Title: **WP 1.6 Whole-State Network Impact Assessment Milestone 1: Literature Review on Subtransmission Network Planning**

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Executive Summary

This report corresponds to "*Milestone 1: Literature Review on Subtransmission Impact Assessment*" of Work Package 1.6 (WP1.6) *"Whole-State Network Impact Assessment"*. WP1.6 will ultimately provide recommendations to Victorian Distribution Network Service Providers (DNSPs, aka distribution companies) about the subtransmission (i.e., 66kV line-to-line) network planning beyond 2030 as part of the Centre for New Energy Technologies (C4NET)'s Enhanced System Planning (ESP) project. This report presents the Victorian context in terms of Distributed Energy Resources (DERs), a literature review on the current practice of Victorian DNSPs regarding the planning of subtransmission networks, including a high-level comparison against what is done by Distribution Network Operators (DNOs) in the United Kingdom (UK), and an overview on the directions to be taken by WP1.6 to carry out the impact assessment studies for the Victorian subtransmission networks.

The key messages of this report are outlined below:

Victorian DER Uptake and Challenges

- The adoption of DERs is on the rise in Victoria, with many households embracing new technologies such as rooftop solar photovoltaics (PVs), electric vehicles (EVs), residential batteries as well as gas electrification (e.g., heat pumps).
- While this surge in DER adoption aligns with the Victorian Government's renewable energy targets, it poses technical challenges (such as voltage issues and/or asset congestion) to the distribution networks as they have not been designed to host excessive generation from solar PVs and new demand from EVs and gas electrification.
- Although most of these DERs and gas electrification will occur in the lower voltage levels (i.e., 22kV and below), the aggregated demand profile seen by subtransmission networks can change significantly. This could make parts of the subtransmission network reach its thermal limits during normal operation, or even create voltage issues.

Current Industry Planning Practice

- In Australia, every DNSP is required to deliver an annual plan for their networks considering the next five years. In general, all DNSPs use very similar methods to make their planning studies. This plan aims to have the networks ready for changes on demand and generation, and it includes the following activities: monitoring and reviewing asset and network performance; preparing demand forecasts; identifying network limitations; identifying feasible options to manage network limitations.
- Each of these activities is carried out for the different voltage levels (i.e., low voltage [LV, 400V line-to-line], medium voltage [MV, e.g. 22kV line-to-line], subtransmission [e.g., 66kV line-to-line]) of the distribution network, which is known as a compartmentalization. The assessment of lower voltage levels (i.e., LV and MV) is usually done with representative network models, meaning that not all networks are assessed, while subtransmission networks are usually individually assessed.

Directions for this Project and Outcomes

- This project will carry out an impact assessment of DERs (including the electrification of transport and gas) on the subtransmission networks produced by Work Package 1.4 (WP1.4) considering normal operating conditions. The assessment will use the scenarios developed within C4NET's ESP project and the corresponding aggregated profiles (per MV feeder) produced by Work Package 1.5 (WP1.5). Furthermore, the results will be extrapolated to estimate the impacts at the State level (including different DNSP areas).

- The impact assessment will include profiles (produced by WP1.5) that consider the use of network and non-network solutions in the lower voltage levels (i.e., 22kV and below) to capture the effects of DER orchestration in the higher voltage levels.
- The impact assessment will help DNSPs to understand the potential subtransmission network impacts due to the future mix of DER technologies. Focus will be given to thermal and voltage issues in Zone Substations (ZSSs), subtransmission lines, and terminal stations (aka transmission-distribution interface).
- This project will provide the maximum and minimum demand profiles at ZSSs and terminal stations produced for the studied sites (based on the networks provided by WP1.4) as well as the corresponding methodology. Such profiles and methodology can help planning engineers to carry out impact assessments in other areas and beyond 2030.

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Abbreviations and Acronyms

AEMO	Australian Energy Market Operator
C4NET	Centre for New Energy Technologies
DER	Distributed Energy Resource
DNSP	Distribution Network Service Provider
ESP	Enhanced System Planning
EV	Electric Vehicle
LV	Low Voltage
MV	Medium Voltage
PV	Photovoltaics
ZSS	Zone Substation

1 Introduction

This report corresponds to "*Milestone 1: Literature Review on Subtransmission Impact Assessment*" of Work Package 1.6 (WP1.6) *"Whole-State Network Impact Assessment"*. WP1.6 will ultimately provide recommendations to Victorian Distribution Network Service Providers (DNSPs, aka distribution companies) about the subtransmission (i.e., 66kV line-to-line) network planning beyond 2030 as part of the Centre for New Energy Technologies (C4NET)'s Enhanced System Planning (ESP) project. This section presents the Victorian context in terms of the uptake of Distributed Energy Resources (DERs), along with an overview of Work Package 1.6 (WP1.6), including the key milestones, their timeline, and the corresponding linkages.

