



NBI-Stage 3: Yea Community Battery Business Plan Development

FINAL REPORT: YEA NETWORK ANALYSIS AND BATTERY SIZING
STUDIES

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MAY 2024

Indigo Power



Executive Summary

The Victorian State Government launched the Neighbourhood Battery Initiative (NBI) in 2021 to fund neighbourhood-scale battery pilots, trials, and demonstration projects across Victoria. The proposal led by Indigo Power in partnership with the RMIT University and the 2030Yea Community Energy group received the NBI Stage 3 funding to develop a business plan for a battery system in Yea. As part of this project, the RMIT conducted the technical feasibility assessment by constructing a detailed power flow model for the Yea covering the geographical area of seven potential battery sites. This report details the technical feasibility study carried out by the RMIT team, including the key outcomes and recommendations.

The study team extracted the network and operational data from the AusNet GridView portal and developed a power-flow model for the Yea. The missing operational data is synthesised using a scientific methodology and the best possible information available to the study team. The model is validated via several power-flow case studies and is in close agreement with the operational data published in the AusNet distribution planning report. In particular, the model agrees well with the feeder loading and voltage levels reported in the AusNet distribution planning report.

The study team has also analysed the net load data extracted from transformers to understand the net load behaviour across various seasons by producing average seasonal net load profiles. The average seasonal net load profiles indicate three sets of demand peaks: 1) 12 pm demand peak, 2) 7 pm demand peak, and 3) 1 am demand peak (due to pre-set electric hot water systems). Moreover, the study team has analysed the seasonal solar-PV self-consumption for each transformer in the model to determine the proportion of solar-PV energy consumed by consumers connected to each transformer. It has indicated significant self-consumption variation across four seasons. The study indicates a significant self-consumption across potential battery sites in Yea.

The hosting capacity is analysed for five potential battery sites, and two sites are ignored due to the unavailability of data. Only four potential battery sites are selected to proceed with the battery system sizing study due to the low hosting capacity of one battery site. The four battery sites indicated substantial potential to host a battery system, and the future potential is also analysed using forecasted net load profiles. The study conducted into the future timeframes has indicated the potential to upgrade battery size in future. Moreover, the study quantified the network benefits of installing a battery system in Yea. The benefits, such as deferring potential network upgrades and better voltage management, are highlighted in this study report. These benefits would also benefit the Yea community as these technical improvements will improve the reliability of the Yea electricity network (e.g. reduce potential outages in future).

The islanding study is conducted for two battery sites in Yea (Yea Railway Park and Yea Industrial Area) and has shown that islanding can be achievable with additional solar-PV in the site with a battery inverter rated at the total hosting capacity of each site. However, further studies are required on islanded operation for these sites, particularly to assess the operational constraints and procedures.

In summary, among the four viable battery sites, the Yea Railway Park and the Yea Recreation Reserve are deemed to be the two most suitable sites to host neighbourhood batteries in Yea. The Yea Railway Park has the following special attributes to suit as one of the two best sites for the neighbourhood battery:

- The electricity network infrastructure is easily accessible to the site, and the proposed battery can be directly connected to the Station Miller (200 kVA) transformer.
- The Station Miller (200 kVA) transformer has average seasonal load variations of 20 – 41%, allowing sufficient headroom to host a battery system.

- The solar-PV generation associated with the Station Miller (200 kVA) transformer varies between 860 – 315 kWh per average day from summer to winter, indicating a strong PV generation to charge the battery from the local generation. More specifically, an average Summer, Autumn and Spring day generates over 500 kWh. Therefore, it is feasible to have a 508 kWh battery on the site as per the energy analytics study.
- The Station Miller transformer has a hosting capacity of 140 kW, and with a 140 kW/ 508 kWh battery system, it can be charged and discharged within a 4-hour time span.
- The Station Miller Transformer serves one of the critical infrastructures in Yea (Yea & District Memorial Hospital) and other medical facilities in the area, including elderly homes. Therefore, constructing a neighbourhood battery at this site would help create a microgrid in the future to serve these critical loads in case of a main grid outage.
- The islanding study also confirmed the technical viability of this site to operate as a microgrid. The energy balance can be achieved with an additional 150 kW solar PV (likely in the future) connected to the Station Miller transformer.
- Hosting a neighbourhood battery (140 kW/ 508 kWh) at the Yea Railway Park would help to improve the LV voltage in the range of 5 – 8%, and also will help reduce the main incoming feeder (SMR 14) peak load by 2.4%.

The Yea Recreation Reserve has the following special attributes to suit as one of the two best sites for the neighbourhood battery;

- The Yea Recreation Reserve has its own solar-PV generation (22 kW); hence, this site is also suitable for a behind-the-meter battery system.
- The Yea Recreation Reserve is fed by the Pechell Snodgrass (500 kVA) transformer, and it has average seasonal load variations of 21 – 46%, allowing sufficient headroom to host a battery system.
- The solar-PV generation associated with the Station Miller (200 kVA) transformer varies between 270 – 738 kWh per average seasonal day from summer to winter, indicating a strong PV generation to charge the battery from the local generation if constructed as a front-of-the-meter battery system. More specifically, an average Summer, Autumn and Spring day generates over 450 kWh.
- If the supply cable can be upgraded, the site can host a 200 kW/ 387 kWh battery system. Also, considering the future PV potential, there is a greater potential to upgrade the battery in future.
- Hosting a neighbourhood battery (200 kW/ 387 kWh) at the Yea Recreation Reserve would help to improve the LV voltage in the range of 3 – 8%, and also will help reduce the main incoming feeder (SMR 14) peak load by 3%.

The RMIT microgrid team produced this progress report for NBI-Stage 3: Yea Community Battery Business Plan Development Project.

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Table of Contents

Executive Summary	i
Table of Contents	iii
Table of Figures	iv
Table of Tables	vi
Acronyms and Terms	vii
1. Introduction.....	1
1.1. Objectives and Study Scope	1
2. Yea Current and Future Renewable Energy Potential.....	2
2.1. General Overview of Yea	2
3. Potential Battery Sites	4
3.1. Summary of Electrical Infrastructure at Each Battery Site	5
4. Project Methodology	6
5. Yea Electricity Network Modelling.....	8
5.1. Yea Electricity Supply Network	8
5.2. Modelling Approach and Data Source	8
5.3. Network Simulation Models.....	10
5.4. Net Load and Solar-PV Data Extraction	12
5.5. Network Base Operating Scenario and Initial Results	13
5.6. Findings from Network Model Assessment.....	15
6. Network Operational Data Analytics and Data Forecasting.....	16
6.1. Net Load Profile Segmentation	16
7. Hosting Capacity Analysis and BESS Sizing for Potential Battery Sites	22
7.1.1. Key Assumptions and Limitations:.....	22
7.1.2. Battery Hosting Capacity of Yea Railway Park.....	23
7.1.3. Battery Hosting Capacity of Yea Industrial Area	23
7.1.4. Battery Hosting Capacity of Yea Swimming Pool.....	24
7.1.5. Battery Hosting Capacity of Yea Recreation Reserve.....	24
7.1.6. Battery Hosting Capacity of Yea Saleyard	25
7.1.7. Battery Hosting Capacity of Yea Racecourse/Golf Club and Wastewater Management Plant.....	25
7.1.8. Summary of Sites Battery Hosting Capacity	26
7.3.1 Sizing based on Current Demand and PV Generation Profiles.....	29
8. Islanded Operation.....	31
8.1. Yea Railway Park.....	31
8.2. Yea Industrial Area.....	32
9. BESS Support Services and Benefits	33
9.1. Impact on Network Voltage	33
9.2. Impact on Supply Incoming Feeder Loading	34
9.3. Frequency control ancillary services from BESS.....	35
10. Study Recommendations	36
Appendix-A: Electrical Infrastructure in Potential Battery Sites	37
Appendix-B: Transformer Rating and Installed Solar-PV Capacity	44
Appendix-C: Model Validation and Results.....	45
Appendix-D: Average Net Load Profiles of Highly Rated Transformers in Yea Residential Area	54
Appendix-E: Average Net Load Profiles of Highly Rated Transformers in Yea Residential Area	54

Table of Figures

Figure 1. The Australian Bureau of Statistics remoteness classification for Yea.	2
Figure 2. Average monthly solar exposure in Yea.	2
Figure 3. Cumulative installed solar PV capacity of Yea.	3
Figure 4. Geographical locations of the potential battery sites.	4
Figure 5. Network modelling and battery sizing methodology.	6
Figure 6. Seymour ZSS SMR14 feeder supplying Yea and neighbourhood.	8
Figure 7. A representative single-line diagram shows the details of the SMR14 feeder and substations.	9
Figure 8. SMR14 feeder complete model.	11
Figure 9. Substation model for behind-the-meter battery sites – Yea Industrial Area and Yea Railway Park.	12
Figure 10. Substation model for front-of-the-meter battery sites.	12
Figure 11. Netload profile of Giffard Snodgrass Distribution Substation.	12
Figure 12. Quasi-dynamic simulation results with 24-hour net load profiles during summer.	14
Figure 13. Average seasonal net load profiles of potential battery sites.	17
Figure 14. The average summer net load profile for several highly rated transformers in residential areas in Yea.	18
Figure 15. The forecasted net load profiles for the transformers associated with four battery sites for the summer.	21
Figure 16. Simulation results showing seasons averaged load profiles for Yea Railway Park with allowable charge and discharge capacities of battery under worst and likely scenarios.	23
Figure 17. Simulation results showing seasons averaged load profiles for Yea Industrial Area with allowable charge and discharge capacities of battery under worst and likely scenarios.	23
Figure 18. Simulation results showing seasons averaged load profiles for Yea Swimming Pool (top two plots) and Transformer serving swimming pool (bottom two plots), with allowable charge and discharge capacities of battery under worst and likely scenarios.	24
Figure 19. Simulation results showing seasons averaged load profiles for Yea Recreation Reserve (top two plots) and Transformer serving Recreation Reserve (bottom two plots), with allowable charge and discharge capacities of battery under worst and likely scenarios.	25
Figure 20. Simulation results showing seasons averaged load profiles for Yea Saleyard Transformer.	25
Figure 21. Simulation results showing net load of supply incoming feeder SMR14 after 5 years and 10 years.	26
Figure 22. Simulation results showing time-constrained operational ratings of BESS based on transformer loading (a) Yea Railway Park (b) Yea Industrial Area (c). Yea Swimming Pool and (d). Yea Recreation Reserve.	27
Figure 23. Battery sizing methodology.	28
Figure 24. Transformers considered for Yea Railway Park battery sizing under Method-2 and 3.	29
Figure 25. Yea Railway network considered for islanded operation (a) Geographical boundary (b). Simulation model.	31
Figure 26. Simulation result showing (a) power balance during islanded operation (b). network voltage during grid-connected operation and islanded operation of Yea Industrial Area.	31
Figure 27. Yea industrial area network considered for islanded operation (a) Geographical boundary (b). Simulation model.	32
Figure 28. Simulation results showing (a) power balance during islanded operation (b). network voltage during grid-connected operation and Islanded operation of Yea Industrial Area.	32
Figure 29. Simulation results showing network voltage at different terminals with and without battery and summary of voltage improvement for (a). Yea Railway Park, (b). Yea Industrial Area, (c). Yea Swimming Pool, (d). Yea Recreation Reserve.	34
Figure 30. Simulation results showing loading (kW in top plot and % in bottom plot) of supply incoming feeder SMR14 without and with battery at each potential site.	35
Figure 31. Voltage magnitudes (in pu) of the transformers' primary side under Scenario 1.	45
Figure 32. Voltage magnitudes (in pu) of the transformers' secondary side under Scenario 1.	46
Figure 33. Voltage unbalance factor (VUF) at the MV side of the transformer under Scenario 1.	46
Figure 34. Voltage unbalance factor (VUF) at the LV side of the transformer under Scenario 1.	47
Figure 35. Loading % of the transformers under Scenario 1.	47
Figure 36. Loading % of the distribution feeders under Scenario 1.	47

Figure 37. Voltage magnitudes (in pu) of the primary side of the transformers under Scenario 2.	48
Figure 38. Voltage magnitudes (in pu) of the secondary side of the transformers under Scenario 2.	49
Figure 39. Voltage unbalance factor (VUF) at the MV side of the transformer under Scenario 2.	49
Figure 40. Voltage unbalance factor (VUF) at the LV side of the transformer under Scenario 2.	50
Figure 41. Loading % of the transformers under Scenario 2.	50
Figure 42. Loading % of the distribution feeders under Scenario 2.	50
Figure 43. Variation of the MV voltage at the busbars under Scenario 3.	51
Figure 44. Variation of the LV voltages at the bus bars under Scenario 3.	52
Figure 45. Variation of the transformer loading under Scenario 3.	52
Figure 46. Variation of the line loading under Scenario 3.	53
Figure 47. The average Autumn net load profile for several highly rated transformers in residential areas in Yea.	54
Figure 48. The average Winter net load profile for several highly rated transformers in residential areas in Yea.	54
Figure 49. The average Spring net load profile for several highly rated transformers in residential areas in Yea.	54

Table of Tables

Table 1. The Potential Battery Sites in Yea	4
Table 2. Summary of electrical infrastructure related to potential battery sites	5
Table 3. Simulation results showing transformer loading and network voltage under two extreme load scenarios	14
Table 4. Average transformer loading for daytime and nighttime across four seasons.....	18
Table 5. The self-consumption for an average day of each season	19
Table 6. Summary of battery energy capacity and inverter rating for four battery sites.	30
Table 7. Battery pack energy capacity based on the forecasted profiles.	30
Table 8. Yea Swimming Pool Site Information.....	37
Table 9. Yea Saleyards Site Information	38
Table 10. Murrindindi Shire Council Work Depot Site Information	39
Table 11. Yea Recreation Reserve Site Information.....	40
Table 12. Yea Railway Park Site Information	41
Table 13. Yea Waste Water Management Facility Site Information	42
Table 14. Yea Racecourse/Golf Club Site Information	43
Table 15. Yea Transformer Rating and Installed Solar-PV Capacity.....	44

Acronyms and Terms

- **ABS:** Australian Bureau of Statistics
 - **AEMO:** Australian Energy Market Operator
 - **CBD:** Central Business District
 - **DER:** Distributed Energy Resources
 - **DNSP:** Distribution Network Service Provider
 - **EG:** Embedded Generator
 - **FCAS:** Frequency Control Ancillary Services
 - **GHG:** Greenhouse Gases
 - **LV:** Low Voltage
 - **MG:** Microgrid
 - **MV:** Medium Voltage
 - **NMI:** National Metering Infrastructure
 - **PV:** Photovoltaic
 - **RE:** Renewable Energy
 - **VEDC:** Victorian Electricity Distribution Code
-
- **Rural Area (As per VEDC):** An area supplied electricity by an electric line which: (a) forms part of a distribution system and is a single feeder, (b) the length of which measured from the relevant zone substation is at least 15 km.

1. Introduction

The Victorian State Government launched the Neighbourhood Battery Initiative (NBI) in 2021 to fund neighbourhood-scale battery pilots, trials, and demonstration projects across Victoria. The proposal led by Indigo Power in partnership with the RMIT and the 2030Yea Community Energy group received the NBI Stage 3 funding to develop a business plan for a battery system in Yea.

As part of this project, the RMIT conducted the technical feasibility assessment by constructing a detailed power-flow model for the Yea township covering the electricity network of potential battery sites. The power flow model can inform the hosting capacity of each potential battery site, and hence it can inform the maximum dispatchable power from the battery at each site. In addition, energy data is analysed to determine each battery's kilo-watt-hour (kWh) energy capacity.

Therefore, this study has informed the technical suitability of potential battery sites to host a battery system and the potential capacity of the battery modules (kWh energy capacity of the battery) and battery converter size (kW/ kVA) that can be installed at each site. The outcome of the technical feasibility assessment would assist Indigo Power and 2030Yea group in selecting the final site/ or sites to construct the Community Battery System and also assist in conducting battery operational economics studies.

1.1. Objectives and Study Scope

Network and battery sizing studies are essential for successfully deploying community battery systems, as these studies will inform how to maximise the benefits to the community, battery system operator and distribution network service provider (DNSP). Furthermore, these studies will assist in overcoming any potential barriers that may arise in the future during the operation of a battery system.

The main objectives of this technical feasibility assessment are to determine the viability of the potential battery sites, determine the optimal size of the battery system (i.e. inverter size and the energy capacity of the battery pack) for each site, and evaluate the network benefits. The following is the scope of the technical feasibility study carried out by the RMIT team;

1. Developing a detailed power-flow model of Yea township including the electricity network of the potential battery sites,
2. Extracting network modelling data and the energy data from the AusNet GridView portal for network model development,
3. Energy and power data analytics to understand the seasonal variations,
4. Synthesizing the missing power and energy data and forecasting power and energy data for future time horizons,
5. Hosting capacity analysis of potential battery sites to determine battery converter size,
6. Energy data analytics of the sites to determine the kWh energy capacity of the battery,
7. Identify the sites for potential off-grid operation (microgrid sites),
8. Potential to relieve network bottlenecks and ability to provide frequency support services.

2. Yea Current and Future Renewable Energy Potential

2.1. General Overview of Yea

The Yea is located in the northeast of Victoria, Australia, about 130 kilometres from the Melbourne Central Business District (CBD). The Yea belongs to the Murrindindi Shire Council, and it is classified under “Inner Regional Australia” according to the Australian Bureau of Statistics (ABS) Remoteness classification (see Figure 1)¹. According to ABS 2021 Census, Yea suburb has 930 private dwellings and has a total population of 1,789².

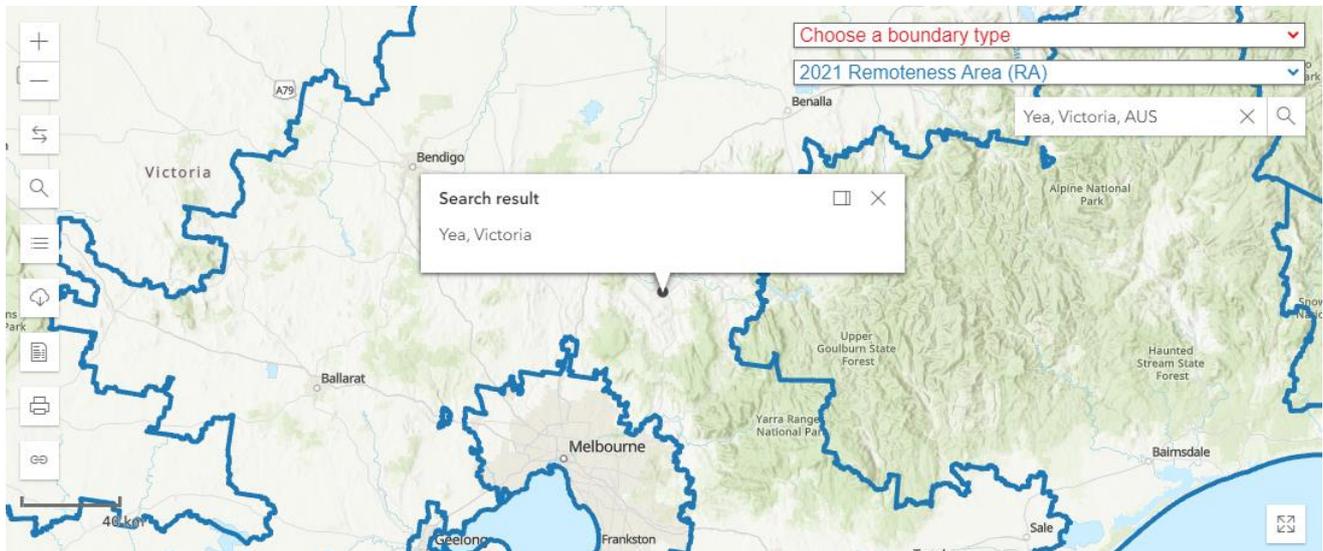


Figure 1. The Australian Bureau of Statistics remoteness classification for Yea.

Also, according to Australian PV Institute, the Yea postcode had a total installed solar-PV capacity of ~4.5 MW by end of 2023, and approximately 44% dwellings have solar PV systems. Therefore, the Yea solar-PV penetration is higher than the Victoria average. Also, Yea postcode has a total solar PV potential of 40 MW. The average monthly solar exposure in Yea is shown in Figure 2.

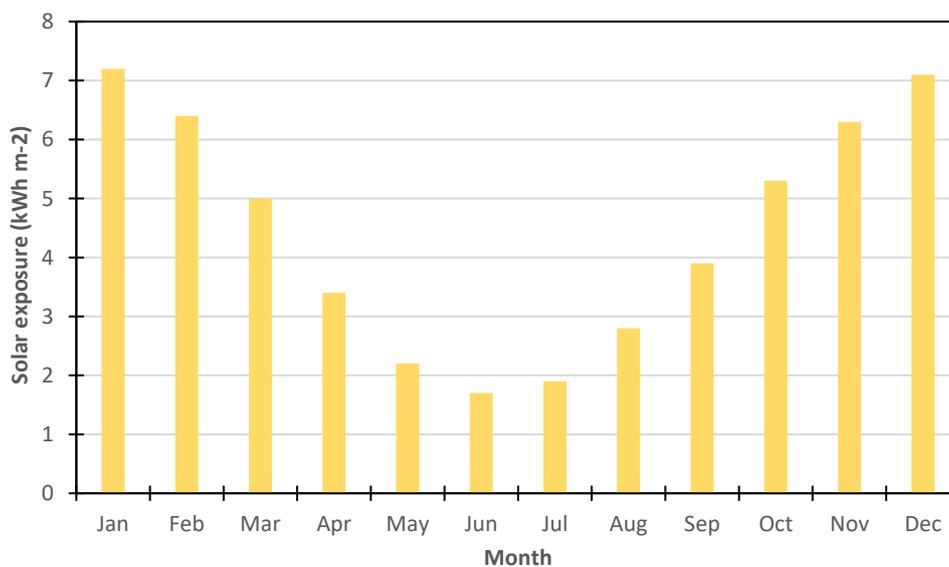


Figure 2. Average monthly solar exposure in Yea.

¹ See <https://maps.abs.gov.au/index.html>.

² Yea postcode (3717) has 1,903 private dwellings and a population of 3,544. Source: <https://www.abs.gov.au/census/find-census-data/quickstats>.

According to Figure 2, the average solar exposure in Yea exceeds 5 kWh/m² during half of the year. In particular, from October to March, the average solar exposure level of Yea exceeds 5 kWh/m².

Over the last decade, the solar PV capacity in Yea has grown by 18% per annum, indicating a strong interest in the community for renewable energy systems. Therefore, the solar-PV capacity will likely increase at the same rate in future years. At the end of 2023, Yea had an installed solar-PV capacity of ~4,500 kW. Figure 3 shows Yea's cumulative installed solar-PV capacity for 2010- 2023.

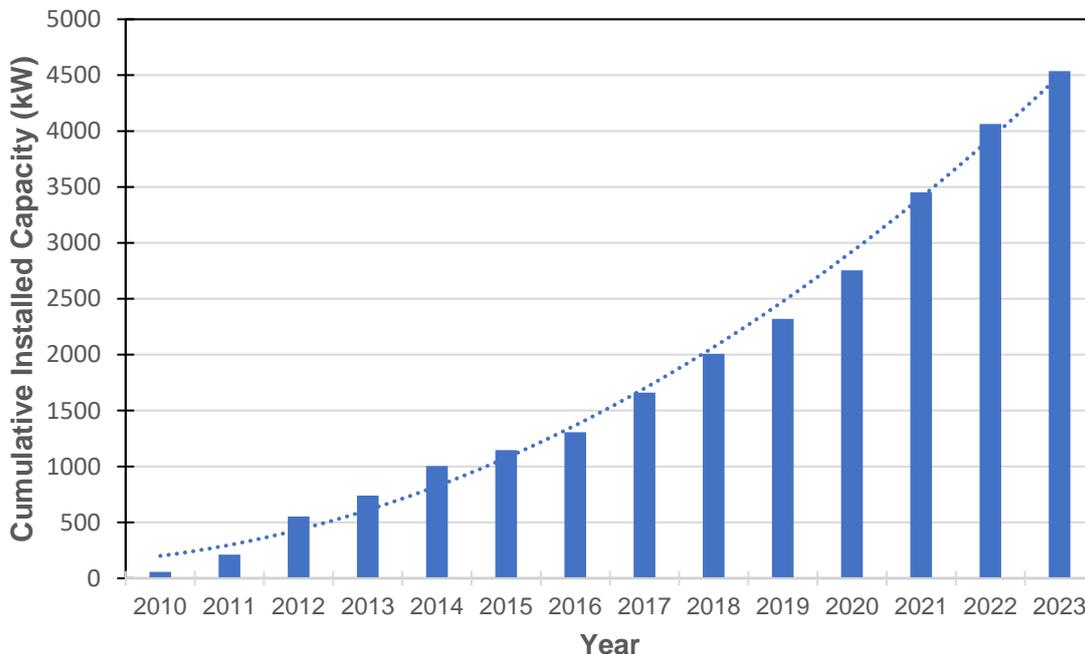


Figure 3. Cumulative installed solar PV capacity of Yea.

If the same trend continues, i.e., a 18% increase in annual solar capacity, Yea's total installed solar-PV capacity could reach 10,000 kW in the next 5 years.

3. Potential Battery Sites

The Indigo Power and 2030Yea Group have proposed several potential battery sites for the RMIT study team to conduct the technical evaluation. The proposed potential battery sites are listed in Table 1.

Table 1. The potential battery sites in Yea

No.	Site Name	Site Address	Front of the Meter	Behind the Meter	Host Site Owner
1	Yea Saleyards	1 Flat Lead Rd, Yea VIC 3717	Y	Y	Murrindindi Council
2	Yea Industrial Area	20 NORTH STREET YEA 3717	Y	N	Murrindindi Council
3	Yea Railway Park	24 STATION STREET YEA 3717	Y	N	Murrindindi Council
4	Yea Recreation Reserve	20 Snodgrass St, Yea VIC 3717	Y	Y	Murrindindi Council
5	Yea Racecourse/Golf Club	98 RACECOURSE ROAD YEA 3717	Y	Y	Murrindindi Council
6	Yea Swimming Pool	101 HIGH STREET YEA 3717	Y	Y	Murrindindi Council
7	Yea Wastewater Management Plant	5976 Goulburn Valley Hwy	Y	Y	GM Water

The geographical locations of the potential battery sites are illustrated in Figure 4.

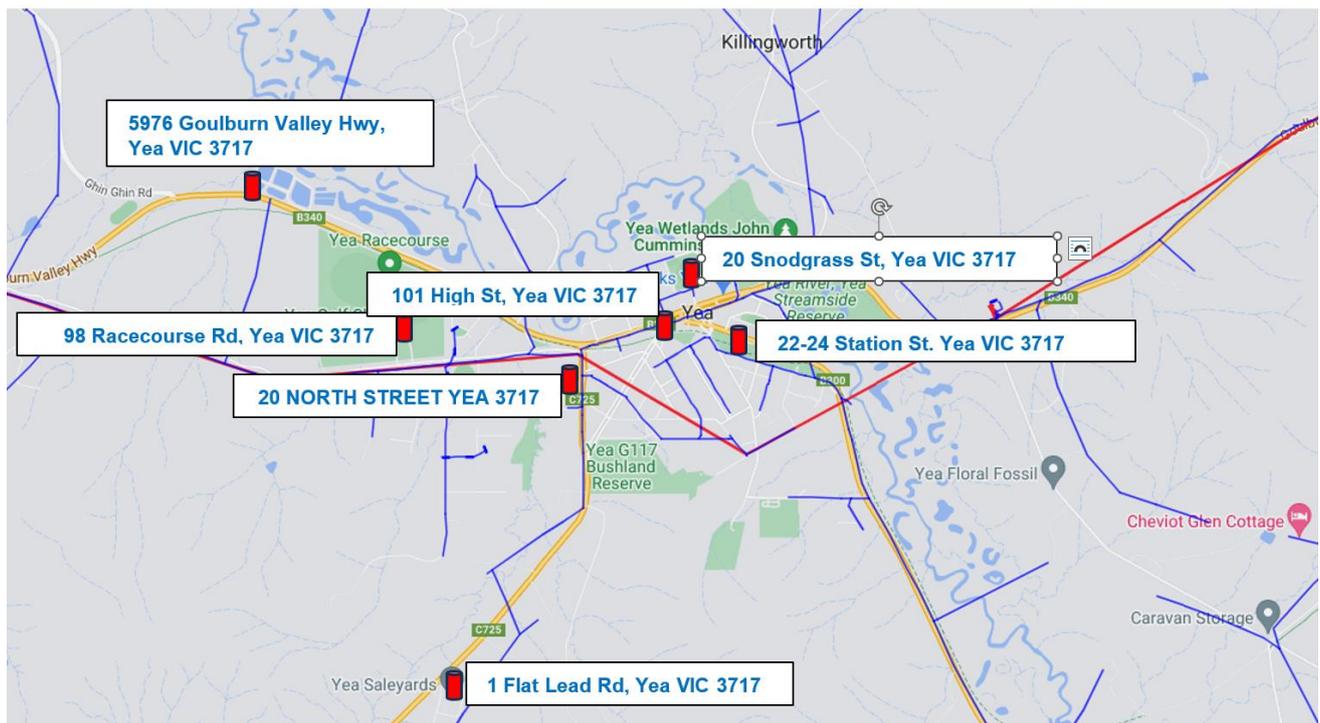


Figure 4. Geographical locations of the potential battery sites.

