Victoria whole-distribution network architecture via synthetic models

October 2024

Report for iMOVE CRC and C4NET

Project Consortium

LEAD AND AUTHOR OF THIS REPORT

Mir Toufikur Rahman, Researcher
Usman Bashir Tayab, Researcher
Kazi Hasan, Lead
Mahdi Jalili, Co-Lead
RMIT University, Melbourne VIC 3000

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Acknowledgement

This work was supported by the iMOVE CRC and Centre for New Energy Technologies, "C4NET", through the Enhanced System Planning project (Grant number: PRJ00001911).

We sincerely acknowledge the support of Victorian distribution network service providers (Ausnet, Jemena, CitiPower, Powercor, and United Energy) through network data and consultation. The guidance and support from Mr John Theunissen were vital for the delivery of the project.

Executive Summary

This report presents a detailed study, results, and analysis of WP1.4 (distribution network architecture via synthetic models) within the Enhanced System Planning (ESP) project, focusing on the development of electricity distribution network models that can be used to broadly represent the Victorian grid in a way that enables simplified "bottom-up" analysis by researchers and industry. The developed network models serve as a foundation for subsequent work packages, which will utilize them to perform various power system studies, including load flow analysis, voltage constraint evaluations, hosting capacity assessments, and techno-economic evaluations.

Structure and Key Focus Areas

The initial plan was to develop the Victorian synthetic distribution network models based on the CSIRO taxonomy models. However, the locational distribution of network data was strongly biased towards New South Wales (63.5%), followed by Tasmania (28.5%) of low-voltage networks in the dataset. On the contrary, only 0.04% of Victorian LV networks participated in the dataset. Selecting representative network examples from the CSIRO HV/MV CSIRO Taxonomy was initially considered; however, the DNSPs were more comfortable with using actual feeder model examples, as it was felt they would be more representative of the Victorian HV/MV networks than synthetically derived CSIRO taxonomic approach. Following reviews by researcher forums and industry/DNSP partners' discussions, ESP WP1.4 shifted from using CSIRO LV network taxonomy to utilising a pseudo-LV network method for representative Victorian networks.

ESP WP1.4 adopted a pseudo-LV network method to appropriately represent the spatial characteristics and network topology of Victoria and support different network analysis functions. ESP WP1.4 further customized the pseudo-LV network method by leveraging the Victorian DNSP data and network attributes to enable a flexible approach to adjusting LV networks for different feeder capacities. The cable specification has been adopted from Victorian DNSP data and the number of customers per feeder and associated cable length are considered from Victorian demographic data. The developed pseudo-LV network models also specifically reflect the appropriate customer type composition in each type of network (i.e. urban, suburban, and rural), which is sourced from DNSPs.

As an extension to this project, ten different types of actual LV network models, provided to RMIT by a Victorian DNSP, were converted to a unified software platform, and corresponding pseudo-LV network models were developed. These models will be utilized in a future ESP work package to assess the correlation between the “actual” and “pseudo” LV networks. Please note that work related to this extension is briefly included in Section 2.4 and the Appendix of this report.

The report begins by describing the methodology for developing synthetic or pseudo-low-voltage (LV) networks, along with the steps for integrating them with their corresponding MV feeders. This section includes detailed considerations of network assumptions and constraints. The report also presents the topology and key characteristics of the five modelled feeders, along with load flow results as a simple validity check of the models, which uses After Diversity Maximum Demand (ADMD) values in OpenDSS software.

Next, the network models provided by different Distribution Network Service Providers (DNSPs) across Victoria have been discussed. The power network models were supplied in various software platforms (such as PSS®SINCAL, PSS®E, and CYMDIST). These models are categorized by network type, geographic location, customer composition, and the number of customers. The network models have been converted into a unified software platform (OpenDSS) and five representative medium voltage (MV) feeders have been selected. These feeders represent distinct network categories, such as urban, suburban, rural-short, rural-long, and CBD.

The power flow analysis is a simplified validation check that for a chosen loading scenario (in our case the diversified average individual ADMD representing a peak summer demand) the network model voltage and thermal characteristics are within normally accepted industry tolerances.

Selected Feeders and Key Characteristics

Five feeders were selected from the datasets provided by CitiPower, Powercor, and United Energy and Jemena. Each feeder represents a distinct network type and geographic area, as detailed below:

- **Urban Feeder (SBY32, Sunbury)**: A 22 kV urban feeder acquired from Jemena, encompassing 48 distribution substation (DSS) transformers over a 19.8 km distance. The feeder serves a total of 3181 customers, with 91.7% residential and 8.3% commercial and industrial (C&I) customers.
- **Suburban Feeder (WBE013, Werribee)**: A 22 kV suburban feeder from CitiPower, Powercor, and United Energy, consisting of 71 DSS transformers across a 33.14 km network. The feeder supplies 5,514 customers, with 96% residential and 4% C&I customers.
- **Rural-Short Feeder (COO12, Coolaroo)**: A 22 kV rural-short feeder provided by Jemena, spanning 93.1 km with 187 DSS transformers. The COO12 feeder supports 724 customers, with a breakdown of 89.5% residential and 10.5% C&I customers.
- **Rural-Long Feeder (BAS033, Ballarat South)**: A 22 kV rural-long feeder acquired from CitiPower, Powercor, and United Energy, extending over 207.3 km and incorporating 877 DSS transformers. It serves 3,942 customers, with 84% residential and 16% C&I and agricultural customers.
- **CBD Feeder (VM034, Victoria Market)**: An 11 kV CBD feeder from CitiPower, Powercor, and United Energy, spanning 3.71 km and consisting of 15 DSS transformers. The feeder serves 1,071 customers, with 74.9% residential and 25.1% C&I and agricultural customers.

Power Flow Simulation Results

A power flow analysis was performed for all five feeders using ADMD values provided by the DNSPs. Key metrics such as MV and LV node voltages, MV line loading, and DSS transformer loading were recorded.

- **Voltage Performance**: The MV and LV node voltages were generally within acceptable operational ranges (0.94 p.u. to 1.10 p.u.) across all feeders.
- **Loading Analysis**: For most feeders, MV line loading levels were within capacity limits. However, representative feeders exhibited occasional overloading on certain distribution transformers (resulting from the simplified ADMD approach).

Summary and Key Observations

This report presents the methodology, data acquisition, modelling, and validation approach for Victorian synthetic distribution network development. It presents 5 representative MV and LV networks across various Victorian regions (CBD, urban, suburban, short rural and long rural). The modelling approach implemented the pseudo-LV network development technique, which is an automated process implemented in OpenDSS. Automation and scalability are the major advantages of this approach.

However, it fails to consider the variation and diversity in the network parameters (such as line impedance, customer per circuit, customer distance, customer loading etc.) within the same network models. The 5 types of networks vary by the diversity in the network parameters (such as line impedance, customer per circuit, customer distance, customer loading etc.) and the voltage regulators and distribution substation (DSS) transformer tap settings are adjusted to regulate the voltages at the LV circuits.

One limitation of the pseudo-LV network development technique is that it considered all commercial and industrial (C&I) customers to be connected to the DSS directly. This is acceptable if there are fewer DSS-adjacent C&I customers in the LV circuits. However, as the number of C&I customers increases to the network and they are far from the DSS, then the error increases in the pseudo-LV network models.

The developed models will form the basis for further impact assessments and power system studies in subsequent ESP work packages.

Glossary of Terms / Abbreviations

ADMD	After Diversity Maximum Demand
DNSP	Distribution Network Service Provider
DPL	DIgSILENT Programming Language
DSS	Distribution Substation
IQR	Interquartile Range
LV	Load Voltage
MV	Medium Voltage
p.u.	Per Unit
ZSS	Zone Substation

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1. Project Overview

Distribution networks are a vital component of national infrastructure, and as such, the dissemination of detailed network diagrams, asset locations, and customer data raises significant privacy concerns. Consequently, very few distribution networks are publicly available for use as test networks in research and development. The limited availability of such networks in the literature has forced the research community to rely heavily on a small number of existing networks, often repurposing them for research objectives that exceed the original scope for which they were developed.

Currently, in Victoria, there is no comprehensive system-wide modelling framework that integrates distribution networks with the transmission system using consistent parameters and assumptions. This gap affects key stakeholders, including researchers, market operators, regulators, and policymakers, by limiting their ability to perform whole-of-system infrastructure planning and development.

This gap becomes particularly evident when forecasting future scenarios for Victoria, such as the large-scale adoption of local renewable generation and distributed energy resources (DERs), the electrification of transport, the transition away from domestic gas, and the integration of new fuel sources. These factors, and their interactions, require accurate modelling for reliable infrastructure planning.

To address these challenges, this project will employ a hybrid modelling approach, combining actual medium-voltage (MV) feeders provided by Distribution Network Service Providers (DNSPs) for five distinct network types, along with pseudo-LV network models. This approach will enable the development of an MV-LV distribution network model for Victoria. The resulting network models will support subsequent work packages in the Enhanced System Planning (ESP) Project, enabling comprehensive impact assessments related to electrification across the state. These assessments will include techno-economic analyses, such as power flow and voltage constraint studies, optimal power flow analyses, and hosting capacity evaluations.

2. Methodology

2.1 Introduction

The aim of ESP-V WP1.4 (Victoria Whole-Distribution Network Architecture via Synthetic Network Models) is to develop a representative model of the Victorian distribution network for conducting impact assessments and power system studies. This model is based on actual medium-voltage (MV) and low-voltage (LV) networks provided by Distribution Network Service Providers (DNSPs) operating across Victoria. Key DNSPs, including CitiPower, Powercor, and United Energy, AusNet Services, and Jemena, contributed to this work package by supplying comprehensive network data, encompassing network topology, transformer specifications, impedance profiles, load characteristics, and customer classifications (residential, commercial, and industrial) for both the MV and LV networks.

2.2 Network Modelling Approach, Development Options and Adopted Methodology

The project WP1.4 aimed to develop electricity distribution network models that can be used to broadly represent the Victorian grid in a way that enables simplified "bottom-up" analysis by researchers and industry. The modelling for representative distribution networks has been conducted by employing various methodologies and validated through different pronged approaches, such as MV and LV voltage analysis, MV line loading, and DSS transformer loading.

2.2.1 CSIRO LV Taxonomy Approach

In 2013, CSIRO developed a comprehensive MV feeder taxonomy by collecting and analyzing sample feeder data from various distribution network service providers across Australia. The dataset, after cleaning, included 370 unique feeders from New South Wales, the Australian Capital Territory, Victoria, Queensland, and Western Australia, ultimately delivering 19 representative MV feeders published in DIgSILENT PowerFactory software. Initially, Work Package 1.4 (WP1.4) planned to utilize selected MV feeder clusters from CSIRO's "National Feeder Taxonomy," focusing on feeders representative of Victoria and ensuring they could be efficiently populated and updated with available industry data. However, Victoria was under-represented in CSIRO's dataset compared to other states, which led WP1.4 to shift its approach. Instead of relying on CSIRO's taxonomy, WP1.4 opted to collect actual MV feeder models directly from Victorian DNSPs, enabling the development of a synthetic yet more targeted representation of the Victorian distribution network.

CSIRO also conducted the "National Low-Voltage Feeder Taxonomy Study" in collaboration with several DNSPs across Australia. The research analysed existing network data from more than 90 thousand low-voltage networks to identify a standard set of 23 low-voltage (LV) networks and disseminated them publicly with OpenDSS as the simulation tool. However, the locational distribution of network data was strongly biased towards New South Wales (63.5%), followed by Tasmania (28.5%) of low-voltage networks in the dataset. On the contrary, only 0.04% of the Victorian LV networks participated in the dataset. Following some extensive reviews by researcher forums and industry/DNSP partners discussions, WP1.4 shifted from using CSIRO LV network taxonomy to utilize a pseudo-LV network method for representing Victorian networks.

2.2.2 Pseudo LV Network Approach

WP1.4 adopted a pseudo-LV network method, to represent spatial characteristics and typical network topology of Victoria and support different network analysis functions. WP1.4 further customized the pseudo-LV network method by leveraging the Victorian DNSP data and network attributes. The pseudo-LV Network approach does not match the real networks, in that it has greatly simplified the connection arrangements for the ease of automation and efficiency (i.e. this approach has adopted a simplified linear approach to the LV connection topology however in practice it's typically non-linear).

The developed pseudo-LV networks, unlike the CSIRO LV models, offer higher flexibility of adjusting LV networks for different LV circuits and customer connection densities. The cable specification has been adopted from Victorian DNSP data and the number of customers per feeder and associated cable length are considered through Victorian demographic data. The developed pseudo-LV network models also specifically reflect the appropriate customer type composition in each type of network (i.e. urban, suburban, rural-short, rural-long, and CBD), which is sourced from DNSPs. This pseudo-LV network approach has been conducted and automated using Python software and power network models are delivered in OpenDSS.

2.2.3 MV-LV Detailed Network Model in OpenDSS

This section will detail the procedure for developing MV-LV network models considering the actual MV feeder model provided by DNSPs and pseudo-LV network model. This process has been conducted in two stages: (i) MV feeder models receiving network data from MS Excel and (ii) developing pseudo-LV networks and connecting them with respective MV bus/node, as shown in Figure 1. Both stages have been automated using Python codes.

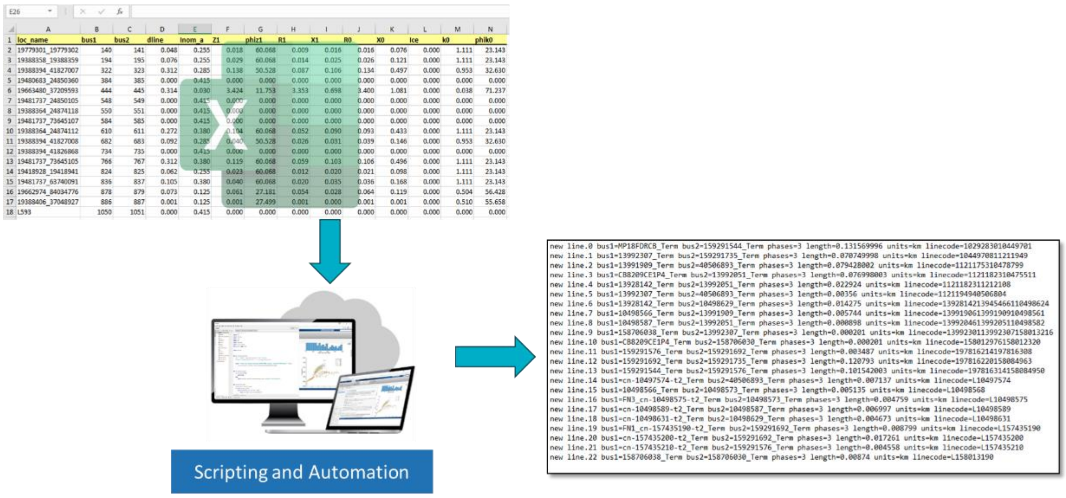


Figure 1: Preparing MV-LV detailed network model in OpenDSS using Python.

2.2.3.1 MV Feeder Model in OpenDSS

At this stage, the `MVLinecode.dss` file was generated by extracting the line parameters from the MS Excel dataset. These parameters include the positive-sequence resistance (`r1`), reactance (`x1`), zero-sequence resistance (`r0`), reactance (`x0`), the number of phases, and the conductor's ampacity. Each MV line in the feeder was assigned a corresponding linecode identifier.

Next, the `MVLinedata.dss` file was created, incorporating bus names for each line connection, line lengths, the number of phases, and their respective linecodes. Subsequently, distribution substation (DSS) transformers were modelled in the `LVTransformer.dss` file, containing all necessary transformer parameters required for OpenDSS simulation.

Finally, an aggregated load was modelled in the `Loads.dss` file, connecting the load at each DSS transformer. This aggregated load was used at this stage to execute load flow simulations and compare the results with the actual models provided by the DNSPs in various software platforms. Figure 2 demonstrates a 22 kV feeder having a different capacity of DSS transformer.