1.1 The Victorian Context

Hundreds of thousands of Australians (including Victorians) are embracing the use of DERs – seizing the opportunity to generate, store, manage or sell their own energy. These DERs include rooftop solar photovoltaics (PVs), electric vehicles (EVs), residential batteries as well as gas electrification (e.g., heat pumps). As shown in Fig. 1 [1], which is based on AEMO's forecast of DER installed capacity by 2050 [2], solar PVs will continue to be the prominent DER technology adopted in Australia. Additionally, while the uptake of batteries will also rise steadily, it will not grow as rapidly as solar PV. However, EVs is the highlight of the forecast since they are expected to become a major DER in the coming years, surpassing the installed capacity of both solar PV and batteries.

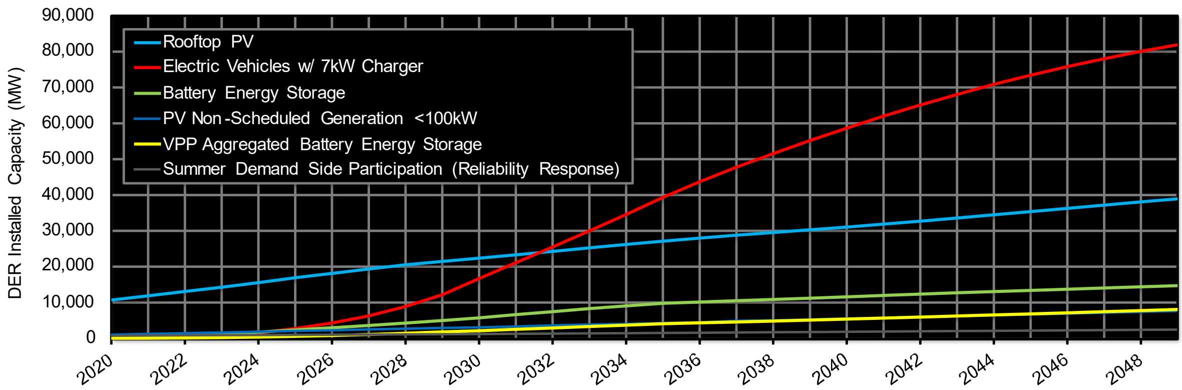

Figure 1. DER Installed Capacity Forecast [1]

In the context of Victoria, according to the State Government's vision [3], 1 in 3 households will have solar PVs installed by 2025, which can deliver up to 60% of our energy demand at times. Additionally, a total of 740MWh of residential batteries will be available by 2025, which is equivalent to the capacity of 25 Ballarat Energy Storage Systems [4]. Furthermore, 50% of all new light-duty vehicle sales are projected to be EVs by 2030. Moreover, a gas substitution roadmap was released in 2022 to speed up the home electrification. This rapid uptake of various DER technologies simultaneously is expected to help Victoria in achieving its legislative renewable energy targets of 40% by 2025, 50% by 2030, and the ultimate goal of reaching net-zero emissions by 2050.

From the technical perspective, the combination of all these new DERs being added to the lower voltage levels of distribution networks is very likely to considerably change the demand profiles of Medium-Voltage (MV) feeders (e.g., 22kV). Inevitably, this change on demand profiles on lower voltage levels will be reflected in subtransmission networks. This could make parts of the subtransmission network reach its thermal limits during normal operation, or even create voltage issues. In fact, according to the forecast daily load profile on minimum demand day from the Victorian Annual Planning Report [5], shown in Fig. 2, a significant increase in both the reverse power flow during midday (11am-1pm) and peak demand during the night (6pm-8pm) is expected in Victoria from the massive PV generation and EV demand, respectively. This forecast makes clear that DERs are bringing big challenges for DNSPs to deal with. However, these challenges can be potentially further exacerbated by the initiative of gas electrification in Victoria that will result in increased electricity demand, which requires further investigation for the network impacts.

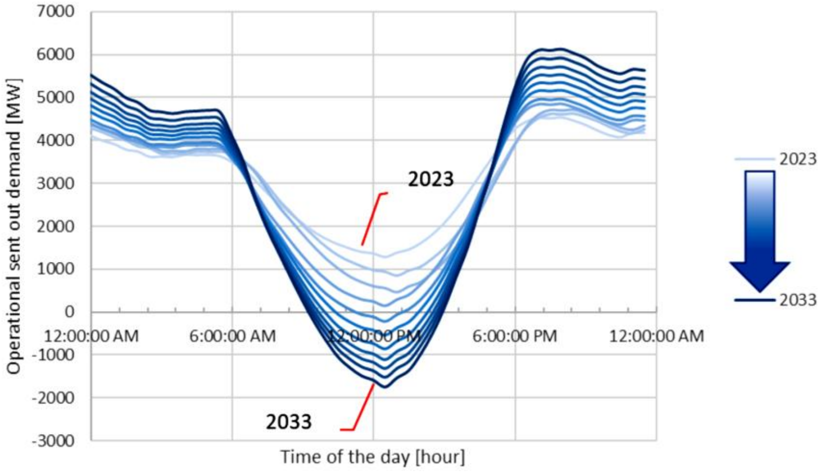

Figure 2. Victorian Daily Load Profile Forecast (2023-33) - Minimum Demand Day [5]

Consequently, to accommodate more DERs within Victorian distribution networks, it is critical for DNSPs to understand the potential challenges posed by different scenarios (i.e., mix of DER technologies and different penetrations) in the subtransmission networks, particularly considering the electrification of loads.

