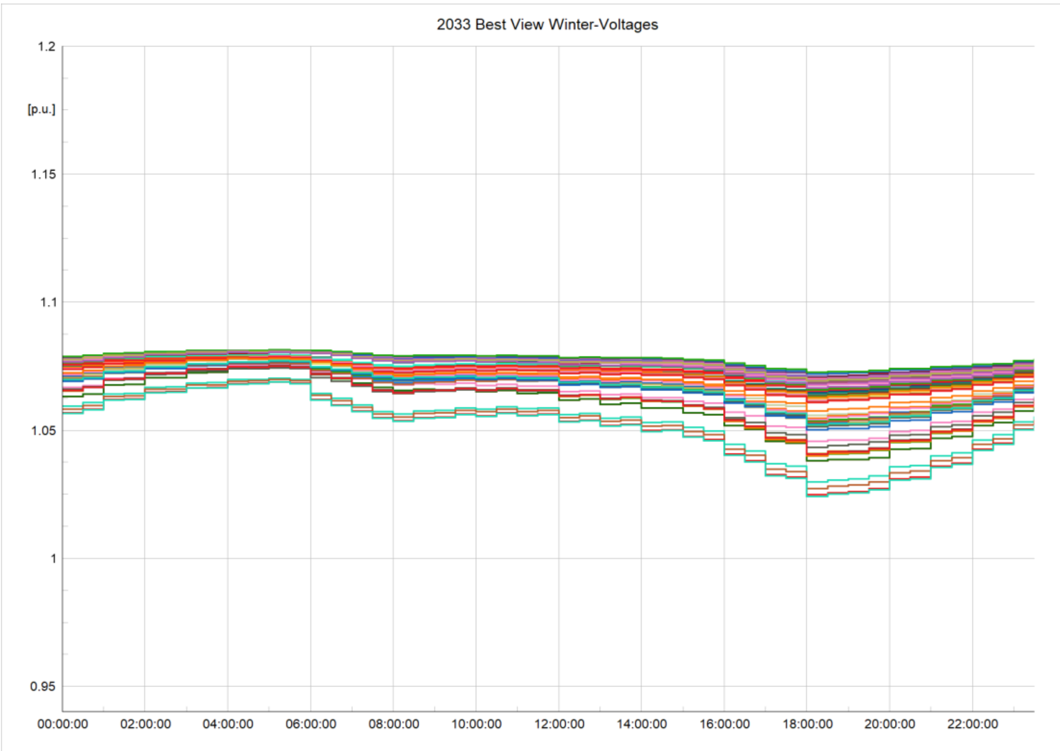

Figure 73 2033 Rural Best View winter voltage profiles

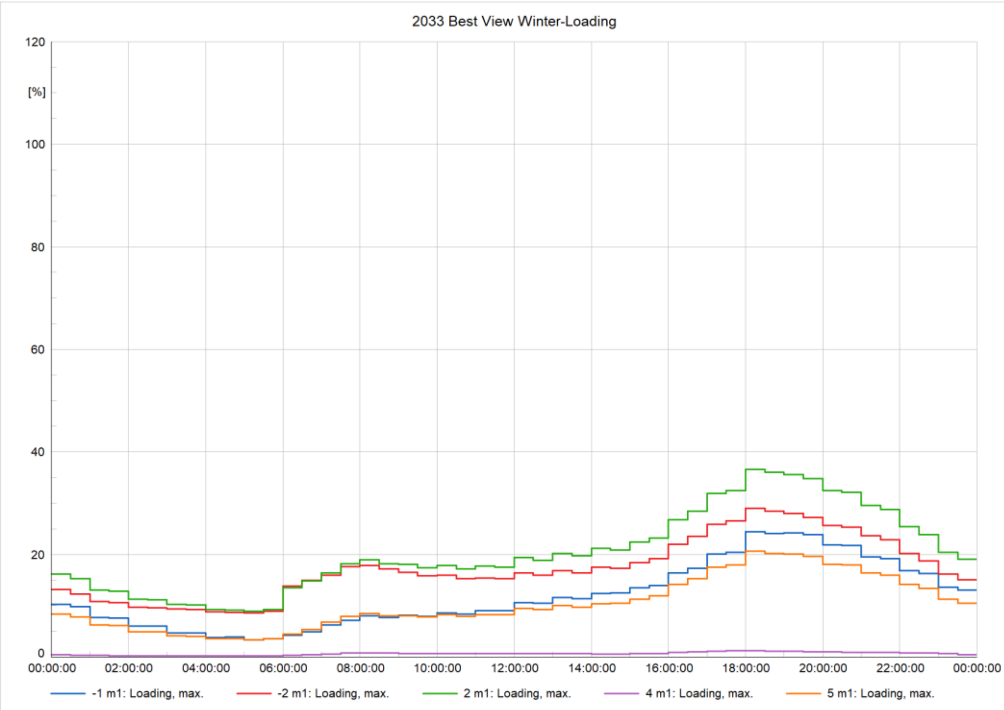

Figure 74 2033 Rural Best View winter loading profiles

6.2.2 Steady Progression

Summer

The summer Steady Progression study which has fewer PV installations shows reducing loading on the feeders overall with some slight rise on the voltages associated with the PV installations. This shows that the reduced loading is as a result of the PV exporting and therefore reducing feeder loading but not sufficient to result in reverse power flows.

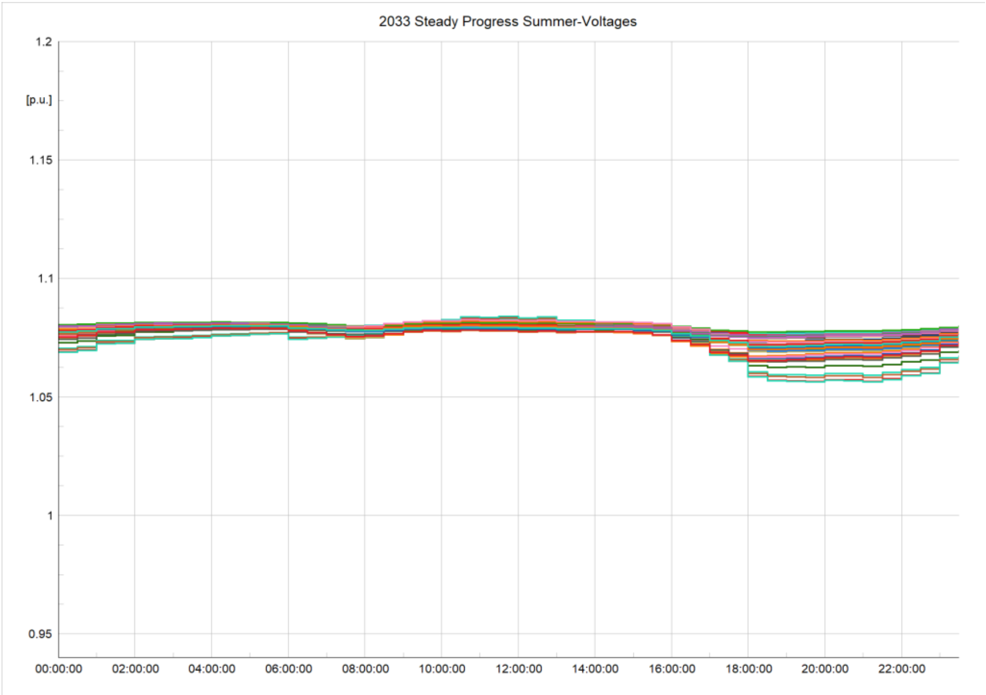

Figure 75 2033 Rural Steady Progression summer voltage profiles

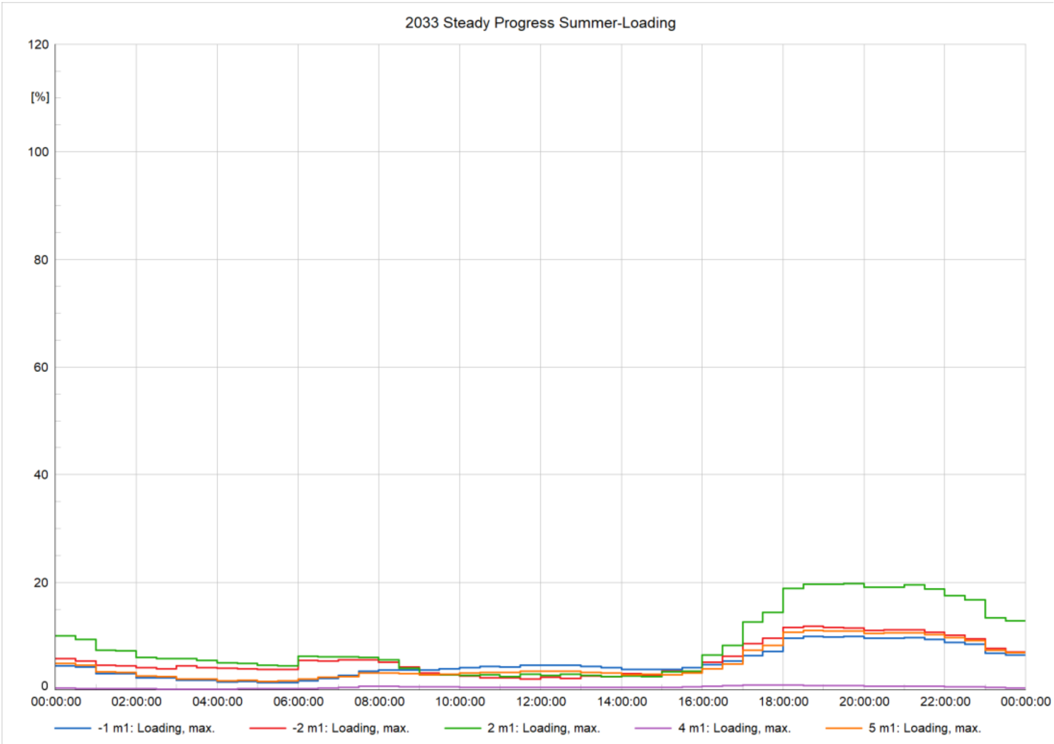

Figure 76 2033 Rural Steady Progression summer loading profiles

Winter

During winter, the Steady Progression loading remains well within the circuit rating, peaking at around 20% during the evening peak. Likewise, the lower levels of LCT uptake mean that voltages remain well within statutory limits with the remote customers voltages remaining above 1.05p.u.