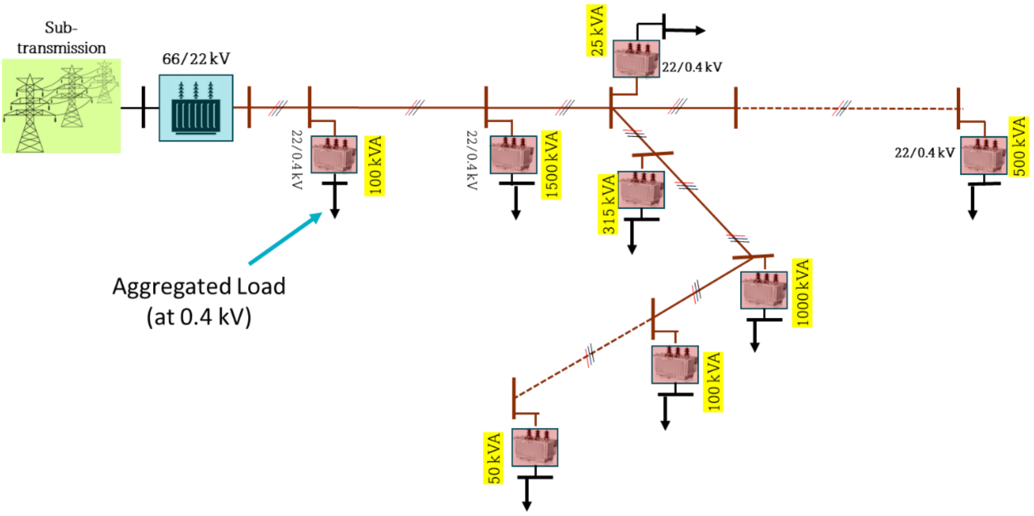
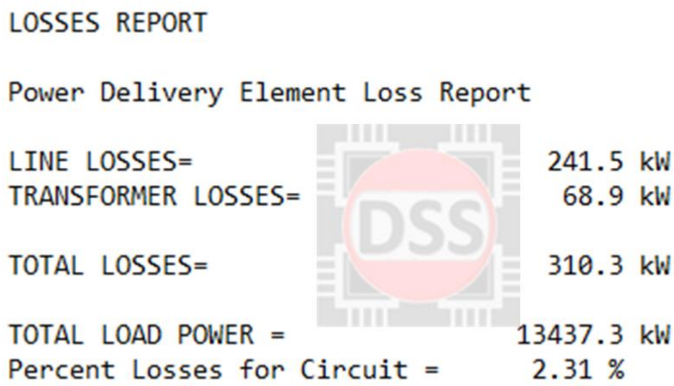


Figure 2: Demonstrating a 22 kV feeder having a different capacity of DSS transformer.

Figure 3 presents a screenshot of load flow results from OpenDSS with the WBE013 MV feeder (suburban type Werribee feeder) and Table 1 compares the load flow results and accuracy between PowerFactory and OpenDSS.



```
LOSSES REPORT

Power Delivery Element Loss Report

LINE LOSSES=                      241.5 kW
TRANSFORMER LOSSES=                68.9 kW

TOTAL LOSSES=                     310.3 kW

TOTAL LOAD POWER =              13437.3 kW
Percent Losses for Circuit =       2.31 %
```

Figure 3: Summary of power flow results in OpenDSS

Table 1: Load flow results comparison between PowerFactory and OpenDSS.

Parameters	**PowerFactory**	**OpenDSS**	**Error**
Total Load Power	13437.9 kW	13437.3 kW	-
Line Loss	256.1 kW	241.5 kW	6.04 %
Transformer Loss	67.4 kW	68.9 kW	-2.17 %
Total Loss	323.5 kW	310.4 kW	4.22 %
Minimum Voltage	0.218 kV (L-N)	0.216 kV (L-N)	-0.8 %

The discrepancies observed between the load flow results in Table 1 obtained from PowerFactory and OpenDSS, despite using a converted model, can be attributed to several potential factors, such as model conversion accuracy, and line and transformer modeling assumptions.

2.2.3.2 Pseudo-LV Network Model in OpenDSS

There are many natural diversities in the actual LV Networks (in terms of size, configuration/topology, and number of connections etc.), it is challenging/impossible to model them efficiently and in a manner that reflects their diversity. Hence the pseudo-LV modelling approach is based on design principles and industry "rules-of-thumb", which allows for automation in the process as well as the flexibility to suit different types of LV Networks. The modelling process for the LV networks is outlined as follows:

Step 1: Number of LV Circuits

Although DNSPs supplied the number of LV circuits and the associated customer counts per DSS, the pseudo-LV methodology necessitated a voltage sensitivity analysis to determine the number of LV circuits. This analysis first establishes the maximum number of customers per LV circuit, which then dictates the required number of LV circuits.

Step 2: Length of LV Circuits

The distance between LV connections in the LV models is a simplified pseudo-electrical parameter that best reflects the typical characteristics of a type of LV Circuit based on network types (urban or suburban), which in turn enables modelling efficiency. This assumption further determined the length of each LV circuit. Though the connection of the customers throughout the LV circuits is considered linear and the distance between customers has been considered uniform within the same type of network (i.e. CBD, urban, etc.), in reality, multiple customers are connected at a pole/pit - i.e. a non-linear arrangement and the distance between customers are not uniform.

Step 3: Overhead and Underground DSS

DNSP guidelines (rule of thumb) were followed to categorize DSS units as overhead or underground and to assign corresponding line impedance values.

Step 4: LV Line Impedances

The DNSPs provided impedance data for both overhead and underground LV conductors, which was directly incorporated into the pseudo-LV network model. In this effort, the most typically installed overhead conductor type and underground cable type were selected (from the various LV conductor types in service) for use in the pseudo-LV network models.

Step 5: Customer Composition and Connection

Detailed data on the number and types of customers (residential and commercial) connected to each DSS was provided by the DNSPs and incorporated into the model. Commercial and industrial (C&I)

customers were modelled as directly connected to the secondary side of the DSS transformer as three-phase loads, without additional LV circuit modelling, unlike residential customer connections.

Step 6: After Diversity Maximum Demand (ADMD)

For some feeders, the DNSPs provided ADMD values for residential customers, which were used for validating the model via power flow analysis. However, realistic ADMD values for residential customers have been considered for other feeders. For C&I customers, ADMD values were calculated using a simplified approach, aligned with DNSP and research forum discussions. The following equation was used, considering a 60% loading of the DSS (C&I only) and a power factor of 0.95:

$$C\&I\ ADMD = round((((kVA - (RES\ customer * RES\_ADMD))) * 0.6)/COM\ customer) \text{ …….. (1)}$$

The above steps were implemented in Python, which generated the `LVLinedata.dss` file for line data, and the `RES_Loads.dss` and `COM_Loads.dss` files for residential and C&I load data, respectively. These developed pseudo-LV networks replaced the aggregated load at the secondary of the DSS transformer, resulting in an integrated MV-LV network model. A demonstration of the MV-LV network model is presented in Figure 4.

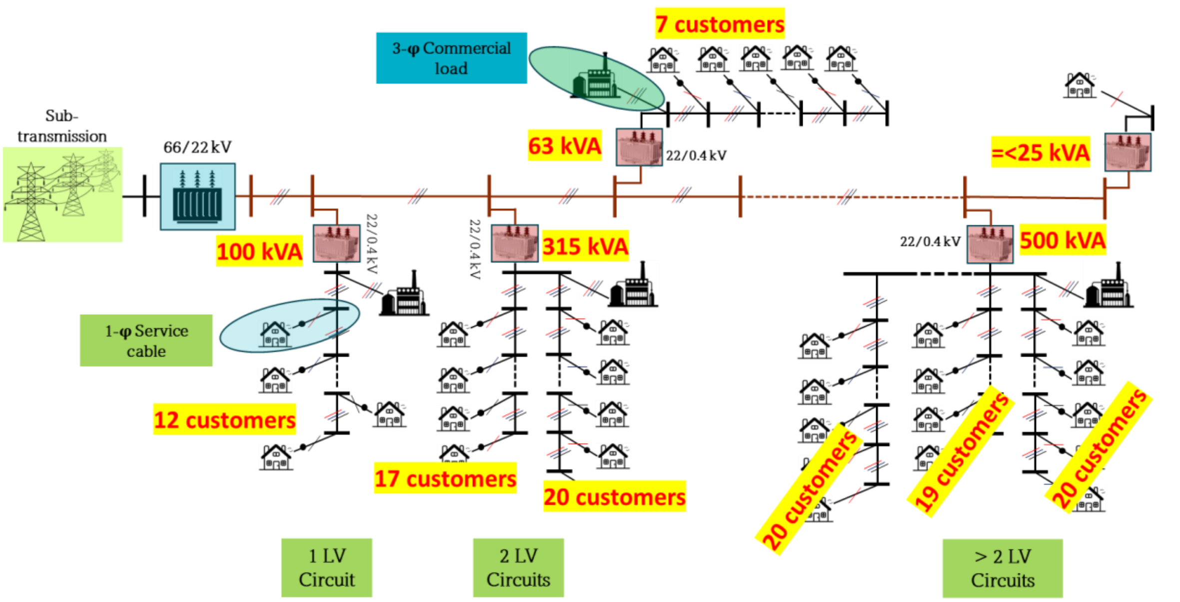


Figure 4: Demonstration of MV-LV detailed network model and configuration.

2.3 Description and Selection of DNSP Network Models

To investigate the state-wide electrification impact, the whole Victorian synthetic distribution network model should have a representation of the geographic locations, such as CBD, urban, suburban, short rural and long rural networks. For this purpose, specific feeder models that could represent a typical example of that feeder "type" or category have been selected. Also, selecting representative network examples from the CSIRO HV/MV Feeder Taxonomy was initially considered however the DNSPs were more comfortable with using actual feeder model examples, as it was felt they would be more representative of the Victorian HV/MV networks than a synthetically derived CSIRO taxonomic approach.

2.3.1 CitiPower, Powercor, and United Energy

CitiPower, Powercor, and United Energy provided 11 medium-voltage (MV) feeder models in PSS®SINCAL, with voltages of 11 kV and 22 kV. These MV feeders originate from various zone substations located across the western suburbs of Melbourne, central and western Victoria, Melbourne's central business district (CBD), and the city's inner suburbs. Detailed information on these feeders is presented in Table 2.

Table 2: MV feeder classification for model received from CitiPower, Powercor, and United Energy.

Classification	Description	Load type	Feeder Name
CBD	CBD feeders, UG cable in conduit, low impedance	Skyscraper, Large commercial centres, apartments, rail etc	MP018, VM034
CBD Fringe	Mixed UG and Overhead feeders. Low to mid impedance	Commercial, apartments, residential	NR016, NR006
Urban	Mixed UG and Overhead feeders. Low to mid impedance	Light commercial, smaller apartment blocks, residential	SSE014,
Suburban	UG feeder exits mainly overhead feeders. Mid impedance	Residential with pockets of light commercial	RD009, WBE013
Rural	Mainly overhead networks, increasing impedance relative to distance from ZSS	Residential, agriculture and light commercial mix	DDL012, GLE033, GLE011
Long Rural	Overhead - High impedance conductors on remote sections	Agricultural, industry, farming and residential	BAS033

As shown in Table 1, the MV feeders are categorized into six types: CBD, CBD fringe, urban, suburban, rural, and long rural. The approximate geographical locations of these feeders are illustrated in Figure 5.

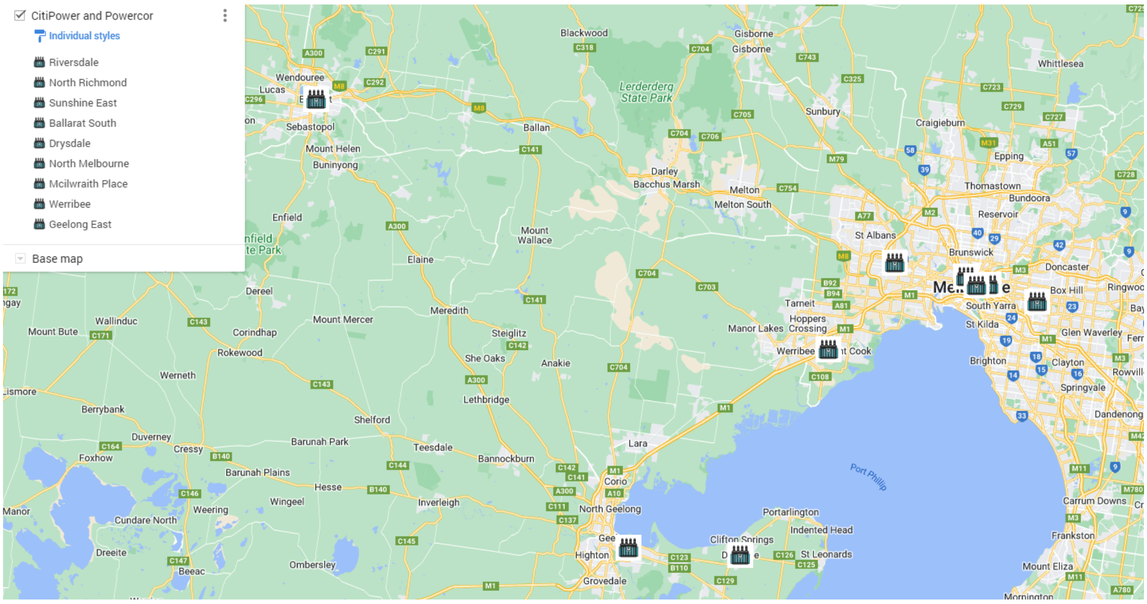


Figure 5: Approximate location of MV feeders provided by CitiPower, Powercor, and United Energy in Google map, Victoria.

2.3.2 Jemena

Jemena provided 17 MV feeder models in CYMDIST with different voltages, such as 11 kV and 22 kV. The provided MV feeders are taken from different zone substations across northwest greater Melbourne, including the Melbourne International Airport. Details of the MV feeders from Jemena have been presented in Table 3.

Table 3: MV feeder classification for model received from Jemena.

Feeder	Description of the service area for the feeder	Feeder classification	Zone Substation	Terminal Station	Voltage (kV)
AW 05	Airport West	Urban	AW	KTS_B125	22
AW 07	Airport West	Urban	AW	KTS_B125	22
COO12	Coolaroo	Rural short	COO	TTS_B34	22
COO22	Coolaroo	Urban	COO	TTS_B34	22
CS 02	Coburg South	Urban	CS	TTS_B34	22
CS 09	Coburg South	Urban	CS	TTS_B34	22
FT 31	Flemington	Urban	FT	WMTS	11
FT 32	Flemington	Urban	FT	WMTS	11
HB 14	Heidelberg	Urban	HB	TSTS	11
HB 32	Heidelberg	Urban	HB	TSTS	11
KLO13	Kalkallo	Rural short	KLO	SMTS	22
KLO21	Kalkallo	Rural short	KLO	SMTS	22
NS 11	North Essendon	Urban	NS	BTS	11
NS 12	North Essendon	Urban	NS	BTS	11
SBY13	Sunbury	Rural short	SBY	KTS_B34	22
SBY32	Sunbury	Urban	SBY	KTS_B34	22
SHM11	Sydenham	Rural short	SHM	KTS_B34	22
SHM21	Sydenham	Urban	SHM	KTS_B34	22
TH 13	Tottenham	Urban	TH	BLTS	22
TH 22	Tottenham	Urban	TH	BLTS	22

As can be seen from Table 3 the MV feeders are classified into two types such as urban and short rural. The approximate location of the above MV feeders has been presented in Figure 6.

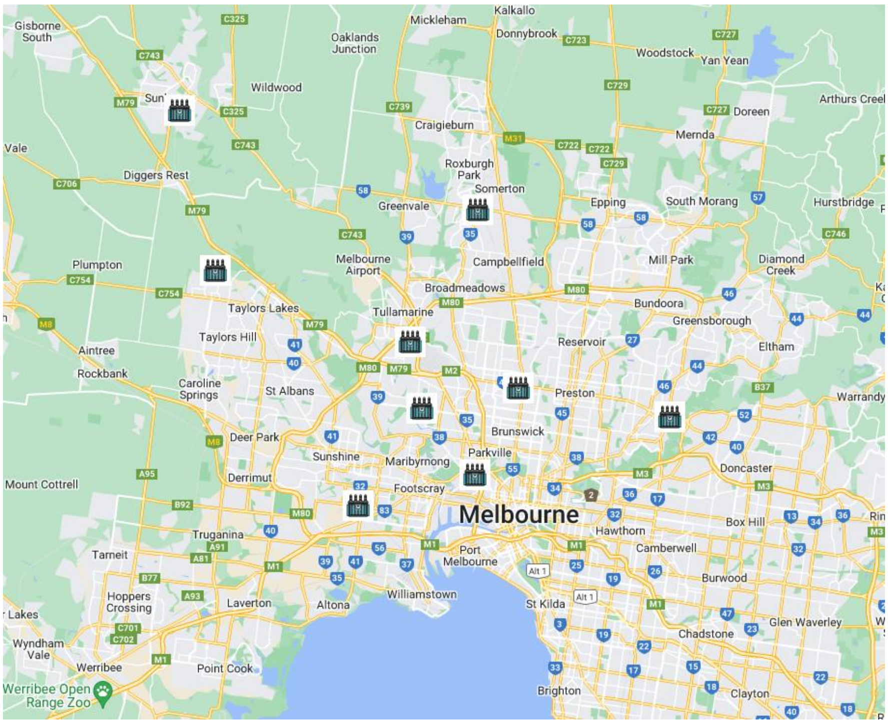


Figure 6: Approximate location of MV feeders provided by Jemena in Google map, Victoria.

2.3.3 AusNet Services

AusNet Services has provided 9 sub-transmission network models in PSS®E with a voltage of 66 KV. The provided sub-transmission networks are taken across eastern and north-eastern Victoria and in Melbourne's north and east. Details of the sub-transmission networks from AusNet Services have been presented in Table 4. However, due to the revised scope of the project, these networks have not been used in WP1.4. Converted OpenDSS files have been provided to WP1.5 and WP1.6.

Table 4: 66 kV sub-transmission network models received from AusNet Services.

Station Name	Description
CBTS	Cranbourne terminal station
ERTS	East Rowville Terminal Station
RWTS	Ringwood Terminal Station
SMTS	South Morang Terminal Station
TSTS	Templestowe Terminal Station
TTS	Thomastown Terminal Station
MWTS	Morwell Terminal Station
GNTS	Glenrowan Terminal Station
WOTS	Wodonga Terminal Station

The approximate location of the above MV feeders has been presented in Figure 7.