1.2 Overview of WP1.6

1.2.1 Aims and Objectives

WP1.6 *"Whole-State Network Impact Assessment",* as part of the C4NET's Enhanced System Planning project, aims to assess the impacts of electrification on the Victorian subtransmission (i.e., 66kV line-to-line) networks based on the modelling and results from WPs 1.1 to 1.5. It will include a combination of EVs and electrification of residential gas under different scenarios (i.e., different DER technology mixes).

Overall, WP1.6 will provide valuable recommendations to Victorian DNSPs about subtransmission network planning beyond 2030. These recommendations will ultimately help accelerate the adoption of DERs (including the electrification of transport and gas) towards the Victorian goal of net-zero emissions.

1.2.2 Key Milestones

The key milestones, their timeline, and the corresponding linkages are shown in Fig. 3, with further details presented below.

Milestone 1: Literature Review on Subtransmission Network Planning (Delivery: Aug 2024)

Provide a short literature review on the current practice of Victorian DNSPs regarding the planning of subtransmission networks, including a high-level comparison against what is done in the United Kingdom, and an overview on how WP1.6 is going to carry out the impact assessment studies for the Victorian subtransmission networks.

Milestone 2: Input Dataset and Modelling Approach (Delivery: Nov 2024)

Provide input datasets (based on WP1.4 and WP1.5) and modelling approaches (including assumptions) to inform the potential impact of electrification scenarios in different subtransmission networks.

Milestone 3: Aggregated Demand Profile at T-D Interface and Impact Assessment (Deadline: Feb 2025)

- Provide an aggregate demand profile (which includes DERs and electrification of loads) view from/for the transmission system (at the terminal stations, aka transmission-distribution interface), carried out in a bottom-up way.
- Provide outputs on the impact of electrification scenarios at the State level for different DNSP areas. The considered impacts are on the maximum and minimum demands, infrastructure limitations and reinforcement requirements, and load shapes.

Milestone 4: Final Report (Delivery: Mar 2025)

A final report presenting the findings of the project WP1.6, with summary of necessary input data, methodology, and assumptions, as well as the impact assessment on the subtransmission networks.