All potential sites will be assessed to have a ‘front-of-the-meter’ battery system as it is the most preferred option by the Department of Energy, Environment and Climate Action (DEECA). Except for the Yea Railway

Park and the Yea Industrial Area (Work Depot), all other sites will be assessed to host a ‘behind-the-meter’ battery system in this study³.

3.1. Summary of Electrical Infrastructure at Each Battery Site

The distribution substation and the electrical infrastructure available at these sites are summarised in Table 2.

Table 2. Summary of electrical infrastructure related to potential battery sites

No.	Site Name	Distribution Substation	Supply Connection	Other Electrical Infrastructure
1	Yea Saleyards	Whittlesea Rd 15 (50 kVA) - 2 Phase Supply	400 V (L-L) two-phase supply	Three-phase back-up generator
2	Yea Industrial Area (Work Depot)	North Francis (200 kVA)	400 V (L-L) three-phase supply.	-
3	Yea Railway Park	Station Miller (200 kVA)	A new supply connection is required	N/A
4	Yea Recreation Reserve	Pechell Snodgrass (500 kVA)	400 V (L-L) three-phase supply. The main switchboard is comprised of 3P 80A 10 kA CB	A 22 kW solar-PV system and a 15 kW/48 kWh battery system (3×5kW SP-Pro inverters and 12×4kWh Eco4940 battery modules). Three-phase back-up generator The 7 kW rooftop solar-PV system at the netball clubrooms is not considered here, since it is supplied by a separate supply meter.
5	Yea Racecourse/ Golf Club	Yea SMR 300 (50 kVA)	400 V (L-L) three-phase supply	Not Available
6	Yea Swimming Pool	Giffard Snodgrass (200 kVA)	400 V (L-L) three-phase supply with a 63 A Type C Main CB. A new supply connection may be needed based on the siting of the battery system.	Three water pumps each supplied through a 3-phase 40 A CB and other loads
7	Yea Wastewater Management Plant	SEWER 2 (50 kVA)	400 V (L-L) three-phase supply	Not Available

According to Table 2, the Yea Recreation Reserve is the only site with solar PV generation. Also, that site has a 15 kW/48 kWh battery system. More details of each battery site are given in Appendix A.

³The 'behind the meter' option will only be evaluated if there are no physical limitations at the site and interval data is obtainable.

4. Project Methodology

The potential sites for the community battery were identified by the 2030Yea community group and Indigo Power, as listed in Table 1. Figure 5 outlines the network modelling and battery sizing methodology.

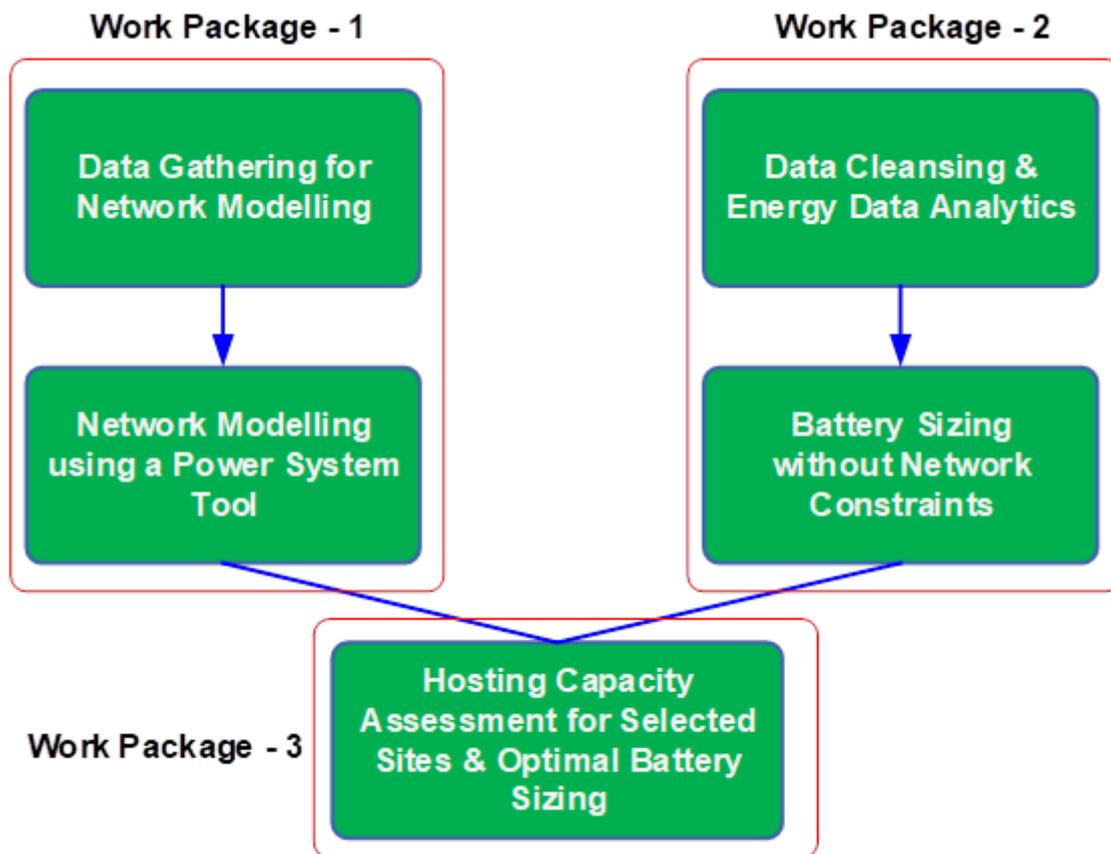


Figure 5. Network modelling and battery sizing methodology.

The methodology consists of three work packages. Work Packages 1 & 2 are carried out simultaneously to develop the Yea electricity network model and determine each potential site's battery storage system size (without considering network constraints). In Work Package-3, the battery system size will be further optimised considering network constraints. In addition, it will quantify the benefits of community battery systems. The specific tasks involved with each work package are described below:

Wok Package-1: Yea Electricity Network Modelling

Data Gathering for Network Modelling – Typically, the Victorian DNSPs model the electricity network to the 22 kV level, and hence, in many cases, detailed network models do not exist for low-voltage (LV) residential networks (i.e., 400 V L-L). Since the battery systems are typically connected to the 400 V (L-L) network (note: connected voltage depends on the battery size) it is essential to model the network in detail. Therefore, as the first stage, the network studies team will gather the required network information (e.g., line/ cable and transformer data) to model the Yea medium-voltage (MV) and LV network for all the potential sites. The team will acquire necessary data directly through the AusNet Services and will make assumptions about the missing network data based on similar studies conducted by the team.

Network Modelling using Power System Tools – Once the network modelling data is gathered, the detailed models are developed for the feeders supplying the potential sites in Yea using a professional power system modelling and analysis tool. This includes MV and LV feeder cables, transformers, voltage regulators,

household solar-photovoltaic (PV) systems, loads and the other special sources and loads in the network. The network feeders that are not directly relevant to potential sites will be represented as aggregated clusters, such as the tail ends of long feeders. Finally, the model's fidelity will be verified with the time-series data from AusNet Services.

Work Package-2: Energy Data Analytics & Battery Sizing

Data Cleansing & Energy Data Analytics – In this task, the energy consumption and generation (from solar-PV) data for the Yea region are analysed to understand their energy requirements and solar PV self-consumption rate under the current scenario, i.e., without individual or community battery systems. Data cleansing is necessary to fix any missing or inaccurate data. Also, the data will be prepared in an appropriate format for the network benefit/hosting and storage sizing studies.

Battery System Sizing without Network Constraints – The battery sizing study will be carried out purely based on the energy analytics without considering the network constraints (e.g., transformer and line limits) for the potential sites. Furthermore, the current and future time horizons (for example, 5 and 10 years into the future) will also be considered when determining battery sizes for potential sites.

Work Package-3: Battery Size Optimisation and Benefit Assessment

Network Hosting Capacity, Benefits Assessment and Optimal Battery System Sizing – The hosting capacity of the network will be assessed by integrating the battery system into the potential sites while considering both current and future generation and load scenarios. This will enable the battery system capacity optimisation based on the network constraints. Moreover, the study team will quantify the energy transfer between the grid and the battery system under two operation models (e.g., retail pricing and ‘solar sponge’ models). It is envisaged that the Indigo Power team will use the energy information to perform the economic analysis. Furthermore, the network benefits will also be assessed for each potential site by integrating the battery system, which includes;

1. Ability to mitigate current and future network constraints (e.g., network overloads such as transformer and line overloading, mitigate voltage issues),
2. Ability to defer network augmentations,
3. Efficiency benefits through optimisation of network infrastructure.

5. Yea Electricity Network Modelling

5.1. Yea Electricity Supply Network

Yea is supplied from the Seymour zone-substation through a 22 kV SMR14 feeder which is approximately 50 km long and serves around 2400 customers⁴, as shown in Figure 6. Yea is positioned towards the tail of the feeder and consumes about 50% of the total feeder load demand. To understand the existing operating state of the supply feeder, loading levels and voltages and to assess the battery hosting capacity of the selected sites along with its network impact, a network model for the SMR14 feeder, shown in Figure 6, has been developed for this project, as detailed below.

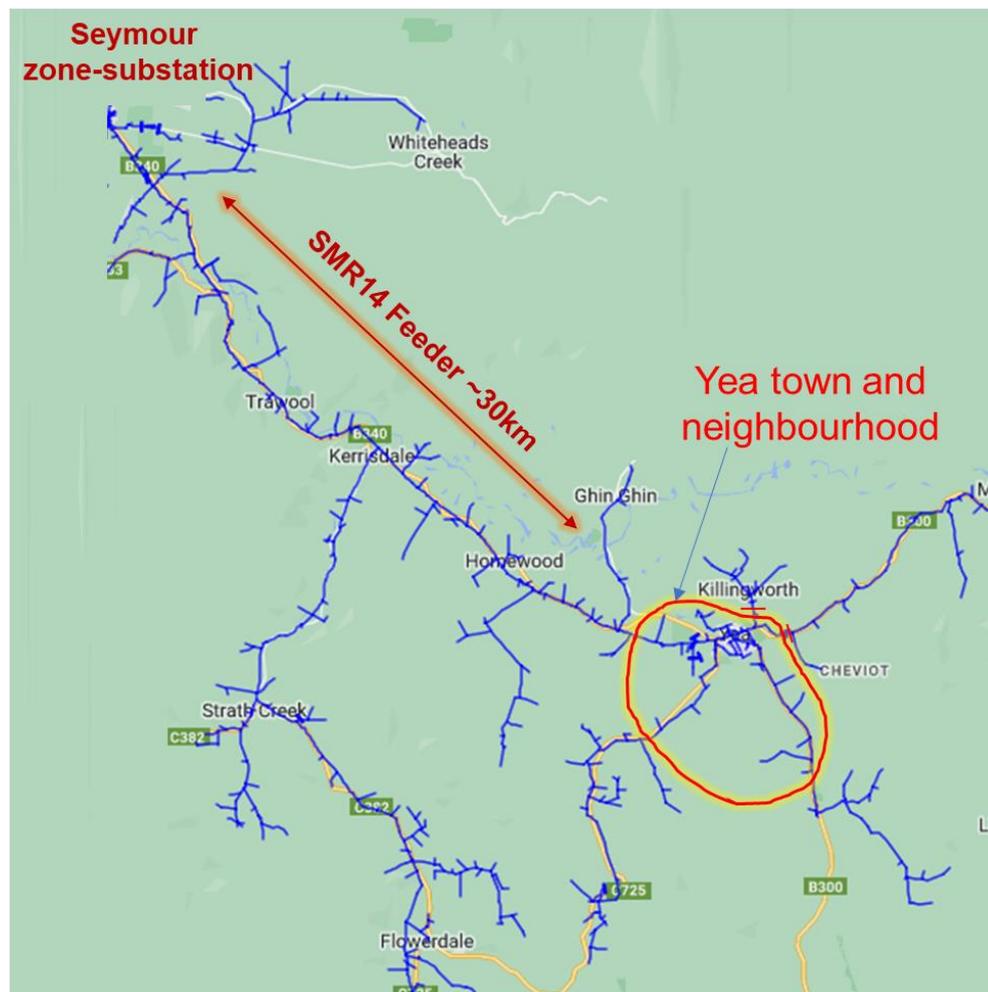


Figure 6. Seymour ZSS SMR14 feeder supplying Yea and neighbourhood⁵

5.2. Modelling Approach and Data Source

The complete model for the SMR14 feeder is developed with varying details. The level of details incorporated in different parts of the model is presented in the single-line diagrams in Figure 7.

⁴ AusNet Services, “Distribution Annual Planning Report 2022-2026”, June 2022.

⁵ AusNet GridView Portal: www.gridview.ausnetservices.com.au.

- The network model for Yea town and neighbourhood (highlighted by red enclosed line in Figure 6) is developed with details. The 22 kV network model, comprising the feeder and substations, is based on the data sourced from the AusNet GridView portal. Each distribution substation model includes an actual-rating transformer, lumped load and residential solar PV system on its LV side. This modelling approach enables creation of both the existing and future scenarios of solar PV.

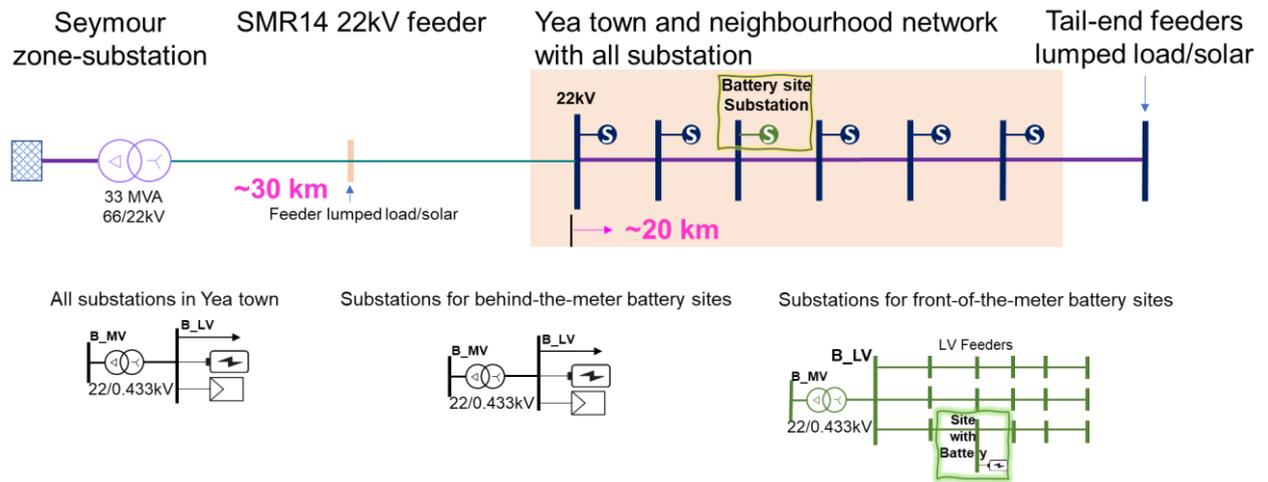


Figure 7. A representative single-line diagram showing the details for SMR14 feeder and substations.

- The substations for behind-the-meter community battery sites are modelled using a similar approach, incorporating actual-rated transformers, lumped loads, solar PV and community battery system on its secondary side, as shown in Figure 7. Conversely, the substations for front-of-the-meter sites are modelled with actual LV feeders (types and lengths), the load points along the feeder and the battery site. This modelling approach facilitates an assessment of battery hosting capacity considering LV feeder and transformer ratings, and its impact on other customers on the same LV network and beyond.
- The medium voltage 22 kV feeder from Seymour zone-substation to Yea is modelled with actual feeder types and lengths. However, loads along the feeders are aggregated and connected to comprehend the feeder overall loading and voltage drop. Moreover, a few tail-end feeders located downstream of Yea town on the SMR14 are represented as lumped-loads to accurately capture the overall loading of the feeder.

The network model developed in this task is suitable for assessing community battery hosting capacity and its impact on the network, extending up to the customer level. However, several assumptions are made due to data unavailability.

- Some 22 kV and LV feeders' and transformer rating data was missing from the AusNet Gridview portal. Consequently, information obtained from alternate sources such as Google Street images and the site visit is used to estimate these missing data. For a few feeder segments, the data for the similar segment feeders are used. See Section 5.4 for further details regarding the estimation methodology.
- The load points and phase connection of loads for the two potential battery sites (i.e., Industrial Area and Railway Park) substations were unavailable. The best effort is made to obtain this information from Google Street images. In cases where this was not possible, assumptions are made to match the overall load on the substation with their actual operational load data.

5.3. Network Simulation Models

The simulation model for the complete SMR14 feeder and selected battery sites substations are shown in Figure 8 to Figure 10.

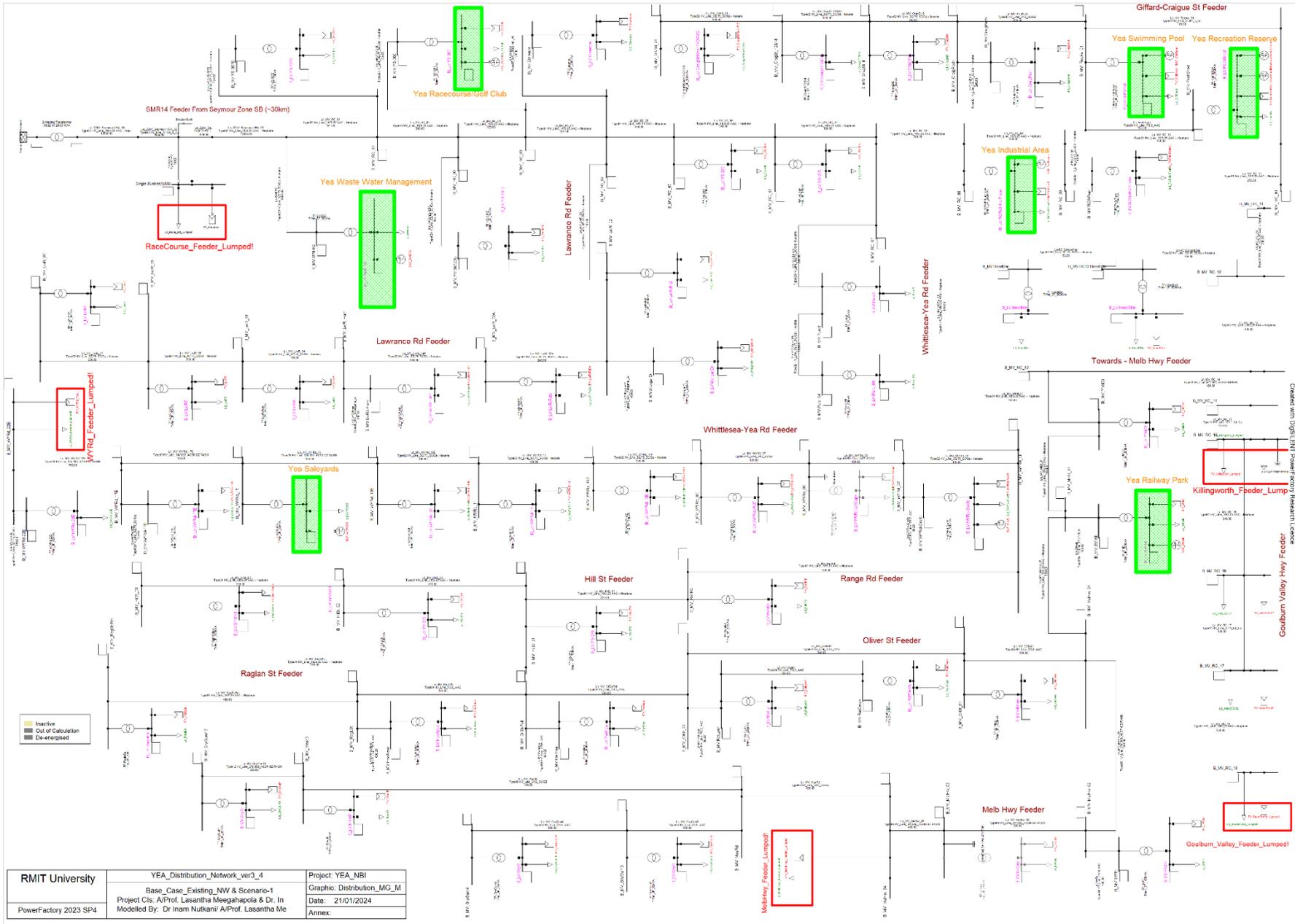


Figure 8. SMR14 feeder complete model.

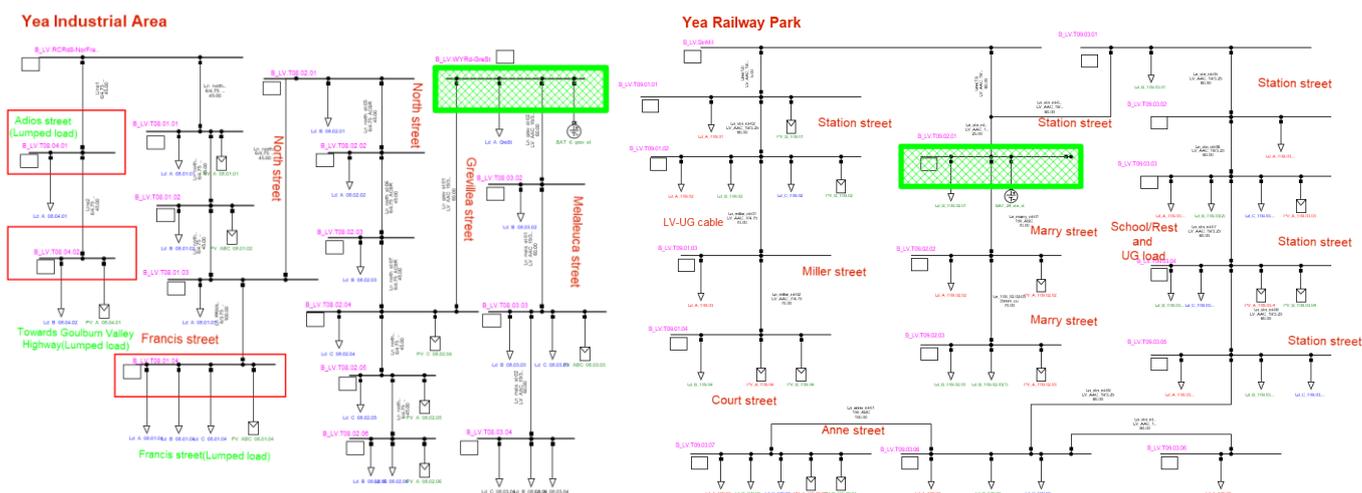


Figure 9. Substation model for behind-the-meter battery sites – Yea Industrial Area and Yea Railway Park.

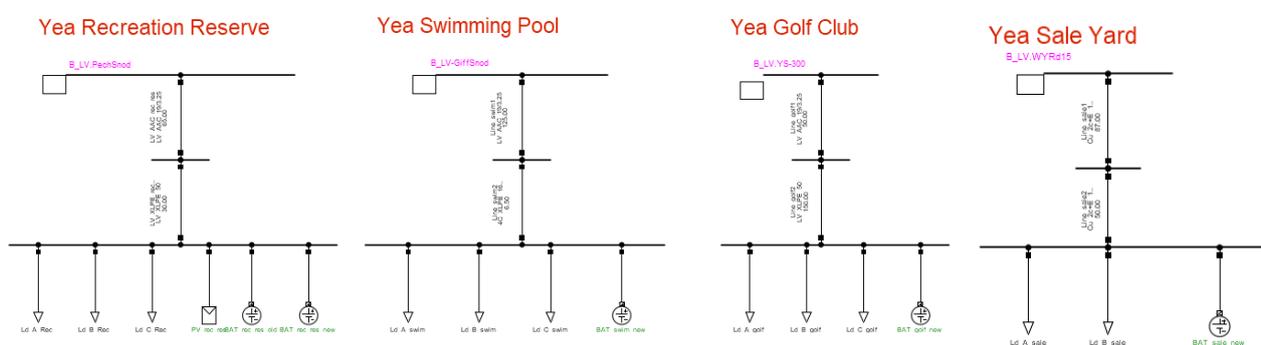


Figure 10. Substation model for front-of-the-meter battery sites.

5.4. Net Load and Solar-PV Data Extraction

The AusNet GridView Portal provides the net load⁶ profile of distribution substations supplying more than ten customers. For example, the netload profile of the Giffard Snodgrass distribution substation is shown in Figure 11.

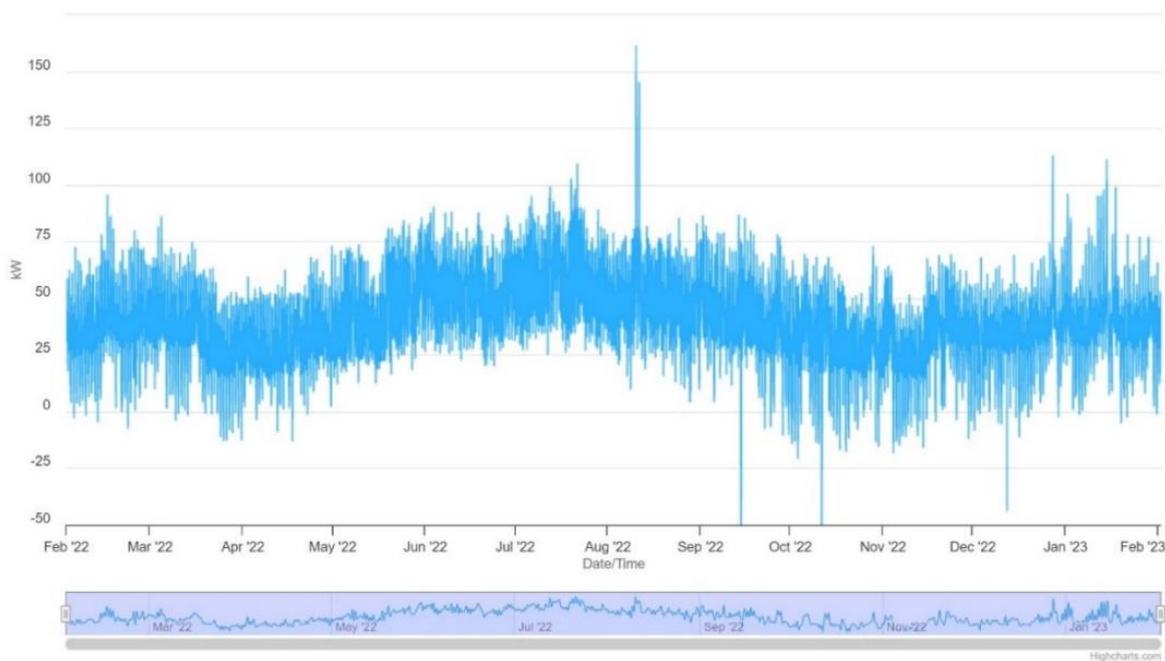


Figure 11. Netload profile of Giffard Snodgrass Distribution Substation.

⁶ Net load = Actual load demand – Solar PV generation. In some cases, battery discharge should be subtracted from actual load demand to determine the net load.