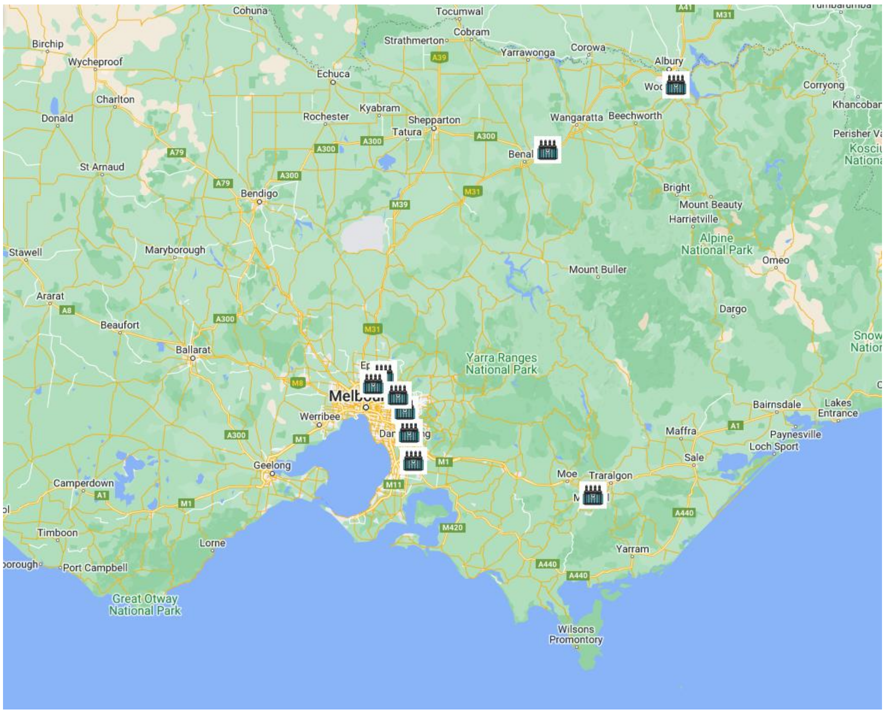


Figure 7: Approximate location of sub-transmission networks provided by AusNet Services in Google map, Victoria.

2.3.4 Conversion of Electrical Network Models into a Unified Software Format

The network models were supplied by DNSPs at various voltage levels (0.4 kV, 11 kV, 22 kV, and 66 kV) across multiple software platforms, including PSS®E, PSS®SINCAL, and CYMDIST. WP1.4 adopted a systematic methodology, starting from sorting network models and culminating in the delivery of a fully integrated package in OpenDSS, to be utilized in subsequent work packages under the ESP project. Figure 8 illustrates the applied workflow to convert and unify the individual DNSP electrical impedance models into a unified software package.

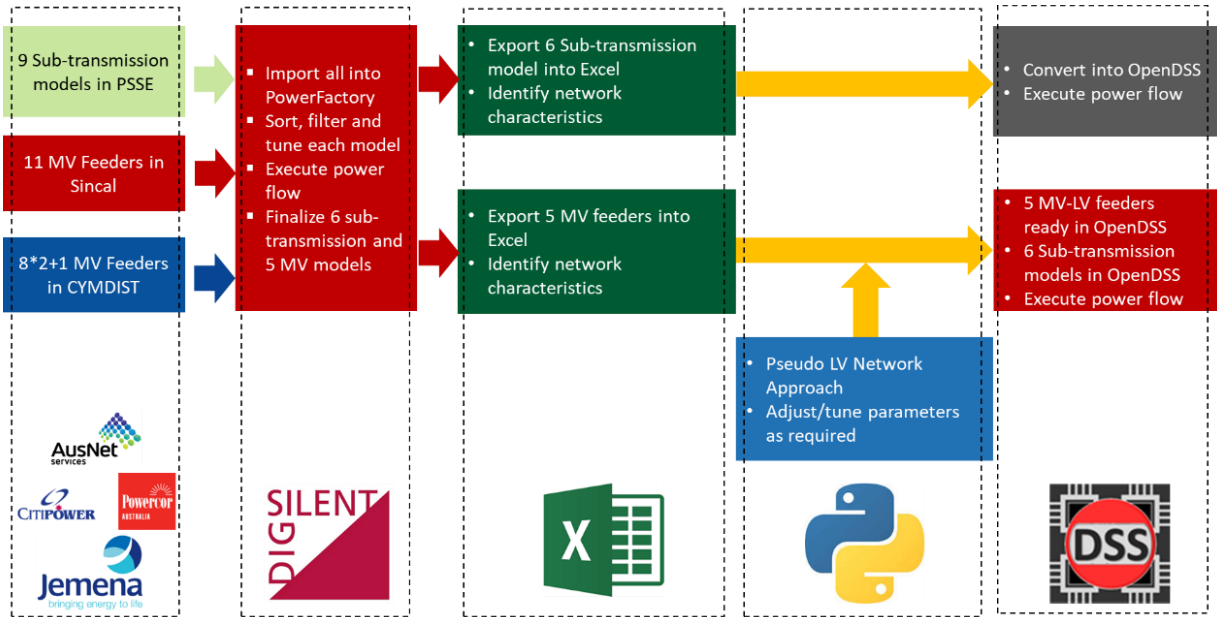


Figure 8: Overall methodology for developing a comprehensive taxonomy and information database for MV-LV network models across Victoria.

2.3.5 Importing Models into a Single Software

WP1.4 received network models from DNSPs across various software platforms, necessitating their conversion into a unified platform for benchmarking purposes. To achieve this, WP1.4 utilized DIgSILENT PowerFactory (commonly referred to as PowerFactory) to import, filter, and tune the models, as required, to perform load flow analysis. PowerFactory's base package supports the import and conversion of network model data from multiple modelling applications using the DGS interface tool, which accommodates a variety of data formats. Table 5 provides a summary of all the MV feeders imported into PowerFactory, classified by feeder type.

Table 5: Feeder classifications for all received models from DNSPs.

Feeder Type	MV Feeder
Urban	17
Suburban	2
Short Rural	4
Long Rural	1
City/CBD Fringe	4
Total	28

2.3.6 Selection of Models

The primary goal of WP1.4 is to develop electricity distribution network models that can be used to broadly represent the Victorian grid in a way that enables simplified "bottom-up" analysis by researchers and industry. These models will be instrumental in addressing gaps in forecasting future scenario outcomes, particularly concerning the widespread adoption of localized renewable generation, distributed energy resources (DERs), transport electrification, the transition from domestic gas, and the integration of new fuel sources. Subsequent work packages require a diverse set of network models that include one representative MV-LV model for each feeder type: urban, suburban, rural-short, rural-long, and CBD.

WP1.4 conducted an extensive network characteristic assessment, incorporating comprehensive feedback from DNSPs and researcher forums, to ensure representative characteristics for each feeder type. Five MV feeders were selected from Table 5 for further analysis, as detailed in Table 6.

Table 6: Selected feeders for WP1.4 and their corresponding DNSPs.

Feeder Type	MV Feeder	ZSS name	DNSP
Urban	SBY32	Sunbury	Jemena
Suburban	WBE013	Werribee	CitiPower, Powercor, and United Energy
Rural-short	COO12	Coolaroo	Jemena
Rural-long	BAS033	Ballarat South	CitiPower, Powercor, and United Energy
CBD	VM034	Victoria Market	CitiPower, Powercor, and United Energy

2.3.7 Network Data Export into MS Excel

In preparation for the subsequent work packages of ESP-V, WP1.4 exported the network data presented in Table 6 into MS Excel for use in OpenDSS software. Customized automation using the DIgSILENT PowerFactory Language (DPL) was developed for this export process. Additionally, the bus/node, line, transformer, and load names were renamed to ensure consistency, as OpenDSS does not support certain special characters used in PowerFactory models. This renaming process was automated using MATLAB 2023b. Figure 9 demonstrates network data exporting into Excel from PowerFactory.

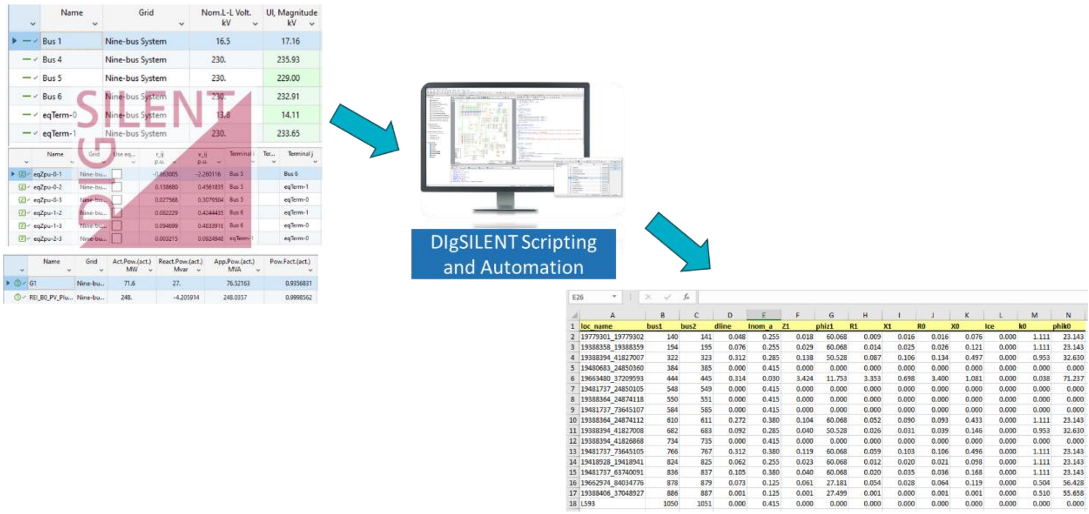


Figure 9: Network Data Exporting into Excel from DIgSILENT PowerFactory using DPL.

2.3.8 Power Flow Simulation for Validity Check

After finalizing the MV feeder models integrated with detailed LV circuits, Work Package 1.4 conducted a power flow simulation using selected ADMD values. This simulation aims to:

1. **Validate Network Models and Data:** Ensure the suitability of the network models, acquired datasets, and simulation software.
2. **Configure Network Parameters:** Establish appropriate tap settings for zone substation transformers and distribution substation (DSS) transformers and investigate conductor ampacities to address any thermal overloading issues.

The results and analyses from this simulation are documented for all types of feeders in the Appendix. During the simulations, the ADMD values for individual feeders were set to consider likely network loading conditions. The applied ADMD was chosen to align with the diversified individual maximum summer peak demand exhibited by the smart metering load profile set that is to be used in the subsequent electrification impact assessment.

Voltage Adjustment Methodology

1. **Initial Voltage Setting at Zone Substation:** The voltage at the Zone Substation (66 kV) was set to 1.02 per unit (p.u.), following standard practice among DNSPs in Victoria.
2. **Adjustment of OLTC and Voltage Regulators:**
    a. On-Load Tap Changer (OLTC): The OLTC at the zone substation features 17 tap positions ranging from +8 to -8, allowing voltage modulation between 0.94 p.u. and 1.10 p.u. Each tap shift results in a voltage change of approximately 1% (0.01 p.u.).
    b. Voltage Regulators: If present on the MV feeder, voltage regulators tap positions were set to ensure all 22 kV (or 11 kV, depending on the feeder type) bus voltages remained within the acceptable range of 0.94 p.u. to 1.10 p.u.

3. **Verification of MV Bus Voltages:** MV bus voltages were monitored to confirm compliance with voltage limits.
4. **Assessment of LV Bus Voltages:** After stabilizing MV bus voltages, all 0.4 kV bus voltages were evaluated. Voltage violations—defined as voltages below 0.94 p.u. or above 1.10 p.u.—were identified along with their corresponding DSS transformers.
5. **Adjustment of DSS Transformer Tap Positions:** If any voltage violation exists at any LV buses (<0.94 p.u. and >1.1 p.u.), the tap positions of DSS transformers were adjusted. Each DSS transformer offers five tap positions, enabling voltage variations between 0.9 p.u. and 1.1 p.u.

Conductor Ampacity Adjustment Procedure

During the base case simulation, the thermal loading of MV conductors was closely monitored to identify any instances of overloading under the applied ADMD values. The following steps were undertaken to address thermal overloading:

1. **Identification of Overloaded Conductors:** Conductors exceeding their thermal capacity were pinpointed.
2. **Replacement with Higher Ampacity Conductors:** Overloaded conductors were replaced with alternatives possessing higher ampacity ratings to accommodate the increased load without surpassing thermal limits.
3. **Validation of Adjustments:** The network was re-simulated to ensure that the new conductors effectively resolved the overloading issues.

The ADMD based power flow simulation successfully validated the network models and enabled the configuration of the voltage-regulating elements within the respective feeder types, as well as the adjustment of conductor capacities. This foundational work is an initial check that the network operates within acceptable voltage and thermal parameters with a typical system loading scenario and provides a representative basis for future network impact assessments.

2.4 Powercor LV Taxonomy Models

Received 10 Low Voltage (LV) network models from; CitiPower, Powercor, and United Energy covering various regions in Victoria. These models, originally developed in the PSS SINCAL environment, required conversion into a common software platform—OpenDSS—to facilitate benchmarking. Table 7 summarizes the key characteristics of these LV models, including their associated MV feeder names, distribution transformer capacities, and customer counts (residential, commercial, and industrial).

Table 7: 10 Low Voltage (LV) network models from; CitiPower, Powercor, and United Energy.

Model	MV Feeder	Transformer Name	Transformer Capacity	Residential	C&I	Total
1	BAS033	CLYDE 8	50 kVA	22	2	**24**
2	BAS033	BERRINGA P10	50 kVA	6	-	**6**
3	BAS033	KIRKPATRICK WHITELAW	315 kVA	2	14	**16**
4	WBE013	BARNSTORMER-KINGSFORD	315 kVA	131	2	**133**
5	BAS033	CAIRNS 3	10 kVA	1	-	**1**
6	BAS033	KIRKPATRICK WHITELAW	315 kVA	2	14	**16**
7	VM034	10 WRECKYN ST	1000 kVA	4	5	**9**
8	BAS033	Skipton 363	315 kVA	44	15	**59**
9	GLE011	Crown Dowsett P2	500 kVA	-	24	**24**
10	GLE013	Birkett West Hede	500 kVA	1	9	**10**

2.4.1. Actual LV Model in OpenDSS

As a first step, the received LV network models were directly converted into OpenDSS without modifying their original configuration. To achieve this, the electrical and physical parameters (transformer ratings, line impedances, and load attributes) were extracted into an MS Excel file. A Python script then automatically generated the LV network models in OpenDSS, preserving the original network topology.

For load representation, a simplified ADMD value—consistent with the MV feeder ADMD—was assigned to residential customers. For commercial and industrial (C&I) customers, a simplified ADMD value was calculated using Equation (1). After setting these load parameters, power flow simulations were performed on the actual LV network models to establish a baseline for subsequent comparisons.

2.4.1. Synthetic LV Model in OpenDSS

Next, synthetic versions of the same 10 LV network models (see Table 7) were developed in OpenDSS following the "Pseudo-LV Network Model" approach described in Section 2.2.3.2. The synthetic models retained the same transformer capacities and the same numbers of residential and C&I customers as the actual models. They were also assigned the same ADMD values used in Section 2.4.1 for both residential and C&I customers. Power flow simulations were then conducted on these synthetic LV models to enable a direct comparison with the actual LV models.

Appendix B presents a detailed comparison of key power flow metrics—phase voltages, line losses, transformer losses, and the percentage of total losses—between the actual and synthetic LV models developed in OpenDSS.

All 10 LV Models and Their Pseudo version are Available in the OpenDSS software - updated link to come.

3. Design of Synthetic LV networks to Integrate into HV/MV Network Models

This section presents the base case simulation conducted to validate the accuracy of the developed network models and associated datasets. A detailed analysis of steady-state voltage, thermal loading at both the MV and LV levels and DSS transformer loading was performed. Table 8 provides a summary of the input parameters used for the MV-LV feeder models.

Table 8: Summary of five MV feeders considered in this project.

Item Description	Urban	Suburban	Rural-short	Rural-long	CBD
Feeder ID	SBY32	WBE013	COO12	BAS033	VM034
Voltage Level	22 kV	22 kV	22 kV	22 kV	11 kV
Maximum demand	10.55 MVA	13 MVA	8.42 MVA	9 MVA	4 MVA
Feeder length	19.82 km	33.14 km	93.1 km	207.3 km	3.71 km
RES/COM customer (%)	91.7/8.3	96.02/3.98	89.5/10.5	84/16	75/25
Number of DSS transformers	48	71	187	877	15
Number of customers	3181	5514	724	3942	1071

3.1 Urban Feeder: SBY32 (Sunbury)

The SBY32 MV Feeder is a 22 kV urban feeder connected with the Sunbury Zone Substation that has been acquired from Jemena. It encompasses 48 DSS transformers. As discussed in the Methodology section, the MV feeder was left unaltered, including line impedances, line lengths, DSS transformer details, and the overall topology. However, the following assumptions and considerations have been made while developing the pseudo-LV model for connecting them to each DSS to develop a comprehensive MV-LV detailed model:

1. LV Line Impedances: Jemena provided the LV line impedances for both overhead and underground conductors, which were directly applied in our model.