6.2.3 Leading the Way

Summer

The summer Leading the Way results show similar results to the Best View studies as the feeders switch from import to export. The increasing level of PV generation is beginning to increase the voltages during mid-day close to the upper statutory limit (1.1p.u.) as the network is in reverse power flow before switching back to import during the evening demand peak.

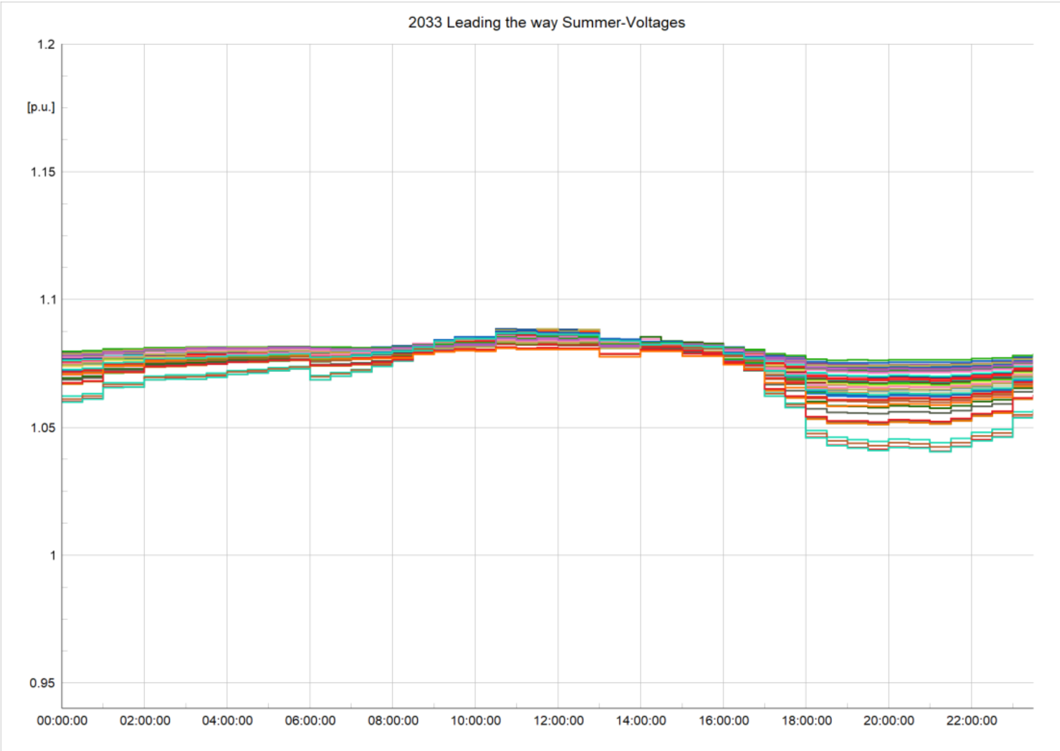

Figure 77 2033 Rural Leading the Way summer voltage profiles

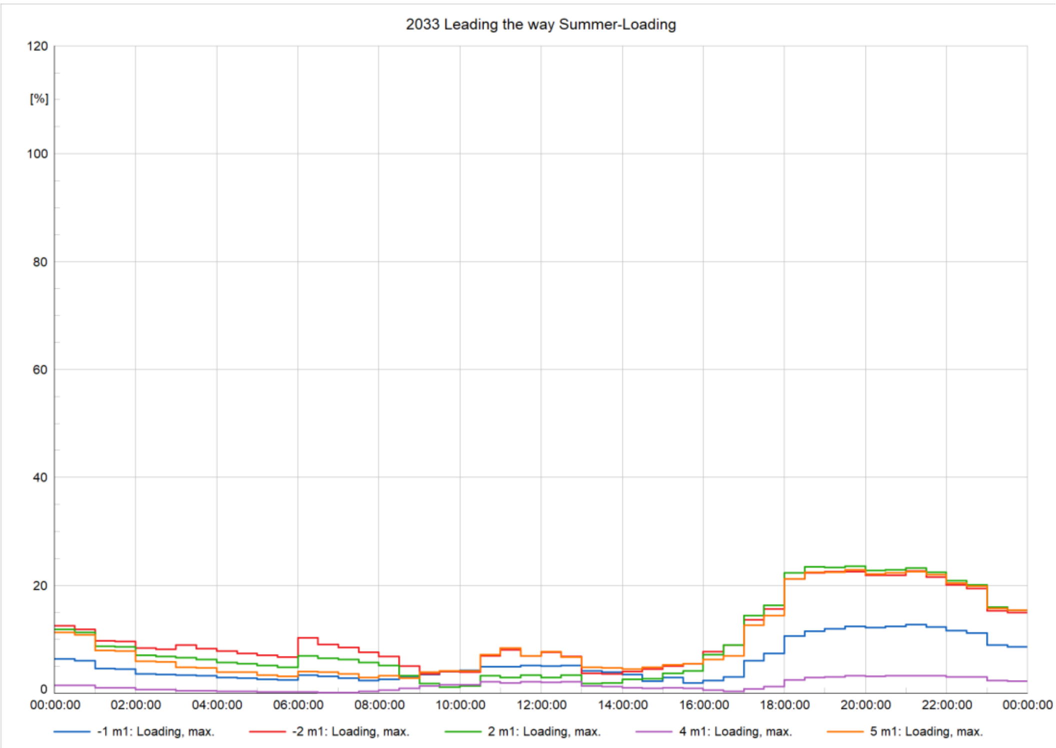

Figure 78 2033 Rural Leading the Way summer loading profiles

Winter

During the winter, although loading increases it still remains well within thermal ratings peaking at around 40% during the evening peak. Likewise, the voltage limits remain well above statutory minimum levels (0.94p.u.) but as can be seen in Figure 79 the voltage at remote customers is now beginning to approach limits.

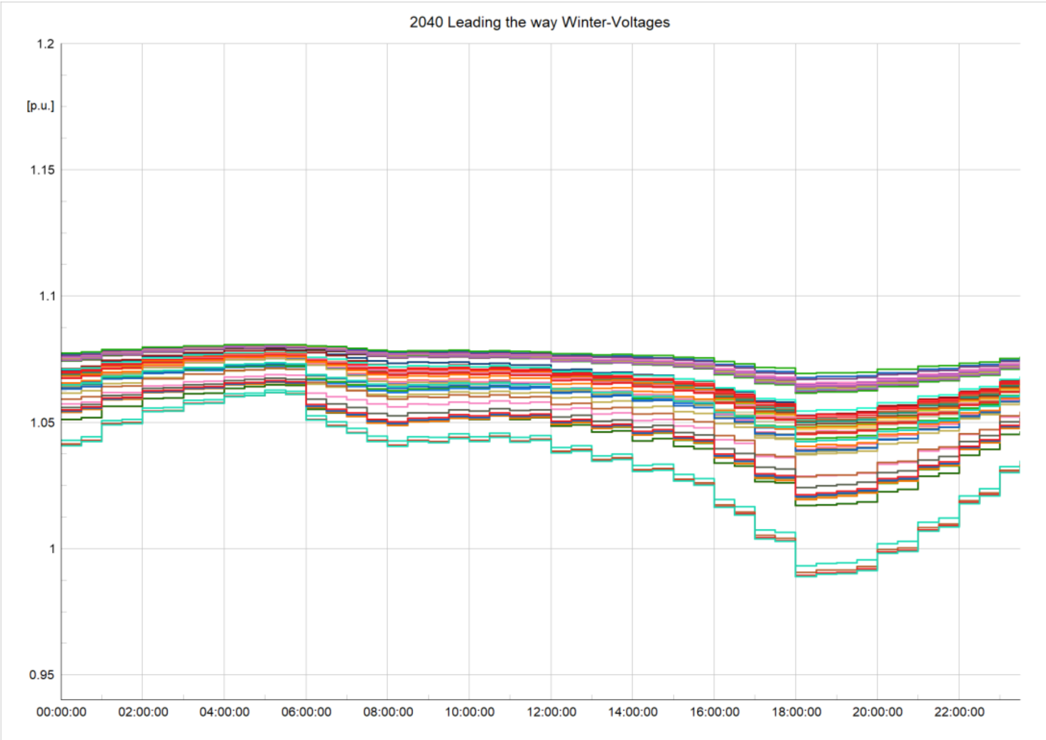

Figure 79 2033 Rural Leading the Way winter voltage profiles

6.3 2040

6.3.1 National Grid's Best View

Summer

In the 2040 Best View summer study we see feeders exporting to the transformer and the voltages rise towards and appear to marginally exceed the upper statutory limit Figure 80). This may be an anomaly as the trace shown for the Leading the Way scenario (Figure 84) does not exceed the limit although it does get very close.