According to Figure 11, the net load profile has dropped below zero in the Spring and Summer months, indicating excess solar generation after fulfilling the load demand of customers connected to this transformer. A similar trend can be observed for transformers with significant solar-PV capacity. However, the AusNet GridView portal does not provide net load profiles if the number of customers connected to the distribution substation is ten or less than ten. Since there are a number of distribution transformers with less than ten customers, their net load profile was estimated by applying a scaling factor on the net load profile of the nearest transformer. The scaling factor was determined based on the following formula.

$$\text{Scaling factor} = (\text{MVA rating of the data unavailable transformer}) / (\text{MVA rating of the data available transformer})$$

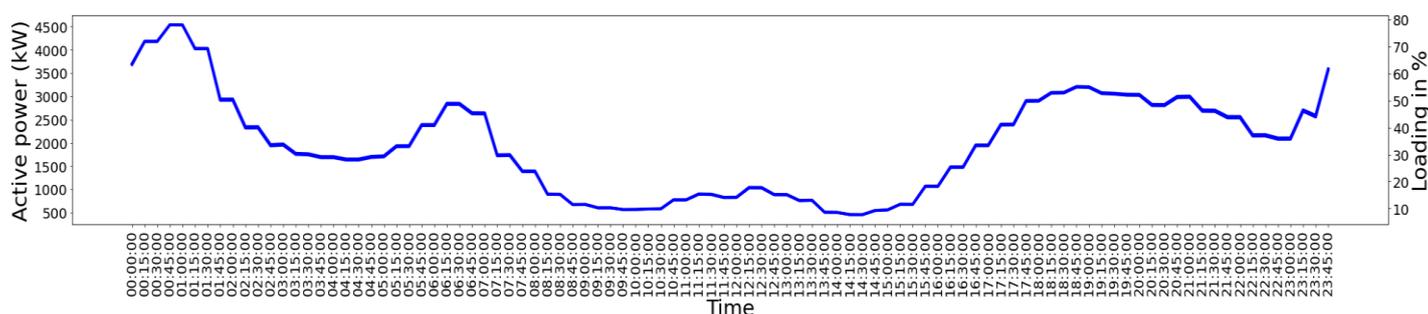
Then, these net load profiles and their maximum, minimum and average loads are applied in the simulation model. In addition, the team also estimated the solar-PV capacity of each distribution transformer due to outdated data on the AusNet GridView portal. Therefore, the Google satellite view was used to estimate the solar-PV capacity associated with each distribution transformer. The estimated solar-PV capacity associated with each distribution transformer are summarised in Appendix B.

5.5. Network Base Operating Scenario and Initial Results

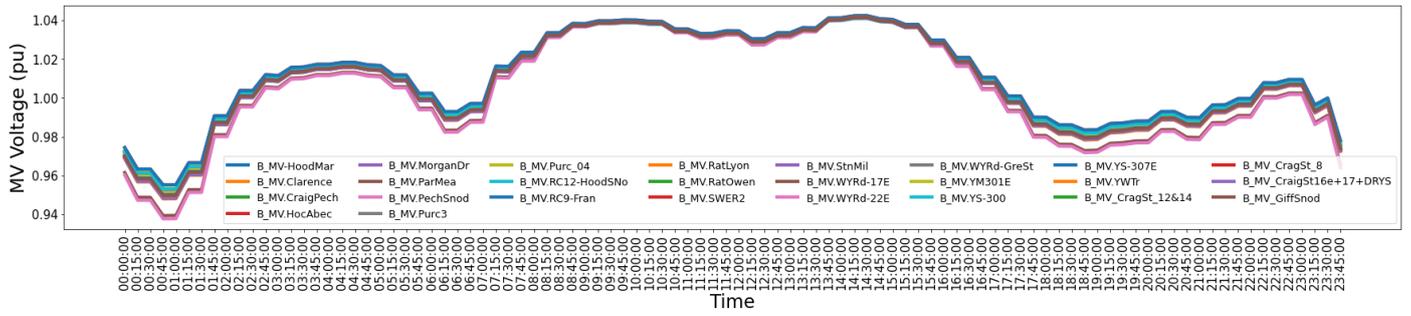
The network shown in Figure 8 is tested using the 24-hour net load profiles for Summer to assess the current state of its assets loading and operating voltages. The quasi-dynamic simulation results with 24-hour net load profiles are shown in Figure 12, revealing the following:

- The maximum load on the incoming supply SMR14 feeder to Yea is approximately 4.53 MW, with the feeder operating at 78% of its rated capacity during Summer. Notably, this feeder loading is approximately 100% during Winter when average peak load is higher than Summer, as captured in Scenario 1 results in the Appendix C. Moreover, feeder is usually overloaded with actual peak (non-averaged) load during Summer and Winter. The minimum load on SMR14 feeder is very low, up to 0.56 MW, observed during Summer between 8:30 am and 3:00 pm.
- The voltage at 22 kV and LV busses varies within the permissible limits, between 0.93 pu and 1.04 pu at 22 kV busses and between 0.94 pu and 1.07 pu at LV busses, with peak voltage recorded between 8:30 am and 3:00 pm when solar PV output is high.
- Most feeders, expect for the supply incoming feeder SMR14, and transformers are moderately loaded, usually below 70%.

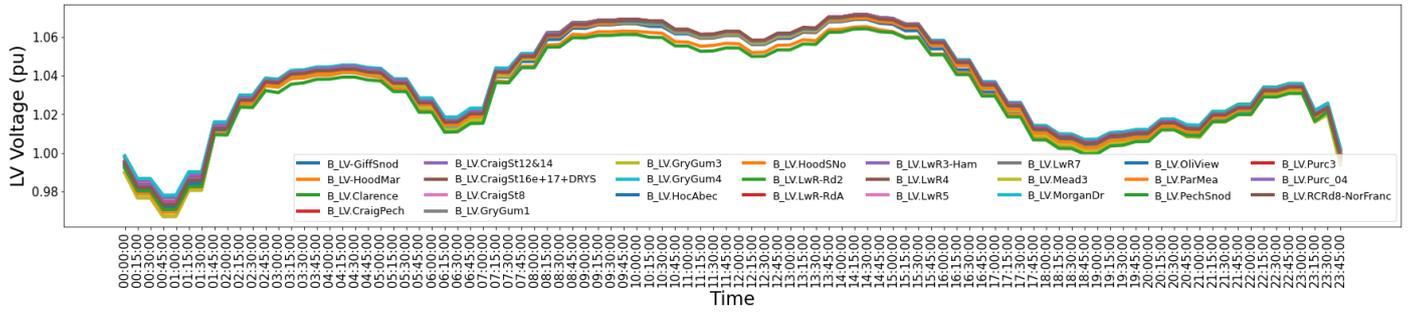
In addition, the simulation results, which include assets loading and network operating voltages during both maximum and minimum loads during the day, are summarised in Table 3 for the potential/selected battery sites and for the selected substations in the network.



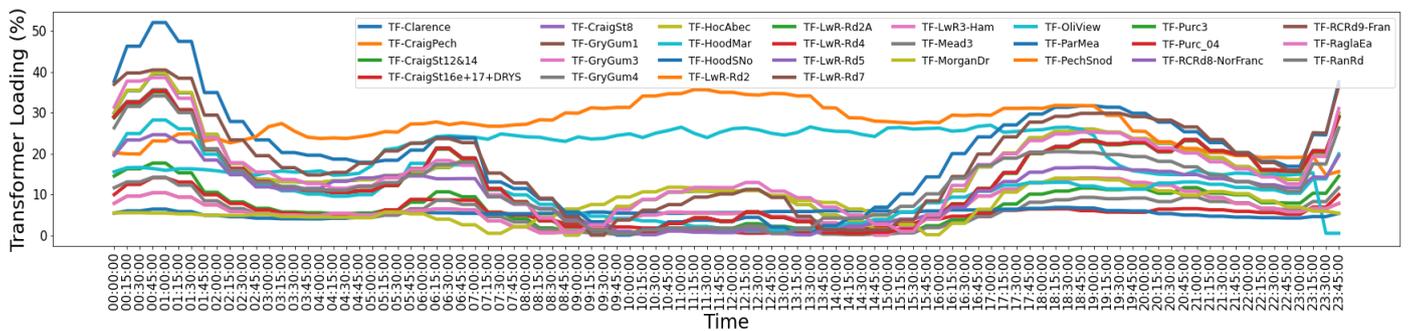
(a). SMR14 feeder load



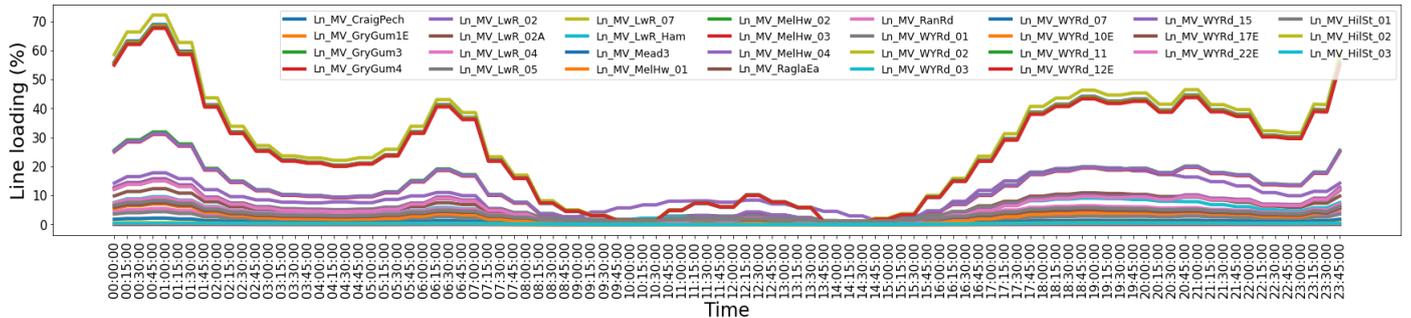
(a). Voltage at 22kV buses.



(b). Voltage at LV buses



(c). Loading of transformers



(d). Loading of 22kV feeders

Figure 12. Quasi dynamic simulation results with 24-hour net load profiles during summer.

Table 3. Simulation results showing transformer loading and network voltage under two extreme load scenarios.

Site/ Network Points (Distribution Substation)	Maximum Load (~1AM)			Minimum Load (~3PM)		
	Transformer Loading (%)	MV Voltage (pu)	LV Voltage (pu)	Transformer Loading (%)	MV Voltage (pu)	LV Voltage (pu)
Yea Recreation Reserve (Pechell Snodgrass -500 kVA)	23	0.95	0.97	28	1.04	1.06
Yea Racecourse/Golf Club (YEA SMR 300 – 50 kVA)	35	0.95	0.97	0.8	1.04	1.07
Yea Swimming Pool (Giffard Snodgrass-200kVA)	31	0.95	0.97	14	1.04	1.07
Yea Railway Park (Station Miller – 200 kVA)	35	0.95	0.94	23	1.04	1.07
Yea Wastewater Management (SWER 2 – 50 kVA)	35	0.95	0.98	0.8	1.04	1.07
Yea Industrial Area TF 1 (North Francis-200 kVA)	24	0.95	0.96	3	1.04	1.07
TF 2 (Grev. St.)	32	0.95	0.97	4	1.04	1.07
Yea Saleyards (Whittlesea RD 15 (50 kVA)	35	0.94	0.96	0.8	1.04	1.07

In addition, the following two scenarios are also simulated for Yea power-flow model and the results are shown in the Appendix C.

- **Maximum Load (Scenario-1):** represent the annual average maximum net load on the network during Summer
- **Minimum Load (Scenario-2):** represent the annual average minimum net load on the network during Summer

5.6. Findings from Network Model Assessment

The key findings from the network model assessment and key results are summarised below:

- The medium voltage 22 kV feeders in Yea and its neighbourhood are currently lightly loaded (mostly below 30% at maximum loading), providing ample capacity for future renewables and neighbourhood battery/ community battery systems. Consequently, the hosting capacity of battery may be (primarily) constrained by the transformers and LV feeders of the potential battery sites.
- Despite the present light loading of the MV feeder in Yea and neighbourhood, the incoming SMR14 feeder is currently operating at its full capacity. Hence, there is a necessity to reduce its load by 10% within 1-2 years to avoid network infrastructure upgrades⁷. This raises the need for battery storage systems in Yea to avoid or defer potential network upgrade.
- Moreover, the 22 kV and LV network operating voltages varies significantly, ranging from lower threshold during heavy load during evening to upper threshold during light load conditions when solar PV output is high. This wide voltage variation poses a challenge for voltage regulation in SMR14 feeder, particularly with increasing load demand and the increasing penetration of solar PV.

As such, these initial findings indicate that the SMR14 feeder and Yea are an ideally positioned for evaluating the non-network-based solutions such as community batteries and microgrids, to address the issues related to overloading or hosting capacity, and voltage regulation.

⁷ AusNet Services, “Distribution Annual Planning Report 2022-2026”, June 2022.

6. Network Operational Data Analytics and Data Forecasting

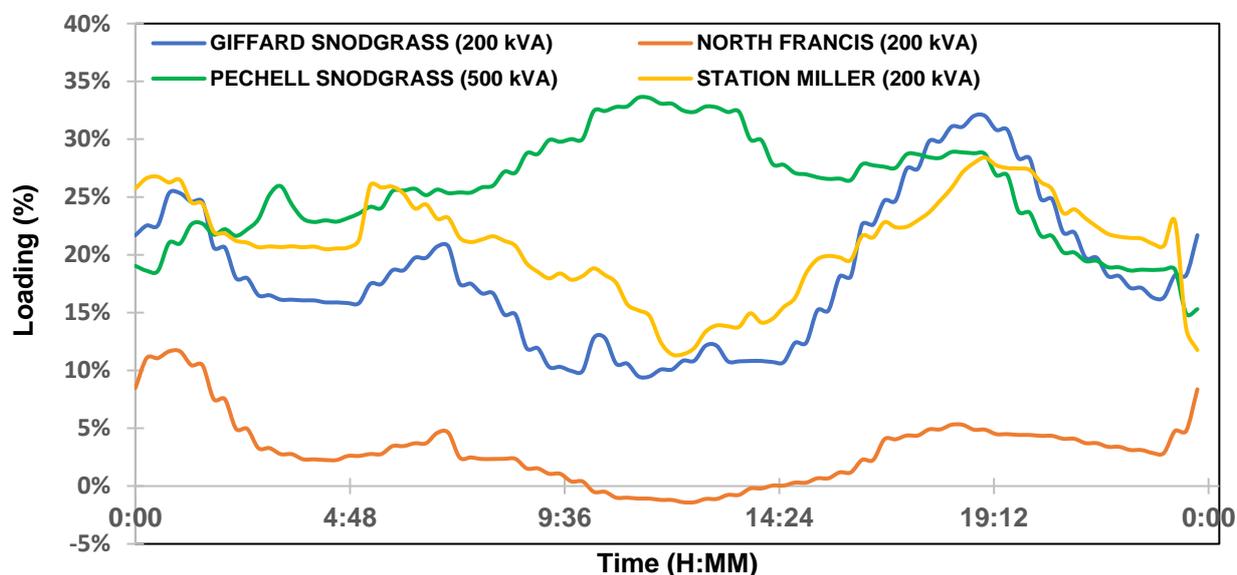
This section discusses the operational data analytics performed on the distribution transformer time-series data and the data forecasting for future time horizons (5 years and 10 years).

6.1. Net Load Profile Segmentation

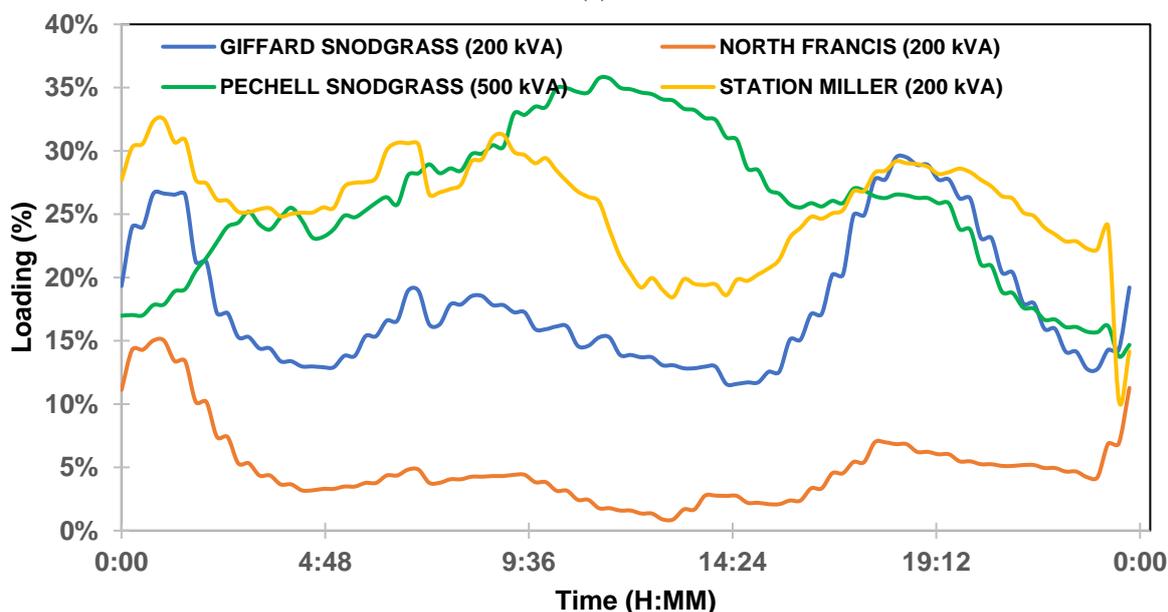
As mentioned in Section 5.4, the net load profiles for all distribution transformers (a total of 52 transformers) in the power-flow model were either extracted from the AusNet GridView portal (2022 – 2023) or estimated for the transformers with less than 10 customers. Then, the extracted transformer net load profiles were averaged based on the seasons. Therefore, each transformer in the model had four different average net-load profiles:

1. Summer Average Net Load Profile
2. Autumn Average Net Load Profile
3. Winter Average Net Load Profile
4. Spring Average Net Load Profile

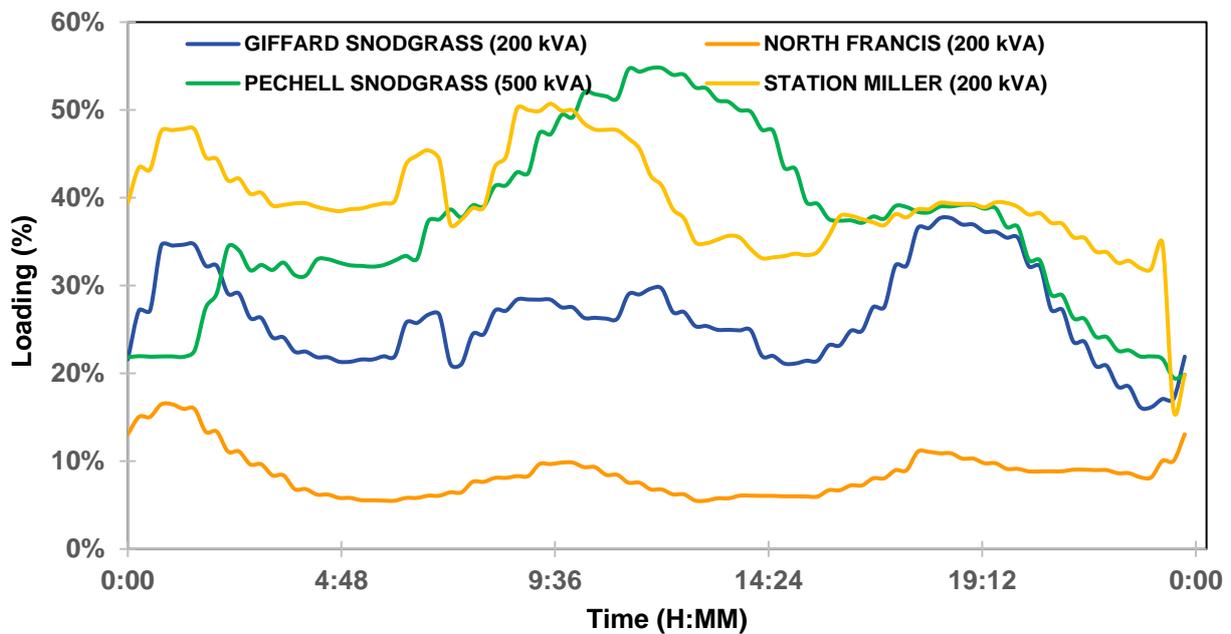
Figure 13 shows the average seasonal net load profiles of transformers associated with potential battery sites.



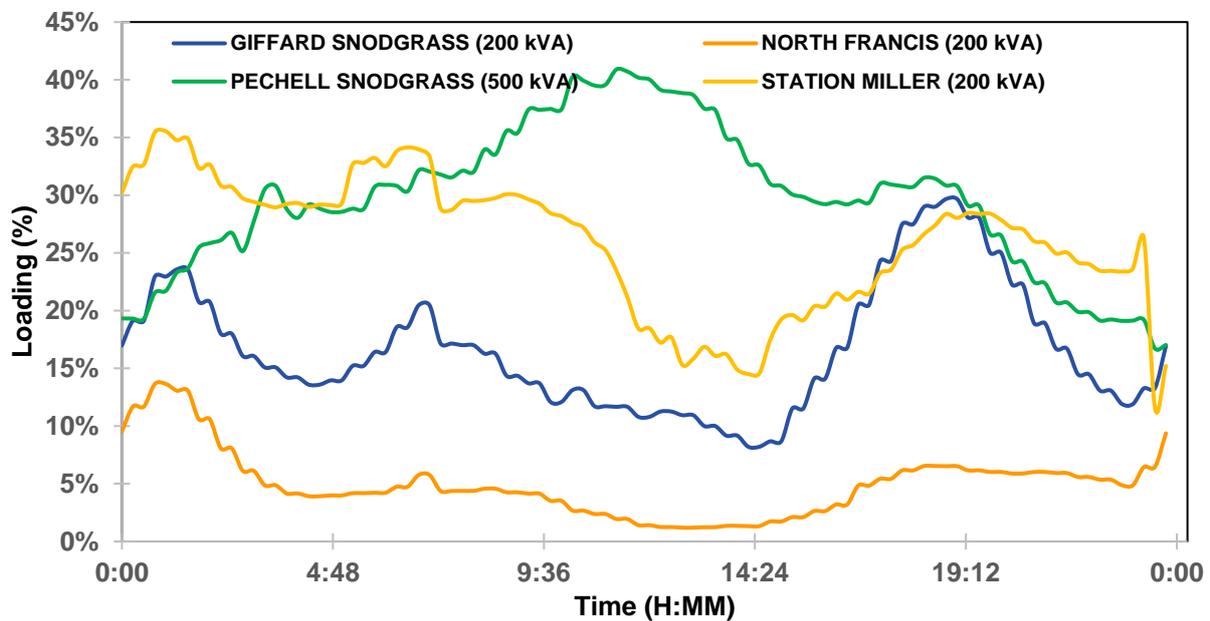
(a)



(b)



(c)



(d)

Figure 13. Average seasonal net load profiles of potential battery sites: (a) Summer, (b) Autumn, (c) Winter, (d) Spring. Note: Profiles of three transformers (Whittlesea Rd 15 (50 kVA), Sewer 2 (50 kVA), YEA SMR 300 (50 kVA)) are not available as they supply the individual customers.

According to Figure 13, except for the Pechell Snodgrass (500 kVA) transformer, the other three transformers have significant solar-PV generation, which has helped decrease the net load during the daytime in three seasons except for Winter. Also, on average, the transformer loadings are higher in Winter than in Summer (5-20% higher average netload demand increase).

Also, several demand peaks can be identified from these netload profiles; 1) 12 pm demand peak, 2) 7 pm demand peak, 3) 1 am demand peak (due to pre-set electric hot water systems). The transformer which supplies the commercial loads in Yea town (Pechell Snodgrass (500 kVA)) has a demand peak around 12pm. The transformers located at residential and semi-residential areas have demand peaks occurring in either 7 pm or around 1 am. The 1 am demand peak will be discussed in later parts of the report.

Table 4 summarises the average transformer loading for daytime and nighttime across four seasons.

Table 4. Average transformer loading for daytime and nighttime across four seasons.

Transformer Name	Summer		Autumn		Winter		Spring	
	Daytime	Nighttime	Daytime	Nighttime	Daytime	Nighttime	Daytime	Nighttime
Giffard Snodgrass (200 kVA)	18%	19%	16%	20%	26%	27%	14%	19%
North Francis (200 kVA)	2%	5%	3%	7%	7%	10%	3%	7%
Pechell Snodgrass (500 kVA)	29%	21%	31%	22%	46%	31%	34%	25%
Station Miller (200 kVA)	20%	22%	25%	26%	41%	39%	24%	28%

According to Table 4, except for Pechell Snodgrass (500 kVA), the other three transformers have less daytime loading than the nighttime due to the solar-PV capacity associated with these three transformers relative to their load demand. On the contrary, the average net load of the Pechell Snodgrass (500 kVA) transformer stays consistently high throughout the daytime (11 am - 4 pm) across all seasons, even with 90 kW solar-PV capacity, as it supplies the Yea town.

The North Francis (200 kVA) transformer indicates a higher peak demand around 1 am due to the hot water system operation during this time. This has been the case for transformers supplying residential areas in Yea. The average summer net load profiles for several highly rated transformers in residential areas in Yea are shown in Figure 14.

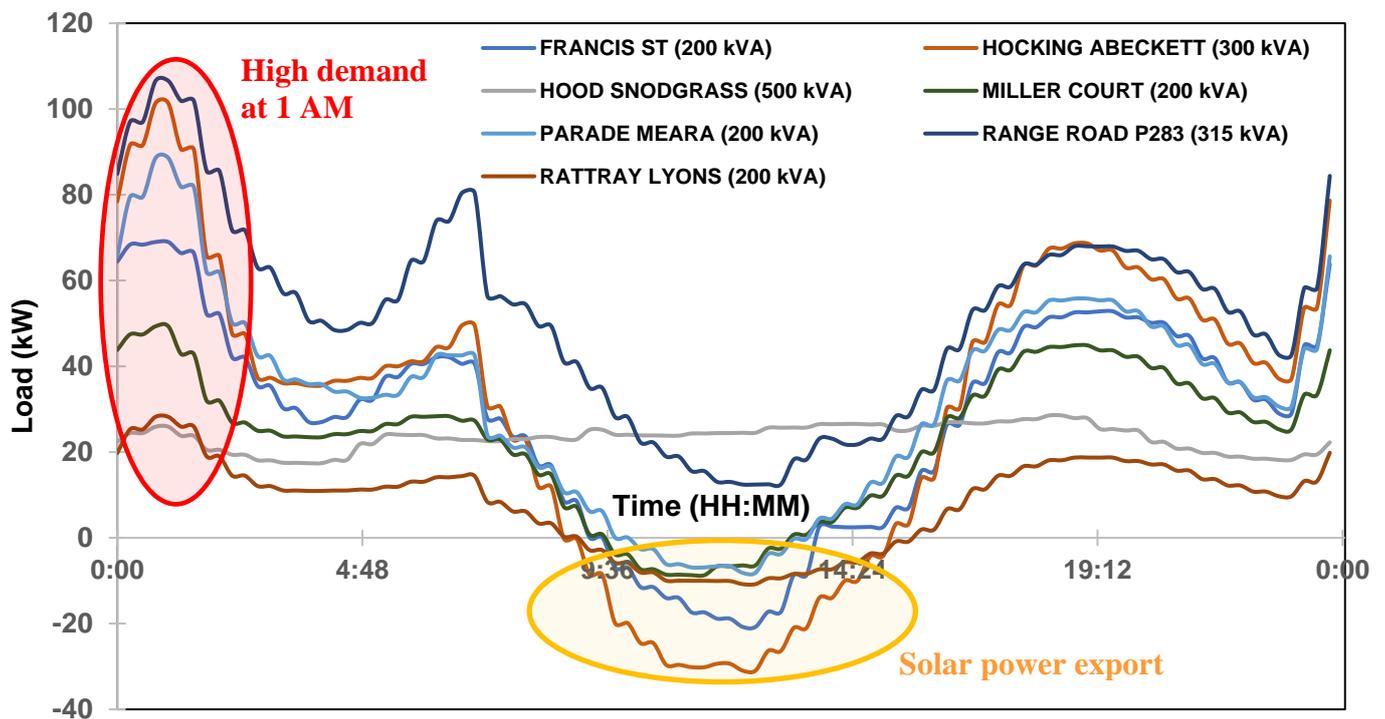


Figure 14. The average summer net load profile for several highly rated transformers in residential areas in Yea.