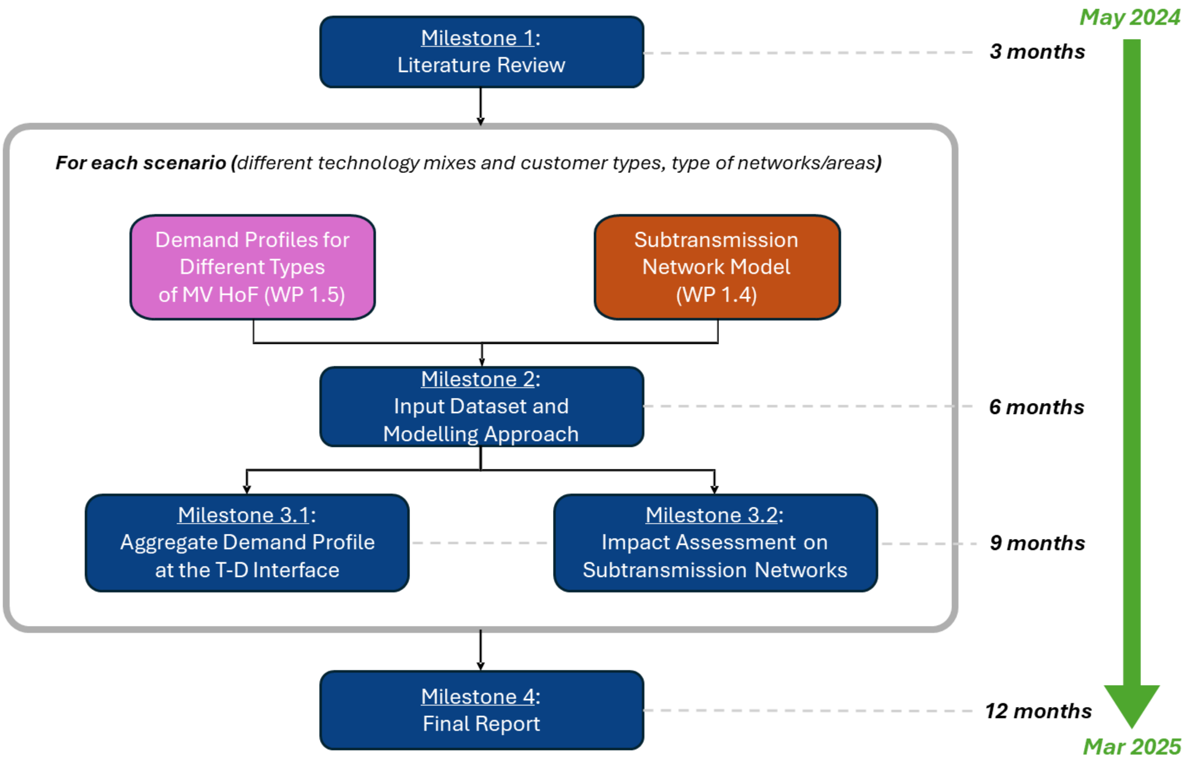

Figure 3. WP1.6 Milestones, Timeline, and Linkages

2 Literature Review

This section presents the current industry practice on distribution network planning, focusing on the planning of subtransmission networks. The literature review is heavily based on the Distribution Annual Planning Report from all five Victorian DNSPs [6-9]. It is complemented by one report from AEMO [5], and by reports on subtransmission planning from United Kingdom's DNOs [10-13] and National Grid [14]. Note that the aim of this literature review is to present a summary of the current industry practice. Comprehensive description of the industry practice can be found in the references presented in Table 1, which summarises the references used for this literature review.

In Australia, every DNSP is required to deliver an annual plan for their networks considering the next five years. In general, all DNSPs use very similar methods to make their planning studies. This plan aims to have the networks ready for changes on demand and generation, and it includes the following activities:

- Monitoring and reviewing asset and network performance;
- Preparing demand forecasts;
- Identifying network limitations; and,
- Identifying feasible options to manage network limitations.

Each of these activities is carried out for the different voltage levels (i.e., LV [i.e., 400V line-to-line], MV [e.g., 22kV line-to-line], subtransmission [e.g., 66kV line-to-line]) of the distribution network, which is known as a compartmentalization. The assessment of lower voltage levels (i.e., LV and MV) is usually done with representative network models, meaning that not all networks are assessed, while subtransmission networks are usually individually assessed. Since that the last three activities are closely related to the impact assessment of subtransmission networks, they are going to be explained in detail. The first activity is out of scope for this project.

2.1 Preparation of Demand Forecast

Demand forecast is critical for the planning of the network since it is the principal driver for investments in the network. It is a very complex task that involves some key drivers, such as economic growth, population growth, temperature, weather trends, growth in the number or solar PV systems, growth in the number of batteries, growth in the number of EVs, gas electrification, air conditioning and heating systems. Some of these key drivers are considered to equally influence customers, other key drivers vary for different locations. Therefore, it is important to have both a system-level forecast (taking in consideration macroeconomic aspects) and a spatial forecast (taking is consideration aspects of specific areas) and to reconcile both, so to create a forecast that captures underlying characteristics of specific areas of the network while including macroeconomic aspects.

For planning purposes, DNSPs need minimum and maximum demand forecast, because they represent the two extreme operation states for the network. These are done for different probability of exceedance and usually for summer and winter, so to better cover the extreme operation states. More specifically, for planning of subtransmission networks, these minimum and maximum demand forecast need to be done for each Zone Substation (ZSS), which, in turn, are based on the forecast of downstream MV feeders (e.g., 22kV). It is also needed

Table 1. List of Planning Reports in AU and UK Used in this Literature Review

Ref.	Type	Year	Organisation	Focus Area	Scope & Objectives	Main Contribution for the Project
[6]	Industrial Report	2023	AusNet Electricity Services (AU)	Planning of Distribution Networks	Describe AusNet distribution network, explain the approach to network planning, provide forecasts for the forward planning period (the five-year planning period from 2024 to 2028), describe constraints on the network and detail plans to address these constraints.	Methodology for planning of subtransmission networks, important metrics, and current network status.
[7]	Industrial Report	2023	Jemena Electricity Networks (AU)	Planning of Distribution Networks	Describe Jemena distribution network and operating environment, presents a proposed network development plan to economically manage the network and network limitations identified within the forward planning period (the five-year planning period from 2024 to 2028).	Methodology for planning of subtransmission networks, important metrics, and current network status.
[8]	Industrial Report	2023	Powercor and Citipower (AU)	Planning of Distribution Networks	Describe Powercor distribution network, presents forecasts, including capacity and load forecasts, at the zone substation, sub-transmission and primary distribution feeder level; presents system limitations, which includes limitations resulting from the forecast load exceeding capacity following an outage, or retirements and de-ratings of assets; presents projects that have been, or will be, assessed under the regulatory investment test; and presents other high level summary information to provide context to Powercor's planning processes and activities.	Methodology for planning of subtransmission networks, important metrics, and current network status.