The circuit loading results (Figure 81) show the overall feeder loadings remain very low but there is a clear transition from import to export as the PV generation begins to increase during the middle of the day.

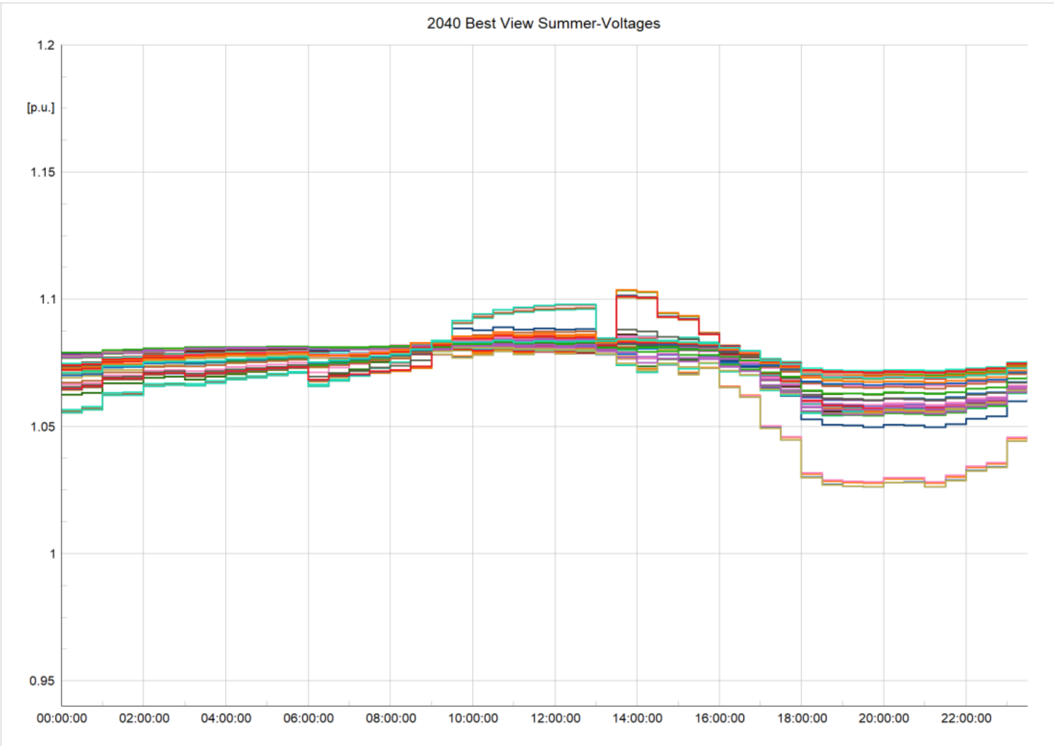

Figure 80 2040 Rural Best View summer voltage profiles

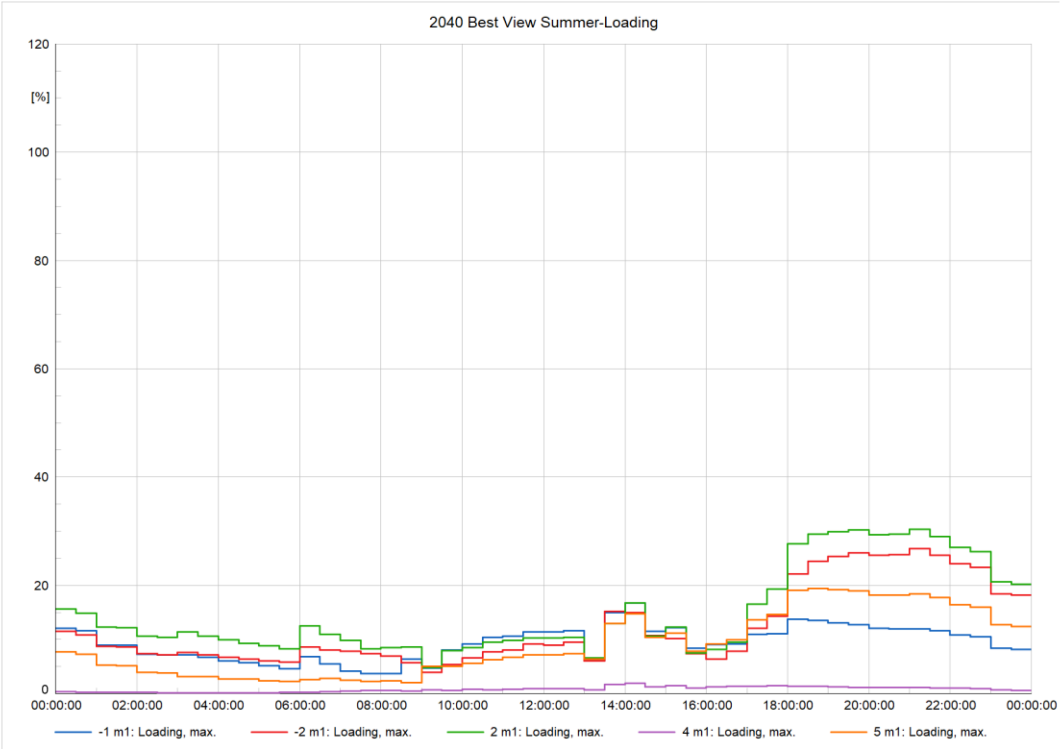

Figure 81 2040 Rural Best View summer loading profiles

Winter

In the winter Best View study, the loading increases across the feeders but remains within the capacity of the feeders and the transformer, peaking at around 50%. The voltage profiles are still within the statutory envelope, but the lower voltages seen at the remote ends of feeders becomes more accentuated and a different distribution of LCTs on these feeders could worsen this condition.