As shown in Figure 14, a high electricity demand occurs around 1 am for transformers in Yea residential areas due to the activation of hot water systems. Also, some of these transformers have a significant solar-PV generation, and they export the additional solar-PV generation to 22 kV network from 9.30 am-12.30 pm. Therefore, the voltage may drop below the allowable limit during the night, and a higher voltage may result in during the high solar export hours. This has been confirmed by the simulation results presented in Section

5.5. This voltage issue can be mitigated by shifting the water heating demand to the daytime. The average net load profiles for other seasons are presented in Appendix D.

6.2 Self-Consumption Analysis

The AusNet GridView portal only provides the net load profiles for transformers. Therefore, it is essential to estimate the solar-PV generation profile and the self-consumption rate for transformers to determine the solar-PV export by each transformer. This information is important to size the battery energy storage systems for potential battery sites. The self-consumption was estimated for each season, considering the average net-load profile for each transformer. The following methodology was followed to determine the average self-consumption for transformers.

1. Determine the average solar-PV profile for each season⁸.
2. Estimate the average seasonal solar-PV generation profile for each transformer using the following formula:

PV curve for each transformer (for each season) = Per-unit PV curve (for each season) × installed solar capacity in kW for each transformer

3. Finally, the average self-consumption for each season was calculated using the following formula:

Self-consumption in kWh for each transformer = solar-PV generated energy in kWh (based on average profile) – exported energy to the grid in kWh (from averaged net load curve)

The self-consumption for an average day of each season is given in Table 5.

Table 5. The self-consumption for an average day of each season

Distribution Substation		Self-consumption on an average day in a season (kWh)			
		Summer	Autumn	Winter	Spring
1	GIFFARD SNODGRASS (200 kVA)	614.63	493.61	224.99	381.29
3	NORTH FRANCIS (200 kVA)	607.36	493.61	224.99	381.29
4	PECHELL SNODGRASS (500 kVA)	737.56	592.33	269.98	457.55
5	STATION MILLER (200 kVA)	860.47	691.06	314.98	533.81

According to Table 5, all four transformers have significant solar-PV consumption rates, and hence, on average, the majority of transformers do not export the solar-PV to the 22 kV network except for the North Francis transformer in Summer. These values also indicate that if a 100-200 kWh community battery system is placed in one of these transformers, it can be fully charged from the solar-PV generation from zero SoC.

6.3 Forecasting Future Net Load Profiles

This study also aims to evaluate the hosting capacity of potential battery sites and the feasibility of the energy storage system capacity considering future time horizons. Therefore, the existing net load profiles of the transformers should be forecasted for future time horizons. The following methodology was adopted to forecast the net load profiles of transformers.

1. Segment transformers' seasonal average net load profiles to daytime and nighttime regions.

⁸ Average solar-PV curve for each season was calculated using the solar-PV generation data taken from <https://pvoutput.org>.

2. The nighttime region is assumed to have consisted of pure load (it is assumed that the home battery system penetration is insignificant in Yea), and hence, it is assumed to grow at a rate of 0.7% as per the AusNet Distribution Planning report⁹. Therefore, the nighttime load has been increased by the following factors for 5- and 10-year future time horizons:

- 5-year factor: **1.036**
- 10-year factor: **1.072**

3. The daytime consisted of both the load demand and the solar-PV generation. Therefore, two different factors were applied for pure-load and solar-PV generation.

4. The load demand was estimated by adding the estimated solar-PV generation for each season at each transformer to the average net load for the daytime as follows:

$$\text{Load Demand} = \text{Net Load} + \text{Estimated Solar PV generation}$$

5. The estimated load demand in Step-4 was forecasted for 5- and 10-year future time horizons using the same factors as given in Step-2.

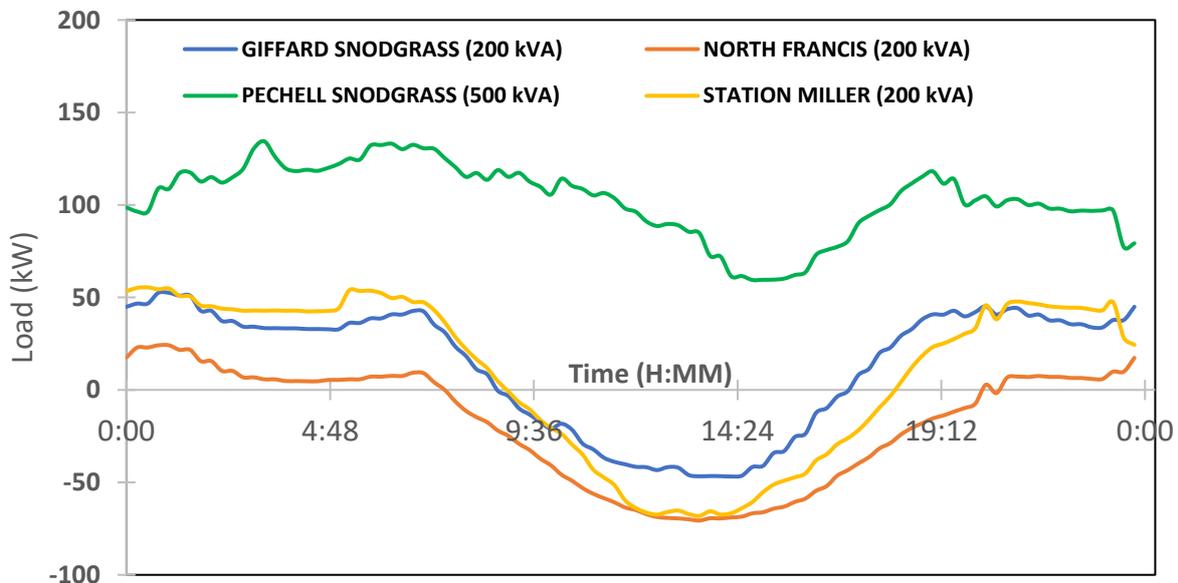
6. The solar-PV generation was forecasted assuming an annual solar-PV growth of 15% for 5 years and 10% for the next 5 years¹⁰. The following factors were applied to estimate solar generation for 5- and 10-year future time horizons:

- 5-year factor: **2.01**
- 10-year factor: **3.23**

7. Finally, the daytime net load was forecasted using the following formula:

$$\text{Forecasted daytime net load} = \text{Load Demand Forecast (Step-5)} - \text{Solar-PV forecast (Step-6)}$$

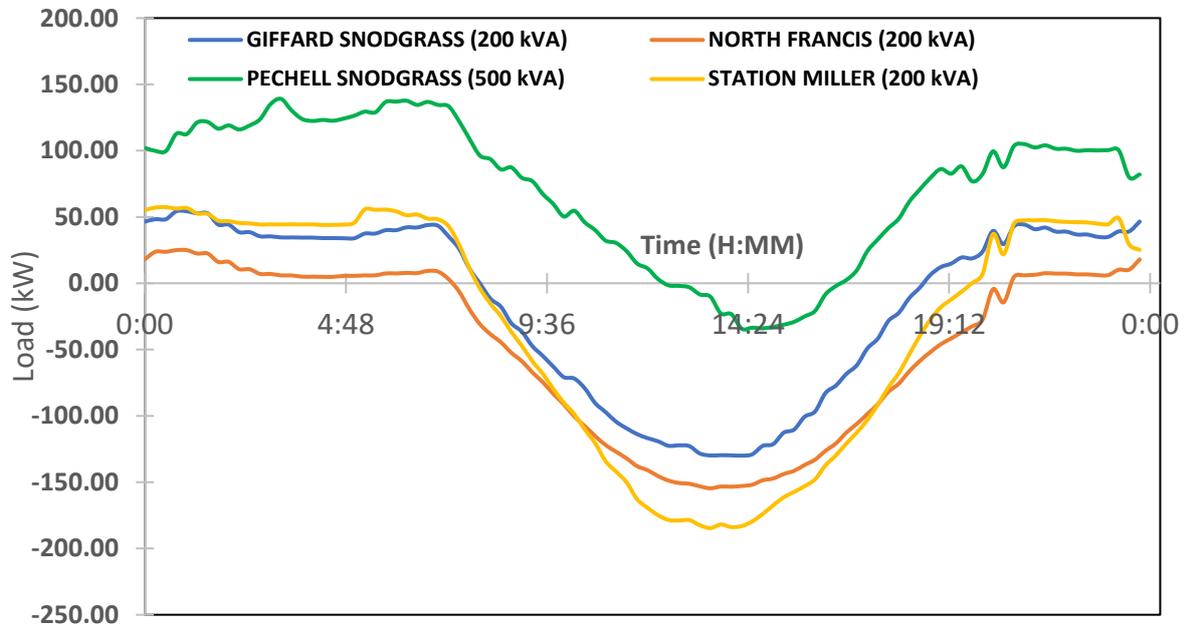
The procedure was followed to forecast each transformer's average net load profile across all seasons. The forecasted net load profiles for the transformers associated with four battery sites for the summer are shown in Figure 15.



(a)

⁹ EV load growth was not considered.

¹⁰ Yea has a 5-year average annual solar-PV growth of 18%, however as the growth rate reduces as the penetration increases, the lower growth was assumed when determining the 5 and 10 year growth factors.



(b)

Figure 15. The forecasted net load profiles for the transformers associated with four battery sites for the summer: (a) 5-year forecasted profile, (b) 10-year forecasted profile.

According to Figure 15, the annual solar-PV growth in Yea will push the net load profiles to the export region (i.e., power export to 22 kV network) during the daytime in summer.

7. Hosting Capacity Analysis and BESS Sizing for Potential Battery Sites

This section delineates the hosting capacity analysis and the BESS battery energy capacity analysis carried out for the potential battery sites in Yea. However, it must be noted that the Yea Racecourse/Golf Club and the Yea wastewater management facility are not analysed, since their net load profiles are not available for the study. Also, it is not possible to artificially synthesise their load profiles as they have unique operation characteristics. Therefore, the rest of the study was carried out for the remaining five potential battery sites in Yea.

7.1 Hosting Capacity Analysis of Battery Sites

The network capacity of potential battery sites is assessed by considering the thermal loading limits of 100% for the relevant local service cables, LV and MV supply feeders, and transformers, as well as the operating voltage limits of +10% and -6%. The maximum allowable battery capacity without breaching any of these limits is estimated for each potential site under the following two battery charging and discharging scenarios:

- **Worst-Case/Unlikely Scenario:** The battery charges when the local site or transformer load demand is High and discharges when local site/ transformer load demand is Low.
- **Favourable/Likely Scenario:** The battery charges when the local site / transformer load demand is Low and discharges when local site / transformer load demand is High.

The worst-case scenario, where battery charges during periods of high load demand and discharges during periods of low load demand, is less likely operating scenario for power/energy supply from the battery. However, it may be a possible scenario of other services, such as Frequency Control Ancillary Services (FCAS). The worst-case scenario estimates the time-unconstrained hosting capacity of the network for battery, implying that a battery of this capacity/rating can be charged and discharged at any time of the day.

The likely scenario, where battery charges during periods of low load demand and discharges during periods of high load demand, is the most probable and favourable operating scenario for power/energy supply from the battery. However, this represents a time-constrained hosting capacity, implying that a battery of this capacity/rating can only be charged/discharged during the specific times of the day, i.e., charges when load is low and discharges when load is high.

A series of quasi-dynamic simulations scenarios involving different capacities of battery, both in charge and discharge modes, are conducted to ascertain the maximum capacity of battery permissible in the network without violating the considered constraints. The results for both scenarios across different seasons are taken into account to establish indicative hosting capacities for each potential site.

7.1.1. Key Assumptions and Limitations:

The following are the key assumptions and limitations of the hosting capacity study:

- The hosting capacities are computed using hourly averaged net-load profiles for different seasons. Hence, these capacities are indicative and may not ensure compliance with network constraints on days when load data significantly varies from the considered average.
- The hosting capacities are determined for power/energy supply with unity power factor from the battery. These results may vary for specific operating strategies, services, and operating modes of the battery in practice.

7.1.2. Battery Hosting Capacity of Yea Railway Park

The load demand for the Yea Railway Park transformer (Station Miller - 200 kVA) is identical to the typical residential load profile for both summer and winter. In both seasons, the load demand is low during the day and high during the evening and mid-night hours, as shown in Figure 16.

The simulation results for the Yea Railway Park, showing allowable battery capacities under both worst-case and likely scenarios, are shown in Figure 16.

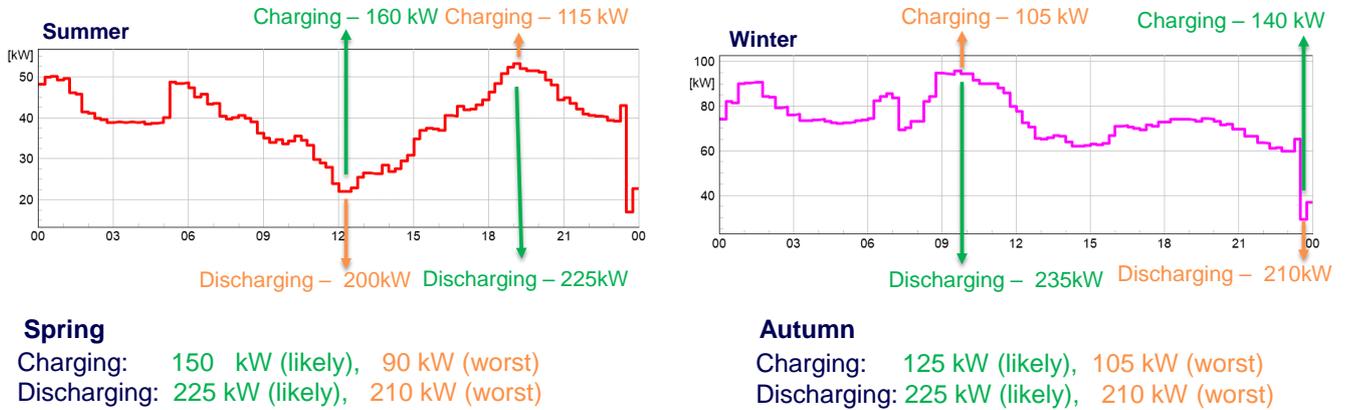


Figure 16. Simulations results showing seasons averaged load profiles for Yea Railway Park with allowable charge and discharge capacities of battery under worst and likely scenarios.

The primarily constraint for the Yea Railway Park site is found to be the thermal loading of the transformer (Station Miller - 200 kVA). The resulting battery hosting capacity for time-unconstrained charging and discharging is approximately 100 kW, and for time-constrained charging and discharging is approximately 140 kW. Specifically, this limit represents the maximum power at which the battery can be charged when the load is low, such as during mid-night in winter. Moreover, for this site network, voltage is identified as the secondary constraint after the transformer loading limit.

7.1.3. Battery Hosting Capacity of Yea Industrial Area

The load demand for the Yea Industrial Area transformer (North Francis - 200 kVA) is also identical to the typical residential load profile for both summer and winter. Notably, the peak demand occurs in the mid-night hours due to pre-set electric hot water systems. Overall, in both seasons, the net load demand is low during the day and high during the morning and evening, reaching its highest during mid-night, as shown in Figure 17.

The simulation results for the Yea Industrial Area, indicating allowable battery capacities under both worst-case and likely scenarios are shown in Figure 17.

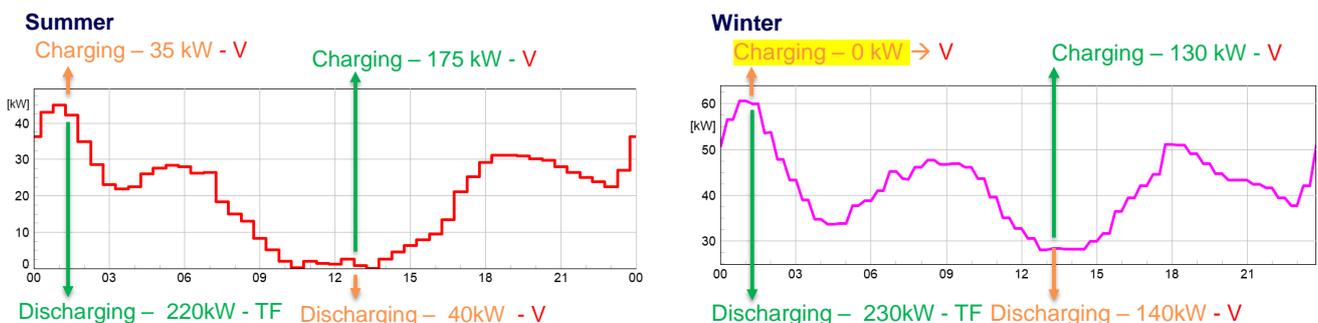


Figure 17. Simulations results showing seasons averaged load profiles for Yea Industrial Area with allowable charge and discharge capacities of battery under worst and likely scenarios.

The primarily constraint for the Yea Industrial Area site is identified to be the network operating voltage. The network voltage falls below threshold at base load during peak demand, thereby, preventing the battery from operating in charge mode at unity power factor. Consequently, the allowable time-unconstrained battery charge and discharge rate is 0 kW. However, the time-constrained charge and discharge rate is approximately 130 kW. This limit represents the maximum power at which battery can be charged when the load is low, typically around 15:00, both in summer and winter. This hosting capacity limit is constrained by both the lower operating voltage of the network and thermal limit of the supply transformer.

7.1.4. Battery Hosting Capacity of Yea Swimming Pool

The load demand for the Yea Swimming Pool is relatively constant throughout both summer and winter, with maximum difference of 5 kW between low and high peaks. However, the loading profile of the transformer serving this site (Giffard Snodgrass (200 kVA) is identical to the typical residential load profile for both seasons, exhibiting a high peak in the evening, as shown in Figure 18.

The simulation results for the Yea Swimming Pool, indicating allowable battery capacities under both worst-case and likely scenarios are shown in Figure 18.

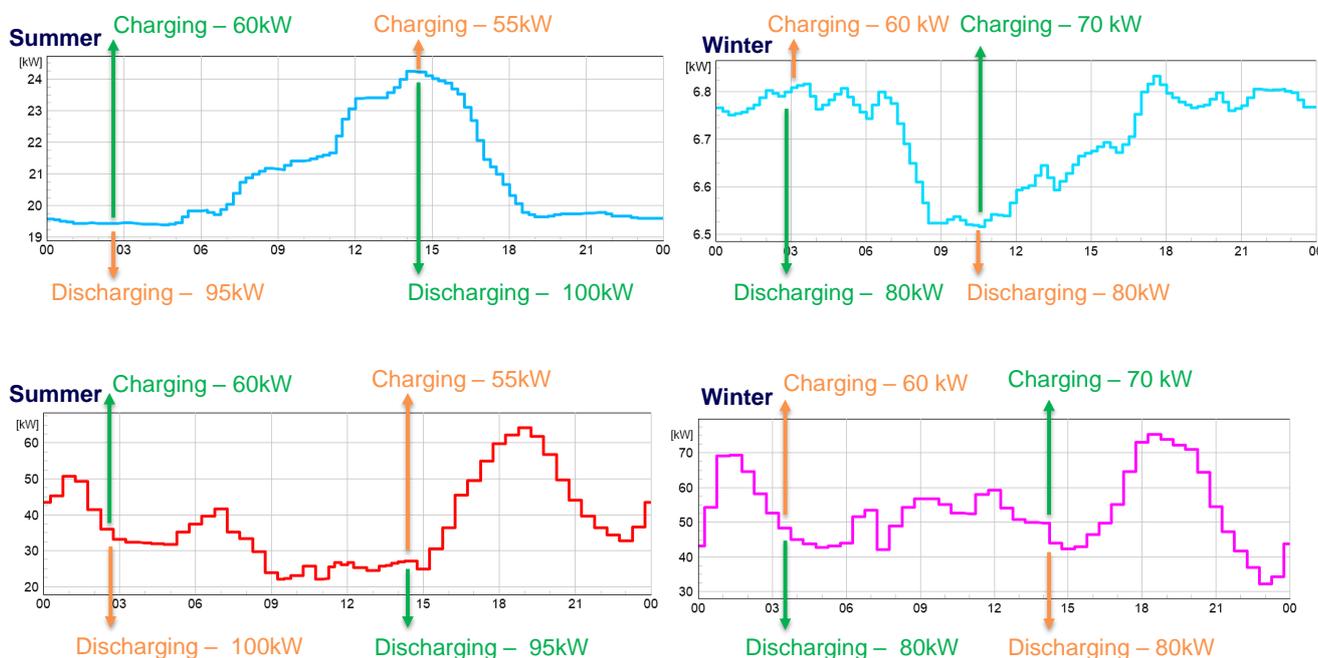


Figure 18. Simulations results showing seasons averaged load profiles for Yea Swimming Pool (top two plots) and Transformer serving swimming pool (bottom two plots), with allowable charge and discharge capacities of battery under worst and likely scenarios.

The primarily constraint for the Yea Swimming Pool site is identified as the local service cable. Due to the fairly constant load demand of the swimming pool, the resulting time-unconstrained charge and discharge rate of battery is approximately 50 kW. However, with the upgradation of the local service cable, this hosting capacity can potentially be increased to above 100 kW, based on the current loading of the transformer, as shown in the lower two plots in Figure 18.

7.1.5. Battery Hosting Capacity of Yea Recreation Reserve

Unlike other sites, the load demand for the Yea Recreation Reserve and the overall load demand of transformer (Pechell Snodgrass - 500 kVA) serving this site, exhibit a different profile, with a high peak observed during the day and low demand during the night, as shown in Figure 19.

The simulation results for the Yea Recreation Reserve, including allowable battery capacities under both worst-case and likely scenarios, are shown in Figure 19.

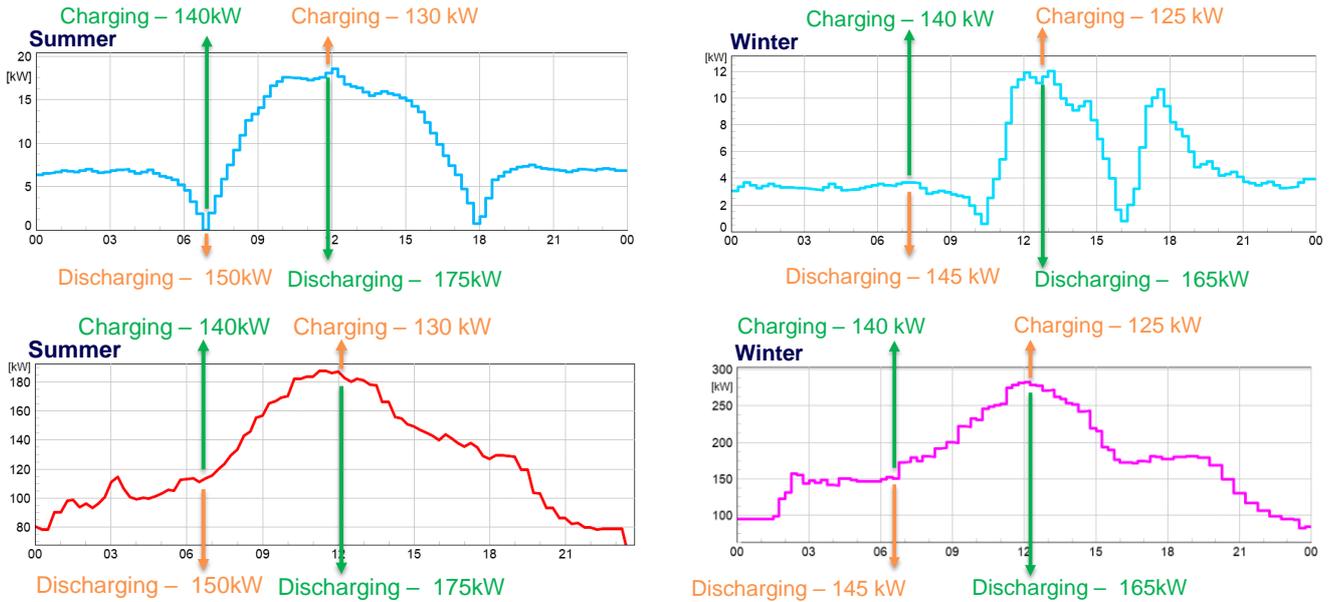


Figure 19. Simulations results showing seasons averaged load profiles for Yea Recreation Reserve (top two plots) and Transformer serving Recreation Reserve (bottom two plots), with allowable charge and discharge capacities of battery under worst and likely scenarios.

Similar to the Yea Swimming Pool site, the primarily constraint for the Recreation Reserve site is found to be the local service cable. The resulting time-unconstrained charge and discharge rate of battery is approximately 120 kW, based on the thermal loading constraint of the local service cable. However, with the upgradation of the local service cable, the hosting capacity for this site can potentially be increased to above 100 kW, considering the current loading of the transformer, as shown in the lower two plots in Figure 19.

7.1.6. Battery Hosting Capacity of Yea Saleyard

The Yea Saleyard is supplied from single-phase transformer and typically loaded above 50%, as shown in Figure 20. The resulting estimated battery hosting capacity for this site under different scenarios is constrained to 5 to 10 kW which is the typical size/capacity of household battery.

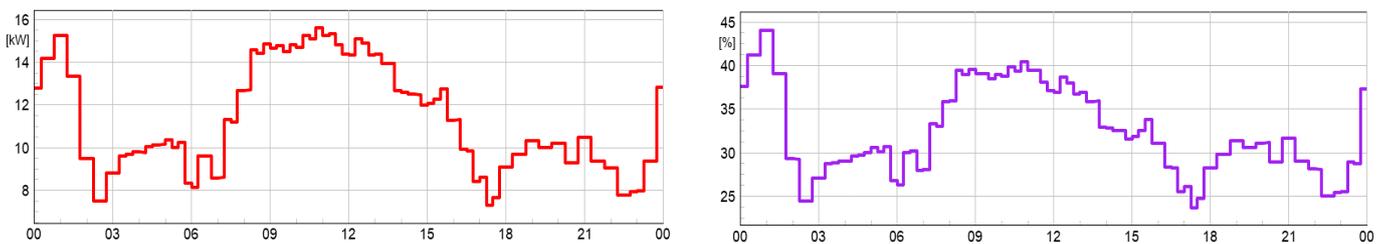


Figure 20. Simulations results showing seasons averaged load profiles for Yea Saleyard Transformer.

7.1.7. Battery Hosting Capacity of Yea Racecourse/Golf Club and Wastewater Management Plant

Hosting capacity analysis for these two sites is not conducted due to the unavailability of load demand data for these sites or the serving transformers.

7.1.8. Summary of Sites Battery Hosting Capacity

The following is the summary of the hosting capacity analysis for each site:

- **Yea Railway Park:** Time-unconstrained battery hosting capacity is 100 kW and time-constrained battery hosting capacity is 140 kW and it is primarily constrained by the transformer loading.
- **Yea Industrial Area:** Time-unconstrained battery hosting capacity is 0 kW and time-constrained battery hosting capacity is 130 kW and it is primarily constrained by LV network voltage.
- **Yea Swimming Pool:** Time-unconstrained battery hosting capacity is 50 kW, primarily constrained by the local service cable. Based on the existing transformer loading, a higher hosting capacity of 100 kW+ is achievable with a local service cable upgrade.
- **Yea Recreation Reserve:** Time-unconstrained battery hosting capacity is 125 kW, primarily constrained by the local service cable. Based on the existing transformer loading, a higher hosting capacity of 200 kW+ is achievable with a local service cable upgrade.
- **Yea Saleyard:** Time-unconstrained battery hosting capacity is 10 kW, primarily constrained by transformer loading. This is typical household battery size and may not be viable commercially.

7.2 Battery Operational Limits for Future Scenarios

In this section of the report, operational limits of battery are identified for future scenarios of load and solar PV system in the network. The net load profiles forecasted for 5 years and 10 years, as detailed in Section 6.3 above, are used to define these future scenarios. Based on this forecast, the net load demand for the Yea supply incoming feeder SMR14 is expected to be highly negative due to solar PV output during the day. According to simulation results shown in Figure 21, the net load for the supply incoming feeder is projected to be -2170 kW after 5 years and -4480 kW after 10 years.