[9]	Industrial Report	2023	United Energy (AU)	Planning of Distribution Networks	Describe United Energy distribution network, presents import capacity and associated maximum demand forecasts, and export capacity and associated minimum demand forecasts at the zone substation, sub-transmission and primary distribution feeder levels; presents system limitations resulting from the forecast maximum demand breaching its import capacity, or from the forecast minimum demand breaching its export capacity, following forced outages, retirements or asset de-ratings; presents projects that have been, or will be, assessed under the Regulatory Investment Test for Distribution (RIT-D); and presents other high-level information providing context for United Energy's planning processes and activities.	Methodology for planning of subtransmission networks, important metrics, and current network status.
[15]	Industrial Report	2023	Ausnet, Jemena, Powercor, Citipower, United Energy (AU)	Planning for Terminal Stations	Provides a high-level indication of the expected balance between capacity and demand at each terminal station (aka T-D interface) over the ten-year forecast period, and the intervention actions that may be required to address an emerging major constraint. Where applicable, this report also identifies the potential risk of curtailing embedded generation to manage reverse power flows at particular terminal stations.	Methodology for planning for terminal stations, important metrics, and current network status.
[5]	Industrial Report	2023	AEMO Victorian Planning (AU)	Planning for Transmission Networks	Provides information relating to electricity supply, demand, network capability, and development for Victoria's electricity transmission declared shared network.	Context of Victorian energy transition and current terminal stations status.
[14]	Industrial Report	2024	National Grid (UK)	Planning of Distribution Networks	Outlines the methodology for preparing the Network Development Plan for the distribution companies in the UK (aka Distribution Network Operators [DNOs]) and any assumptions made.	Methodology for planning of subtransmission networks in the UK.

[12]	Industrial Report	2018	Western Power Distribution (UK)	Planning of Subtransmission Networks	Assess the potential growth in distributed generation (e.g., PV, wind, Storage, etc); consider potential demand changes that can come from electrification of transport, electrification of heating and cooling, or growth in industrial, commercial and domestic demand; identify thermal and voltage constraints that may occur on the 132kV networks; assess options for reinforcement; and provide recommendations for 'low regret' investment.	Methodology for planning of subtransmission networks and important metrics in the UK.
[13]	Industrial Report	2018	Western Power Distribution (UK)	Planning of Subtransmission Networks	Assess the potential growth in distributed generation (e.g., PV, wind, Storage, etc); consider potential demand changes that can come from electrification of transport, electrification of heating and cooling, or growth in industrial, commercial and domestic demand; identify thermal and voltage constraints that may occur on the 132kV and 66kV networks; assess options for reinforcement; and provide recommendations for 'low regret' investment.	Methodology for planning of subtransmission networks and important metrics in the UK.
[11]	Industrial Report	2019	Western Power Distribution (UK)	Planning of Subtransmission Networks	Assess the potential growth in distributed generation (e.g., PV, wind, Storage, etc); consider potential demand changes that can come from electrification of transport, electrification of heating and cooling, or growth in industrial, commercial and domestic demand; identify thermal and voltage constraints that may occur on the 132kV and 66kV networks; assess options for reinforcement; and provide recommendations for 'low regret' investment.	Methodology for planning of subtransmission networks and important metrics in the UK.
[10]	Industrial Report	2020	Western Power Distribution (UK)	Planning of Subtransmission Networks	Assess the potential growth in distributed generation (e.g., PV, wind, Storage, etc); consider potential demand changes that can come from electrification of transport, electrification of heating and cooling, or growth in industrial, commercial and domestic demand; identify thermal and voltage constraints that may occur on the 132kV networks; assess options for reinforcement; and provide recommendations for 'low regret' investment.	Methodology for planning of subtransmission networks and important metrics in the UK.

forecast for large loads and generators that are directly connected to the subtransmission network. Then, the forecast of ZSS and large loads and generators can be used as a base to create forecasts for the terminal stations, which also needs to consider planned load transfers, or any other change that may affect the forecast.

For comparison, the demand forecast at ZSS made by DNOs (UK) is created based on an underlying demand (from a recent ZSS measurement data) plus the forecasted profiles for heat pumps, EVs, air conditioning, and conventional demand growth. The DNOs forecast the demand profile at ZSSs for 24h (resolution of 30min) of four representative days for peak demand (i.e., winter peak, summer peak, intermediate warm peak demand) and a representative day for the smallest peak demand (called summer peak generation day). For large loads connected to the subtransmission networks, they are considered to be fully using their agreed supply capacity for peak demand days and considered as zero demand in summer peak generation days. For solar farms (larger than 1MW installed capacity) and wind farms, the profile was selected from historical generation data for each of the four representative days. For other generators connected to the subtransmission networks, they are considered to be generating at the agreed supply capacity for the summer peak generation day and considered as zero generation for the peak demand days. Finally, utility-scale storage was considered to be operating with continuous demand at agreed import capacity for peak demand days and considered as continuous generation at agreed export capacity for summer peak generation day. However, these assumption for utility-scale storage created an unrealistic negative impact to the network, so they are revising these assumptions.