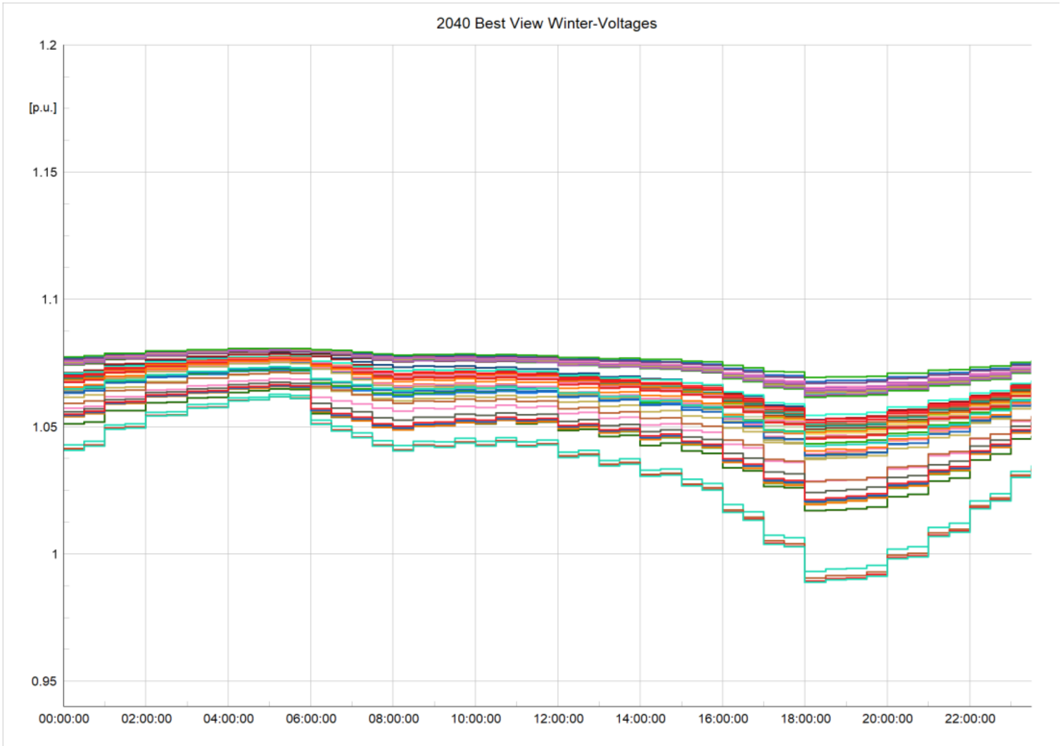

Figure 82 2040 Rural Best View winter voltage profiles

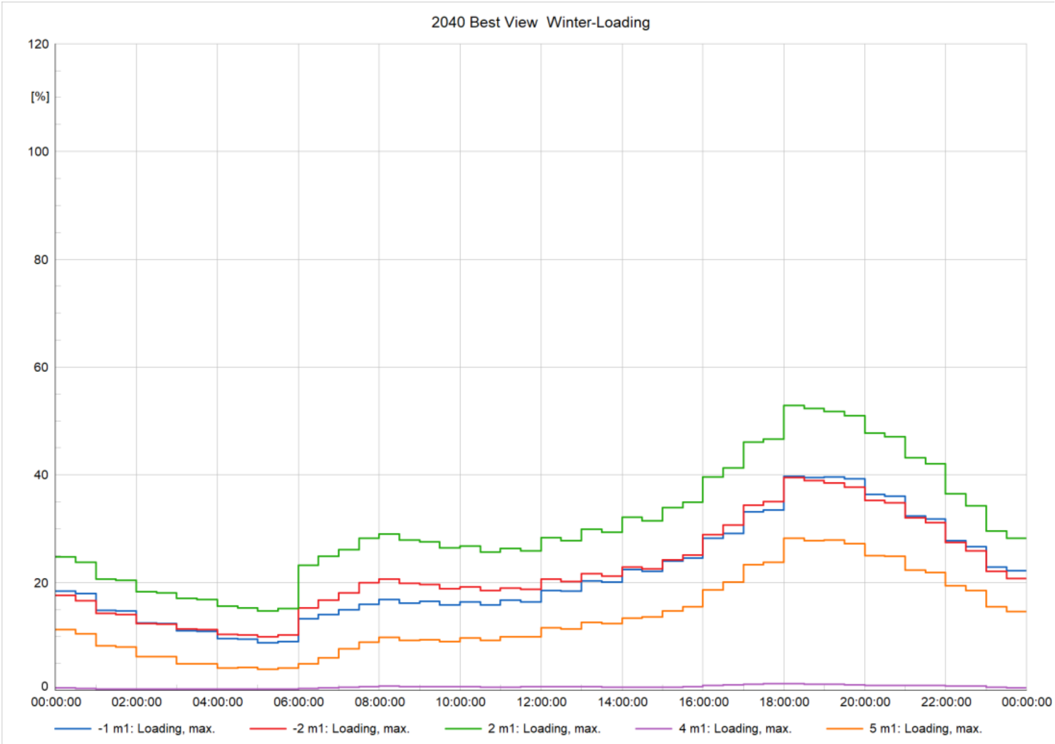

Figure 83 2040 Rural Best View winter loading profiles

6.3.2 Steady Progression

Summer

The Steady Progression summer results show voltages and circuit loading remain well within statutory limits. There is a very slight rise in voltage corresponding to a reduction in circuit loading during maximum PV export, but the system does not appear to enter into a reverse power flow condition.

Winter

During winter, the increasing levels of LCT demand in the Steady Progression scenario now means peak demands have increased with feeder 2 reaching 50%. This is not of a level to cause concern and voltages remain well within statutory limits.

6.3.3 Leading the Way

Summer

The Leading the Way scenario sees significantly higher levels of PV penetration by 2040 and this is reflected in the high daytime voltages seen during the summer (Figure 84). However, the high levels of EV and HP also result in a comparatively higher level of voltage reduction during the evening, though still remaining well above statutory minimum limits.

During maximum PV export the network is clearly in a reverse power flow as energy is exported back into the upstream system (Figure 85).

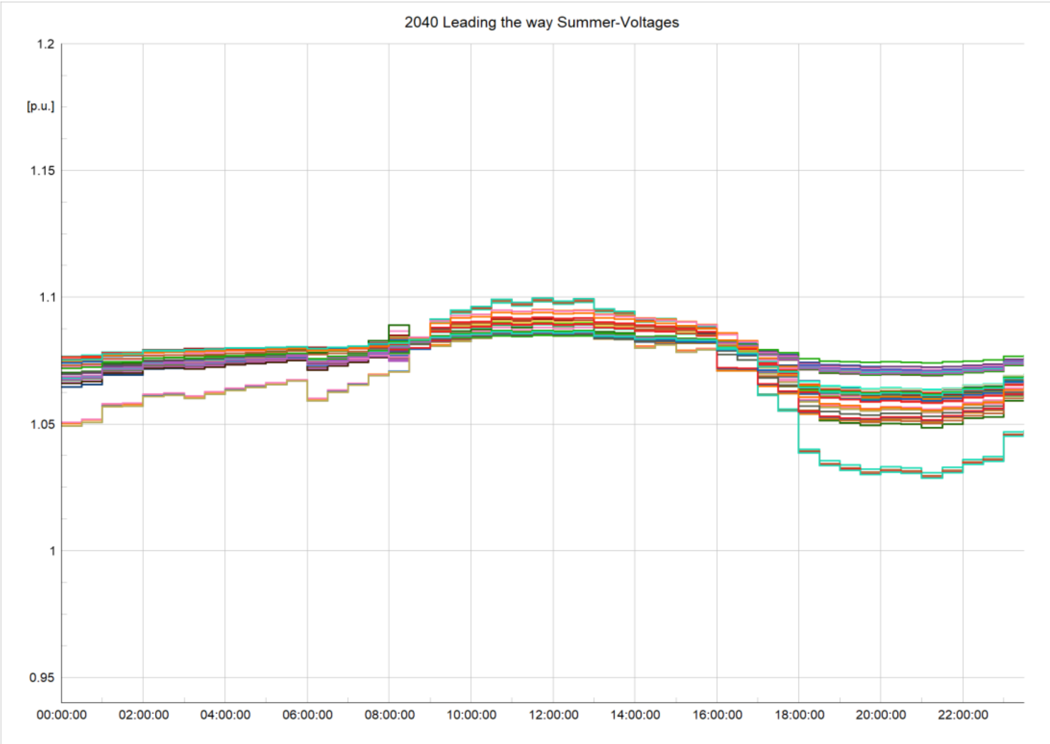

Figure 84 2040 Rural Leading the Way summer voltage profiles

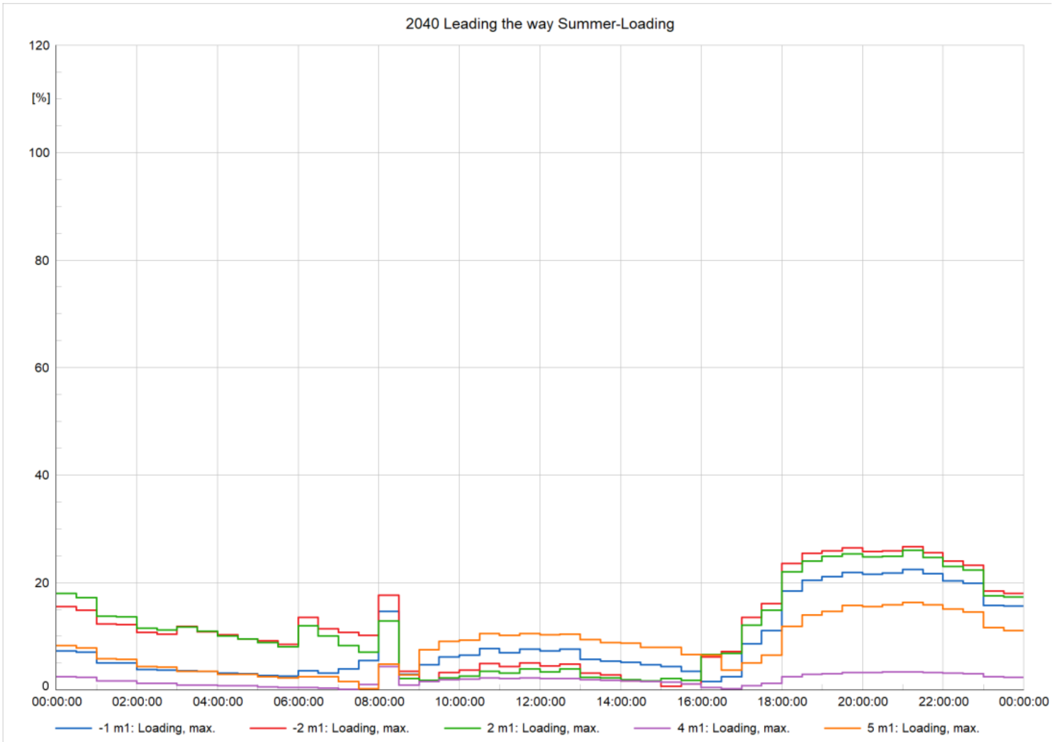

Figure 85 2040 Rural Leading the Way summer loading profiles

Winter

During the winter, the Leading the Way scenario has relatively high levels of EV and HP installations resulting in significant loadings during the evening peak. Circuit loading on both feeders 2 and 5 exceed 50% which although still well below their rating is causing significant voltage drops for customers at the ends of those feeders. Figure 86 shows that some of the customers have voltages as low as 0.96p.u., approaching the lower Statutory limit of 0.94p.u.