OH/UG	R1	X1	R0	X0	Ampacity	Phase	Conductor
OH	0.388	0.66	0.68	3.18	230	3ph	19/3.25
UG	0.161	0.101	0.654	0.189	440	3ph	240mm 4c

2. Customer Data: Detailed data on the number and types of customers (residential and commercial) connected to each DSS was provided by Jemena.

3. Commercial/Industrial (C&I) Customers: C&I customers were modelled as directly connected to the secondary of the DSS, without further LV circuit modelling.
4. Residential ADMD: The After Diversity Maximum Demand (ADMD) values for each DSS, provided by Jemena, were directly incorporated into our modelling.
5. C&I ADMD: We calculated the ADMD values for C&I customers using a simplified approach, assuming 60% loading of the DSS (C&I only) and a power factor of 0.95. Equation (1) was used to calculate ADMD values for C&I customers.
6. Overhead/Underground DSS: We adhered to the Powercor guideline (rule of thumb), considering DSS units greater than 1000 kVA as underground and the remainder as overhead.
7. Max. Customer Number per LV Circuit: Although Jemena provided the number of LV circuits and associated customer counts for each DSS, we applied the Powercor guideline due to the limitations of the pseudo-LV methodology, capping the maximum number of customers per LV circuit at 25.
8. Distance Between Customers: Given that DNSPs do not typically model LV circuits based on customer distance, we assumed a 15-meter “virtual” distance between customers.

3.2 Suburban Feeder: WBE013 (Werribee)

WBE013 feeder is connected with the Werribee zone substation. It is a 22 kV feeder and is classified as a Suburban type of feeder. This feeder has 253 buses and spreads 33 km long covering Manor Lakes, Werribee, Werribee South, Cocoroc, Wyndham Vale, and Mambourin. There are 71 DSSs with varying capacities between 50 kV to 1000 kV.

As discussed in the Methodology section, the MV feeder was left unaltered, including line impedances, line lengths, DSS transformer details, and the overall topology. However, the following assumptions and considerations have been made while developing the pseudo-LV model for connecting them to each DSS to develop a comprehensive MV-LV detailed model:

OH/UG	R1	X1	R0	X0	Ampacity	Phase	Conductor
OH	0.206	0.344	0.805	1.23	255	3ph	4-19/3.25 AA
UG	0.162	0.078	0.648	0.051	350	3ph	240mm UG cable

1. LV Line Impedances: CitiPower, Powercor and United Energy provided the LV line impedances for both overhead and underground conductors, which were directly applied in our model.
2. Customer Data: Detailed data on the number and types of customers (residential and commercial) connected to each DSS was provided by CitiPower, Powercor and United Energy.
3. Commercial/Industrial (C&I) Customers: C&I customers were modelled as directly connected to the secondary of the DSS, without further LV circuit modelling.
4. Residential ADMD: We incorporated 2 kW ADMD values into our modelling which aligned with the ADMD provided by Jemena.

5. C&I ADMD: We calculated the ADMD values for C&I customers using a simplified approach, assuming 60% loading of the DSS (C&I only) and a power factor of 1. Equation (1) was used to calculate ADMD values for C&I customers.
6. Overhead/Underground DSS: We adhered to the Powercor guidelines (rule of thumb):
    a. DSS units greater than 1000 kVA as underground. These DSS are C&I type.
    b. DSS units between 500 to 1000 kVA are considered 19% underground and 81% overhead. There are 11 DSS in this range.
    c. DSS units between 300 to 500 kVA are considered 17% underground and 83% overhead. There are 48 DSS in this range.
    d. DSS units between 25 to 300 kVA are considered 100% overhead. There are 9 DSS in this range.
7. Max. Customer Number per LV Circuit: We applied the Powercor guideline (rule of thumb) due to the limitations of the pseudo-LV methodology, capping the maximum number of customers per LV circuit at 20.
8. Distance Between Customers: Given that DNSPs do not typically model LV circuits based on customer distance, we assumed a 15-meter “virtual” distance between customers, following a sensitivity analysis.

3.3 Rural-short Feeder: COO12 (Coolaroo)

The COO12 MV Feeder is a 22 kV short rural feeder connected with Coolaroo Zone Substation that has been acquired from Jemena. It encompasses 187 distribution substation (DSS) transformers. As discussed in the Methodology section, the MV feeder was left unaltered, including line impedances, line lengths, DSS transformer details, and the overall topology. However, the following assumptions and considerations have been made while developing the pseudo-LV model for connecting them to each DSS to develop a comprehensive MV-LV detailed model:

1. LV Line Impedances: Jemena provided the LV line impedances for both overhead and underground conductors, which were directly applied in our model.

OH/UG	R1	X1	R0	X0	Ampacity	Phase	Conductor
OH	0.388	0.66	0.68	3.18	230	3ph	19/3.25
UG	0.161	0.101	0.654	0.189	440	3ph	240mm 4c

2. Customer Data: Detailed data on the number and types of customers (residential and commercial) connected to each DSS was provided by Jemena.
3. Commercial/Industrial (C&I) Customers: C&I customers were modelled as directly connected to the secondary of the DSS, without further LV circuit modelling.
4. Residential ADMD: We incorporated 3 kW ADMD values into our modelling which aligned with the ADMD provided by Jemena.

5. C&I ADMD: We calculated the ADMD values for C&I customers using a simplified approach, assuming 60% loading of the DSS (C&I only) and a power factor of 0.95. Equation (1) was used to calculate ADMD values for C&I customers.
6. Overhead/Underground DSS: We adhered to the Powercor guideline (rule of thumb), considering DSS units greater than 1000 kVA as underground and the remainder as overhead.
7. Max. Customer Number per LV Circuit: Although Jemena provided the number of LV circuits and associated customer counts for each DSS, we applied the Powercor guideline due to the limitations of the Pseudo LV methodology, capping the maximum number of customers per LV circuit at 25.
8. Distance Between Customers: Given that DNSPs do not typically model LV circuits based on customer distance, we assumed a 20-meter "virtual" distance between customers, following a sensitivity analysis.
9. Voltage Regulator: There is one voltage regulator (±10% tap range, 0.625% steps,) at 22 kV bus approximately 14 km away along the feeder with a capacity of 110 kVA, to improve the voltage across the MV-LV model. The voltage regulator was incorporated and positioned in the original DNSP model - we replicated that to be consistent.
10. Capacitor Bank: There are two capacitor banks at 22 kV bus with a capacity of 4 MVAr each at the ZSS. The capacitor banks were incorporated and positioned in the original DNSP model - we replicated that to be consistent.

3.4 Rural-long Feeder: BAS033 (Ballarat South)

The BAS033 MV Feeder is a 22 kV rural-long feeder connected with Ballarat South zone Substation that has been acquired from CitiPower, Powercor and United Energy. It encompasses 877 distribution substation (DSS) transformers. As discussed in the Methodology section, the MV feeder was left unaltered, including line impedances, line lengths, DSS transformer details, and the overall topology. However, the following assumptions and considerations have been made while developing the pseudo-LV model for connecting them to each DSS to develop a comprehensive MV-LV detailed model:

1. LV Line Impedances: Powercor provided the LV line impedances for both overhead and underground conductors, which were directly applied in our model.

OH/UG	R1	X1	R0	X0	Ampacity	Phase	Conductor
OH	0.206	0.344	0.805	1.23	255	3ph	4-19/3.25 AA
UG	0.162	0.078	0.648	0.051	350	3ph	240mm UG cable

2. Customer Data: Detailed data on the number and types of customers (residential and commercial) connected to each DSS was provided by Powercor.
3. Commercial/Industrial (C&I) Customers: C&I customers were modelled as directly connected to the secondary of the DSS, without further LV circuit modelling.

4. Residential ADMD: The After Diversity Maximum Demand (ADMD) value at the MV feeder level, provided by Powercor, was initially incorporated into our modelling which is 4 kW. However, it results in extreme DSS overloading; thus, we reduced it to 1.8 kW.
5. C&I ADMD: We calculated the ADMD values for C&I customers using a simplified approach, assuming 60% loading of the DSS (C&I only) and a power factor of 1. Equation (1) was used to calculate ADMD values for C&I customers.
6. Overhead/Underground DSS: We adhered to the Powercor guideline (rule of thumb):
    a. DSS units greater than 1000 kVA as underground. These are mostly C&I DSS.
    b. DSS units between 500 to 1000 kVA are considered 25% underground and 75% overhead. There are 5 DSS units in this range.
    c. DSS units between 300 to 500 kVA are considered 16% underground and 84% overhead. There are 25 DSS units in this range.
    d. DSS units between 100 to 300 kVA are considered 15% underground and 85% overhead. There are 50 DSS units in this range.
    e. DSS units between 25 to 100 kVA are considered 100% overhead. There are 365 DSS units in this range.
    f. DSS units between 5 to 25 kVA are considered 100% overhead. There are 430 DSS units in this range.
7. Max. Customer Number per LV Circuit: We applied the Powercor guideline due to the limitations of the Pseudo LV methodology, capping the maximum number of customers per LV circuit at 18.
8. Distance Between Customers: Given that DNSPs do not typically model LV circuits based on customer distance, we assumed a 15-meter "virtual" distance between customers, following a sensitivity analysis.
9. Voltage Regulator: There is a voltage regulator along the feeder. CitiPower, Powercor and United energy has provided detailed modelling of a voltage regulator, including capacity in MVA, number of taps, location in the feeder, etc. The voltage regulator was incorporated and positioned in the original DNSP model - we replicated that to be consistent.
10. Shunt Capacitor: There is a capacitor bank along the feeder. CitiPower and Powercor has provided detailed modelling of a shunt capacitor, including capacity in MVAR. The capacitor bank was incorporated and positioned in the original DNSP model - we replicated that to be consistent.

3.5 CBD Feeder: VM034 (Victoria Market)

The VM034 MV Feeder is an 11 kV CBD feeder connected with the Victoria Market Zone Substation that has been acquired from CitiPower, Powercor and United Energy. It encompasses 15 distribution substation (DSS) transformers. As discussed in the Methodology section, the MV feeder was left unaltered, including line impedances, line lengths, DSS transformer details, and the overall topology. However, the following assumptions and considerations have been made while developing the pseudo-LV model for connecting them to each DSS to develop a comprehensive MV-LV detailed model:

1. LV Line Impedances: Powercor provided the LV line impedances for both overhead and underground conductors, which were directly applied in our model.

OH/UG	R1	X1	R0	X0	Ampacity	Phase	Conductor
OH	0.206	0.344	0.805	1.23	255	3ph	19/3.25 AA
UG	0.128	0.118	0.654	0.189	350	3ph	185mm Cu

2. Customer Data: Detailed data on the number and types of customers (residential and commercial) connected to each DSS was provided by CitiPower, Powercor and United Energy.
3. Commercial/Industrial (C&I) Customers: C&I customers were modelled as directly connected to the secondary of the DSS, without further LV circuit modelling.
4. Residential ADMD: The After Diversity Maximum Demand (ADMD) value at the MV feeder level, provided by CitiPower and Powercor, were initially incorporated into our modelling which is 4 kW. However, it results in extreme DSS overloading; thus, we reduced it to 3.5 kW, which aligned with ADMD provided by Jemena.
5. C&I ADMD: We calculated the ADMD values for C&I customers using a simplified approach, assuming 60% loading of the DSS (C&I only) and a power factor of 0.95. Equation (1) was used to calculate ADMD values for C&I customers.
6. Overhead/Underground DSS: We adhered to the Powercor guideline (rule of thumb), considering all DSS units as underground.
7. Max. Customer Number per LV Circuit: We applied the Powercor guideline due to the limitations of the Pseudo LV methodology, capping the maximum number of customers per LV circuit at 25.
8. Distance Between Customers: Given that DNSPs do not typically model LV circuits based on customer distance, we assumed a 15-meter distance between customers, following a sensitivity analysis.

All 5 MV-LV Models are Available in OpenDSS software package at the C4NET Data Repository - updated link to come.

4. Conclusions

This report presents a detailed study, results, and analysis of WP1.4 (distribution network architecture via synthetic models) within the Enhanced System Planning (ESP) project, focusing on the development of electricity distribution network models that can be used to broadly represent the Victorian grid in a way that enables simplified "bottom-up" analysis by researchers and industry. The developed network models serve as a foundation for subsequent work packages, which will utilize them to perform various power system studies, including load flow analysis, voltage constraint evaluations, hosting capacity assessments, and techno-economic evaluations.

4.1 Selected Feeders and Key Characteristics

Five feeders were selected from the datasets provided by CitiPower, Powercor, and United Energy, Jemena, and AusNet Services. Each feeder represents a distinct network type and geographic area, as detailed below:

- **Urban Feeder (SBY32, Sunbury)**: A 22 kV urban feeder acquired from Jemena, encompassing 48 distribution substation (DSS) transformers over a 19.8 km distance. The feeder serves a total of 3181 customers, with 91.7% residential and 8.3% commercial and industrial (C&I) customers.
- **Suburban Feeder (WBE013, Werribee)**: A 22 kV suburban feeder from CitiPower, Powercor, and United Energy, consisting of 71 DSS transformers across a 33.14 km network. The feeder supplies 5,514 customers, with 96% residential and 4% C&I customers.
- **Rural-Short Feeder (COO12, Coolaroo)**: A 22 kV rural-short feeder provided by Jemena, spanning 93.1 km with 187 DSS transformers. The COO12 feeder supports 724 customers, with a breakdown of 89.5% residential and 10.5% C&I customers.
- **Rural-Long Feeder (BAS033, Ballarat South)**: A 22 kV rural-long feeder acquired from CitiPower, Powercor, and United Energy, extending over 207.3 km and incorporating 877 DSS transformers. It serves 3,942 customers, with 84% residential and 16% C&I and agricultural customers.
- **CBD Feeder (VM034, Victoria Market)**: A 11 kV CBD feeder from CitiPower, Powercor, and United Energy, spanning 3.71 km and consisting of 15 DSS transformers. The feeder serves 1,071 customers, with 74.9% residential and 25.1% C&I and agricultural customers.

4.2 Power Flow Simulation Results

A power flow analysis was performed for all five feeders using ADMD values provided by the DNSPs. Key metrics such as MV and LV node voltages, MV line loading, and DSS transformer loading were recorded.

- **Voltage Performance**: The MV and LV node voltages were generally within acceptable operational ranges (0.94 p.u. to 1.10 p.u.) across all feeders.
- **Loading Analysis**: For most feeders, MV line loading levels were within capacity limits. However, representative feeders exhibited occasional overloading on certain distribution transformers (resulting from the simplified ADMD approach).

4.3 Summary and Key Observations

This report presents the methodology, data acquisition, modelling, and a validation approach for Victorian synthetic distribution network development. It presents 5 representative MV and LV networks across various Victorian regions (CBD, urban, suburban, short rural and long rural). The modelling approach implemented the pseudo-LV network development technique, which is an automated process implemented in OpenDSS. Automation and scalability are the major advantages of this approach.

However, it fails to consider the variation and diversity in the network parameters (such as line impedance, customer per circuit, customer distance, customer loading etc.) within the same network models. The 5 types of networks vary by the diversity in the network parameters (such as line impedance, customer per circuit, customer distance, customer loading etc.) and the voltage regulators and distribution substation (DSS) transformer tap settings are adjusted to regulate the voltages at the LV circuits.

One limitation of the pseudo-LV network development technique is that it considered all commercial and industrial (C&I) customers to be connected to the DSS directly. This is acceptable if there are fewer DSS-adjacent C&I customers in the LV circuits. However, as the number of C&I customers increases to the network and in reality, they are far from the DSS, then the error increases in the pseudo-LV network models.

The developed models will form the basis for further impact assessments and power system studies in subsequent ESP work packages.