2.2 Identification of Network limitations

The second key activity for the planning of subtransmission networks is the identification of network limitations. To do so, three main datasets are required, the forecast for demand at ZSSs and large-scale loads and generators connected to the subtransmission network, subtransmission network models (e.g., impedances, topology), and network limitations (physical or regulatory). The demand forecast was discussed previously, while the subtransmission networks are readily available to DNSPs. Regarding network limitations, the following limits are usually needed:

- N import (or export) rating: the import (or export) capacity of the ZSS, the subtransmission line, or the terminal station according to the nameplate value.
- Cyclic N-1 import rating: the import capacity of the ZSS or terminal station assuming the outage of one asset (i.e., transformer). This is also known as “firm import rating”.
- N-1 export rating: the export capacity of the ZSS or terminal station assuming the outage of one asset (i.e., transformer). This is also known as “firm export rating”.
- Station power factor: the measure of how effectively the current is being converted into output and is also a good indicator of the effect of the current on the efficiency of the supply system.
- Voltage limits: the standard nominal voltage limits for each voltage level.
- Load transfer capacity: the forecast of available capacity of adjacent ZSS, or terminal station, or sub-transmission lines, and feeder connections to take load away from a given ZSS, or terminal station, or sub-transmission lines in emergency situations.

Once the necessary input data (i.e., demand forecast, network model, and network limits) is ready, DNSPs run power flows for the forecasted maximum and minimum demand to assess the impact on the subtransmission network. This power flow assessment is carried out for normal operation (N) and for one contingency (N-1). The following metrics are used to quantify the involved risks when a ZSS, terminal station, or subtransmission line pass their technical limits. Note that different DNSPs may use slightly different names.

- Hours at risk: the number of hours per annum that a ZSS, terminal station, or subtransmission line could operate beyond its firm import (or export) rating due to an N-1 contingency.
- Load at risk: the maximum amount of load that would be shed should an N-1 contingency within the ZSS, terminal station, or subtransmission line occur. This metric is calculated considering the firm import (or export) rating. Similarly, a "generation at risk" can also be calculated.
- Energy at risk: The amount of energy, weighted by the demand conditions considered, that would not be able to be imported or exported from a ZSS, terminal station, or subtransmission line in case a N-1 contingency happens in a particular year.
- Expected unserved energy: The energy at risk weighted by the probability of a potential N-1 contingency to happen and their repair times.

DNSPs will also check the voltage compliance for each considered demand forecast, calculate fault levels, and other technical aspects that are not going to be discussed here since it gets out of the scope of the project.

Note that DNSPs prefer to use a probabilistic approach since it takes in consideration the chances of an event, that may bring some issues to the network, to happen. This strategy allows the DNSPs to take calculated risks, so to avoid overinvesting in the network. However, deterministic analysis is also used in the planning process.

For comparison, the DNOs (UK) follow similar assessment in their subtransmission networks to identify network limitations. The only significant difference is the consideration of two outages occurring simultaneously (N-2 contingency) in the network impact assessment, where one of the outages is planned and the other unplanned.

2.3 Identification of Feasible Solutions

The third key activity to be described for the planning of subtransmission networks is the identification of feasible options to manage network limitations. Note that this section only lists some potential technical solutions according to three identified problems: thermal, overvoltage, and undervoltage issues. Thus, it does not delve into the economic feasibility of each solution since it is usually very case sensitive.

The solutions are divided as network solution and non-network solution. Network solutions use network assets to solve or mitigate potential issues, while non-network solutions involve third-party assets, such as DERs or generators, to solve or mitigate issues. They are presented in Table 2.

For comparison, the DNOs (UK) use similar solutions for the technical issues presented above.

WP 1.6 will use some of the industry practices presented in this section (Section 2) to make its own impact assessment of subtransmission networks. This will be discussed in the next section.

Table 2. Potential Solution According to Type of Issue

Potential Solutions		Types of Issues		
		Assets Overload	Overvoltage	Undervoltage
Network Solutions	Emergency Load Transfer	✓	✓	✓
	Network Augmentation	✓	✓	✓
	Transformer OLTC	✗	✓	✓
	Capacitor Banks	✗	✗	✓
	Line Reactors	✗	✓	✗
	Rebalancing	✓	✓	✓
Non-Network Solutions	Curtailment of Generation	✓	✓	✗
	VV and VW for PV Inverter	✓	✗	✓
	Demand Response	✓	✓	✓
	Smart Energy Storage	✓	✓	✓
	EV Smart Charging	✓	✓	✓
	Operating Envelopes	✓	✓	✓
	Time-of-Use Tariffs	✓	✓	✓

✓: Solution can mitigate or solve the problem depending on the situation
✗: Solution will not mitigate or solve the problem
OLTC: On-Load Tap changer
VV: Volt-Var function
VW: Volt-Watt function

3 Directions for Subtransmission Network Impact Assessment and Expected Outcomes

Based on the literature review of the industry practice on distribution network planning, this section provides general directions for the subtransmission impact assessment to be carried out by WP1.6.