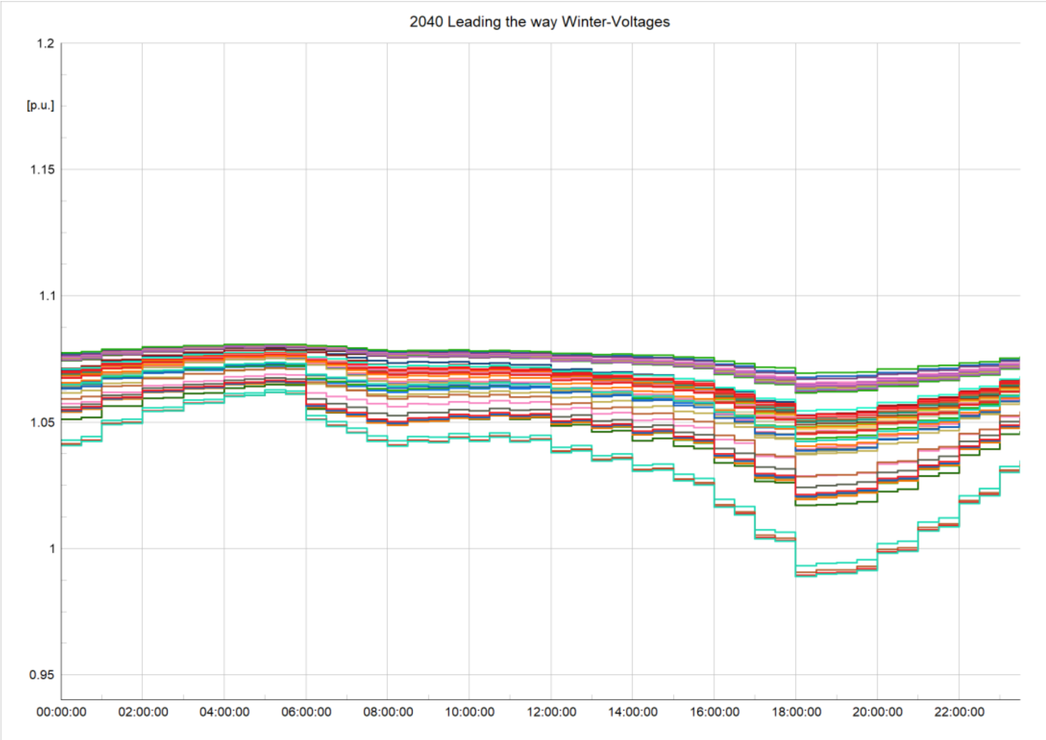

Figure 86 2040 Rural Leading the Way winter voltage profiles

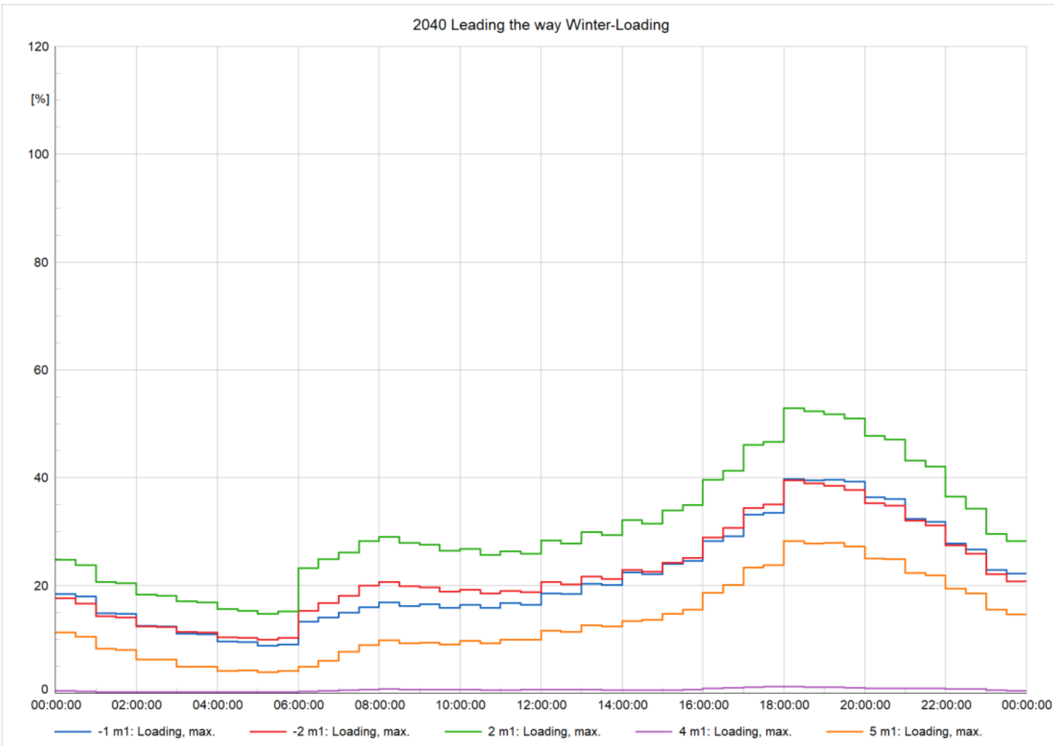

Figure 87 2040 Rural Leading the Way winter loading profiles

6.4 2050

6.4.1 National Grid's Best View

Summer

By 2050 the level of PV generation within the rural network is sufficient to result in exceedance of the upper statutory voltage limit of 1.1p.u. Figure 88shows that voltages at some customers terminals are approaching 1.11p.u. (256V) during peak PV export and likewise the feeders have a nearly 20% loading as a result of the network exporting upstream (Figure 89).

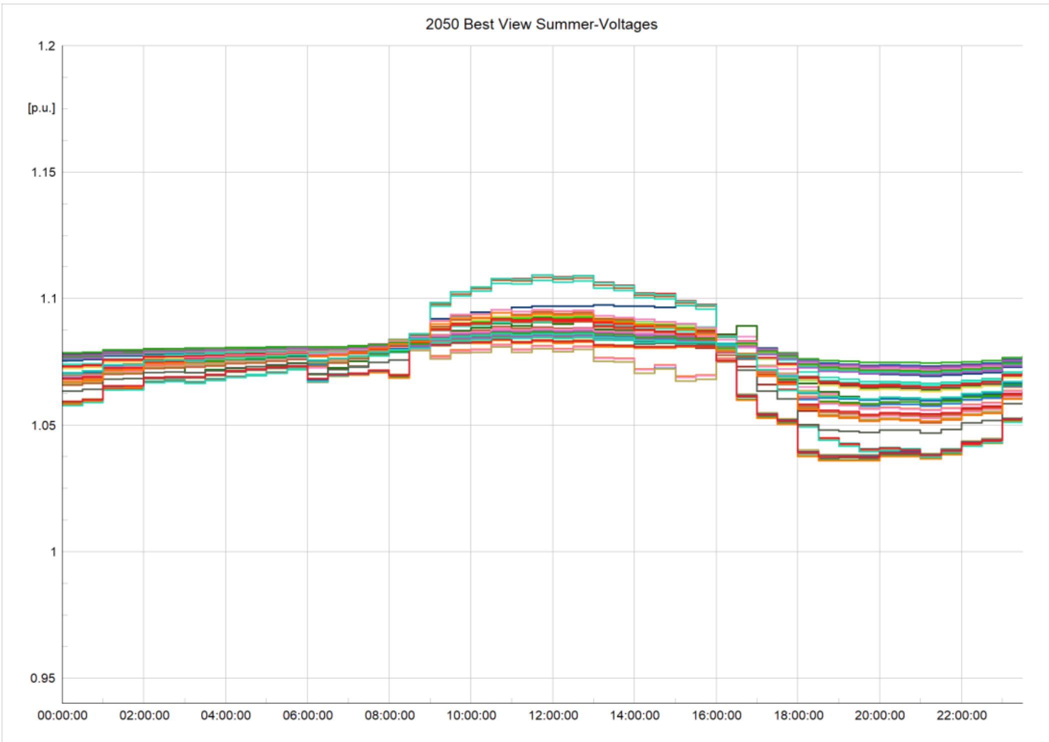

Figure 88 2050 Rural Best View summer voltage profiles

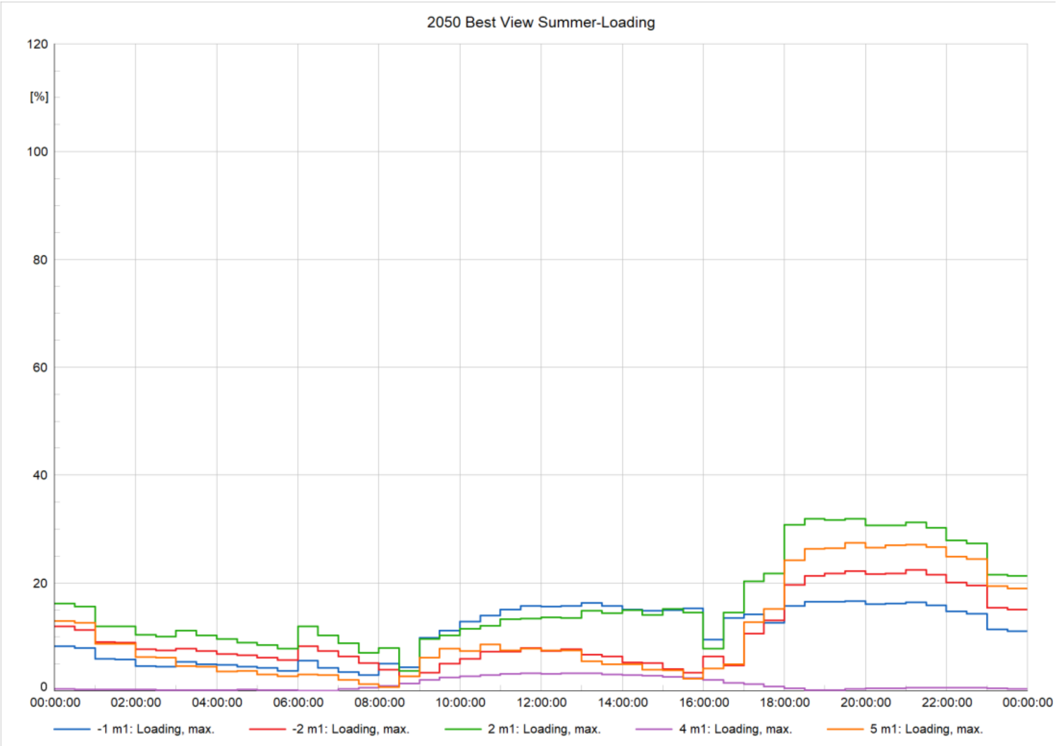

Figure 89 2050 Rural Best View summer loading profiles

Winter

Under the Best View scenario, the spread in voltages at customer terminals shown in Figure 90 is ranging from 1.08p.u. to 1.0p.u. during winter peak demand. These are still within statutory limits but beginning to show the challenges a high level of LCT uptake can create with regards to maintaining all customer terminals within voltage limits. During the evening peak, demand is now exceeding 30% on all feeders and approaching 60% on feeder 2 (Figure 91).