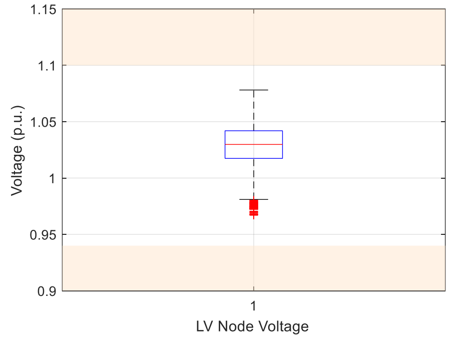
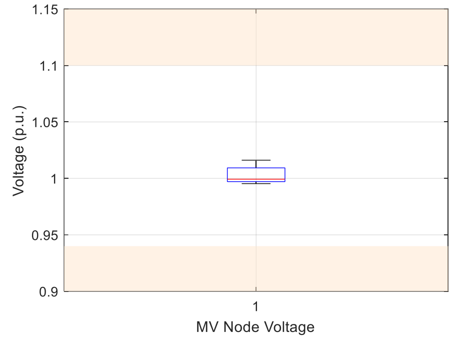
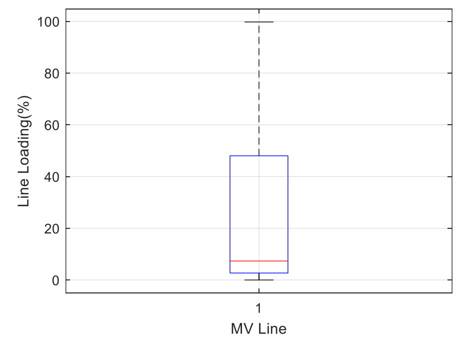
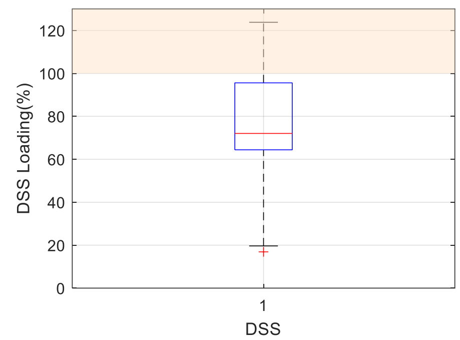
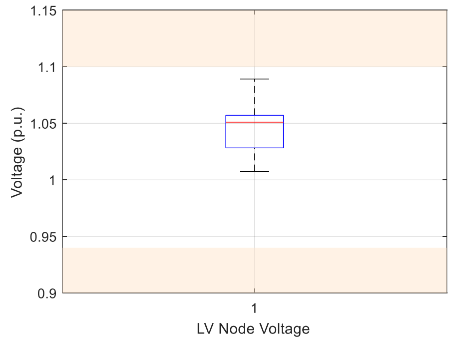
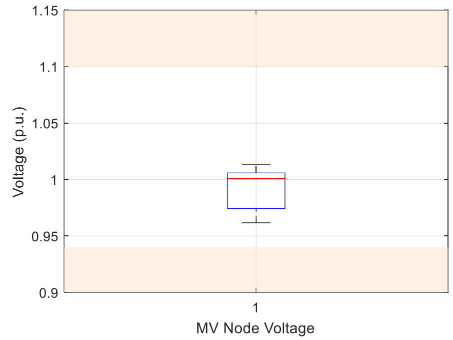
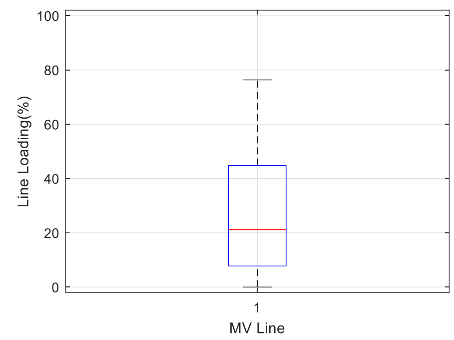
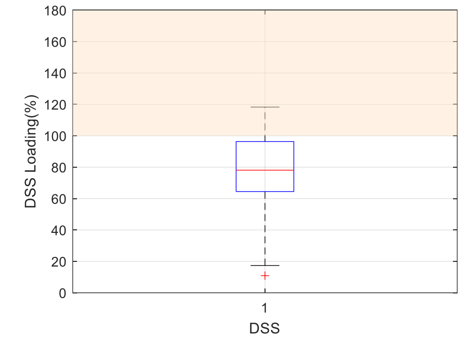
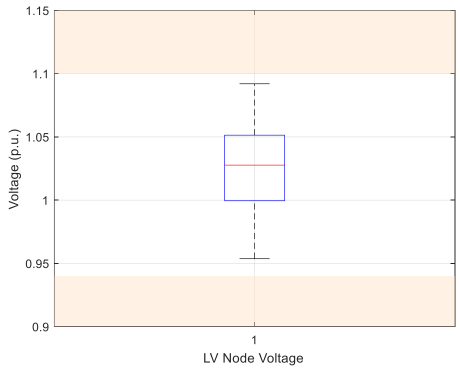
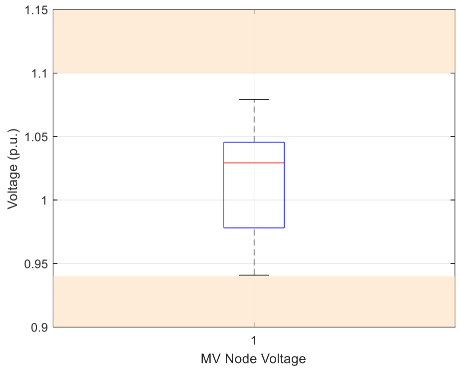
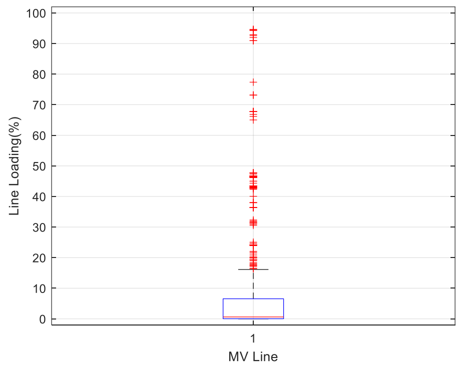
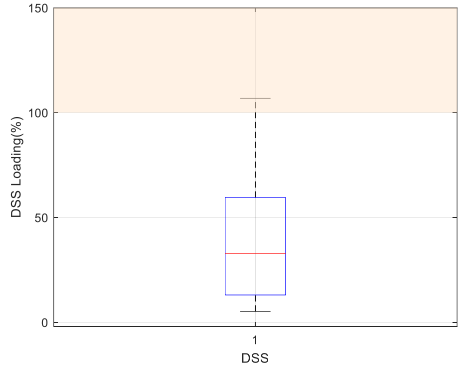
4.4 Limitations of this Study

The study presented in this report offers a foundational analysis of MV-LV network models for power system studies in Victoria. However, several limitations need to be acknowledged, primarily due to data constraints and design assumptions made during the pseudo-LV network modelling process. These limitations could influence the accuracy and applicability of the results, particularly when extrapolating them to real-world scenarios.

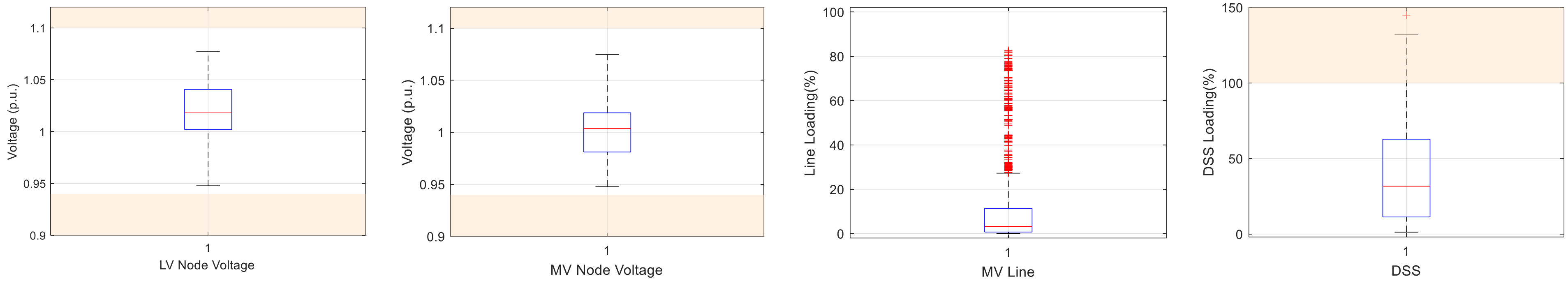
- **In this modelling approach, a single pole in the LV circuit was modelled for supplying only one customer.** In reality, LV circuits may supply multiple customers from one pole/node, and distances between customer connections can vary substantially, including lengths of service cables etc. Hence, this modelling approach may not align with the operational characteristics of actual LV networks, where multiple customers share a single pole or connection point. Consequently, the study's representation of customer distribution within LV circuits lacks the complexity of real-world configurations, potentially leading to an oversimplification of power flow characteristics and voltage profiles.

- **The maximum number of customers per LV circuit at 25 (or 20 or 18).** Additionally, due to the pseudo-automation involved in developing the LV network models, the maximum number of customers on an LV circuit may not match the actual number of customer connections on that circuit. The design criterion also assumes a full complement of customer connections on a circuit before another circuit is added - this is often not the case as it may be determined by geographic considerations. This constraint limited our ability to model the full customer base for each LV circuit and might underrepresent the overall loading and voltage variation that typically occurs in densely populated areas.
- **We assumed a 15 (or 20) meter “virtual” distance between customers, following a sensitivity analysis.** The distance between customers along LV circuits is another limitation of this modelling approach. The synthetic network design doesn't mirror the actual geographic nature of the network, as illustrated in the earlier points relating to customer connections. This "distance" represents a virtual distance between customer connections, which is designed to represent an "average" electrical impedance between customer connections for the purpose of modelling efficiency and automation. In this case, we relied on generalized estimates based on the feeder’s geographic locations. Although these estimates are based on reasonable assumptions, they introduce a degree of uncertainty into the network model, particularly in areas with highly variable distances between customers.
- **LV conductors for OH lines and UG cables are considered 19/3.25 (or 4-19/3.25 AA) and 240 mm (or 240mm 4c, or 185 mm), respectively.** For each MV feeder, we considered only one type of conductor for overhead lines and one for underground lines. In reality, distribution networks employ a variety of conductor types based on local conditions, customer requirements, and specific grid needs. The use of a single conductor type does not reflect the diversity and complexity of the actual network infrastructure and may influence the calculated line losses and loading, especially in mixed-configuration feeders.
- **Except for the urban feeder, simplified ADMD values of 2 kW, 3 kW, 1.8 kW and 3.5 kW to validate the developed suburban, rural-short, rural-long and CBD feeders, respectively, have been considered in load flow analysis.** This assumption was necessary due to the lack of detailed customer demand data. While ADMD values are widely used as a proxy for customer demand in power system studies, their simplified nature introduces biases into the results. For example, the variability in customer demand due to seasonal, geographic, or demographic factors is not fully captured.

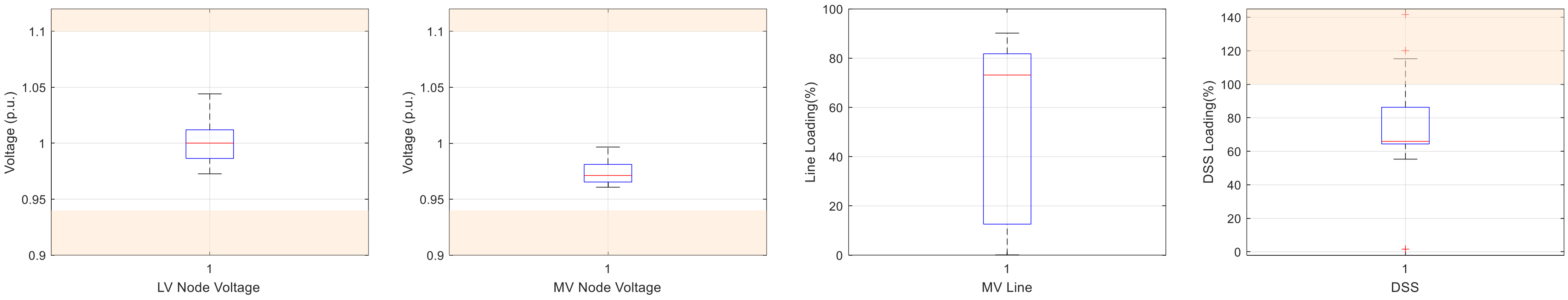
An assessment of the above limitations, using ten different types of actual LV network models (provided by a Victorian DNSP) and equivalent pseudo-LV network models (developed by RMIT using the methodology outlined in this report), will be informed by a subsequent ESP work package to assess the degree of correlation between corresponding “actual” and “pseudo” LV networks for given DER penetration and loading conditions.

	LV node Voltage	MV node Voltage	MV Line Loading	DSS Loading
Urban (SBY32)				
Suburban (WBE013)				
Rural-Short (COO12)				

Rural-long (BAS033)



CBD (VM034)



5. Appendix A: Power Flow Results for Developed MV-LV Models

5.1 Urban Feeder: SBY32 (Sunbury)

The SBY32 MV Feeder is a 22 kV urban feeder connected with the Sunbury Zone Substation that has been acquired from Jemena. It encompasses 48 DSS transformers. As discussed in the Methodology section, the MV feeder was left unaltered, including line impedances, line lengths, DSS transformer details, and the overall topology.

5.1.1 Power Flow Results and Observations

We conducted a base case power flow analysis using the provided ADMD values. Figure 10 illustrates a boxplot of the LV node voltage distribution in p.u. values. The voltages range between approximately 0.984 p.u. and 1.078 p.u., which are represented by the lower and upper whiskers, respectively. The box itself captures the interquartile range (IQR), with the bottom of the box representing the 25th percentile at around 1.019 p.u., and the top of the box indicating the 75th percentile at approximately 1.042 p.u. The red line inside the box denotes the median voltage, which appears to be close to 1.030 p.u. Overall, this distribution shows that most of the LV node voltages remain within acceptable operational limits (within 0.94 p.u. and 1.10 p.u.), with no extreme outliers in this data set.

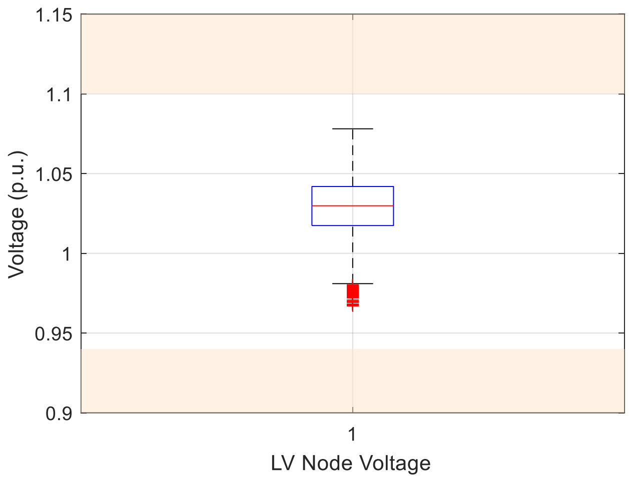


Figure 10: LV Node Voltage Distribution for SBY32.

Figure 11 presents a boxplot of the MV node voltage distribution in p.u. values. The voltages range between approximately 0.995 p.u. and 1.016 p.u., as indicated by the whiskers. The IQR is displayed by the box, where the lower bound represents the 25th percentile voltage around 0.996 p.u., and the upper bound represents the 75th percentile voltage around 1.009 p.u. The red line within the box marks the median voltage, which is close to 0.999 p.u. This figure suggests that the MV node voltages are slightly below the nominal value (1.0 p.u.) but remain within a relatively tight range, with no extreme outliers, reflecting a relatively consistent voltage profile across the MV network, considering the simulated loading conditions.

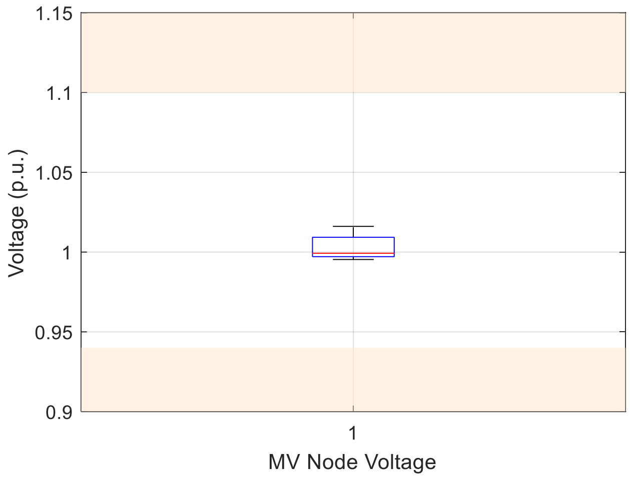


Figure 11: MV Node Voltage Distribution for SBY32

Figure 12 illustrates a boxplot representing the distribution of MV line loading in percentage terms. The line loading ranges from 0% to approximately 100%, as indicated by the whiskers. The IQR, captured by the box, shows that 25% of the lines are loaded at or below roughly 10%, and 75% of the lines are loaded at or below around 50%. The median line loading, represented by the red line inside the box, appears to be around 9%, indicating that the majority of MV lines are operating well below their capacity. This results in due to very specific simulated loading conditions; however, this could highly be unlikely in reality as we considered the worst-case loading conditions.

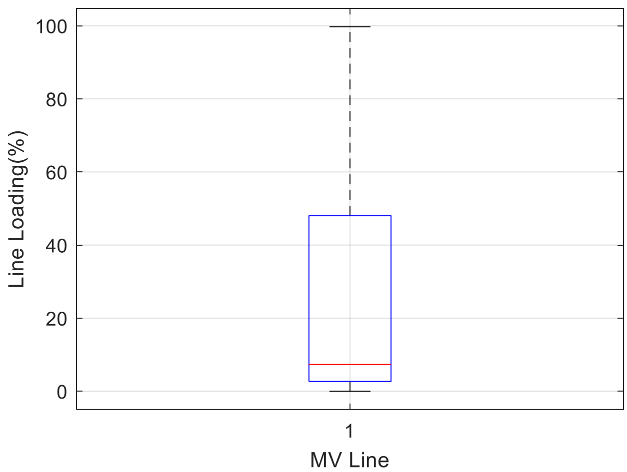


Figure 12: MV Line Loading for SBY32.