In order to perform the impact assessment of DERs (including the electrification of transport and gas) on the subtransmission networks, a model-based approach is used to simulate the power flows passing through the network for each demand profile (i.e., considering all the years, seasons, and scenarios). For this, three main datasets are required, the forecast for demand at ZSSs and large-scale loads and generators connected to the subtransmission network, subtransmission network models (e.g., impedances, topology), and network limitations (physical or regulatory).

The required demand forecast for each ZSS connected to the subtransmission network will be based on aggregated profiles for each scenario developed within C4NET's ESP project. These aggregated profiles will be produced by WP 1.5, and they will represent five different types of MV feeders (i.e., CBD, urban, suburban, short-rural, and long-rural). Once these aggregated profiles are available, it is possible to create the demand forecast of each ZSS by following the steps below:

- Aggregate the demand forecast corresponding to the types of MV feeders connected to the ZSS.
- Scale the aggregate demand forecast profile so to match its peak demand with the measured peak demand of the ZSS.

It is important to note that the demand forecast for each type of MV feeder includes the base load, rooftop solar, light-duty EVs, residential batteries, and gas electrification. It is given as a 24h profile (with time steps of 30 min) for multiple years and seasons, as well as for multiple scenarios of DER adoption and gas electrification. Therefore, the step above regarding the peak matching is only carried out for the base demand forecast (e.g., next year). The forecasted demand change of further years will be added on top of the base demand forecast, which can move the profile up or down according to the forecast.

Regarding the forecast for large-scale loads and generators not included in the ZSSs demand, this project is still to decide what to consider.

Regarding the subtransmission network models, they were implemented in OpenDSS [16] by WP 1.4 from DNSPs' PSSE models. The OpenDSS models are going to be used in this project to run the power flow simulations.

Regarding the network limitations, this project is going to assess normal operational conditions (N) only, so the following should be used:

- <u>N import (or export) rating</u>: the import (or export) capacity of the ZSS, the subtransmission line, or the terminal station according to the nameplate value.
- <u>Voltage limits</u>: the standard nominal voltage limits for each voltage level.

Once this data is fully available to this project, a Python [17] algorithm is going to be created to manage the input data to be used on the subtransmission network power flow simulations. The output data will also be managed by this algorithm, as well as the necessary results analyses. To integrate Python and OpenDSS – where the network is modelled and power flows are calculated – the library dss-python [18] will be used. This setup allows to easily manage this data-intensive simulations that will consider demand forecast profiles (i.e., 24h, for every 30 minutes) across multiple years, different seasons and scenarios.

Power flow results for every demand forecast situation will be checked for thermal and voltage violations. Thermal violations are assessed by comparing the N import (or export) rating of ZSS, subtransmission lines, and terminal stations with the corresponding power flow (in kVA) passing through these network components. Similarly, voltage violations are assessed by comparing the voltage limits with corresponding voltages for a given power flow result at the subtransmission network buses (e.g., ZSS, terminal stations). This impact assessment will be extrapolated to estimate the impacts at the State level (including different DNSP areas), and it will allow us to discuss on potential solutions for the likely issues.

Overall, WP1.6 should provide valuable information to Victorian DNSPs about subtransmission network planning beyond 2030. This information is intended to help accelerate the electrification of distribution networks towards the Victorian goal of net-zero emissions.

The following information is going to be produced:

- A multi-scenario electrification impact assessment on the subtransmission for the next 30 years, which will include profiles (produced by WP1.5) that consider the use of network and non-network solutions in the lower voltage levels (i.e., 22kV and below).
- The maximum and minimum demand profiles at ZSSs and terminal stations for the studied sites (based on the networks provided by WP1.4), as well as the corresponding methodology.

DNSPs can be benefited from following perspectives:

- The multi-scenario electrification impact assessment can help DNSPs to understand the potential network impacts in the subtransmission of a mix of DER technologies (e.g., PVs, EVs, residential batteries and gas electrification) in the next 30 years. Focus will be given to thermal and voltage issues in ZSSs, subtransmission lines, and terminal stations.
- The consideration of profiles that consider both network solutions (e.g., on-load tap changers) and non-network solutions (e.g., flexible export limits) in the lower voltage levels (i.e., 22kV and below) can provide good insights on how DER orchestration may impact the higher voltage levels.
- The produced maximum and minimum demand profiles (considering electrified loads) at ZSSs and terminal stations as well as the corresponding methodology can help planning engineers to carry out impact assessments in other areas beyond 2030.

4 Conclusions

In conclusion, this report presents a high-level summary of the current industry practice on distribution network planning, focusing on the planning of subtransmission networks. The literature review is heavily based on the Distribution Annual Planning Report from all five Victorian DNSPs, and it is compared to reports on subtransmission planning from United Kingdom's DNOs. This literature review helps to inform the directions to be taken by WP 1.6 when carrying out the subtransmission impact assessment of electrification. Overall, WP1.6 should provide valuable information to Victorian DNSPs about subtransmission network planning beyond 2030. This information is intended to help accelerate the electrification of distribution networks towards the Victorian goal of net-zero emissions.