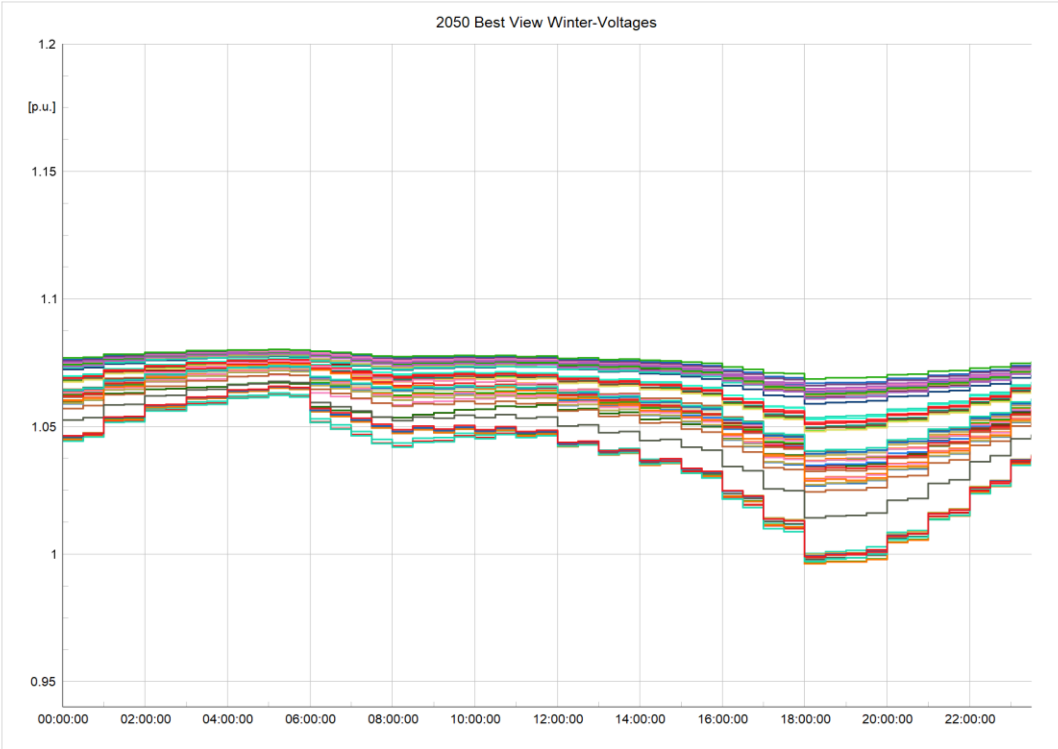

Figure 90 2050 Rural Best View winter voltage profiles

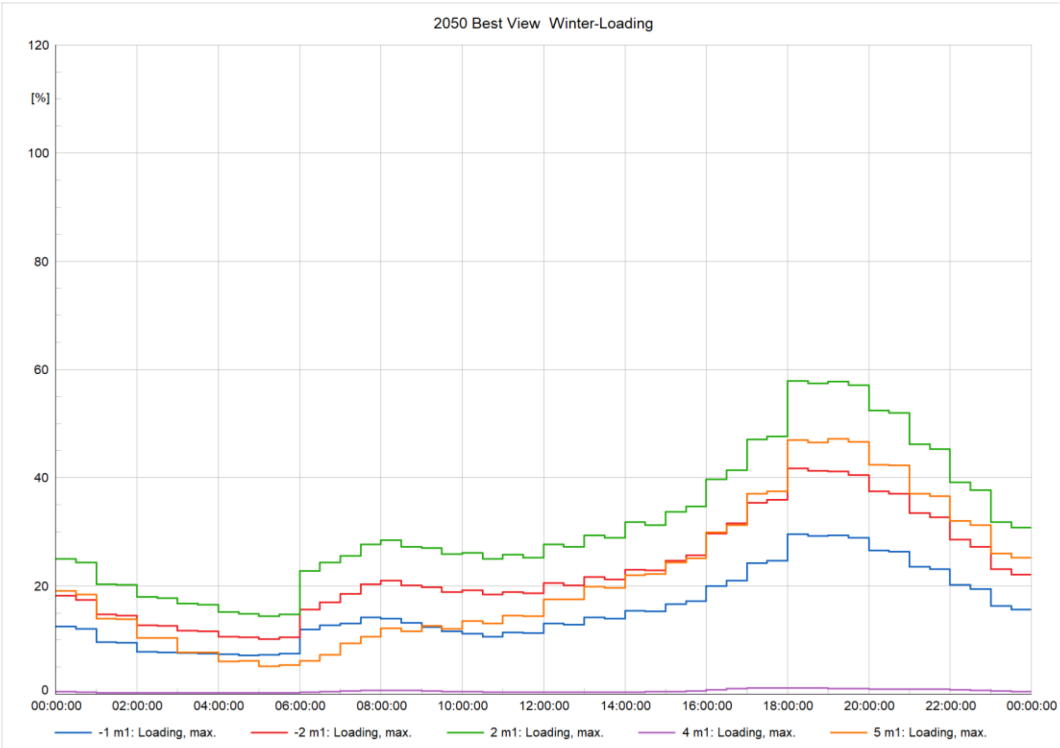

Figure 91 2050 Rural Best View winter loading profiles

6.4.2 Steady Progression

Summer

During summer, the lower PV installations for the 2050 Steady Progression scenario means voltages will remain well within statutory limits during maximum export and the system only marginally enters a reverse power flow condition.

Winter

During winter, loading on feeders 2 and 5 approaches 50% and voltages on some customers terminals are approaching 1.0p.u. during maximum demand.

6.4.3 Leading the Way

Summer

Following on from the 2040 analysis of the Leading the Way scenario, voltages continue to exceed the upper statutory limit during maximum PV export (Figure 92 with reverse power flow (Figure 93) reaching 20% of the circuits thermal rating. During summer the feeders export during the day is equal in magnitude to its import loading during the evening.