Figure 13 shows a boxplot representing the loading of distribution transformers (DSS) as a percentage of their capacity. The DSS loading values range from around 20% to slightly above 120%, as indicated by the whiskers. The box shows that the 25th percentile is approximately 65% loading, and the 75th percentile is around 93% loading. The red line within the box marks the median loading, which appears to be close to 68%. The figure also contains an outlier below 20%, represented by a red cross, indicating a transformer with notably low loading compared to the rest of the dataset.

In conclusion, the load flow results validate that the model is sufficiently representative for use in subsequent work packages. While worst-case loading conditions were considered, leading to some instances of transformer overloading, this aligns with expected feeder behavior under extreme scenarios. Despite not utilizing actual peak loading or load distribution, the transformer loading and network performance align with realistic expectations, confirming the model's suitability for sensitivity analysis and further ESP research.

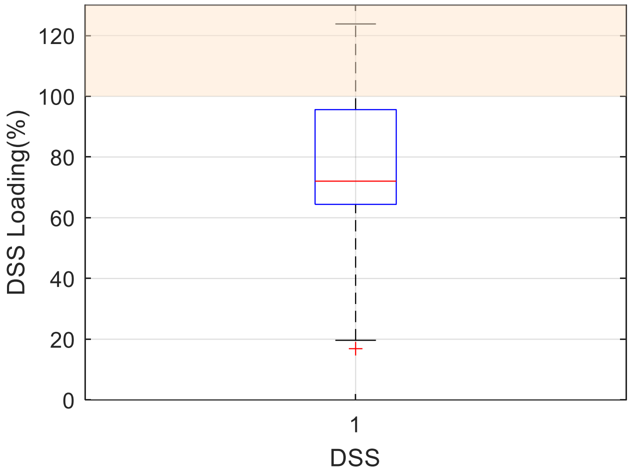


Figure 13: Distribution Transformer Loading for SBY32.

5.2 Suburban Feeder: WBE013 (Werribee)

WBE013 feeder is connected with the Werribee zone substation. It is a 22 kV feeder and is classified as a Suburban type of feeder. This feeder has 253 buses and spreads 33 km long covering Manor Lakes, Werribee, Werribee South, Cocoroc, Wyndham Vale, and Mambourin. There are 71 DSSs with varying capacities between 50 kV to 1000 kV. As discussed in the Methodology section, the MV feeder was left unaltered, including line impedances, line lengths, DSS transformer details, and the overall topology.

5.2.1 Power Flow Results and Observations

We conducted a base case power flow analysis using the provided ADMD values. Figure 14 illustrates a boxplot of the LV node voltage distribution in p.u. values. The voltages range between approximately 1.008 p.u. and 1.09 p.u., which are represented by the lower and upper whiskers, respectively. The box itself captures the IQR, with the bottom of the box representing the 25th percentile at around 1.028 p.u., and the top of the box indicating the 75th percentile at approximately 1.059 p.u. The red line inside the box denotes the median voltage, which appears to be close to 1.05 p.u. Overall, this distribution shows that most of the LV node voltages remain within acceptable operational limits, with no extreme outliers in this data set.

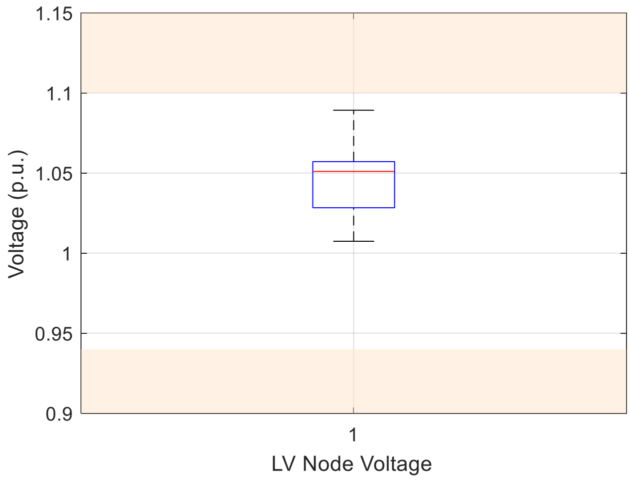


Figure 14: LV Node Voltage Distribution for WBE013.

Figure 15 presents a boxplot of the MV node voltage distribution in p.u. values. The voltages range between approximately 0.96 p.u. and 1.012 p.u., as indicated by the whiskers. The lower bound represents the 25th percentile voltage around 0.975 p.u., and the upper bound represents the 75th percentile voltage around 1.005 p.u. The red line within the box marks the median voltage, which is close to 1.00 p.u. This figure suggests that the MV node voltages remain within a relatively tight range, with no extreme outliers, reflecting a relatively consistent voltage profile across the MV network.

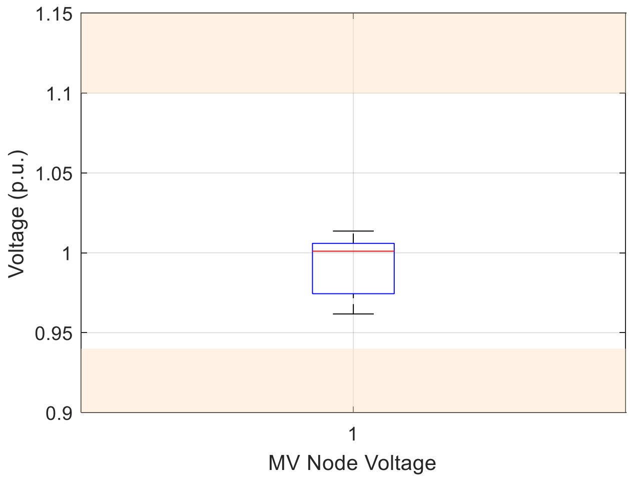


Figure 15: MV Node Voltage Distribution for WBE013.

Figure 16 illustrates a boxplot representing the distribution of MV line loading in percentage terms. The line loading ranges from 0% to approximately 77%, as indicated by the whiskers. The boxplot shows that 25% of the lines are loaded at or below roughly 12%, and 75% of the lines are loaded at or below around 45%. The median line loading, represented by the red line inside the box, appears to be around 21%, indicating that the majority of MV lines are operating well below their capacity based on the simulated loading condition.

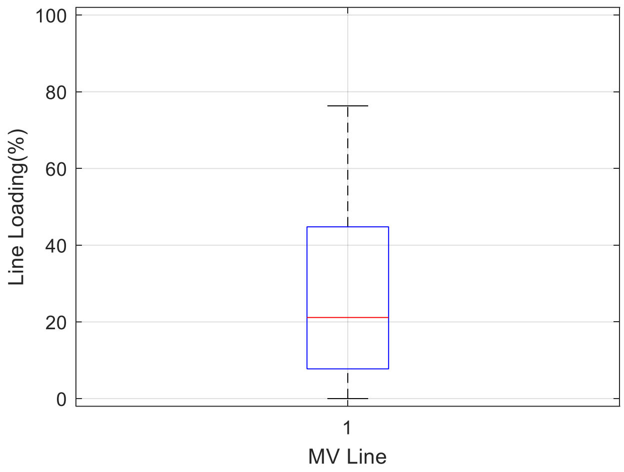


Figure 16: MV Line Loading for WBE013.

Figure 17 shows a boxplot representing the loading of distribution transformers (DSS) as a percentage of their capacity. The DSS loading values range from around 15% to slightly above 120%, as indicated by the whiskers. The box shows that the 25th percentile is approximately 65% loading, and the 75th percentile is slightly above 97% loading. The red line within the box marks the median loading, which appears to be close to 80%.

In conclusion, the load flow results validate that the model is sufficiently representative for use in subsequent work packages. While worst-case loading conditions were considered, leading to some instances of transformer overloading, this aligns with expected feeder behavior under extreme scenarios. Despite not utilizing actual peak loading or load distribution, the transformer loading and network performance align with realistic expectations, confirming the model's suitability for sensitivity analysis and further ESP research.

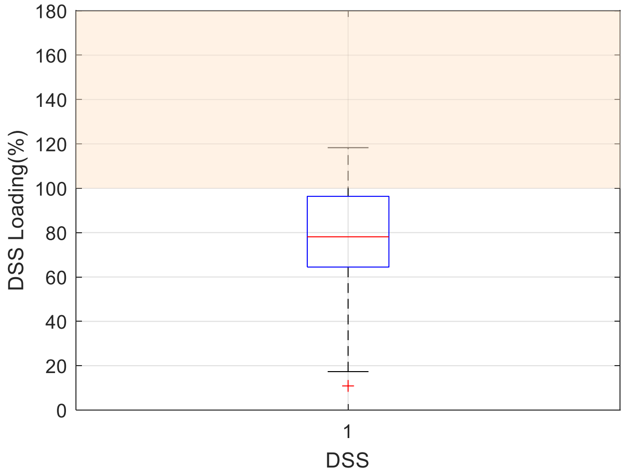


Figure 17: Distribution Transformer Loading for WBE013.

5.3 Rural-short Feeder: COO12 (Coolaroo)

The COO12 MV Feeder is a 22 kV short rural feeder connected with Coolaroo Zone Substation that has been acquired from Jemena. It encompasses 187 distribution substation (DSS) transformers. As discussed in Methodology section, the MV feeder was left unaltered, including line impedances, line lengths, DSS transformer details, and the overall topology.

5.3.1 Power Flow Results and Observations

We conducted a base case power flow analysis using the provided ADMD values. Figure 18 illustrates a boxplot of the LV node voltage distribution in p.u. values. The voltages range between approximately 0.953 p.u. and 1.092 p.u., which are represented by the lower and upper whiskers, respectively. The box itself captures the IQR, with the bottom of the box representing the 25th percentile at around 0.999 p.u., and the top of the box indicating the 75th percentile at approximately 1.051 p.u. The red line inside the box denotes the median voltage, which appears to be close to 1.027 p.u. Overall, this distribution shows that most of the LV node voltages remain within acceptable operational limits, with no extreme outliers in this data set.

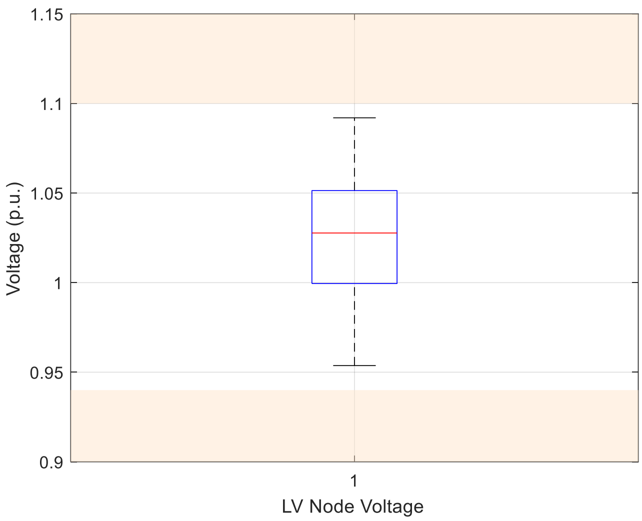


Figure 18: LV Node Voltage Distribution for COO012.

Figure 19 presents a boxplot of the MV node voltage distribution in p.u. values. The voltages range between approximately 0.940 p.u. and slightly above 1.079 p.u., as indicated by the whiskers. The lower bound represents the 25th percentile voltage around 0.978 p.u., and the upper bound represents the 75th percentile voltage around 1.045 p.u. The red line within the box marks the median voltage, which is close to 1.029 p.u. Considering the simulated loading, this figure suggests that the MV node voltages remain within a relatively tight range, with no extreme outliers, reflecting a relatively consistent voltage profile across the MV network.

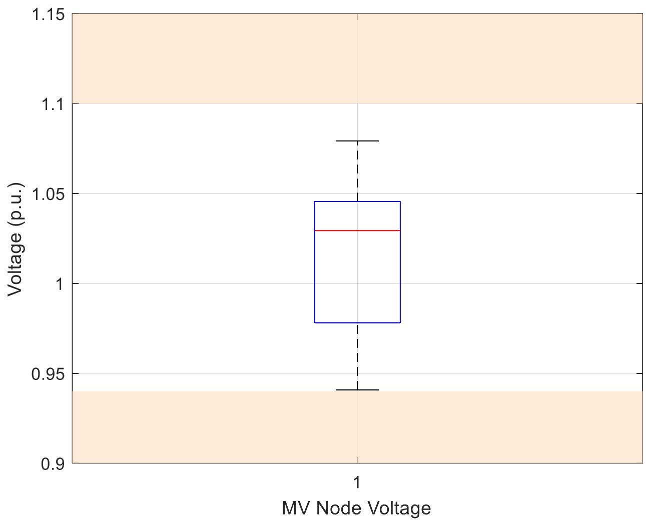


Figure 19: MV Node Voltage Distribution for COO012.

Figure 20 illustrates a boxplot representing the distribution of MV line loading in percentage terms. The line loading ranges from 1% to approximately 16.5%, as indicated by the whiskers. The boxplot shows that 25% of the lines are loaded at or below roughly 1.2%, and 75% of the lines are loaded at or below around 7%. The median line loading, represented by the red line inside the box, appears to be around 1.6%, indicating that the majority of MV lines are operating well below their capacity based on the simulated loading condition.

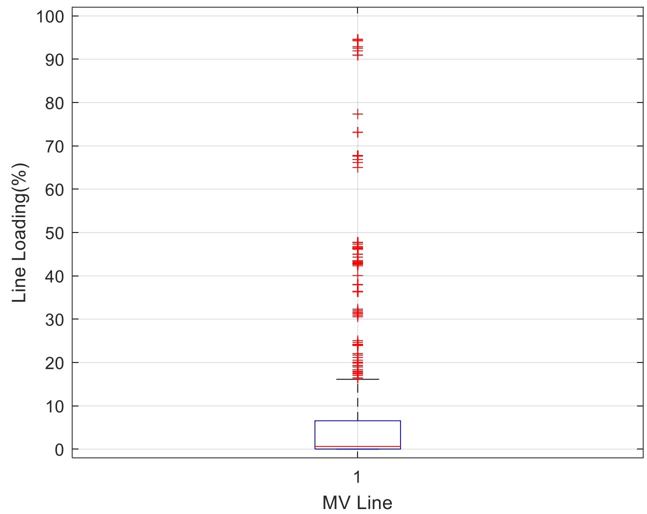


Figure 20: MV Line Loading for COO012.

Figure 21 shows a boxplot representing the loading of distribution transformers (DSS) as a percentage of their capacity. The DSS loading values range from around 5% to slightly above 100%, as indicated by the whiskers. The box shows that the 25th percentile is approximately 13% loading, and the 75th percentile is approximately 60% loading. The red line within the box marks the median loading, which appears to be close to 32%.

In conclusion, the load flow results validate that the model is sufficiently representative for use in subsequent work packages. While worst-case loading conditions were considered, leading to some instances of transformer overloading, this aligns with expected feeder behavior under extreme scenarios. Despite not utilizing actual peak loading or load distribution, the transformer loading and network performance align with realistic expectations, confirming the model's suitability for sensitivity analysis and further ESP research.

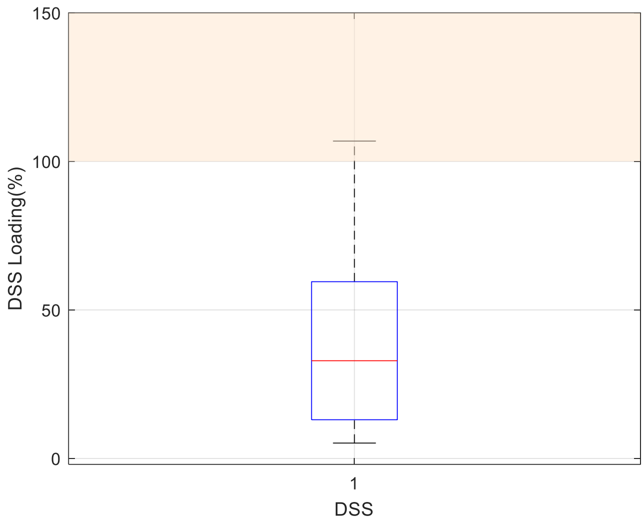


Figure 21: Distribution Transformer Loading for COO012.

5.4 Rural-long Feeder: BAS033 (Ballarat South)

The BAS033 MV Feeder is a 22 kV rural-long feeder connected with Ballarat South zone Substation that has been acquired from CitiPower and Powercor. It encompasses 877 distribution substation (DSS) transformers. As discussed in the Methodology section, the MV feeder was left unaltered, including line impedances, line lengths, DSS transformer details, and the overall topology.

5.4.1 Power Flow Results and Observations

Figure 22 displays a boxplot of the LV node voltage distribution in p.u. values. The voltages range between approximately 0.947 p.u. and 1.075 p.u., as shown by the lower and upper whiskers, respectively. The box indicates that the 25th percentile voltage is approximately 1.005 p.u., and the 75th percentile voltage is around 1.045 p.u. The red line inside the box represents the median voltage, which is close to 1.02 p.u. This plot shows that the majority of LV node voltages are below the acceptable voltage (0.94 p.u.), with a significant spread from 0.94 p.u. to 1.1 p.u.