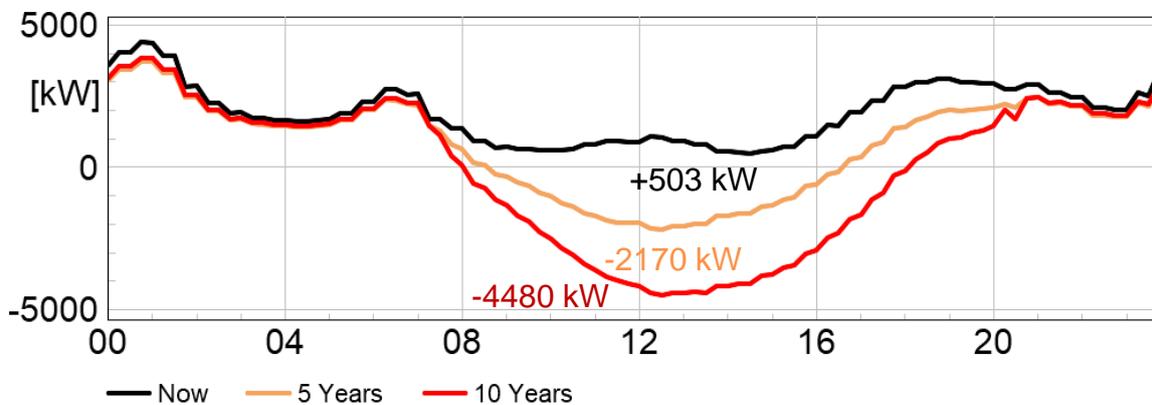


Figure 21. Simulations results showing net load of supply incoming feeder SMR14 after 5 years and 10 years.

The negative net load is anticipated to have a significant adverse impact on network operation. Specifically, the network voltage at all four battery sites exceeds the permissible threshold during periods of negative load, indicating the possibility of 0 kW time-unconstrained charge/discharge of the battery. Furthermore, these results also imply that user in Yea will be forced to significantly curtail their solar PV system. Therefore, this highlights the necessity for large placement and strategic operation of battery—charging during light load periods and discharging during heavy load periods. Consequently, simulation scenarios are conducted to estimate the indicative operational charge/discharge rate limits of the battery for future scenario of net load and transformer thermal ratings. The simulation results showing the battery operational limits for the four potential battery sites are shown in Figure 22 and the results are summarized as follows:

- **Yea Railway Park:** Time-constrained charge/discharge rate of battery can be 235 kW for both 5-year and 10-year scenarios.
- **Yea Industrial Area:** Time-constrained charge/discharge rate of battery can be 230 kW for both 5-year and 10-year scenarios.
- **Yea Swimming Pool:** Time-constrained charge/discharge rate of battery can be 230 kW for both 5-year and 10-year scenarios.
- **Yea Recreation Reserve:** Time-constrained charge/discharge rate of battery can be 400 kW for 5-year and 450kW for 10-year scenario.

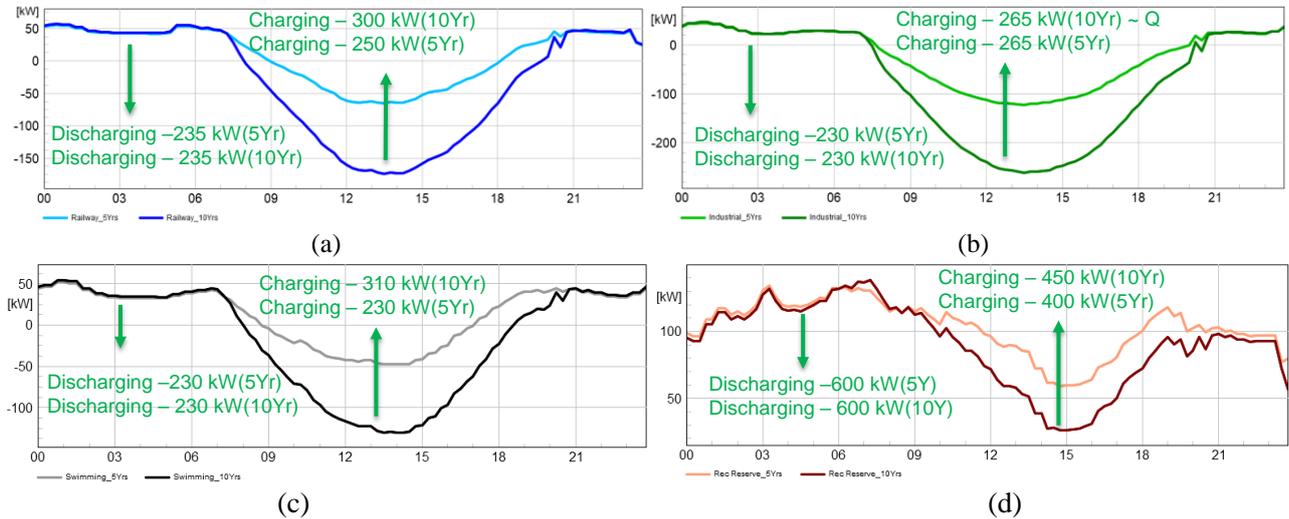


Figure 22. Simulations results showing time-constrained operational ratings of BESS based on transformer loading (a) Yea Railway Park (b) Yea Industrial Area (c). Yea Swimming Pool and (d). Yea Recreation Reserve.

In summary,

- Highly negative net load implies that management of network voltage will be a significant issue and user in Yea will be forced to significantly curtail their solar PV systems in future unless these issues is addressed, e.g. by large scale storage systems in the area.
- While the time-unconstrained charge/discharge rate of the battery is zero, it can still be charged at a rate higher than its respective transformer rating during periods of negative load in the network. Similarly, it can be discharged at a rate higher than the transformer rating during periods of high load demand in the network. Again, these higher limits highlight the opportunity to increase the battery capacity in future and ultimately leading to better management of network load and effectively utilise solar PV system.

7.3 BESS sizing for Battery Sites

The methodology shown in Figure 23 was adopted to determine the battery energy capacity and the battery inverter size for potential battery sites in Yea.

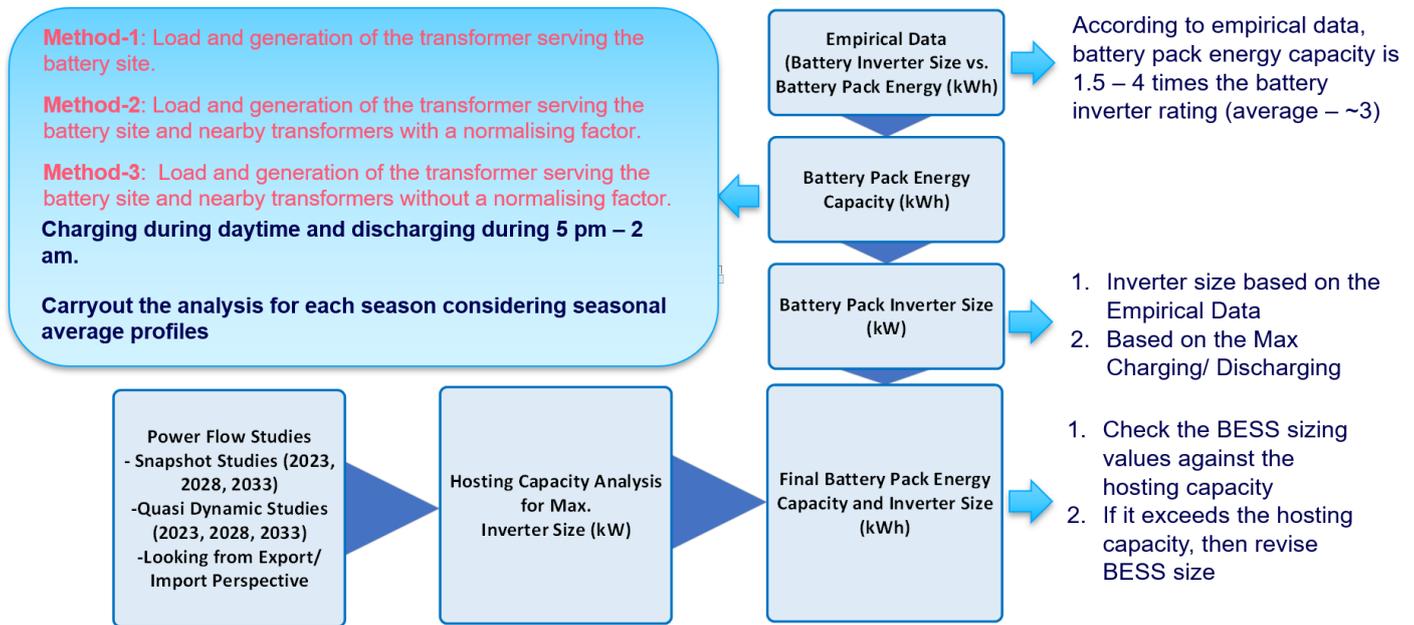


Figure 23. Battery sizing methodology.

The battery sizing process is designed with two major analytical processes; 1) Hosting capacity analysis and energy data analysis. The hosting capacity at each site was determined using quasi-dynamic simulation studies as delineated in Section 7.1. Those, hosting capacity constraints were applied when determining the inverter rating of the battery system.

The energy data extracted from the AusNet GridView portal was used to develop methodologies for battery energy capacity determination for potential battery sites. The following three methods are used to determine the battery energy capacity of potential sites:

- **Method-1:** Load and generation of the transformer serving the battery site.
- **Method-2:** Load and generation of the transformer serving the battery site and nearby transformers with a normalising factor.
- **Method-3:** Load and generation of the transformer serving the battery site and nearby transformers without a normalising factor.

Each method considers same charging and discharging strategy for the battery, however, load energy consumption and energy generation considered for sizing are different for each method. Method-1 considers only the load and generation of the transformer associated with the battery site. On the contrary, Method-2 and -3 considers net load of adjacent transformers as they are interconnected by the 22 kV network and hence their load and generation can directly influence the charge and discharge characteristics of the battery. For example, in Method-2 and -3 the load/generation profiles of the Oliver View (100 kVA) and Miller Court (200 kVA) transformers were also considered when determining battery energy capacity for Yea Railway Park battery system other than the net load profile of the main transformer (e.g. Station Miller (200 kVA)) of the site as shown in Figure 24. The normalisation factor applied in Method-2 is determined based on the ratio of the rating of the main transformer serving the battery to the rating of all considered transformers. This factor is used to determine the amount of energy considered for the battery sizing from the adjacent transformers.



Figure 24. Transformers considered for Yea Railway Park battery sizing under Method-2 and 3.

Also, it must be noted that the maximum charge/ discharge power at a given instance is constrained by the hosting capacity of the transformer where the battery system is connected. This will be taken into account when determining the final battery pack energy capacity and the inverter size.

The minimum state-of-charge of the battery is assumed as 20% in the sizing study¹¹. The following charging and discharging strategies/ timeframes were considered in the study:

- **Charging Time:** During day light time and this time varies from season to season. It is expected that the battery is fully charged between 10 am – 1 pm on a typical sunny day in each season.
- **Discharging Time:** Also, it is envisaged that the battery system is programmed to discharge between 5 pm to 2 am.

7.3.1 Sizing based on Current Demand and PV Generation Profiles

This section outlines the battery energy capacity and the inverter sizing for four battery sites. It must be noted that, the Yea Saleyard appears to have a smaller hosting capacity and a 2-phase supply. Therefore, the site infrastructure should be upgraded to host a large battery system. Considering these facts the Yea Saleyard was not considered in the battery sizing study. A summary of battery energy capacity and inverter rating for four battery sites are listed in Table 6¹².

¹¹ Most modern Li-Ion battery systems can be discharged up to 10%. However, the minimum SoC depends on the manufacturer and the battery technology. Hence, most widely accepted minimum SoC of 20% was adopted in the sizing study.

¹² The details of the battery sizing studies under each method are presented in Appendix E.

Table 6. Summary of battery energy capacity and inverter rating for four battery sites.

Site Name	Battery Pack Energy	Battery Inverter Rating	Hosting Capacity Constraint
Yea Railway Park	225 – 508 kWh	75 – 140 kW	140 kW (Transformer Constraint)
Yea Recreation Reserve (Front-of-the-Meter)	193 – 387 kWh	65 – 200 kW	200 kW (Transformer Constraint)
Yea Recreation Reserve (Behind-the-Meter)	109 kWh	36 – 45 kW	125 kW (LV Service Cable)
Yea Swimming Pool	161 - 538 kWh	54 – 100 kW	100 kW (Transformer Constraint)
Yea Industrial Area	162 -312 kWh	54 – 105 kW	130 kW (LV Voltage Constraint)

The battery pack energy capacities and inverter ratings are presented as a range in Table 6, since three different techniques have been used to calculate the battery size. Therefore, any battery capacity within the given range can be deployed for each site. Moreover, the inverter rating can also be selected accordingly to match with the energy capacity of the battery pack within the given feasible range in Table 6. Also, it must be noted that, except for the behind the meter battery scenario for Yea Recreation Reserve and the Yea Industrial Area, the inverter size of other sites is constrained by the hosting capacity constraint of the serving transformer. For example, 508 kWh battery pack is chosen for the Yea Railway Park, then the inverter rating should be 140 kW to obtain the maximum benefit from the battery system.

7.3.2 Sizing based on Future Demand and PV Generation Profiles

The sizing studies have been carried out to determine the possibilities to expand the battery system in future timeframes. The forecasted net load profiles (based on the methodology outlined in Section 6.3) have been used for the battery sizing. Table 7 shows the future battery pack energy capacity potential for each four sites in Yea. It must be noted that behind the meter option was not considered for the Yea Recreation Reserve site.

Table 7. Battery pack energy capacity based on the forecasted profiles.

Site Name	Battery Pack Energy (5 Year Forecast)
Yea Railway Park	508 – 1097 kWh
Yea Recreation Reserve (Front-of-the-Meter)	380 – 913 kWh
Yea Swimming Pool	426 - 1373 kWh
Yea Industrial Area	271 – 562 kWh

According to Table 7, it the solar-PV uptake continues with an annual increase of 18%, the battery pack energy capacity can be doubled in 5 years timeframe. However, a decrease in solar-PV uptake was seen in 2023.

8. Islanded Operation

In this section, a few basic islanded operating scenarios are simulated for the Yea Railway Park and Yea Industrial Area sites. These simulation scenarios aim to demonstrate power balance within the islanded system and showcase improved operating voltage compared to current grid-connected scenarios.

8.1. Yea Railway Park

The Yea Railway Park is supplied via a 200 kVA transformer “Station Miller”. The entire substation and associated loads are islanded on the secondary side of this transformer. The geographical boundary and simulation model of the Yea Railway network considered for the islanded operation are shown in Figure 25(a) and (b), respectively. The summary of the current net load, considered additional solar PV and battery system is as follows:

- Peak Load: 55 kW
- Additional solar PV: 150kW
- Battery Rating: 140 kW

The simulation results showing power balance in the network during islanded operation are given in Figure 26 (a). The surplus power produced by the solar PV system during the day is stored in battery, which is then used to meet the load demand during the evening and night. The Yea network operating voltage under the current grid-connected operation and during islanded operation when battery forms the grid is shown in Figure 26 (b). The results show that the network voltage can be maintained within a narrow range as compared to the significant variation observed under the current grid-connected scenario.

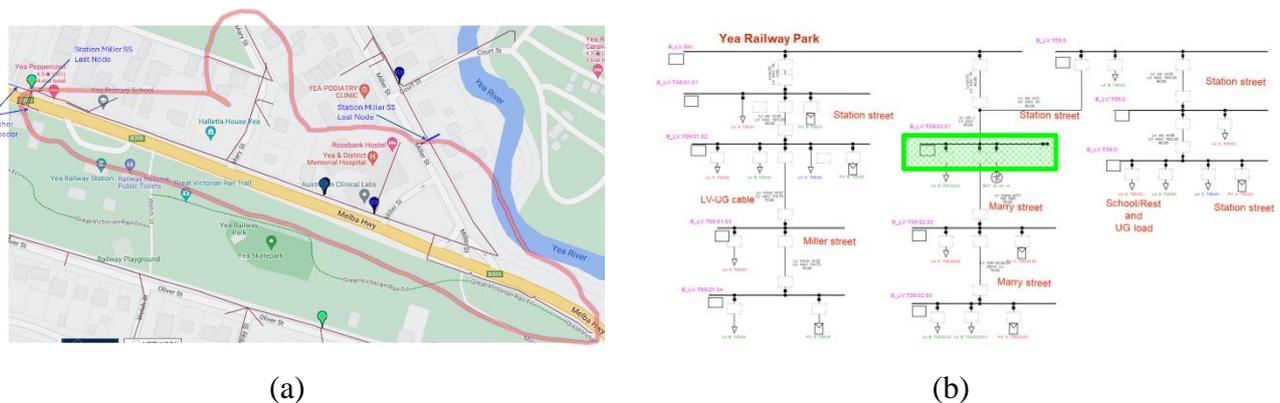


Figure 25. Yea Railway network considered for islanded operation (a) Geographical boundary (b). Simulation model.

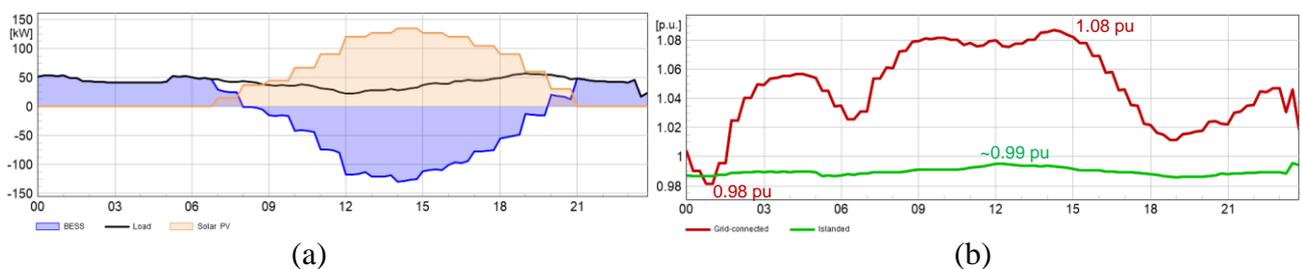


Figure 26. Simulation results showing (a) power balance during islanded operation (b). network voltage during grid-connected operation and islanded operation of Yea Industrial Area.

8.2. Yea Industrial Area

The Yea Industrial Area is supplied by a 100 kVA transformer named “Grevillea Street”. Entire substation and associated loads are islanded on the secondary side of this transformer. The geographical boundary and simulation model of the Yea Industrial Area network considered for the islanded operation are shown in Figure 27 (a) and (b), respectively. The summary of the current net load, considered additional solar PV and battery system is as follows:

- Peak Load: 25 kW
- Additional solar PV: 50 kW
- Battery Rating: 100 kW

The simulation results showing power balance in the network during islanded operation are given in Figure 28 (a). The surplus power produced by the solar PV is stored in battery, which is then used to meet the load demand during the evening and night. The Yea Industrial Area network operating voltage under the current grid-connected operation and during islanded operation when battery forms the grid is shown in Figure 28 (b). The results show that the network voltage can be maintained within a narrow range as compared to the current grid-connected scenario.

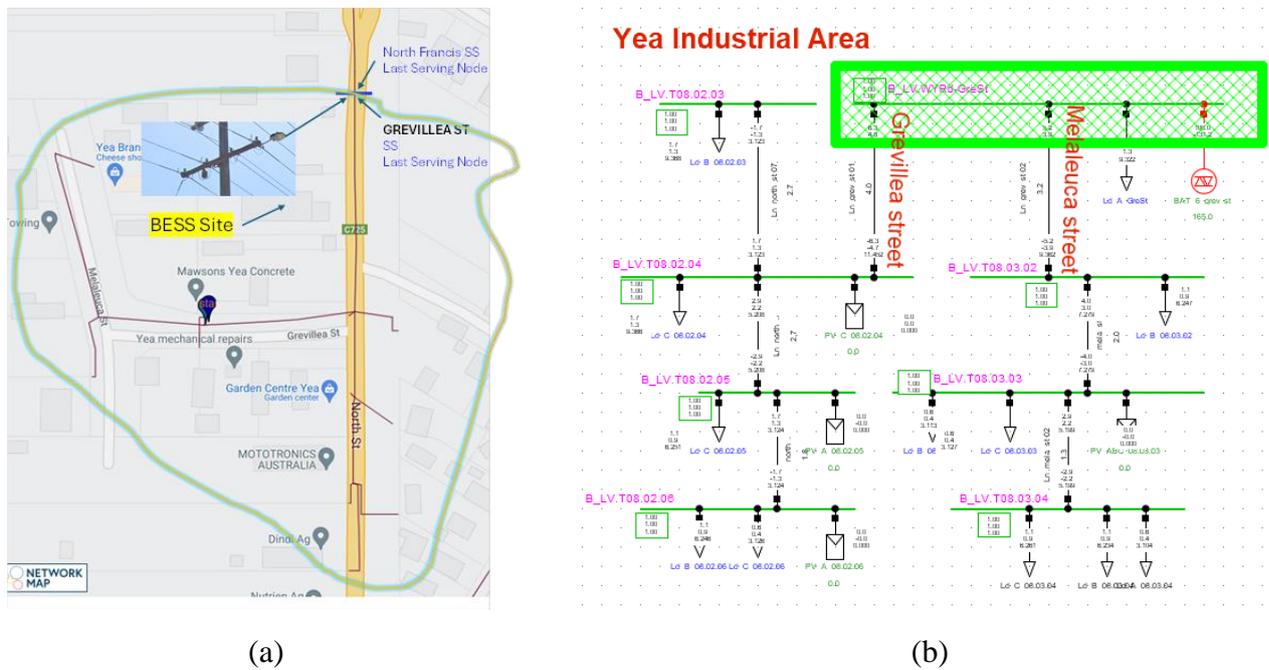


Figure 27. Yea industrial area network considered for islanded operation (a) Geographical boundary (b). Simulation model.

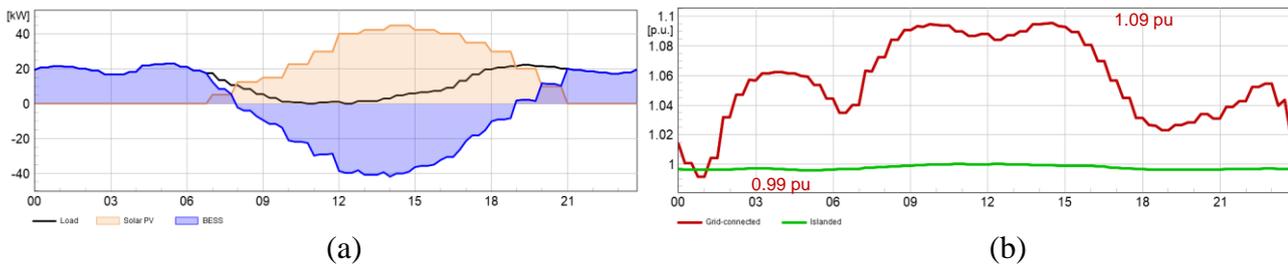


Figure 28. Simulation results showing (a) power balance during islanded operation (b). network voltage during grid-connected operation and Islanded operation of Yea Industrial Area.

9. Battery Support Services and Benefits

This section of the report explores the potential benefits of community batteries in providing support services. The focus is on two key areas: peak load shaving and voltage regulation.

Peak Loading Shaving: Community battery can be strategically charged during periods of low demand from solar PV system and supply local loads during periods of high load demand. This approach helps alleviate network congestion issue by reducing the peak load of the system.

Voltage Regulation: Community battery can help improve network voltage in its typical operating mode discussed above. Additionally, battery can be operated in voltage regulation mode to actively manage and significantly improve voltage in the local network.

The impact of community batteries of typical sizes/capacities, calculated in Sections 7.1 and 7.2, are used to quantify the potential benefits for improving network operating voltage and managing peak loads.

9.1. Impact on Network Voltage

The potential to regulate network voltage is assessed for following scenarios of battery capacities:

- Yea Swimming Pool 100 kW
- Yea Industrial Area 130 kW
- Yea Railway Park 140 kW
- Yea Recreation Reserve 200 kW

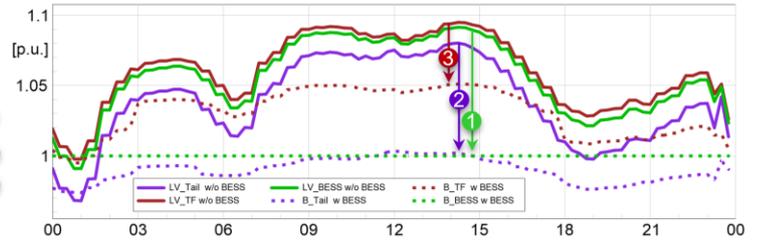
The analysis is conducted for each site individually. The battery operating scenario is set to charge during periods of low demand, i.e., daytime, and discharge during high demand, i.e., the night hours. Moreover, the battery operating mode is set to voltage regulation at its local node/terminal.

The simulation results, showing the network voltage both without and with the battery at all four potential battery sites, are presented in Figure 29. The extent of indicative voltage improvement for each network is also summarised. In summary,

- **Yea Railway Park:** Voltage can be regulated to a nominal value at the battery terminal and improved in the neighbourhood/the same feeder by up to 8% and on the transformer LV side by up to 5%.
- **Yea Industrial Area:** Voltage can be regulated to a nominal value at the battery terminal and improved in the neighbourhood/the same feeder by up to 9% and on the transformer LV side by up to 0.7%.
- **Yea Swimming Pool:** Voltage can be regulated to a nominal value at the battery terminal and improved on the transformer LV side by up to 3.1%.
- **Yea Recreation Reserve:** Voltage can be regulated to a nominal value at the battery terminal and improved on the transformer LV side by up to 2.8%.

Overall, the analysis revealed that batteries of the considered rating, while operating in specific mode, can significantly improve user voltage. However, the benefits are more pronounced on the same feeder, although other users served by the same substation are benefited too.

Location	Voltage w/o BESS (pu)	Voltage w/ BESS (pu)	ΔV (%)
BESS Bus	1.091	1	9%
LV Feeder Tail End	1.08	1	8%
Transformer LV Side	1.094	1.05	5%



Location	Voltage w/o BESS (pu)	Voltage w/ BESS (pu)	ΔV (%)
BESS Bus	1.094	1	9.4%
Transformer LV Side	1.097	1.09	0.7%



Location	Voltage w/o BESS (pu)	Voltage w/ BESS (pu)	ΔV (%)
BESS Bus	1.087	1.006	8.1%
Transformer LV Side	1.094	1.063	3.1%



Location	Voltage w/o BESS (pu)	Voltage w/ BESS (pu)	ΔV (%)
BESS Bus	1.087	1.00	8.7%
Transformer LV Side	1.088	1.060	2.8%



Figure 29. Simulations results showing network voltage at different terminals with and without battery and summary of voltage improvement for (a). Yea Railway Park, (b). Yea Industrial Area, (c). Yea Swimming Pool, (d). Yea Recreation Reserve.

9.2. Impact on Supply Incoming Feeder Loading

According to DNSP report¹³, the supply incoming feeder is operating at its fully capacity, as discussed in Section 5 of this report. Therefore, impact of community battery on the loading of supply incoming feeder is analysed for each potential site individually. The following battery capacity scenarios are considered in this analysis:

- Yea Swimming Pool 100 kW
- Yea Industrial Area 130 kW
- Yea Railway Park 140 kW
- Yea Recreation Reserve 200 kW

¹³ AusNet Services, “Distribution Annual Planning Report 2022-2026”, June 2022.

The simulation results showing the loading of supply incoming feeder with and without battery at each site is presented in Figure 30.