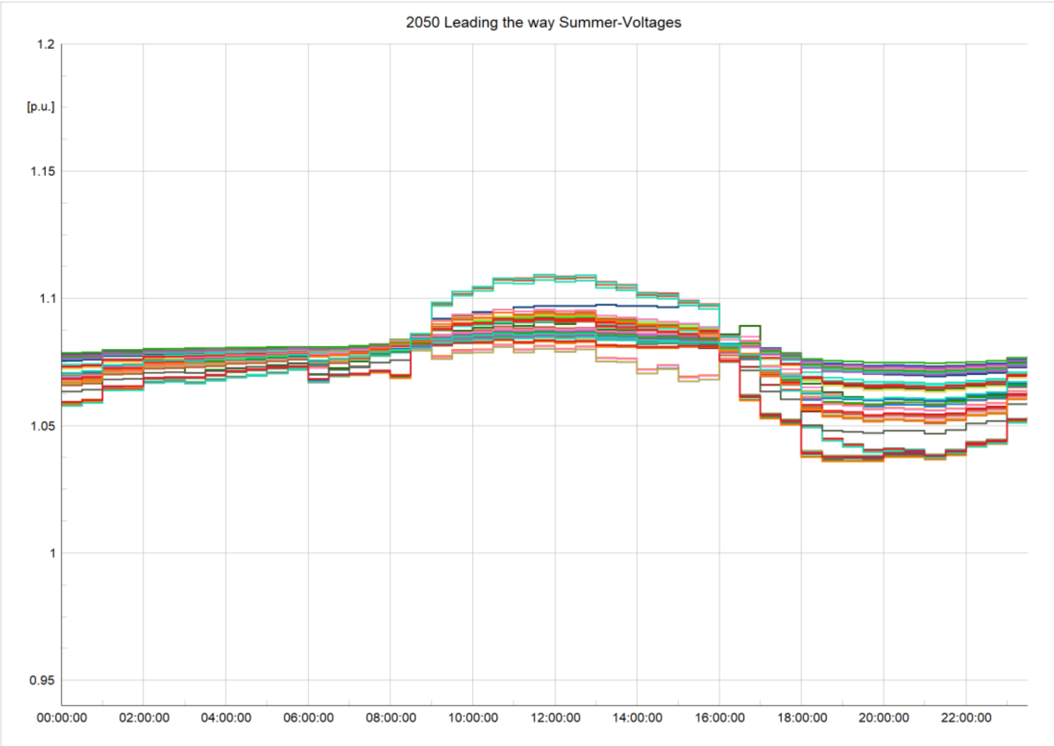

Figure 92 2050 Rural Leading the Way summer voltage profiles

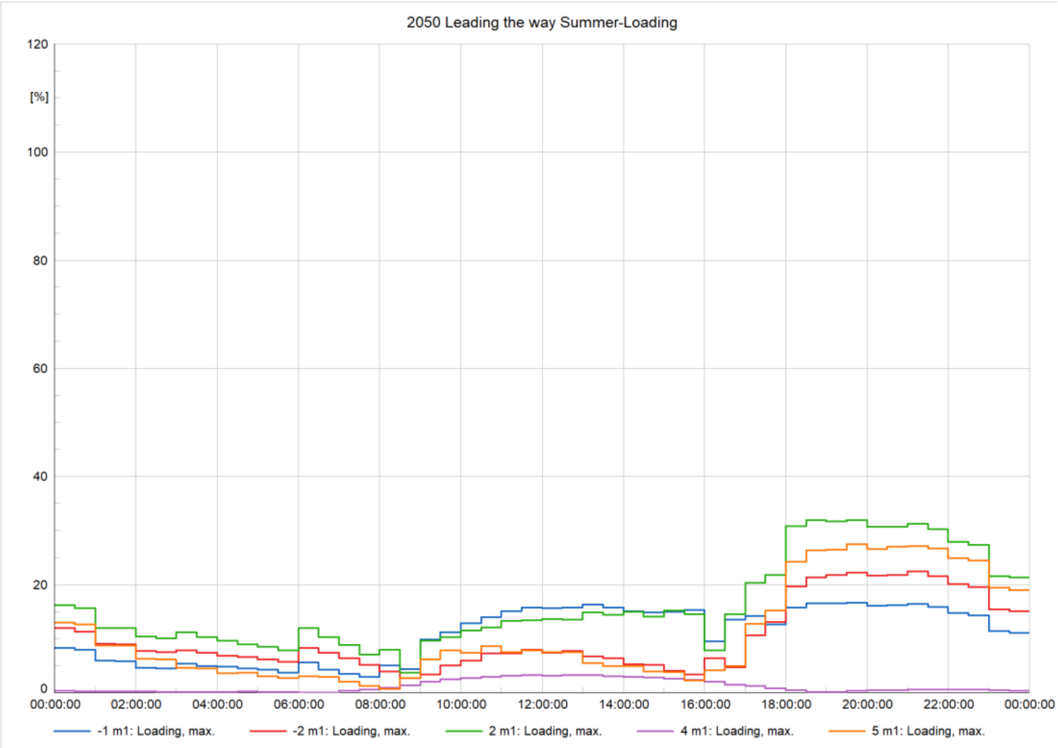

Figure 93 2050 Rural Leading the Way summer loading profiles

Winter

During winter peak the voltages at some customers terminals are approaching 0.95 p.u. (Figure 94) and therefore at risk of breaching the lower statutory limit of 0.94 p.u. for a slightly different customer clustering level. Interestingly, the feeders still have spare capacity and have not reached their maximum capacity with peaks of 50-60% on feeders 2 and 5 (Figure 95) but the total demand does exceed the supply transformer capacity.

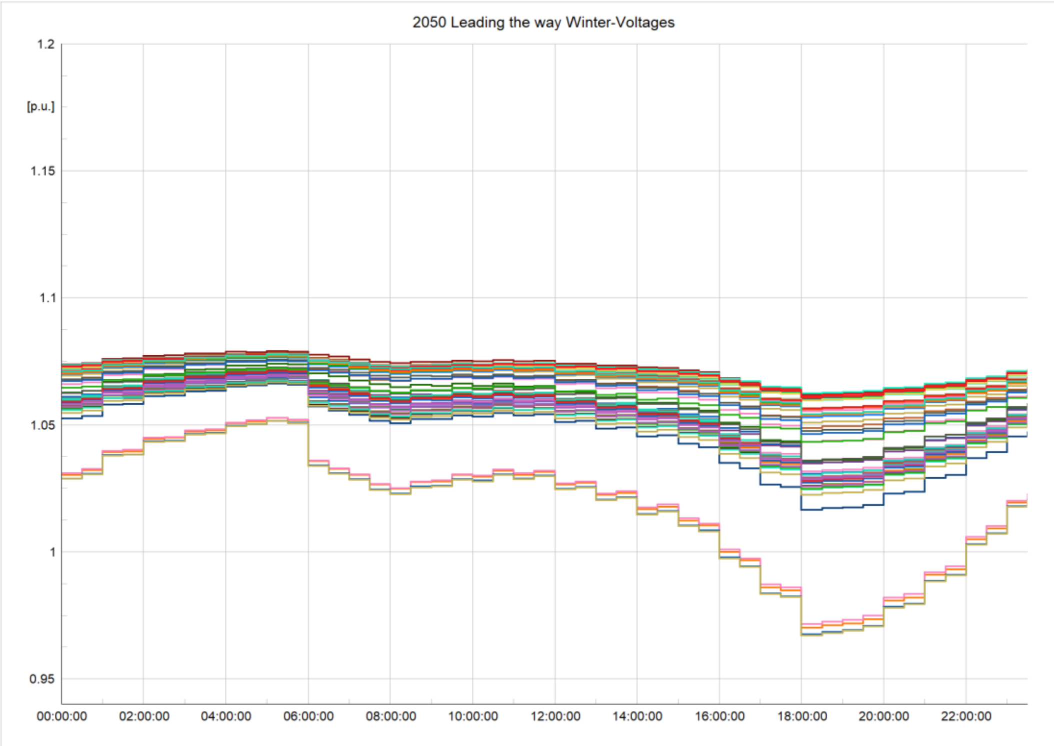

Figure 94 2050 Rural Leading the Way winter voltage profiles

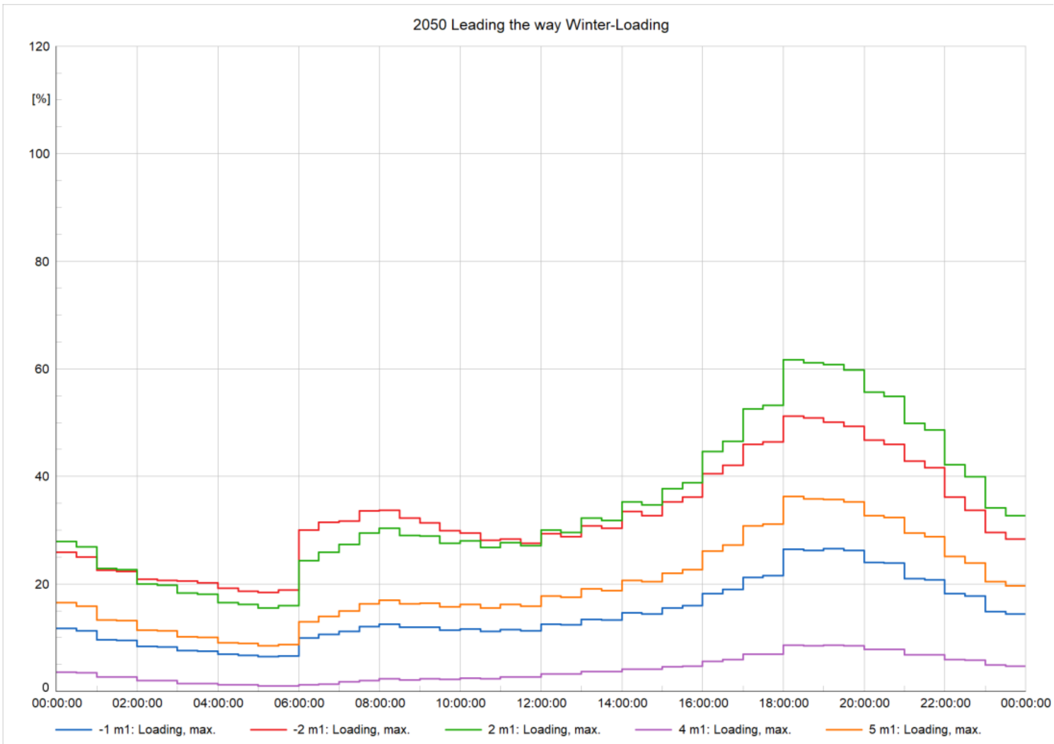

Figure 95 2050 Rural Leading the Way winter loading profiles

7. Analysis

7.1 Dense Urban Network

Table 4 Dense Urban Network Thermal Summary

Thermal	Summer			Winter		
	Steady Progress	NGED Best View	Leading the Way	Steady Progress	NGED Best View	Leading the Way
2028	Pass	Pass	Pass	Pass	Pass	Pass
2033	Pass	Pass	Pass	Pass	Pass	Pass
2040	Pass	Pass	Pass	Pass	Pass	Pass
2050	Pass	Pass	Pass	Pass	Pass	Pass

Table 5 Dense Urban Network Voltage Summary

Voltage	Summer			Winter		
	Steady Progress	NGED Best View	Leading the Way	Steady Progress	NGED Best View	Leading the Way
2028	Pass	Pass	Pass	Pass	Pass	Pass
2033	Pass	Pass	Pass	Pass	Pass	Pass
2040	Pass	Pass	Pass	Pass	Pass	Pass
2050	Pass	Pass	Pass	Pass	Pass	Pass

The results for the Dense Urban network have shown that for all LCT uptake scenarios the voltages remain well within statutory limits with little movement away from remaining within a 1.05 to 1.08p.u. banding during both summer and winter periods. This can be explained due to the relatively high levels of system strength and short lengths of circuit the impact of increasing demand and generation has less impact.

The loading results in the Dense Urban network show that under all the LCT uptake scenarios (Leading the Way, Best View, and Steady Progression) the network is expected to remain within rating. The peak loading seen on feeder 3 just exceeds 80% of the feeder rating, even at this level of loading the voltages remain well within statutory limits.

C1. The Dense Urban network is more likely to experience breaches in thermal capacity significantly before statutory voltage limits are breached.