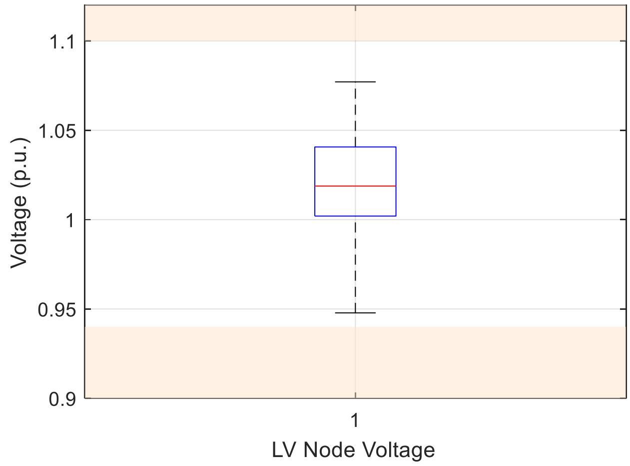


Figure 22: LV Node Voltage Distribution for BAS033.

Figure 23 illustrates a boxplot of the MV node voltage distribution in p.u. values. The voltage ranges between approximately 0.947 p.u. and 1.072 p.u. The box shows that the 25th percentile voltage is approximately 0.985 p.u., and the 75th percentile voltage is around 1.0299 p.u. The median voltage, indicated by the red line within the box, is close to 1.00 p.u. This distribution highlights the need for potential voltage regulation in the MV network to ensure consistent and reliable voltage delivery across all nodes.

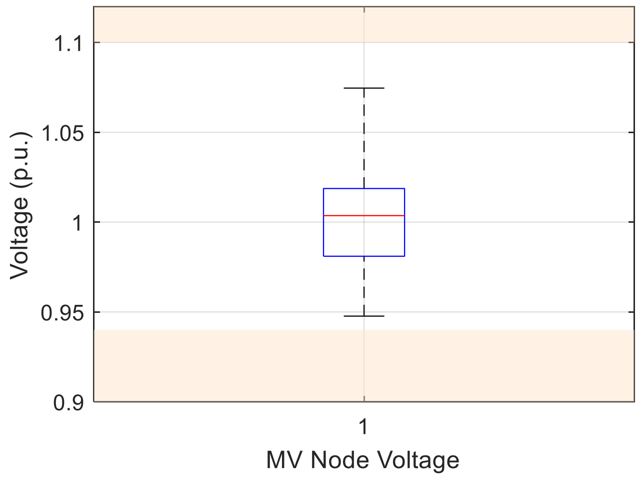


Figure 23: MV Node Voltage Distribution for BAS033.

Figure 24 presents a boxplot depicting the distribution of MV line loading as a percentage of capacity. The line loadings range from 0% to over 28.5%, with the main portion of the data concentrated between 0.5% and 15%, as indicated by the box and whiskers. The box shows that the 25th percentile line loading is approximately 0.5%, while the 75th percentile line loading is about 15%. The median loading, shown by the red line inside the box, is around 6%.

There are numerous outliers, represented by red crosses, extending well beyond 30%. The overall distribution suggests that while the majority of MV lines are operating at relatively low levels of loading, a small subset is experiencing considerable stress, considering the simulated loading condition. While the study does not use the actual peak loading or load distribution for this feeder, the distribution of line loading aligns with realistic expectations, confirming that the model can effectively support further research in the ESP project.

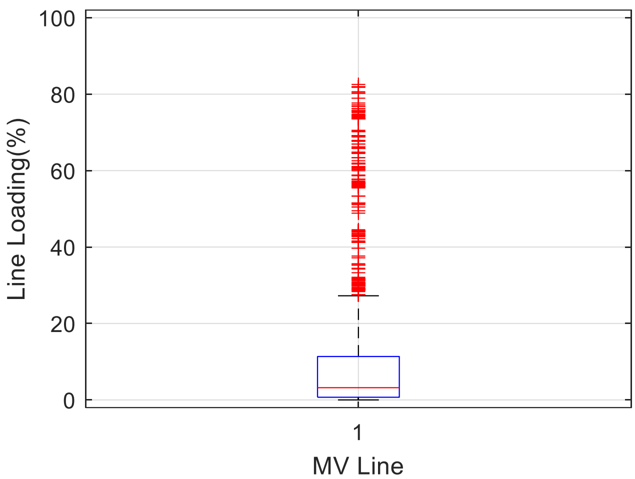


Figure 24: MV Line Loading for BAS033.

Figure 25 presents a boxplot depicting the loading of distribution transformers (DSS) as a percentage of their capacity. The DSS loading values range from around 10% to slightly above 140%, as indicated by the whiskers. The box shows that the 25th percentile is approximately 15% loading, and the 75th percentile is slightly above 60% loading. The red line within the box marks the median loading, which appears to be close to 32%.

In conclusion, the load flow results validate that the model is sufficiently representative for use in subsequent work packages. While worst-case loading conditions were considered, leading to some instances of transformer overloading, this aligns with expected feeder behavior under extreme scenarios. Despite not utilizing actual peak loading or load distribution, the transformer loading and network performance align with realistic expectations, confirming the model's suitability for sensitivity analysis and further ESP research.

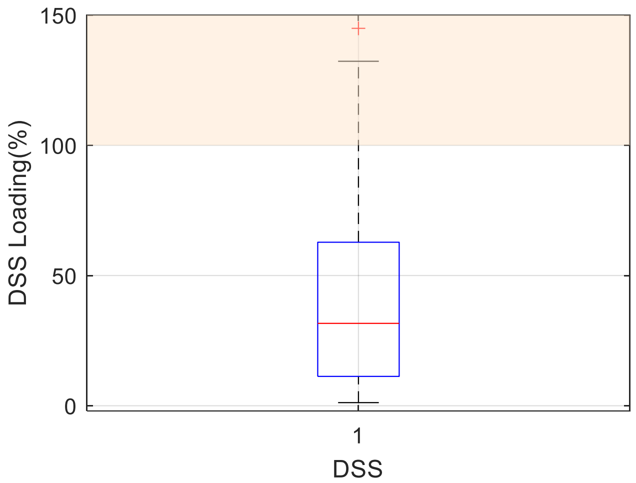


Figure 25: Distribution Transformer Loading for BAS033.

5.5 CBD Feeder: VM034 (Victoria Market)

The VM034 MV Feeder is an 11 kV CBD feeder connected with the Victoria Market Zone Substation that has been acquired from CitiPower, Powercor and United Energy. It encompasses 15 distribution substation (DSS) transformers. As discussed in the Methodology section, the MV feeder was left unaltered, including line impedances, line lengths, DSS transformer details, and the overall topology.

5.5.1 Power Flow Results and Observations

We conducted a base case power flow analysis using the provided ADMD values. Figure 26 illustrates a boxplot of the LV node voltage distribution in p.u. values. The voltages range between approximately 0.977 p.u. and 1.042 p.u., which are represented by the lower and upper whiskers, respectively. The box represents the 25th percentile at around 0.985 p.u., and the top of the box indicates the 75th percentile at approximately 1.016 p.u. The red line inside the box denotes the median voltage, which appears to be close to 1.005 p.u. Overall, this distribution shows that most of the LV node voltages remain within acceptable operational limits, with no extreme outliers in this data set.

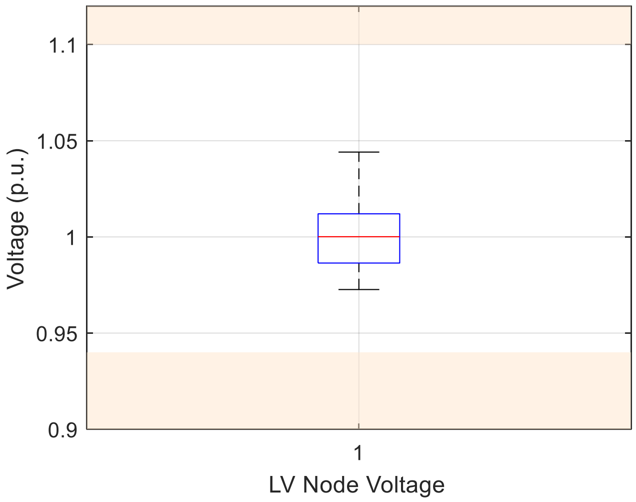


Figure 26: LV Node Voltage Distribution for VM034.

Figure 27 presents a boxplot of the MV node voltage distribution in p.u. values. The voltages range between approximately 0.961 p.u. and 0.996 p.u., as indicated by the whiskers. The lower bound of the box represents the 25th percentile voltage around 0.965 p.u., and the upper bound represents the 75th percentile voltage around 0.981 p.u. The red line within the box marks the median voltage, which is close to 0.972 p.u. This figure suggests that the MV node voltages are slightly below the nominal value (1.0 p.u.) but remain within a relatively tight range, with no extreme outliers, reflecting a relatively consistent voltage profile across the MV network.

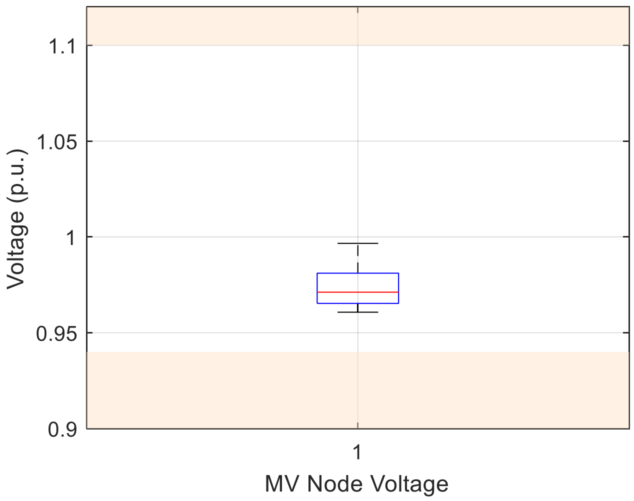


Figure 27: MV Node Voltage Distribution for VM034.

Figure 28 illustrates a boxplot representing the distribution of MV line loading in percentage terms. The line loading ranges from 0% to approximately 90%, as indicated by the whiskers. The box shows that 25% of the lines are loaded at or below roughly 20%, and 75% of the lines are loaded at or below around 80%. The median line loading, represented by the red line inside the box, appears to be around 76%, indicating that the majority of MV lines are operating well below their capacity based on the simulated loading condition.

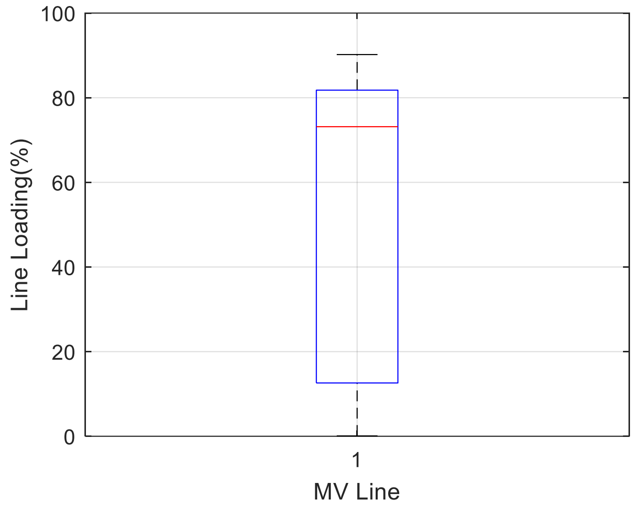


Figure 28: MV Line Loading for VM034.

Figure 29 shows a boxplot representing the loading of DSS transformers as a percentage of their capacity. The DSS loading values range from around 55% to slightly below 115%, as indicated by the whiskers. The box shows that the 25th percentile is approximately 64% loading, and the 75th percentile is around 90% loading. The red line within the box marks the median loading, which appears to be close to 65%. The figure also contains an outlier below 5%, represented by a red cross, indicating a transformer with notably low loading compared to the rest of the dataset.

In conclusion, the load flow results validate that the model is sufficiently representative for use in subsequent work packages. While worst-case loading conditions were considered, leading to some instances of transformer overloading, this aligns with expected feeder behavior under extreme scenarios. Despite not utilizing actual peak loading or load distribution, the transformer loading and network performance align with realistic expectations, confirming the model's suitability for sensitivity analysis and further ESP research.

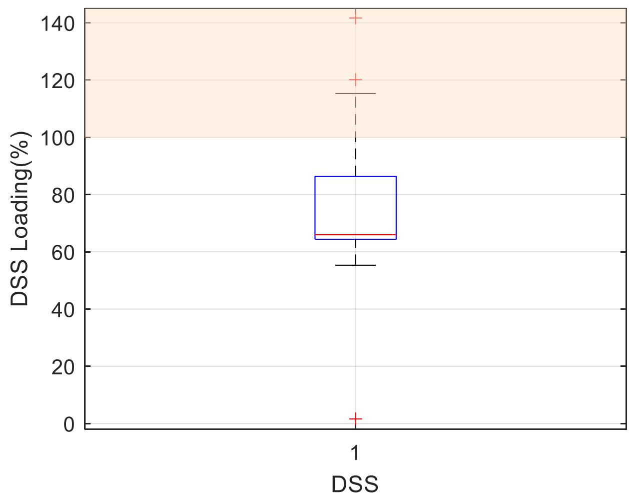


Figure 29: Distribution Transformer Loading for VM034.

6. Appendix B: Power Flow Results and Comparison: Actual and Pseudo LV Models

The results below present a detailed comparison of key power flow metrics—phase voltages, line losses, transformer losses, and the percentage of total losses—between the actual and synthetic LV models developed in OpenDSS.

It is observed that the line loss in the pseudo model is less due to the consideration of C&I customers being connected to the DSS. Similarly, the voltage profiles are affected by the same reason and this trend is consistent in all LV models.

<table>
<tr><th></th><th>Actual Model</th><th>Pseudo Model</th></tr>
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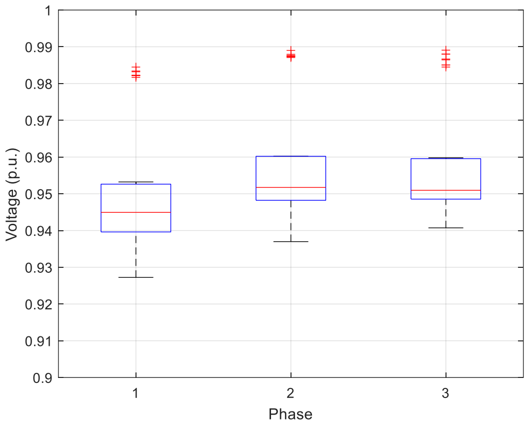
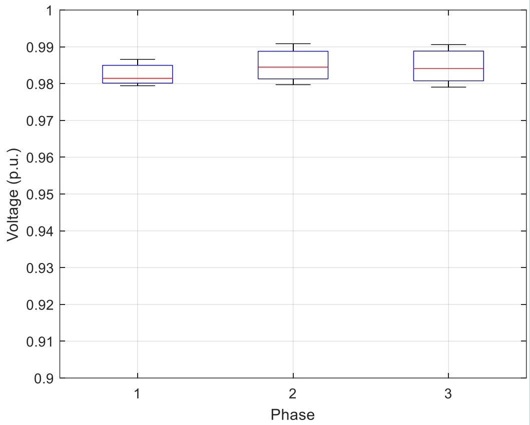
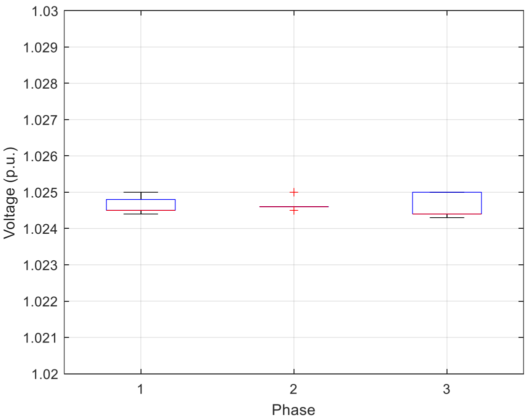
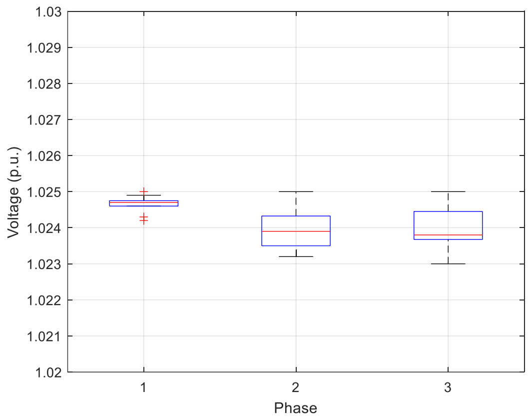
(residential customer 22 and C&I customer 2)</td><td>
</td><td>
</td></tr>
<tr><td>LINE LOSSES= 2.1 kW
TRANSFORMER LOSSES= 2.1 kW

TOTAL LOSSES= 4.3 kW

TOTAL LOAD POWER = 59.6 kW
Percent Losses for Circuit = 7.17 %</td><td>LINE LOSSES= 0.2 kW
TRANSFORMER LOSSES= 2.0 kW