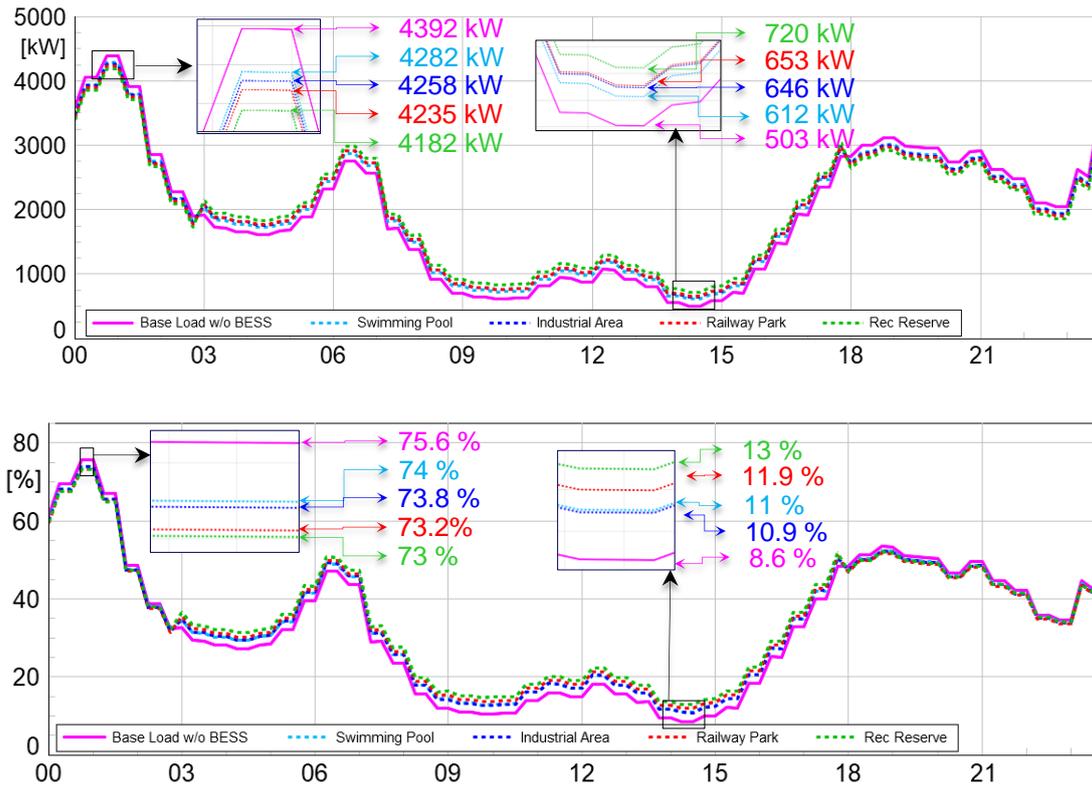


Figure 30. Simulations results showing loading (kW in top plot and % in bottom plot) of supply incoming feeder SMR14 without and with battery at each potential site.

As shown from the simulation results, the community battery can have a direct and determinantal impact on the overall network loading, particularly in peak load shaving. This is attributed to the battery being charged during low-demand periods and discharged during high-demand periods, thereby alleviating stress on the supply feeder. The result shows that a battery of approximately 200 kW can reduce network loading by up to 3% on the incoming feeder SMR14 during high peak load, while it may increase loading on the same feeder by up to 4.4% during low peak load due to load shifting. This increase at low loading shows that batteries will be instrumental in managing the negative load issue in future.

9.3. Frequency control ancillary services from BESS

The FCAS is procured typically only for a limited duration of the day. The FCAS can be obtained from battery systems proposed for YEA with a proper operational planning. During the FCAS provision period, it is essential for the battery storage system to have sufficient energy capacity, inverter capacity, and transformer capacity to provide FCAS. Therefore, the battery control system should be designed to manage an optimal reserve capacity to provide FCAS to grid, and also additional optimisation should be done on regular basis based on the weather and demand forecasts to maximise the revenue from both the energy arbitrating and FCAS.

10. Study Recommendations

The study was started with seven potential battery sites for Yea informed by the Indigo Power and 2030Yea group. The network study team has progressively ruled out three sites considering various practical and operational constraints. Therefore, study team has finally determined battery sizes for four potential battery sites. In addition, the study team has conducted a network benefit analysis and an islanded operation study for two sites. The main recommendations are summarised below:

- The four potential battery sites (Yea Railway Park, Yea Recreation Reserve, Yea Swimming Pool, Yea Industrial Area) are viable for hosting a community/ neighbourhood battery per the analysis. Anyway, battery size within the range given in Table 6 deemed viable based on the existing solar-PV generation and load demand.
- Among these four sites, Yea Railway Park and Yea Recreation Reserve are the most viable sites due to following facts:
 - The transformers have sufficient spare capacity to host a battery system. For example, the Station Miller (200 kVA) transformer (Yea Railway Park) has a hosting capacity of 140 kW and the Pechell Snodgrass (500 kVA) transformer (Yea Recreation Reserve) has a hosting capacity of 200 kW.
 - Significant solar PV generation is connected to the transformers of both sites and hence the battery systems can be charged from the local generation during the daytime without importing power from the main grid. This would also help regulate the LV feeder voltages under high PV generation.
 - Yea Railway Park site is within the vicinity of the Yea & District Memorial Hospital and other medical related facilities. This uplifts its importance as a candidate site for a microgrid. The energy balancing study also proves the viability of islanding this site. Therefore, by hosting a neighbourhood battery at this site, it can be upgraded with additional hardware in future to facilitate islanding operation (microgrid operation). Thus, it will enhance the reliability of the electricity network supplying the critical loads in Yea.
- Battery system of estimated rating and capacity in Yea would help mitigate the anticipated capacity bottlenecks (e.g. SMR 14 Feeder) to an extent and can significantly improve user voltage, particularly those fed by the same feeder and substation. For example, hosting a battery at the Yea Railway Park (140 kW/ 508 kWh) would help reduce the main incoming feeder (SMR 14) peak load by 2.4%. The Yea Recreation Reserve battery system (200 kW/ 387 kWh) can reduce the main incoming feeder (SMR 14) peak load by 3%.
- Anticipated high negative net load in future implies that management of network voltage will be a significant issue, and prosumers in Yea may be forced to significantly curtail their solar PV output unless these issues are timely addressed, e.g. by installing a large-scale storage system in the area. Moreover, analysis shows that the future operational limits of batteries will be significantly high for the same network, highlighting the need for a higher-rating inverter and high-capacity batteries in future to manage high and low peak demand and voltage in the network.
- It is recommended to analyse the yearly extreme profiles (i.e., max demand and maximum solar-PV generation) when conducting battery operation studies. Therefore, additional control mechanisms can be implemented at the battery system to avoid undesirable operating conditions.
- The islanded operation (microgrid mode) can be achievable for Yea Railway Park and Industrial Area with some additional solar-PV capacity (150 kW for the Yea Railway Park and 50 kW for Yea Industrial Area) and appropriate control and management systems for microgrids.

Appendix-A: Electrical Infrastructure in Potential Battery Sites

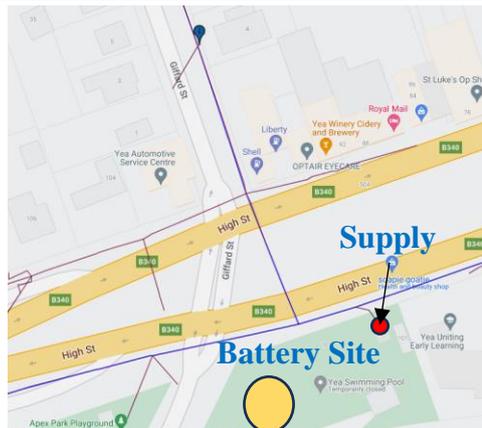
The representatives from Indigo Power, RMIT, 2030Yea Community Group, and the Murrindindi Council visited the potential battery sites on 17th November 2023. The purpose of the site visit is to observe the electrical infrastructure at these sites and identify a feasible location for constructing the battery system within the site. In addition, the team made general observations on the electrical distribution infrastructure available at those sites. This section outlines the key findings and observations the site visit team made.

A.1 Yea Swimming Pool

The Yea Swimming Pool is supplied by a 400 V (L-L) three-phase supply. The supply switchboard has a three-phase 63 A Type C Circuit Breaker (CB). The site also has three water pumps each supplied through a 3-phase 40 A CB in addition to other general loads (e.g., lighting). The site is considered for a behind-the-meter battery system and the battery is to be located at the corner of High Street and Melbourne Road. Therefore, the existing main switchboard should be relocated to the battery site, which is currently located at the front entrance (at the High Street side) of the Yea Swimming Pool.

Table 8. Yea Swimming Pool Site Information

Site Name	Site Address	In Front Meter	Behind the Meter	Host Site Owner	Distribution Substation
Yea Swimming Pool	101 HIGH STREET YEA 3717	Y	Y	Murrindindi Council	GIFFARD SNODGRASS (200 kVA)



Since this site is proposed to have a behind-the-meter battery system, the RMIT study team requires the following data to carry out the technical study:

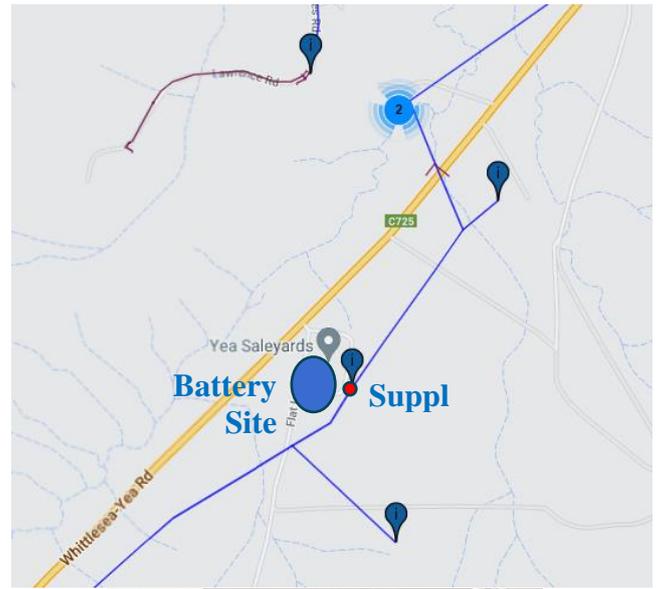
- Swimming Pool Smart Meter Data for the last three years including 2023. Also, the data from pre-COVID year (e.g., 2019) would be helpful in making an accurate assessment of load behaviour at the site.

A.2 Yea Saleyards

This is another site owned by the Murrindindi Council. The site has a 22/2×0.24 kV 50 kVA 2-phase transformer and a backup generator. Access to a three-phase supply is one of the major concerns for this site as the battery charging or discharging may cause a significant imbalance in the Yea supply system. However, a two-phase battery system configuration (battery units with single-phase inverters) is still possible. The site will be assessed for the front-of-the-meter and behind-the-meter battery systems.

Table 9. Yea Saleyards Site Information

Site Name	Site Address	In Front Meter	Behind the Meter	Host Site Owner	Distribution Substation
Yea Saleyards	1 Flat Lead Rd, Yea VIC 3717	Y	Y	Murrindindi Council	WHITTLESEA RD 15 (50 kVA) - 2 Phase Supply



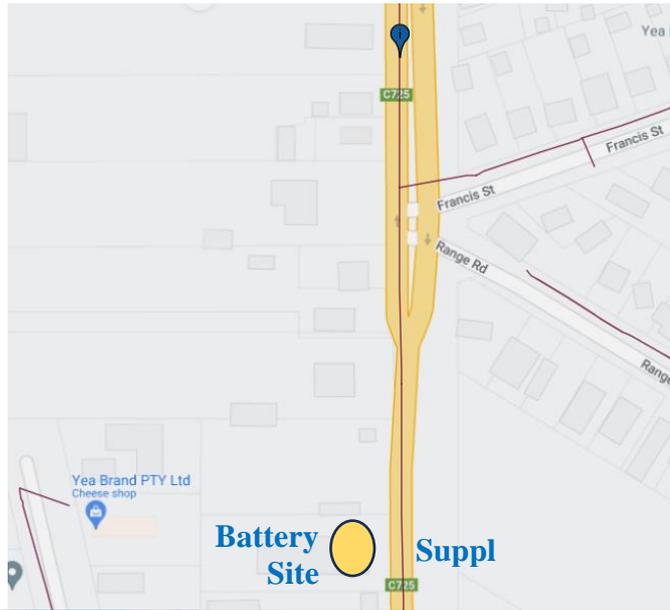
- To carry out the technical feasibility assessment, the study team requires the site's smart meter data (last three years including 2023 and one pre-COVID year, e.g., 2019).

A.3 Yea Industrial Area

The proposed battery site is located within the work depot of the Murrindindi Shire Council. The existing supply system is too old to be utilised for the proposed community battery system. Due to the abundant space and its proximity to the Yea city centre, this site is proposed as an in-front-of-the-meter battery site with the option to upgrade the battery system to facilitate a microgrid in the future.

Table 10. Murrindindi Shire Council Work Depot Site Information

Site Name	Site Address	In Front Meter	Behind the Meter	Host Site Owner	Distribution Substation
Yea Industrial Area	20 NORTH STREET YEA 3717	Y	N	Murrindindi Council	NORTH FRANCIS (200 kVA)

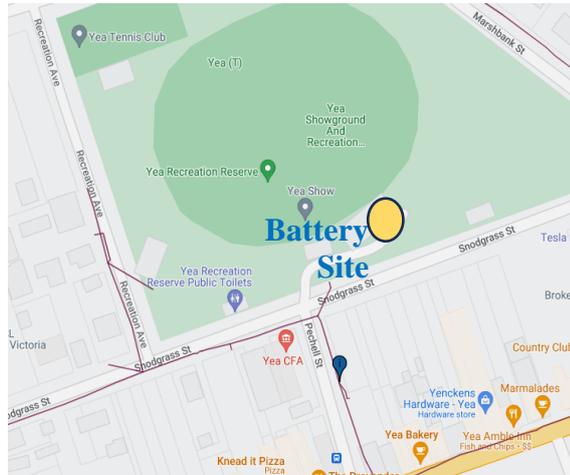


A.4 Yea Recreation Reserve

The Yea Recreation Reserve is a highly recommended battery site due to its significance in the Yea disaster management plan. This site is also owned by the council and is proposed for a behind-the-meter battery system. The site has a 22 kW solar-PV capacity and a 15 kW/48 kWh battery system (3×5kW SP-Pro inverters and 12×4kWh Eco4940 battery modules). The switchboard is supplied by a 4×50mm² XLPE cable from the pole located near the front entrance of the Yea Recreation Reserve. The main switchboard is comprised of 3P 80A 10kA CB, and the site also has a backup generator.

Table 11. Yea Recreation Reserve Site Information

Site Name	Site Address	In Front Meter	Behind the Meter	Host Site Owner	Distribution Substation
Yea Recreation Reserve	20 Snodgrass St, Yea VIC 3717	Y	Y	Murrindindi Council	PECHELL SNODGRASS (500 kVA)



Since this site is proposed to host a behind-the-meter battery system, the study team requires the following data to carry out the technical study:

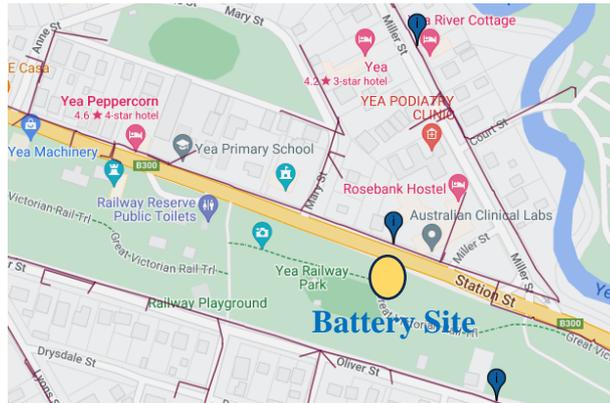
- Yea Recreation Reserve Smart Meter Data for the last three years including 2023. Also, the data from pre-COVID year (e.g., 2019) would be helpful in making an accurate assessment of load behaviour at the site.

A.5 Yea Railway Park

The railway park is one of the heritage sites in Yea, and this site was proposed for constructing a front-of-the-meter battery system. Since the battery is closer to the Yea hospital, it has the potential to develop into a microgrid to maintain supply continuity under emergency conditions. Due to the geographic spread of the battery site, there are two options for battery connection. However, following the site visit, the team determined it should be constructed closer to the Station Miller 22/ 0.433 kV 200 kVA transformer.

Table 12. Yea Railway Park Site Information

Site Name	Site Address	In Front Meter	Behind the Meter	Host Site Owner	Distribution Substation
Yea Railway Park	22-24 STATION STREET YEA 3717	Y	N	Murrindindi Council	STATION MILLER (200 kVA)



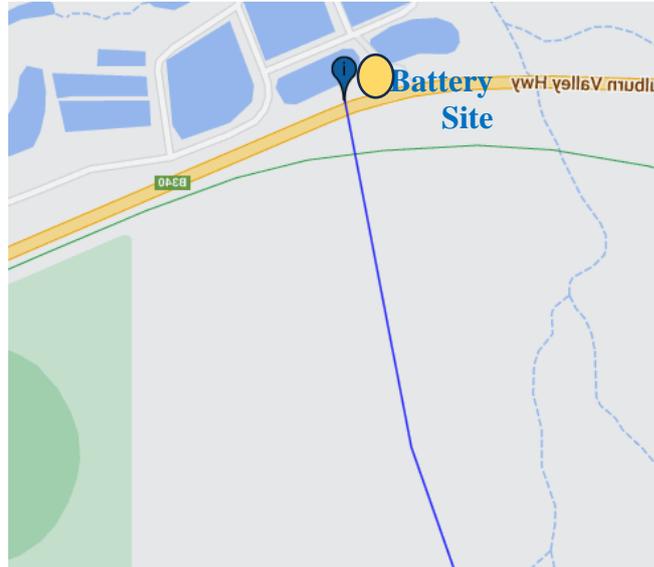
Since this is a front-of-the-meter battery site, the technical study team will develop a detailed 400 V LV model for this site.

A.6 Yea Waste Water Management Facility

This site is supplied by a 22/0.433 kV 50 kVA 3-phase transformer and is owned by GM Water. The site will be assessed for its feasibility to host either an in-front-of-the-meter or the behind-the-meter battery system.

Table 13. Yea Waste Water Management Facility Site Information

Site Name	Site Address	In Front Meter	Behind the Meter	Host Site Owner	Distribution Substation
Yea Waste Water Management	5976 Goulburn Valley Hwy	Y	Y	GM Water	SEWER 2 (50 kVA)



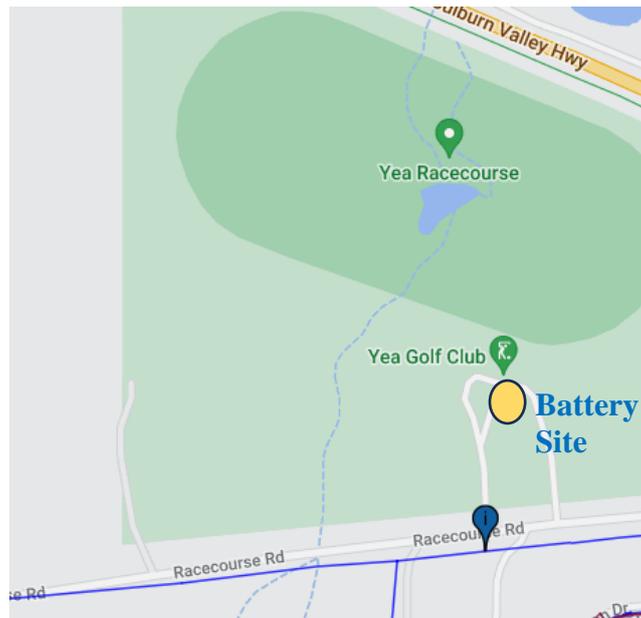
To carry out the technical feasibility assessment, the study team requires the site's smart meter data (last three years including 2023 and one pre-COVID year, e.g., 2019).

A.7 Yea Racecourse/Golf Club

This site is supplied by a 22/0.433 kV 50 kVA 3-phase transformer and is owned by the Murrindindi Council. The site will be assessed for its feasibility to host either an in-front-of-the-meter or the behind-the-meter battery system.

Table 14. Yea Racecourse/Golf Club Site Information

Site Name	Site Address	In Front Meter	Behind the Meter	Host Site Owner	Distribution Substation
Yea Racecourse/Golf Club	98 RACECOURSE ROAD YEA 3717	Y	Y	Murrindindi Council	YEA SMR 300 (50 kVA)



To carry out the technical feasibility assessment, the study team requires the site's smart meter data (last three years including 2023 and one pre-COVID year, e.g., 2019).

Appendix-B: Transformer Rating and Installed Solar-PV Capacity

Table 15. Yea Transformer Rating and Installed Solar-PV Capacity

Transformer ID	Name Plate Rating (kVA)	Installed Solar PV Capacity
SEWER 2	50	0
YEA SMR 307E	10	5
YEA SMR 301E	10	10
YEA SMR 300	50	10
ROYCROFT MORGAN	200	70
MULQUEENY CLARENCE	300	170
LAWRENCE RD 2	315	40
LAWRENCE RD 2A	63	30
YEA SPRINGS HAMILTON	315	35
LAWRENCE RD 4	25	10
LAWRENCE RD 5	50	5
LAWRANCES RD 7	50	30
YEA SMR 296	50	10
YEA SMR 295	10	10
PURCELL 3	25	0
PURCELL 4	10	0
NORTH FRANCIS	200	75
GREVILLEA ST	100	70
LV CAP NORTH 6	N/A	N/A
WHITTLESEA RD 7	10	5
WHITTLESEA RD 10E	10	5
WHITTLESEA RD 11	10	5
WHITTLESEA RD 12E	10	10
WHITTLESEA RD 15	50	0
WHITTLESEA RD 17E	16	10
WHITTLESEA RD 22E	10	0
RANGE ROAD P283	315	85
YEA SMR 276	100	60
YEA SMR 269	100	30
SMITH VIEW	100	70
FRANCIS ST	200	80
HOCKING ABECKETT	300	125
RAGLAN EAST	100	80
PARADE MEARA	200	90
RATTRAY LYONS	200	35
RATTRAY-OWEN	200	20
MILLER COURT	200	105
STATION MILLER	200	105
OLIVER VIEW	100	25
YEA WATERTRUST	100	0
GREY GUM 1E	25	20
MEADOW 3	25	10
GREY GUM 3	50	15
GREY GUM 4	25	10
HOOD SNODGRASS	500	90
HOOD MARSHBANK	500	0
GIFFARD SNODGRASS	200	75
PECHELL SNODGRASS	500	90
CRAIGIE-PECHELL	50	15
CRAIGIE ST 8	50	10
CRAIGIE ST 12 & 14	10	0
CRAIGIE ST 16E & 17& DRY5 2	100	15

Appendix-C: Model Validation and Results

Scenario 1: Model validation based on the maximum yearly average loading of the transformers.

Under this scenario, the developed network model is validated using the maximum loading of the transformers captured from the yearly average loading profiles. The following approaches have been used to determine the appropriate loading points in the network.

1. **Aggregated load points:** Maximum loading values (in kW) have been determined from the yearly average loading profiles of the transformers. Active power dispatch from solar PV generators is maintained at zero as the net load profiles of the transformers are considered.
2. **Lumped load points:** For the five lumped load points used in the network model, the loads have been estimated based on the loading of all the transformers connected to the downstream of the distribution feeder.
3. **Load points in the Industrial area and the Railway Park:** Since the load points are modelled in detail for these two sites, loading values have been determined based on the number of houses connected to each transformer associated with each site.

Furthermore, when analysing the network, the maximum charging is assumed for the 15 kW/ 48 kWh BESS at the Recreation Reserve. This assumption ensures the network is analysed under worst possible scenario. After updating the loading points of the network as mentioned above, load-flow studies have been performed, and the critical parameters have been analysed to validate the developed network model. Figure 31 represents the primary-side voltages (i.e. MV voltages) of the transformers under scenario 1.

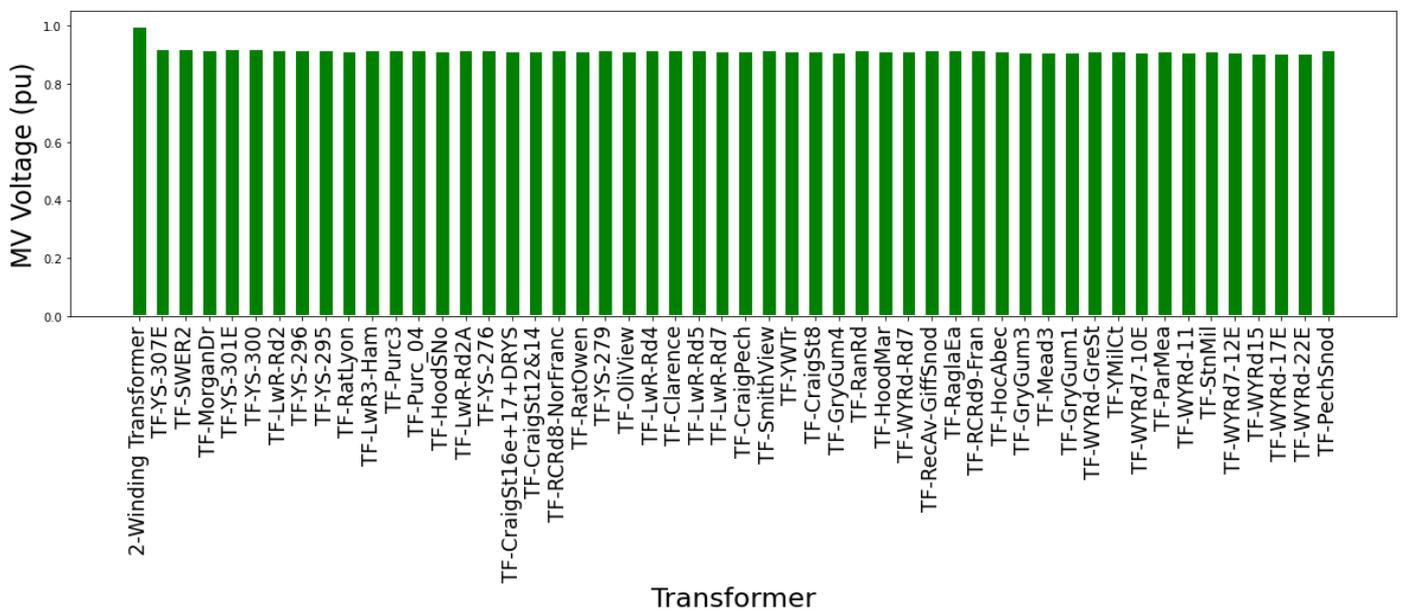


Figure 31. Voltage magnitudes (in pu) of the transformers' primary side under Scenario 1.

To validate the developed network model under the worst loading conditions, maximum loading of all the transformers is assumed to occur at the same time. According to Figure 31 the captured MV voltages fall within 0.91-0.92 pu which is within the standard limits stipulated in Victorian Electricity Distribution Code (VEDC) of Practice¹⁴ for MV (adopted from AS 61000.3.100). Inadequate voltage management capability of the network is also identified as a primary factor for the captured low voltage values.

¹⁴ <https://www.esc.vic.gov.au/electricity-and-gas/codes-guidelines-and-policies/electricity-distribution-code-practice>

The captured LV voltages from the transformers from the load flow study are represented in Figure 32.

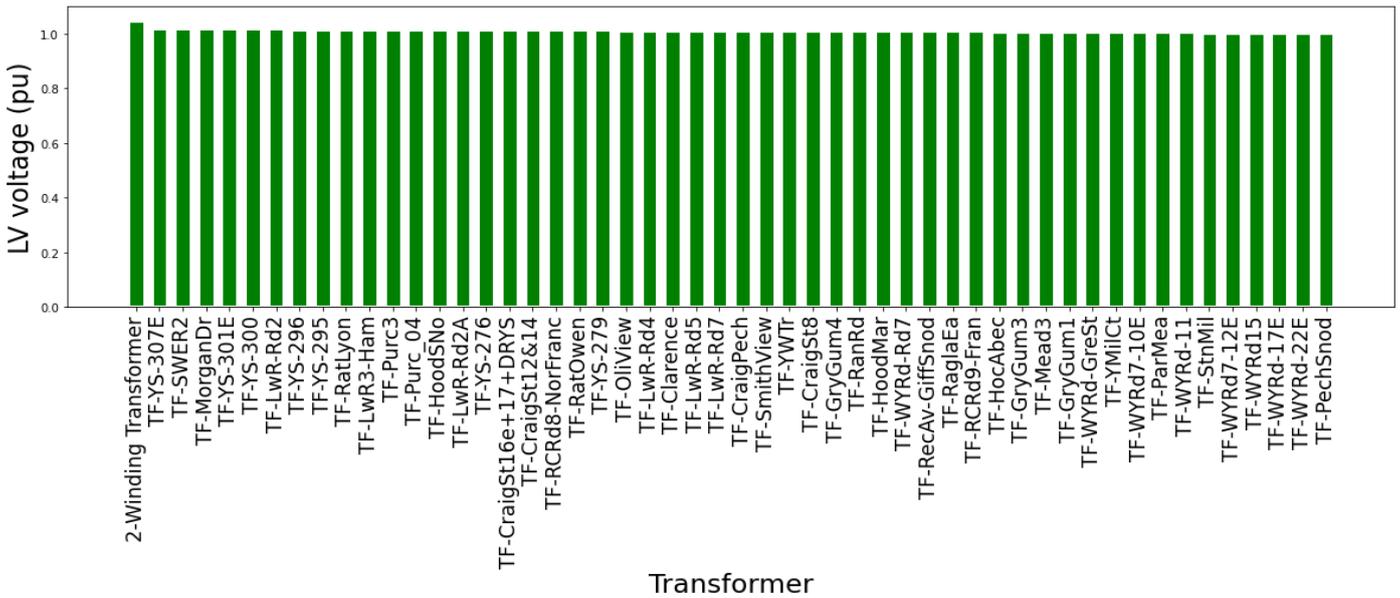


Figure 32. Voltage magnitudes (in pu) of the transformers' secondary side under Scenario 1.