The key messages of this report are outlined below:

Victorian DER Uptake and Challenges

- The adoption of DERs is on the rise in Victoria, with many households embracing new technologies such as rooftop solar photovoltaics (PVs), electric vehicles (EVs), residential batteries as well as gas electrification (e.g., heat pumps).
- While this surge in DER adoption aligns with the Victorian Government's renewable energy targets, it poses technical challenges (such as voltage issues and/or asset congestion) to the distribution networks as they have not been designed to host excessive generation from solar PVs and new demand from EVs and gas electrification.
- Although most of these DERs and gas electrification will occur in the lower voltage levels (i.e., 22kV and below), the aggregated demand profile seen by subtransmission networks can change significantly. This could make parts of the subtransmission network reach its thermal limits during normal operation, or even create voltage issues.

Current Industry Planning Practice

- In Australia, every DNSP is required to deliver an annual plan for their networks considering the next five years. In general, all DNSPs use very similar methods to make their planning studies. This plan aims to have the networks ready for changes on demand and generation, and it includes the following activities: monitoring and reviewing asset and network performance; preparing demand forecasts; identifying network limitations; identifying feasible options to manage network limitations.
- Each of these activities is carried out for the different voltage levels (i.e., low voltage [LV, 400V line-to-line], medium voltage [MV, e.g. 22kV line-to-line], subtransmission [e.g., 66kV line-to-line]) of the distribution network, which is known as a compartmentalization. The assessment of lower voltage levels (i.e., LV and MV) is usually done with representative network models, meaning that not all networks are assessed, while subtransmission networks are usually individually assessed.

Directions for this Project and Outcomes

- This project will carry out an impact assessment of DERs (including the electrification of transport and gas) on the subtransmission networks produced by Work Package 1.4 (WP1.4) considering normal operating conditions. The assessment will use the scenarios developed within C4NET's ESP project and the corresponding aggregated profiles (per MV feeder) produced by Work Package 1.5 (WP1.5). Furthermore, the results will be extrapolated to estimate the impacts at the State level (including different DNSP areas).

- The impact assessment will include profiles (produced by WP1.5) that consider the use of network and non-network solutions in the lower voltage levels (i.e., 22kV and below) to capture the effects of DER orchestration in the higher voltage levels.
- The impact assessment will help DNSPs to understand the potential subtransmission network impacts due to the future mix of DER technologies. Focus will be given to thermal and voltage issues in Zone Substations (ZSSs), subtransmission lines, and terminal stations (aka transmission-distribution interface).
- This project will provide the maximum and minimum demand profiles at ZSSs and terminal stations produced for the studied sites (based on the networks provided by WP1.4) as well as the corresponding methodology. Such profiles and methodology can help planning engineers to carry out impact assessments in other areas and beyond 2030.

References

[1] L. N. Ochoa, A. G. Givisiez, D. Jaglal, M. Z. Liu, and W. Nacmanson, "CSIRO Australian Research Planning forGlobal Power Systems Transformation: Topic 8 "Distributed Energy Resources"," The University of Melbourne, 2021.

[2] AEMO. "2022 ISP Inputs, Assumptions and Scenarios." https://aemo.com.au/en/energy-systems/major-publications/integrated-system-plan-isp/2022-integrated-system-plan-isp/2022-isp-inputs-assumptions-and-scenarios (accessed.

[3] L. The State of Victoria Department of Environment, Water and Planning,, "Harnessing Victoria's Distributed Energy Resources," 2022.

[4] AusNet Services, "Ballarat Battery Energy Storage System," 2021.

[5] AEMO Victorian Planning, "Victorian Annual Planning Report," 2023.

[6] AusNet Electricity Services, "Distribution Annual Planning Report 2024-2028," 2023.

[7] Jemena Electricity Networks, "2023 Distribution Annual Planning Report," 2023.

[8] Powercor, "Powercor Distribution Annual Planning Report," 2023.

[9] United Energy, "United Energy Distribution Annual Planning Report," 2023.

[10] Western Power Distribution, "Strategic Investment Options: Shaping Subtransmission - East Midlands," 2020.

[11] Western Power Distribution, "Strategic Investment Options: Shaping Subtransmission - South Wales," 2019.

[12] Western Power Distribution, "Strategic Investment Options: Shaping Subtransmission - South West," 2018.

[13] Western Power Distribution, "Shaping Subtransmission to 2030 - West Midlands," 2018.

[14] National Grid, "Network Development Plan: Introduction & Methodology Report," 2024.

[15] AusNet, Jemena, Powercor, Citipower, and United Energy, "2023 Transmission Connection Planning Report," 2023.

[16] R. C. Dugan and T. E. McDermott, "An open source platform for collaborating on smart grid research," presented at the 2011 IEEE Power and Energy Society General Meeting, 2011.

[17] "Python Software Foundation." https://www.python.org/ (accessed 2022).

[18] *DSS-Python*. (2024). [Online]. Available: https://dss-extensions.org/DSS-Python/#