TOTAL LOSSES= 2.2 kW

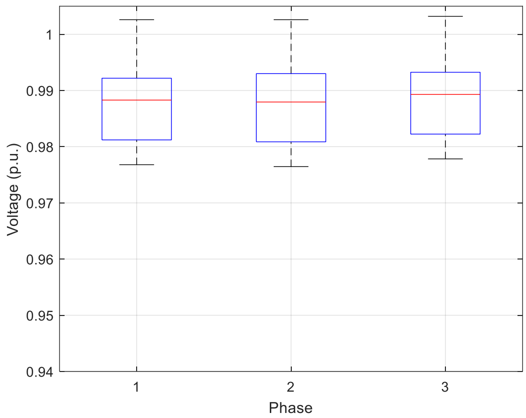
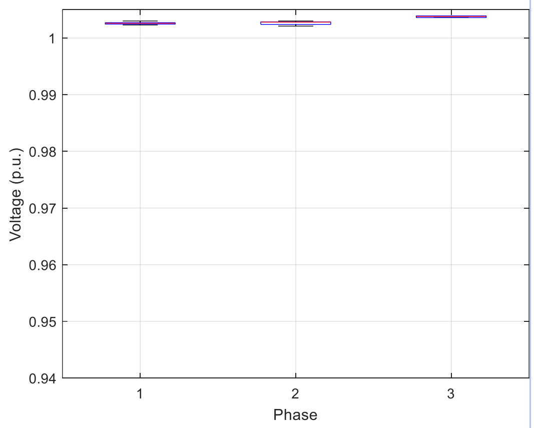
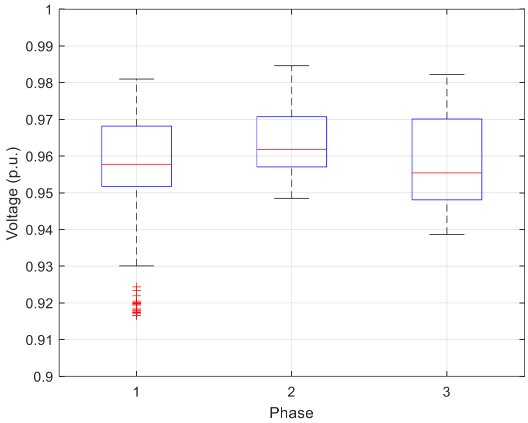
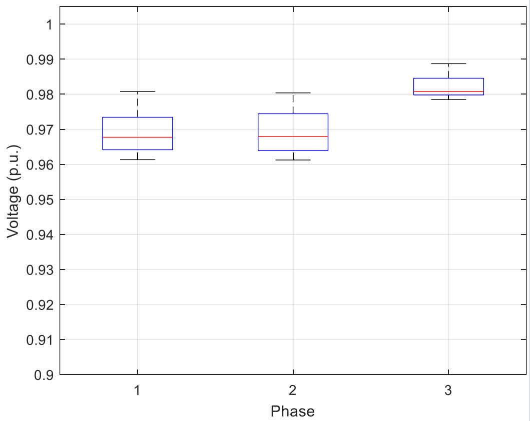
TOTAL LOAD POWER = 59.6 kW
Percent Losses for Circuit = 3.64 %</td></tr>
<tr><td rowspan="2">Model 2
(residential customer 6)</td><td>
</td><td>
</td></tr>
<tr><td>LINE LOSSES= 0.0 kW
TRANSFORMER LOSSES= 0.1 kW

TOTAL LOSSES= 0.2 kW

TOTAL LOAD POWER = 10.8 kW
Percent Losses for Circuit = 1.43 %</td><td>LINE LOSSES= 0.0 kW
TRANSFORMER LOSSES= 0.1 kW

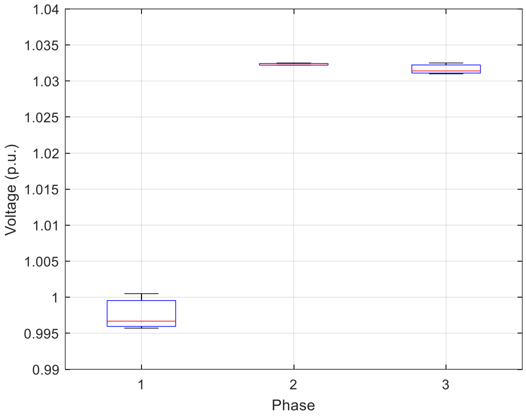
TOTAL LOSSES= 0.2 kW

TOTAL LOAD POWER = 10.8 kW
Percent Losses for Circuit = 1.47 %</td></tr>
</table>

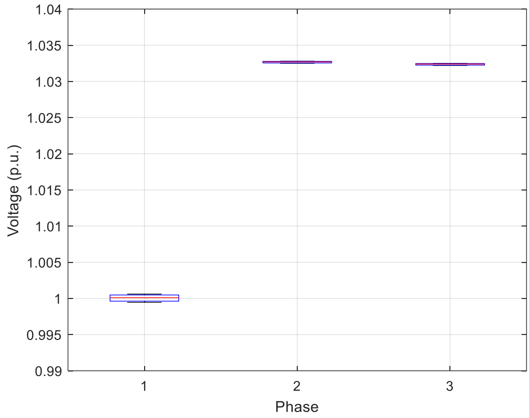
Model 3 (residential customer 2 and C&I customer 14)	 LINE LOSSES= 3.7 kW TRANSFORMER LOSSES= 6.1 kW TOTAL LOSSES= 9.7 kW TOTAL LOAD POWER = 255.6 kW Percent Losses for Circuit = 3.81 %	 LINE LOSSES= 0.0 kW TRANSFORMER LOSSES= 5.9 kW TOTAL LOSSES= 5.9 kW TOTAL LOAD POWER = 255.6 kW Percent Losses for Circuit = 2.31 %
Model 4 (residential customer 131 and C&I customer 2)	 LINE LOSSES= 10.7 kW TRANSFORMER LOSSES= 15.9 kW TOTAL LOSSES= 26.6 kW TOTAL LOAD POWER = 413.0 kW Percent Losses for Circuit = 6.44 %	 LINE LOSSES= 4.2 kW TRANSFORMER LOSSES= 15.5 kW TOTAL LOSSES= 19.7 kW TOTAL LOAD POWER = 413.0 kW Percent Losses for Circuit = 4.76 %

Model 5

(residential customer 1)



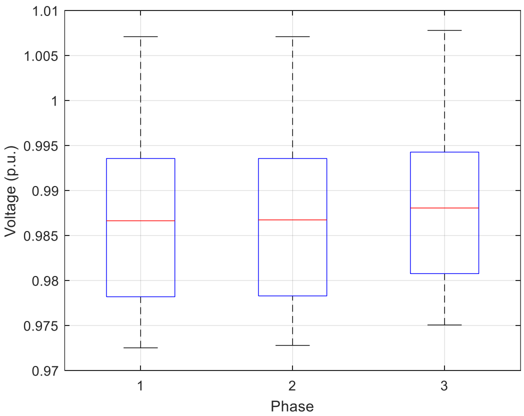

```
LINE LOSSES=                          0.0 kW
TRANSFORMER LOSSES=                   0.1 kW

TOTAL LOSSES=                         0.1 kW

TOTAL LOAD POWER =                    3.0 kW
Percent Losses for Circuit =      3.43 %
```



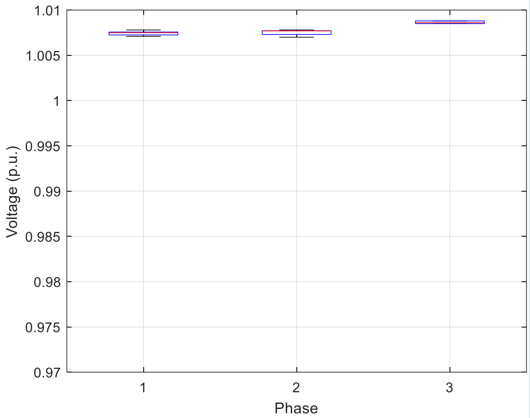

```
LINE LOSSES=                          0.0 kW
TRANSFORMER LOSSES=                   0.1 kW

TOTAL LOSSES=                         0.1 kW

TOTAL LOAD POWER =                    3.0 kW
Percent Losses for Circuit =      3.04 %
```

Model 6

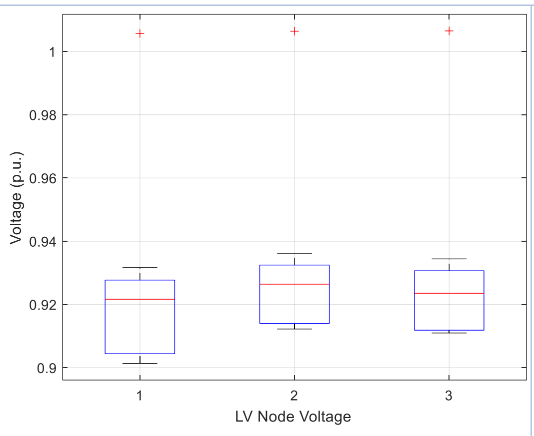
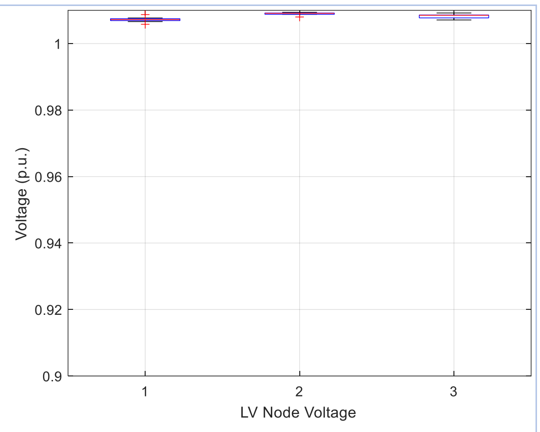
(residential customer 2 and C&I customer 14)




```
LINE LOSSES=                          3.9 kW
TRANSFORMER LOSSES=                   6.1 kW

TOTAL LOSSES=                        10.0 kW

TOTAL LOAD POWER =                  255.6 kW
Percent Losses for Circuit =      3.92 %
```



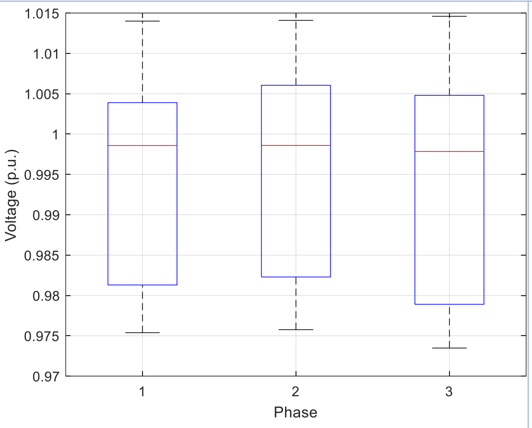
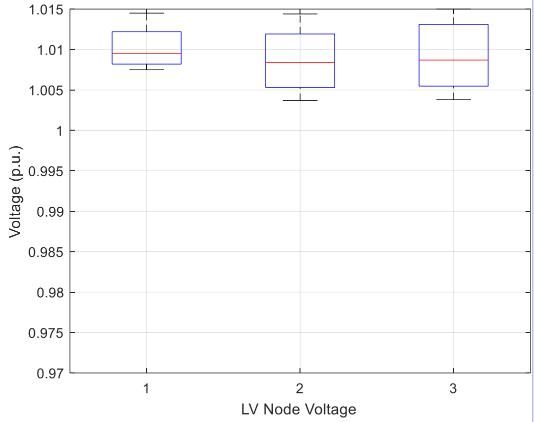

```
LINE LOSSES=                          0.0 kW
TRANSFORMER LOSSES=                   5.9 kW

TOTAL LOSSES=                         5.9 kW

TOTAL LOAD POWER =                  255.6 kW
Percent Losses for Circuit =      2.31 %
```

<table>
<tr>
<td rowspan="2">Model 7
(residential customer 4 and C&I customer 5)</td>
<td>
</td>
<td>
</td>
</tr>
<tr>
<td>LINE LOSSES= 37.6 kW
TRANSFORMER LOSSES= 12.9 kW

TOTAL LOSSES= 50.5 kW

TOTAL LOAD POWER = 614.0 kW
Percent Losses for Circuit = 8.23 %</td>
<td>LINE LOSSES= 0.0 kW
TRANSFORMER LOSSES= 11.5 kW

TOTAL LOSSES= 11.5 kW

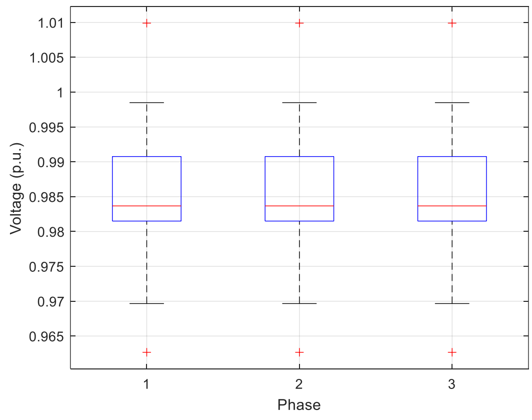
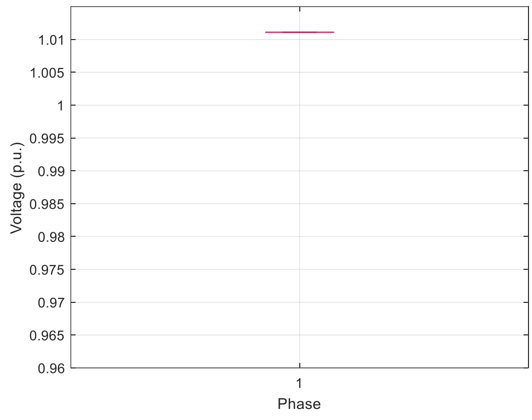
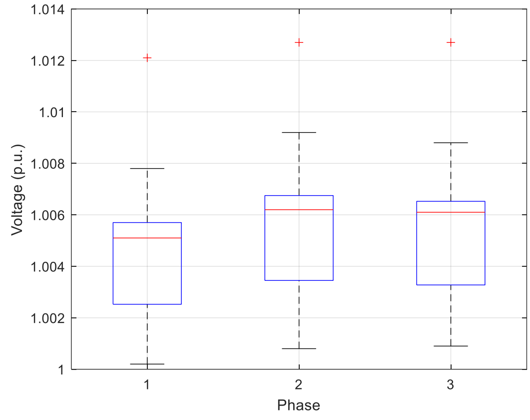
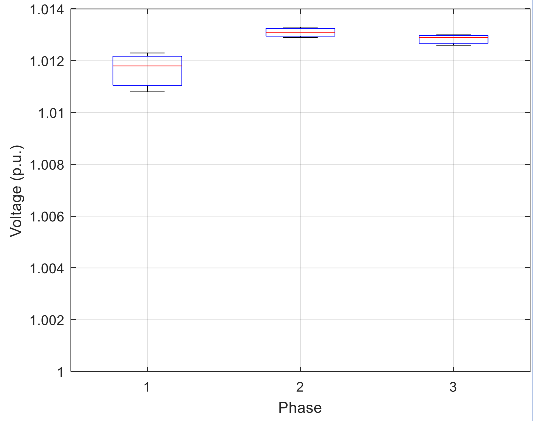
TOTAL LOAD POWER = 614.0 kW
Percent Losses for Circuit = 1.87 %</td>
</tr>
<tr>
<td rowspan="2">Model 8
(residential customer 44 and C&I customer 15)</td>
<td>
</td>
<td>
</td>
</tr>
<tr>
<td>LINE LOSSES= 4.3 kW
TRANSFORMER LOSSES= 3.9 kW

TOTAL LOSSES= 8.2 kW

TOTAL LOAD POWER = 199.2 kW
Percent Losses for Circuit = 4.11 %</td>
<td>LINE LOSSES= 0.3 kW
TRANSFORMER LOSSES= 3.8 kW

TOTAL LOSSES= 4.1 kW

TOTAL LOAD POWER = 199.2 kW
Percent Losses for Circuit = 2.07 %</td>
</tr>
</table>

Model 9 (C&I customer 24)		
	LINE LOSSES= 8.4 kW TRANSFORMER LOSSES= 7.9 kW TOTAL LOSSES= 16.3 kW TOTAL LOAD POWER = 360.0 kW Percent Losses for Circuit = 4.53 %	LINE LOSSES= 0.0 kW TRANSFORMER LOSSES= 7.5 kW TOTAL LOSSES= 7.5 kW TOTAL LOAD POWER = 360.0 kW Percent Losses for Circuit = 2.09 %
Model 10 (residential customer 1 and C&I customer 9)		
	LINE LOSSES= 2.5 kW TRANSFORMER LOSSES= 4.7 kW TOTAL LOSSES= 7.2 kW TOTAL LOAD POWER = 273.0 kW Percent Losses for Circuit = 2.65 %	LINE LOSSES= 0.0 kW TRANSFORMER LOSSES= 4.7 kW TOTAL LOSSES= 4.7 kW TOTAL LOAD POWER = 273.0 kW Percent Losses for Circuit = 1.71 %