As shown in Figure 32, the captured LV voltages stay within 1.0 – 1.1 pu, and it is adhering to the permissible voltage limits imposed in Victoria (i.e., 6% to 13%). The optimal tap position is determined as 1 to achieve the most desirable LV voltage values for all transformers. These results confirm that the developed model can retain the LV voltages within the permissible limits even under the worst-case loading conditions.

Moreover, since the network modelling is performed by carefully investigating the actual installation conditions, VUF has been determined at both the MV and LV sides of the transformers to further verify the accuracy of the developed network model. As depicted in Figure 33, the captured VUFs stay within 1%. Therefore, the modelled network is considered to operate within the acceptable VUF limits (i.e. VUF<5%). The captured VUFs at the LV are also within 1% except few loading points (refer to Figure 33). As the detailed LV network modelling has been performed on Industrial Area and the Railway Park sites, the corresponding transformers (i.e., North Francis, Grevillea Street, and the Station Mill transformers) have shown a comparatively high VUF at the low voltage values compared to the other transformers where the three-phase aggregated loads are considered. However, the recorded VUFs for the transformers located at the sites mentioned above are still less than 1%; hence, the network model's accuracy can be further justified.

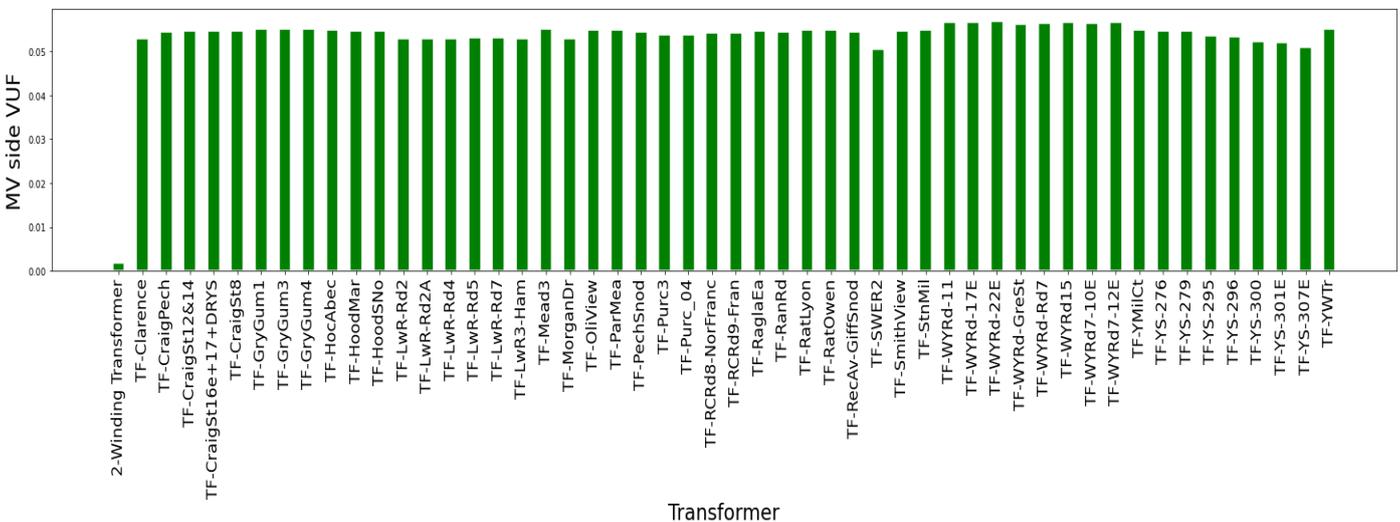


Figure 33. Voltage unbalance factor (VUF) at the MV side of the transformer under Scenario 1.

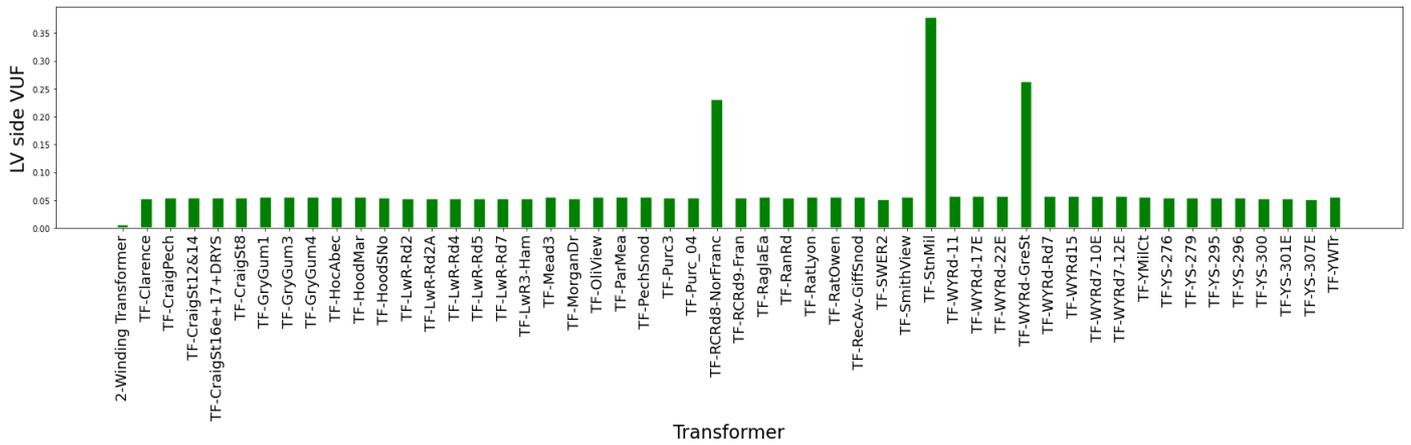


Figure 34. Voltage unbalance factor (VUF) at the LV side of the transformer under Scenario 1.

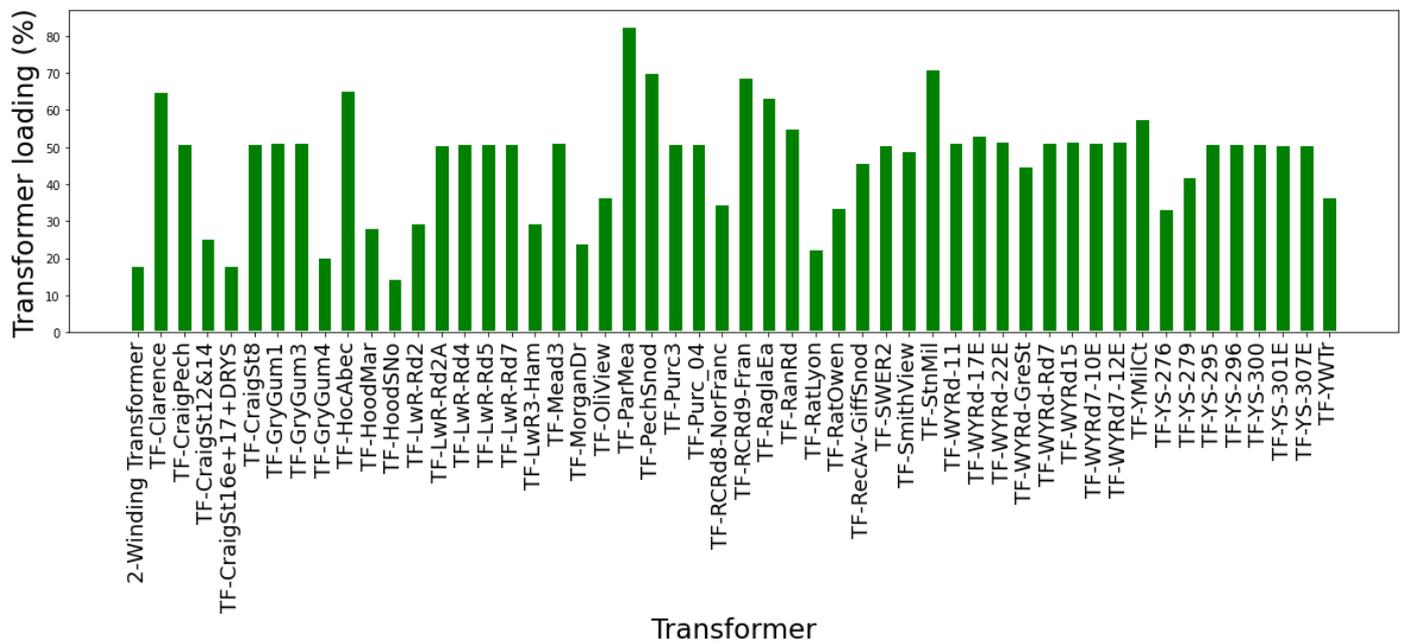


Figure 35. Loading % of the transformers under Scenario 1.

Moreover, the transformer loading (in %) is represented in Figure 35. As the maximum of the yearly average values is considered, most of the transformers are loaded more than 50%. However, over-loading conditions are not recorded under Scenario 1, where the maximum loading is recorded from the Parde Meara transformer, and it was 82%.

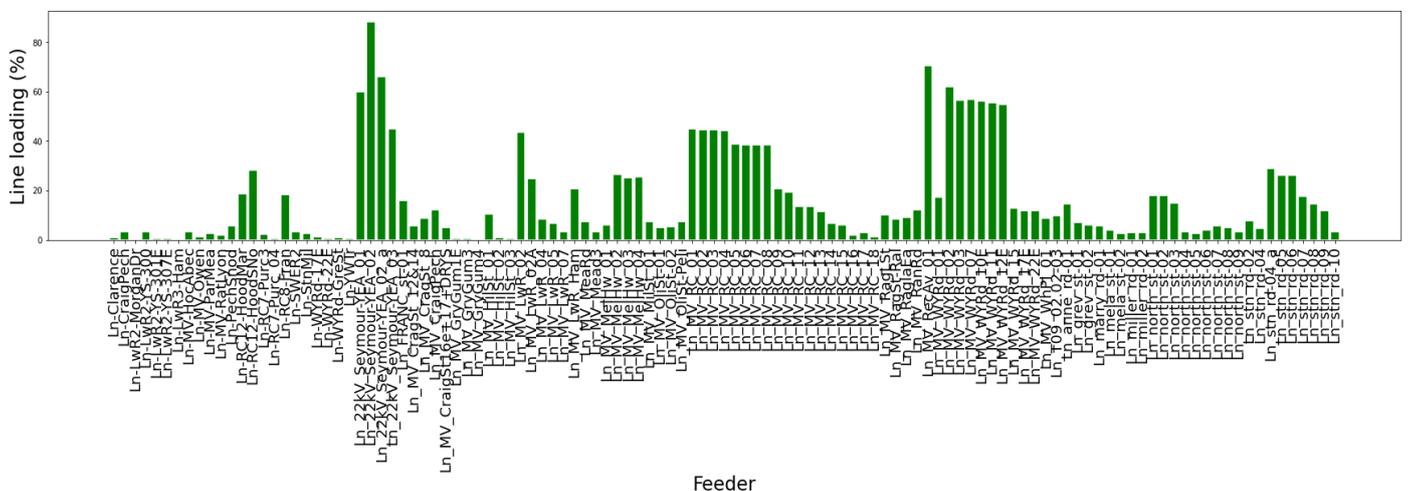


Figure 36. Loading % of the distribution feeders under Scenario 1.

Finally, the feeder loading is depicted in Figure 36. As clearly shown, the captured loading values of the distribution feeder is <100% under Scenario 1. More interestingly, the highest loaded feeder is recorded as the incoming supply feeder from the Seymour substation, and it is recorded as 88%. The captured results align with the loading profile of the Seymour substation available in the AusNet grid portal.

Scenario 2: Model validation based on the yearly average loading of the transformers

In this scenario, the developed network model is validated based on the yearly average loading of the transformers. The following approaches have been used to determine the appropriate loading points in the network.

1. *Aggregated load points:* Average loading values (in kW) have been determined from the yearly average loading profiles from the transformers. Active power dispatch from solar PV generators is maintained at rated power output.
2. *Lumped load points:* For the five lumped load points used in the network model, the loads have been estimated based on the loading of all the transformers connected to the corresponding distribution feeder.
3. *Load points in the Industrial area and the Railway Park:* Since the load points are modelled in detail for these two sites, average loading values have been determined based on the number of houses connected to each transformer associated with each site.

Furthermore, when analysing the network, the maximum charging is assumed for the 15 kW/ 48 kWh BESS at the Recreation Reserve. This assumption ensures the network is analysed under the worst possible scenario. After updating the network's loading points as mentioned above, load-flow studies were performed, and the critical parameters were analysed to validate the developed network model.

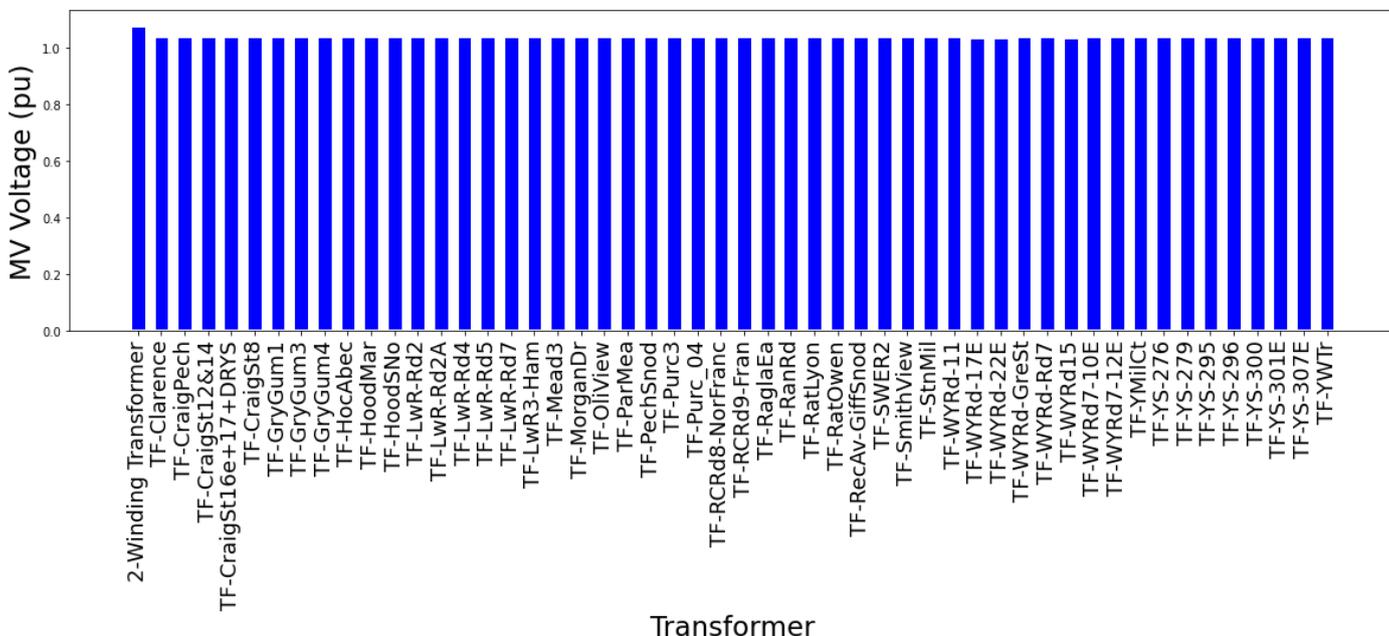


Figure 37. Voltage magnitudes (in pu) of the primary side of the transformers under Scenario 2.

Figure 37 represents the primary-side voltages (i.e. MV voltages) of transformers under scenario 2. To validate the developed network under the low loading conditions, the maximum active power output of all the PV generators is assumed to occur simultaneously. Therefore, captured MV voltages fall around 1.0 pu, which is notably high compared to the captured voltages under Scenario 1.

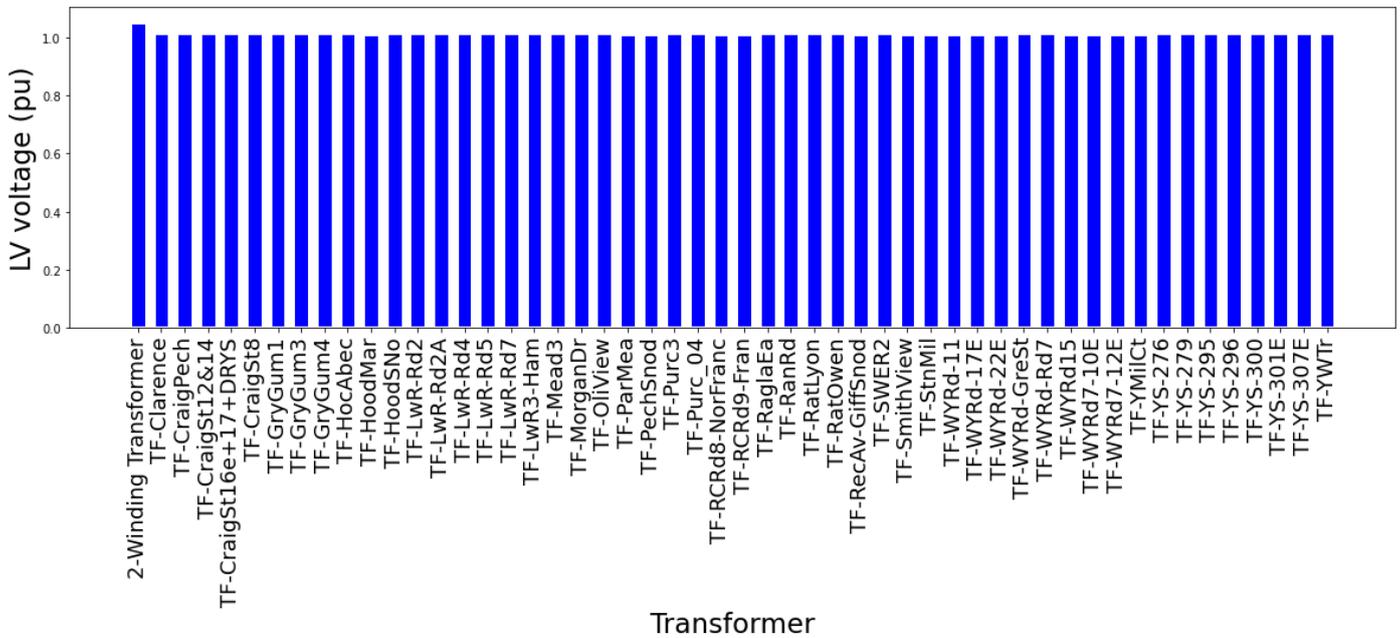


Figure 38. Voltage magnitudes (in pu) of the secondary side of the transformers under Scenario 2.

As shown in Figure 38, the captured LV voltages lie within 1.0 – 1.1 pu, and it is adhering to the permissible voltage limits imposed in Victoria (i.e., 6% to 13%)¹¹. The optimal tap position is determined as -4 to achieve the most desirable LV voltage values for all transformers. These results verify that the developed model can retain the LV voltages within the desired limits, even under low loading conditions.

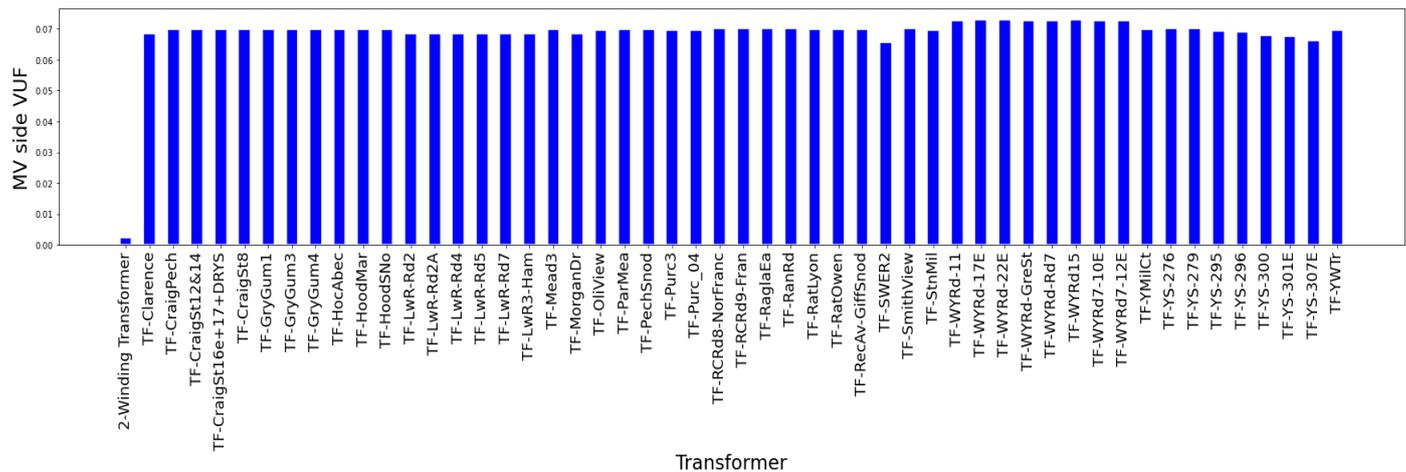


Figure 39. Voltage unbalance factor (VUF) at the MV side of the transformer under Scenario 2.

The VUF has been determined at both the MV and LV sides of the transformers further to verify the accuracy of the developed network model. As shown in Figure 40, the captured VUFs stay within 1%. Therefore, the modelled network operates within the stipulated VUF limits. The captured VUFs at the LV are also within 1%, and a few loading points (refer to Figure 40) have shown a relatively high VUF. This closely matches with the VUF captured in Scenario 1. However, the recorded VUFs for the transformers at the sites mentioned above are still less than 1; hence, the network model's accuracy can be further verified.

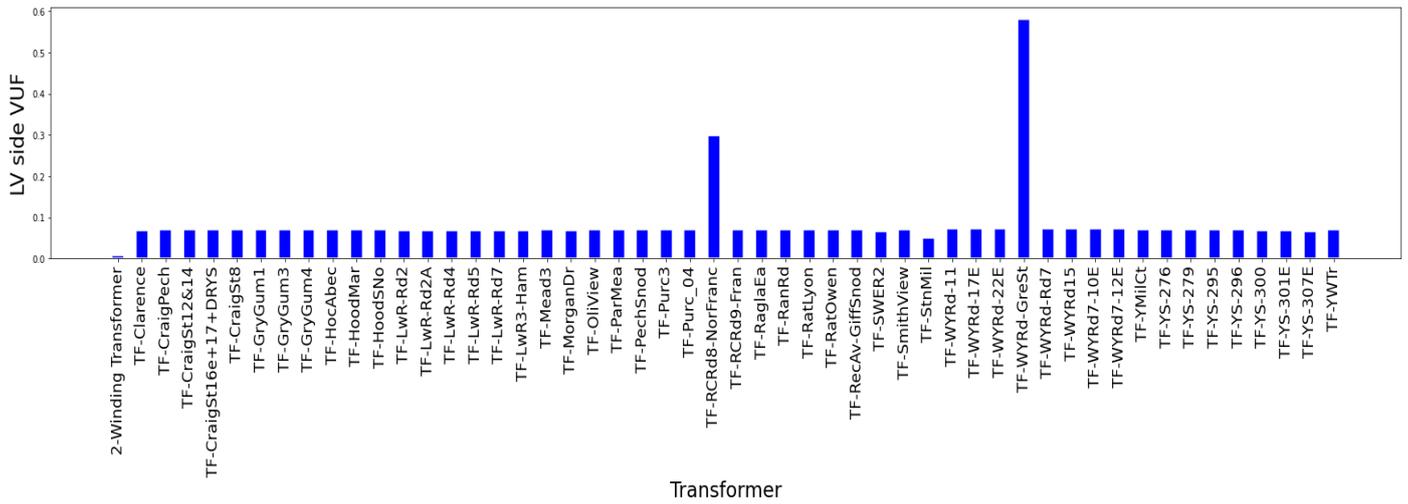


Figure 40. Voltage unbalance factor (VUF) at the LV side of the transformer under Scenario 2.

Furthermore, the transformer loading (in %) is represented in Figure 41. As opposed to Scenario 1, the transformer loading is mainly affected by the maximum PV generation. Moreover, over-loading conditions are not recorded, which is similar to Scenario 1.

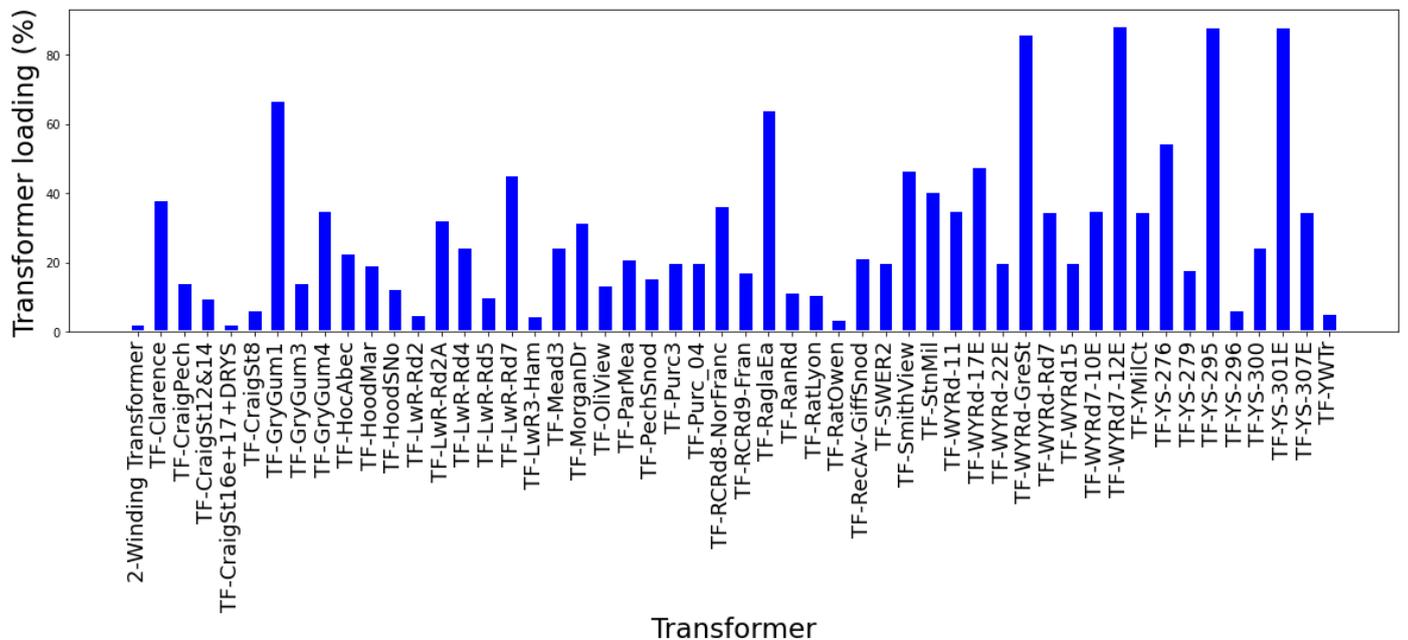


Figure 41. Loading % of the transformers under Scenario 2.