The relatively low levels of roof space available for PV generation in the Dense Urban network means there is relatively low levels of generation and therefore reverse power flow is not identified as a concern. Likewise, the lack of any high voltage issues is explained by the low levels of PV generation compared to customer numbers in this network.

As a result of this analysis, solutions for the Dense Urban network will likely favour those which relate to improvements in capacity for the LV circuits rather than options to improve voltage management. It should also be considered that the greatest challenge will be during the winter where circuit loading could be nearly 50% greater than summer.

C2. Solutions which may become necessary for the Dense Urban network will favour those which can reduce circuit loading, particularly during the winter evening peak periods.

7.2 Urban Network

Table 6 Urban Network Thermal Summary

Thermal	Summer			Winter		
	Steady Progress	NGED Best View	Leading the Way	Steady Progress	NGED Best View	Leading the Way
2028	Pass	Pass	Pass	Pass	Pass	Pass
2033	Pass	Pass	Pass	Pass	Pass	Overload
2040	Pass	Pass	Pass	Pass	Overload	Overload
2050	Pass	Pass	Pass	Overload	Overload	Overload

Table 7 Urban Network Voltage Summary

Voltage	Summer			Winter		
	Steady Progress	NGED Best View	Leading the Way	Steady Progress	NGED Best View	Leading the Way
2028	Pass	Pass	Pass	Pass	Pass	Pass
2033	Pass	Pass	Upper Breech	Pass	Pass	Pass
2040	Pass	Pass	Upper Breech	Pass	Pass	Pass
2050	Pass	Upper Breech	Upper Breech	Pass	Pass	Pass

Analysis of the Urban Network base case study (prior to increases in LCT uptake numbers) shows that the voltage at customers' terminals are already significantly more varied than the Dense Urban network. This is likely to be due to the introduction of longer feeders and therefore associated lower system strength along the feeder.

The higher levels of PV generation and longer feeders in the Urban Network shows that high voltage issues are more likely to occur with voltage limits being exceeded in 2033 for the Leading the Way scenario and the other scenarios shortly after 2040 (Best View and Steady Progression). As LCT uptake continues, the magnitude of breach in the upper voltage limit continues and by 2050 is impacting a significant number of customers during periods of maximum PV export.

C3. In the Urban Network, higher levels of PV generation and longer feeders than the Dense Urban network shows that statutory upper voltage limits (+10%) could begin to be breached from 2033.

The high levels of LCT uptake mean that, during 2033 winter peak, thermal limits begin to be breached during the Leading the Way scenario. Initially this is only on a single feeder where there are significantly more customers than on the other two similar capacity feeders but could be expected to be a challenge on other feeders as LCT levels continue. Similarly, from 2040 under the Best View scenario circuits begin to become overloaded during winter peak.

C4. In the Urban Network, thermal loadings begin to become overloaded during winter peak from 2033 (Leading the Way) and 2040 (Best View) at which point some intervention would be necessary to continue supporting LCT uptake.

It should also be recognised that during winter the higher levels of demand means voltage drop although not breaching statutory limits is operating much closer to the lower limit. During winter peak voltages at some customer terminals can be around 0.98 p.u. As a result, changes to the transformer tap position would be unlikely to resolve the summer high voltages without causing winter low voltage issues.

C5. For the Urban Network, interventions which reduce the thermal loading during the winter whilst also improving voltage management in the summer will be necessary.

One additional consideration with regards to the Urban Network loading is the basis on which the ratings have been determined. It is assumed that some level of cyclic rating has been considered and therefore although in some situations the maximum loading limit may not be reached, the cyclic characteristic has changed which may reduce the overall rating. This is something that National Grid may wish to consider further once the load profiles associated with LCTs, heat pumps in particular, begin to be realised on the network.

R1. Investigate the load profiles associated with heat pumps, their diversity and potentially impact surrounding cyclic rating assumptions of transformers, cables, and overhead lines.

7.3 Rural Network

Table 8 Rural Network Thermal Summary

Thermal	Summer			Voltage		
	Steady Progress	NGED Best View	Leading the Way	Steady Progress	NGED Best View	Leading the Way
2028	Pass	Pass	Pass	Pass	Pass	Pass
2033	Pass	Pass	Pass	Pass	Pass	Pass
2040	Pass	Pass	Pass	Pass	Pass	Pass
2050	Pass	Pass	Pass	Pass	Pass	Pass

Table 9 Rural Network Voltage Summary

Voltage	Summer			Voltage		
	Steady Progress	NGED Best View	Leading the Way	Steady Progress	NGED Best View	Leading the Way
2028	Pass	Pass	Pass	Pass	Pass	Pass
2033	Pass	Limited upper Breech	Pass	Pass	Pass	Pass
2040	Pass	Upper Limit	Pass	Pass	Pass	Pass
2050	Pass	Upper Limit	Upper Limit	Pass	Pass	Pass

The reduced size of the rural network and therefore fewer customers means that from 2028 to 2040 there are few issues seen with regards to voltage limit exceedance or circuit loading. However, it is clear that the length of customer feeders means customers along each feeder will experience different voltages as LCT uptake continues to increase.

The rural network having a lower capacity transformer giving a higher relative impedance coupled with the smaller cross-sectional area of the conductors makes this network more prone to greater changes in the voltage on the network as the loading changes. From 2040 there is evidence of exceeding the upper voltage limits for the Best View and Leading the Way scenarios.

C6. For the Rural Network, some customers will experience high voltages breaching the upper statutory voltage limits during peak PV export from 2040 onwards.

The transformer capacity is exceeded for the peak loading in the 2050 Leading the Way scenario. Capacity issues may be addressed by solutions which are able to free up capacity by moving the time of operation of some loads, this will also help to alleviate the lower voltages seen at the ends of feeders under the peak load conditions.

C7. For the Rural Network, although circuit loadings remain well below their 100% rating the total loading on the supply transformer will begin to be exceeded for the highest LCT uptake scenarios (Leading the Way).

The extent of the voltage drop at the maximum load conditions is such that were the transformer tap to be changed to lower the voltage to avoid the exceedance under max PV output the lower voltage limit may be breached under peak load conditions. The location of these low voltages is at the end of the feeders remote from the transformer tapping position. Accessing data regarding the voltage level at these remote locations would inform the operation of the any voltage control device applied to the network to maintain the network voltages within statutory limits at all times.

C8. In some situations, circuit loading remains within thermal limits but in Rural networks voltage issues may begin to occur at different points along the feeder.

The Rural network analysis has flagged the importance of understanding the voltage profile and impact of LCT uptake along the length of the feeder for all customers. The results clearly show that during high demand customers at the remote end will experience significantly different voltages to those closer to the substation. Therefore, new solutions which are able to efficiently improve the voltage profile along the feeder will be valuable to National Grid in supporting LCT uptake.

Additionally, to ensure any such system can be operated efficiently it is important that accurate information on the voltages at customer terminals is available. Depending on the technology solution this may need to be near to real-time and therefore the following recommendation is made.

R2.	Investigate technology and software solutions to measure or estimate the voltages at customers terminals along a feeder.

8. Conclusions and Recommendations

This report has presented analysis carried out in PowerFactory for 3 specific LV networks covering Dense Urban, Urban and Rural network archetypes. This analysis presents the first stage in better understanding the impact of LCT uptake on different network archetypes to then understand how novel technologies and approaches may be considered to increase capacity.

8.1 Conclusions

The following conclusions have been made in carrying out this phase of the study and analysis.

C1. The Dense Urban network is more likely to experience breaches in thermal capacity significantly before statutory voltage limits are breached.

C2. Solutions which may become necessary for the Dense Urban network will favour those which can reduce circuit loading, particularly during the winter evening peak periods.

C3. In the Urban Network, higher levels of PV generation and longer feeders than the Dense Urban network shows that statutory upper voltage limits (+10%) could begin to be breached from 2033.

C4. In the Urban Network, thermal loadings begin to become overloaded during winter peak from 2033 (Leading the Way) and 2040 (Best View) at which point some intervention would be necessary to continue supporting LCT uptake.

C5. For the Urban Network, interventions which reduce the thermal loading during the winter whilst also improving voltage management in the summer will be necessary.

C6. For the Rural Network, some customers will experience high voltages breaching the upper statutory voltage limits during peak PV export from 2040 onwards.

C7. For the Rural Network, although circuit loadings remain well below their 100% rating the total loading on the supply transformer will begin to be exceeded for the highest LCT uptake scenarios (Leading the Way).

C8. In some situations, circuit loading remains within thermal limits but in Rural networks voltage issues may begin to occur at different points along the feeder.

8.2 Recommendations

During the delivery of this study, there are several recommendations which National Grid and other distribution networks may wish to consider with regards to the impact of increasing LCT uptake levels.

R1. Investigate the load profiles associated with heat pumps, their diversity and potentially impact surrounding cyclic rating assumptions of transformers, cables, and overhead lines.

R2. Investigate technology and software solutions to measure or estimate the voltages at customers terminals along a feeder.

9. References

[1] T. Stone and D. Mills, “EA16141-TR1 - SILVERSMITH Network Study Results,” EA Technology, Chester, UK, 2022.

[2] National Grid Electricity Distribution, “Distribution Future Energy Scenarios,” National Grid Electricity Distribution, Nottingham, UK, 2021.

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Safer, Stronger, Smarter Networks

EA Technology Limited
Capenhurst Technology Park
Capenhurst, Chester CH1 6ES

t +44 (0) 151 339 4181
e sales@eatechnology.com
www.eatechnology.com