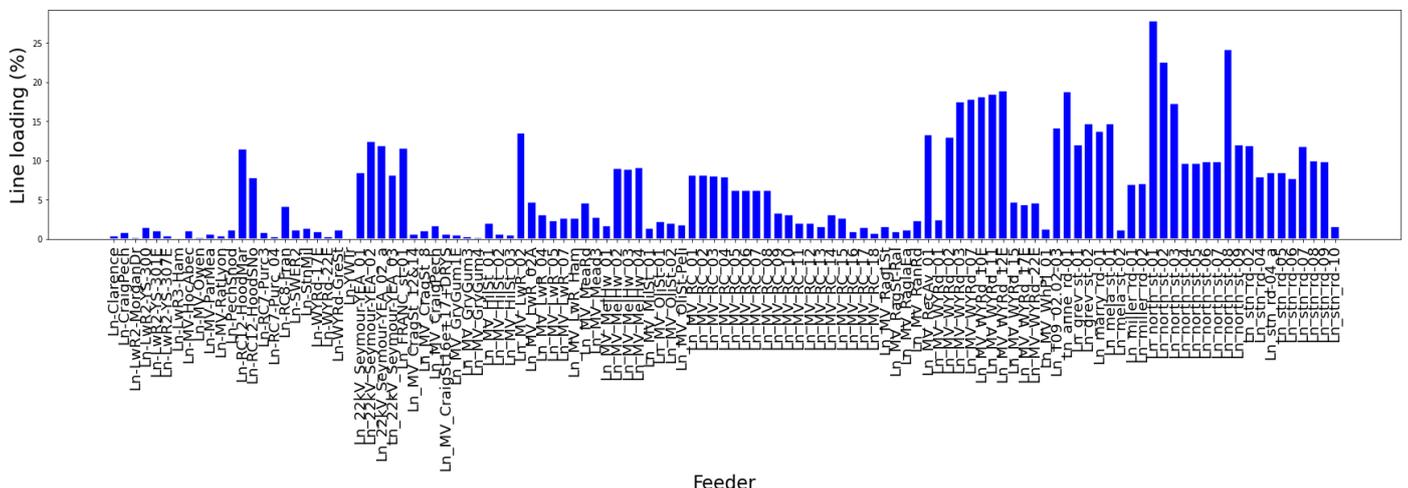


Figure 42. Loading % of the distribution feeders under Scenario 2.

Finally, the feeder loading is represented in Figure 42. As clearly shown, the captured loading values of the distribution feeder are less than 100% when the yearly average loading values are used for the simulation. More interestingly, the line loading is also impacted by PV penetration.

Scenario 3: Model validation based on the Quasi-Dynamic simulations.

In this scenario, as the final validation, the network model is tested under quasi-dynamic simulation with the 24-hour net load profiles for the transformers. The following approaches have been followed to determine the appropriate loading profiles in the network.

- *Aggregated load points:* Loading profiles (in kW) have been determined from the average summer net load profiles of the transformers. PV generators are disabled as the net load profiles have been used.
- *Lumped load points:* For the five lumped load points used in the network model, the loading profiles have been estimated based on the loading profiles of all the transformers connected to the corresponding distribution feeder.
- *Load points in the Industrial area and the Railway Park:* Since the load points are modelled in detail for these two sites, average summer loading profiles have been determined based on the number of houses connected to the corresponding transformers.

The optimum tap position determined based on Scenario 1 and 2 is used in this scenario. After importing the loading profiles, the quasi-dynamic simulations have been performed, and the critical parameters are analysed to validate the developed network model. Figure 43 represents the variation of the primary side voltages of the transformers under the scenario 3.

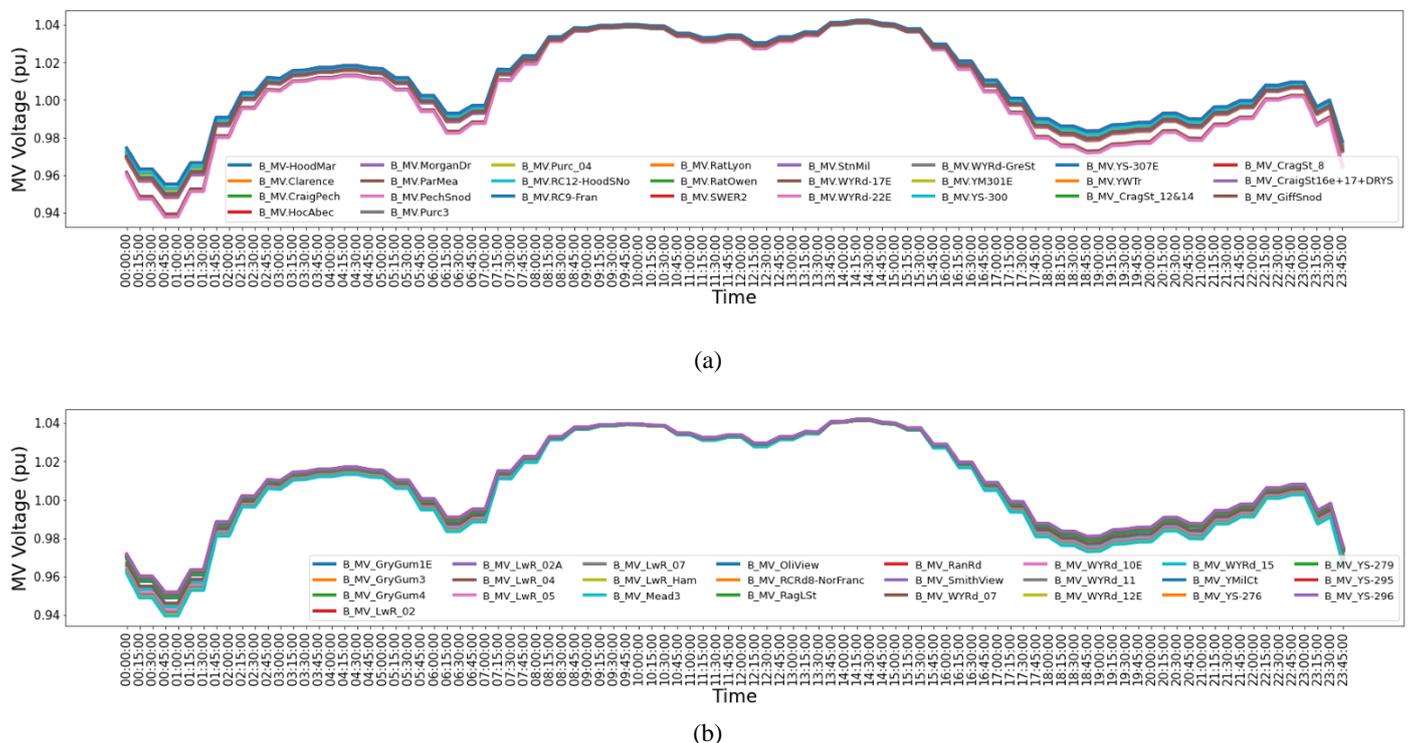
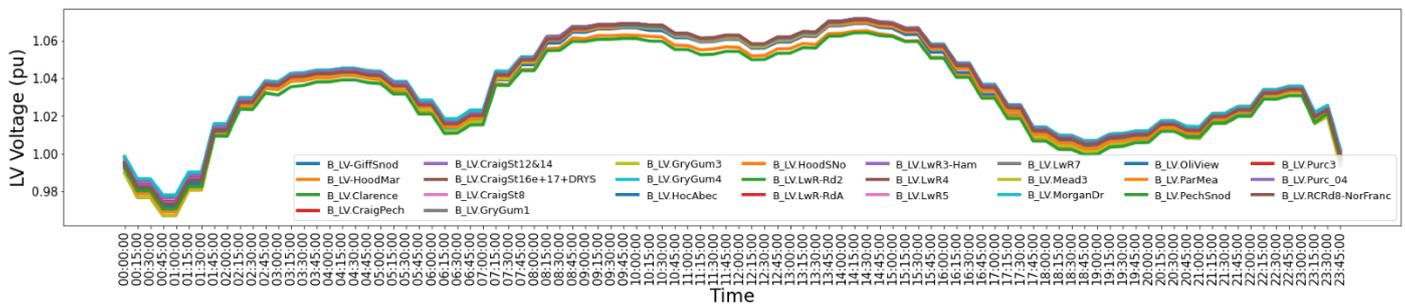
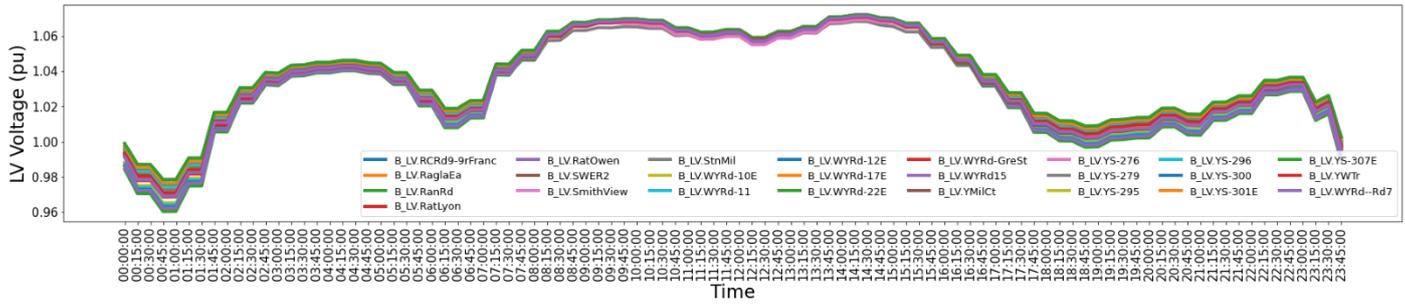


Figure 43. Variation of the MV voltage at the busbars under Scenario 3.

The captured MV voltages stay within 0.94-1.04 pu during the day. As depicted in Figure 43, the maximum voltages were recorded between 8:30 AM and 3:00 PM, which is closely related to the individual loading profiles of transformers. The increased solar penetration is the main reason for these high voltage values.



(a)

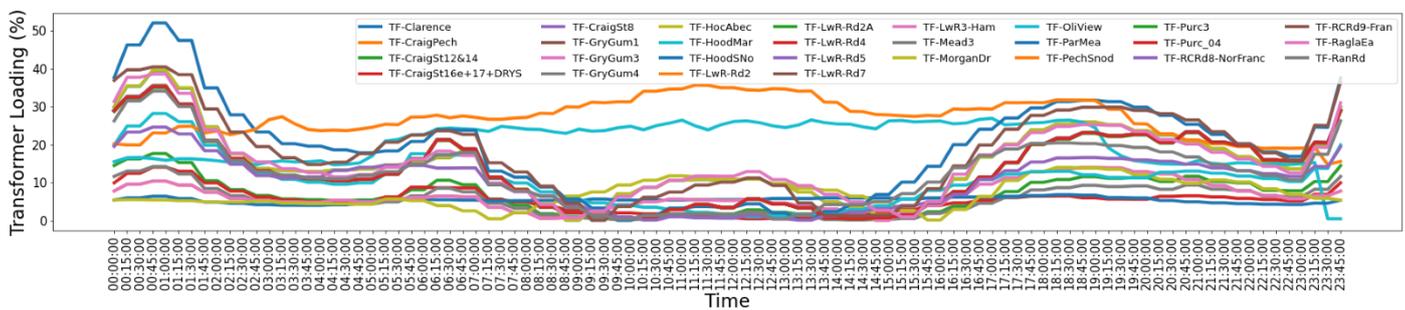


(b)

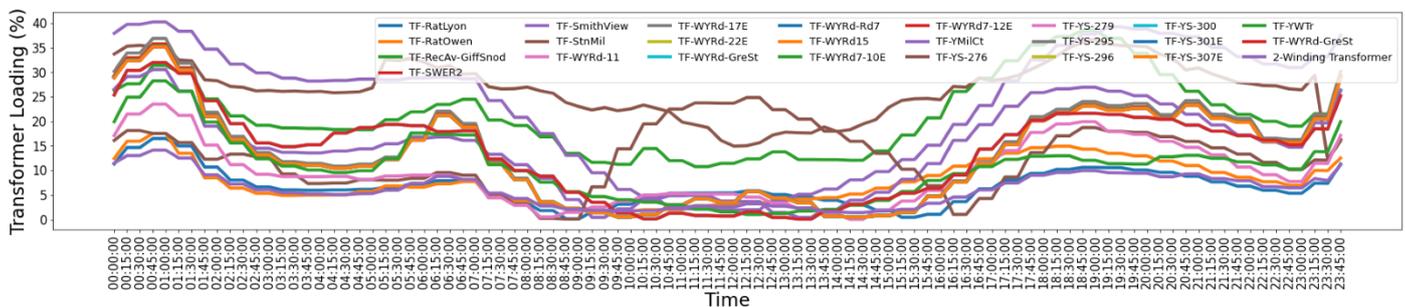
Figure 44. Variation of the LV voltages at the bus bars under Scenario 3.

Figure 44 depicts the LV voltage variation during an average day in the summer. As shown, the voltages are within the permissible limits (within 0.96-1.07 pu), adhering to Victoria's LV network regulation standards¹¹.

The above MV and the LV voltage variation are closely aligned with the loading profiles of the individual transformers, and this consistency further verifies the accuracy of the established network model.



(a)

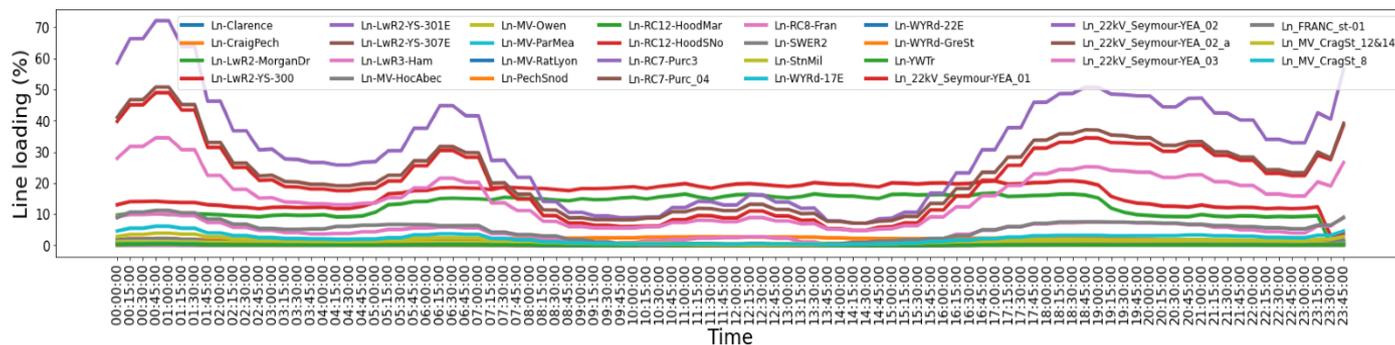


(b)

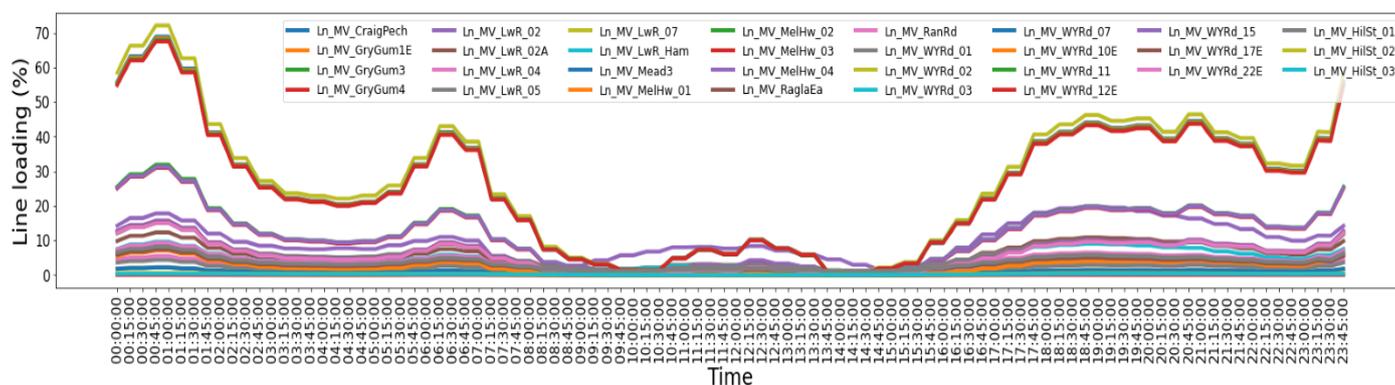
Figure 45. Variation of the transformer loading under Scenario 3.

As shown in Figure 45, except for a few transformers, the minimum loading period occurs between 8:30 AM and 3:00 PM due to the high renewable energy penetration, which is clearly reflected in the captured

transformer loading profiles. Furthermore, since the summer loading profiles are used, the loading of the transformers is comparatively low compared to the maximum loading values obtained under Scenario 1. Moreover, when analysing the individual transformer profiles during the summer, the solar PV injection is relatively higher than the active power consumption of the loads.



(a)



(b)

Figure 46. Variation of the line loading under Scenario 3.

Finally, the loading of the main feeders is represented in Figure 46, and the captured variation also aligns with the individual loading profiles of the transformers shown in Figure 45.

Appendix-D: Average Net Load Profiles of Highly Rated Transformers in Yea Residential Area

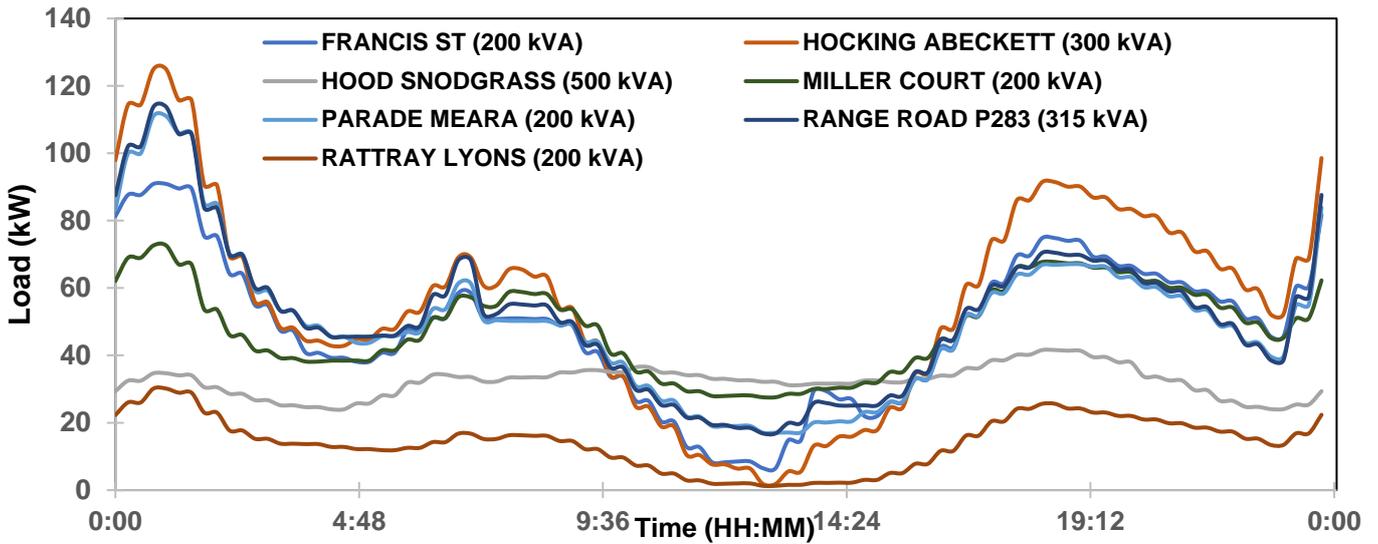


Figure 47. The average Autumn net load profile for several highly rated transformers in residential areas in Yea.

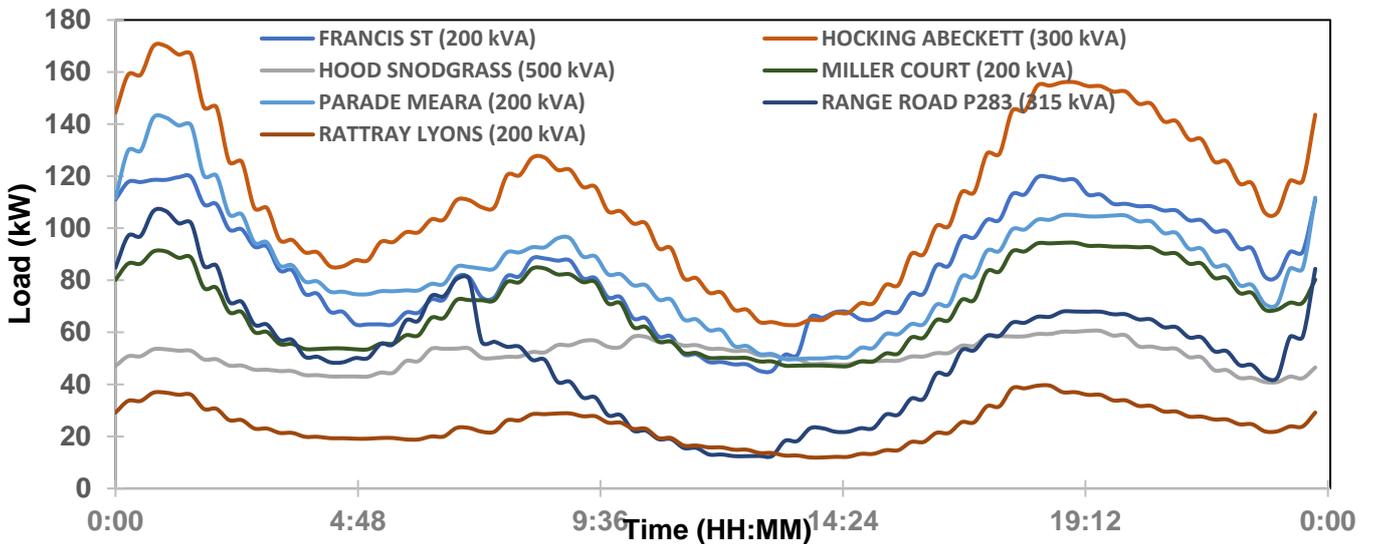


Figure 48. The average Winter net load profile for several highly rated transformers in residential areas in Yea.

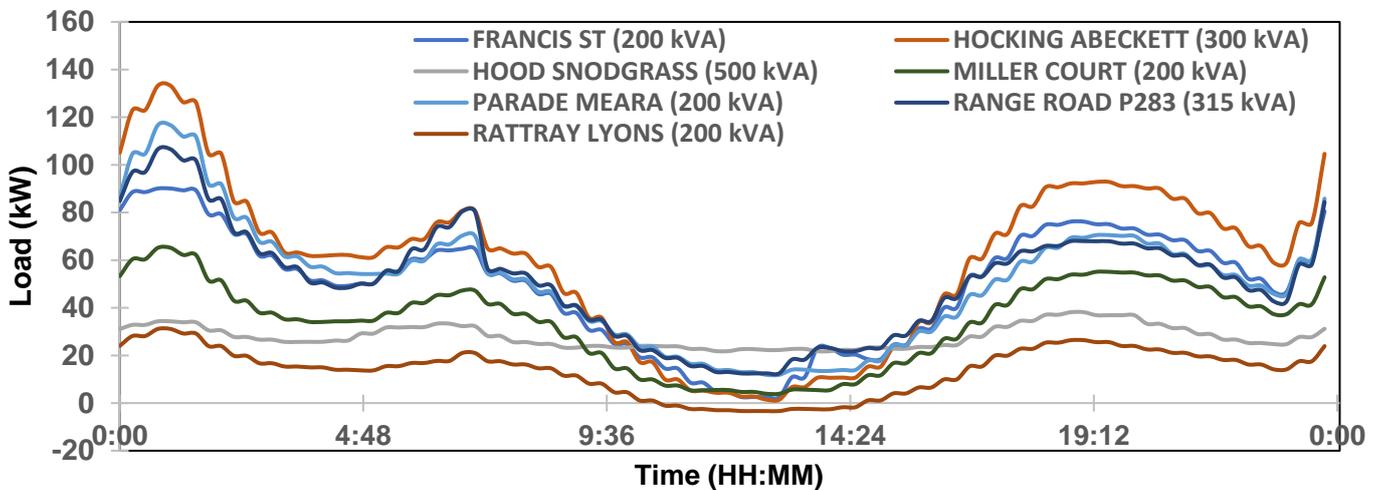


Figure 49. The average Spring net load profile for several highly rated transformers in residential areas in Yea.

Appendix-E: Battery Sizing Results for each Potential Battery Site

Yea Railway Park Battery Sizing Results

Site Name	Site Address	Front of the Meter	Behind the Meter	Host Site Owner	Distribution Substation
Yea Railway Park	22-24 STATION STREET YEA 3717	Y	N	Murrindindi Council	STATION MILLER (200 kVA)

Battery Pack Sizing (Energy Capacity)

Method-1 (Range)	Method-1 (Average)	Method-2 (Range)	Method-2 (Average)	Method-3 (Range)	Method-3 (Average)
118 - 333 kWh	225 kWh	105 – 313 kWh	208 kWh	265 – 740 kWh	508 kWh

Battery Inverter Rating (kW/ kVA)

Method-1	Method-2	Method-3
75 kW/ 82.5 kVA	69 kW/ 76 kVA	170 kW/ 187 kVA

Hosting Capacity Constraint: Within the hosting capacity constraint met for Methods-1 and -2! <140 kW

Battery Pack Energy Capacity Range: 225 – 508 kWh **Battery Inverter:** 75 – 140 kW

Yea Recreation Reserve - Front-of-the-Meter (FoM) Scenario

Site Name	Site Address	Front of the Meter	Behind the Meter	Host Site Owner	Distribution Substation
Yea Recreation Reserve	20 Snodgrass St, Yea VIC 3717	Y	Y	Murrindindi Council	PECHELL SNODGRASS (500 kVA)

Front-of-the-Meter (FoM) Scenario – Transformer Load & Generation Analysis

Battery Pack Sizing (Energy Capacity)

Method-1 (Range)	Method-1 (Average)	Method-2 Range	Method-2 Average	Method-3 Range	Method-3 Average
101 – 277 kWh	193 kWh	135 – 375 kWh	259 kWh	203 – 560 kWh	387 kWh

Battery Inverter Rating (kW/ kVA)

Method-1	Method-2	Method-3
65 kW/ 71 kVA	86 kW/ 95 kVA	129 kW/ 142 kVA

Hosting Capacity Constraint: Within the hosting capacity constraint met for Methods-1, 2 and 3! < 200 kW

Battery Pack Energy Capacity Range: 193 – 387 kWh **Battery Inverter:** 65 – 200 kW

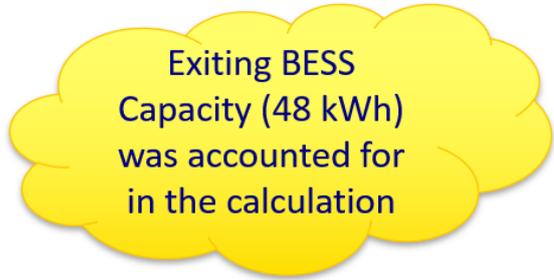
Yea Recreation Reserve - Behind-the-Meter (BTM) Scenario

Site Name	Site Address	Front of the Meter	Behind the Meter	Host Site Owner	Distribution Substation
Yea Recreation Reserve	20 Snodgrass St, Yea VIC 3717	Y	Y	Murrindindi Council	PECHELL SNODGRASS (500 kVA)

Behind-the-Meter (BTM) Scenario – Optimising Local Generation and Demand

Battery Pack Sizing (Energy Capacity)

Method-1 (Range)	Method-1 (Average)
35 – 177 kWh	109 kWh



Battery Inverter Rating (kW/ kVA)

Method-1	Method-1
36 kW/ 40 kVA	45 kW/ 50 kVA

Hosting Capacity Constraint: Within the hosting capacity constraint met **< 125 kW**

Battery Pack Energy Capacity: 109 kWh

Battery Inverter: 36 – 45 kW

Yea Swimming Pool

Site Name	Site Address	In Front Meter	Behind the Meter	Host Site Owner	Distribution Substation
Yea Swimming Pool	101 HIGH STREET YEA 3717	Y	Y	Murrindindi Council	GIFFARD SNODGRASS (200 kVA)

Since there are no distributed energy resources at the site same approach is used for FoM and BTM analysis.

Battery Pack Sizing (Energy Capacity)

Method-1 (Range)	Method-1 (Average)	Method-2 (Range)	Method-2 (Average)	Method-3 (Range)	Method-3 (Average)
85 – 231 kWh	161 kWh	92 – 316 kWh	191 kWh	276 – 803 kWh	538 kWh

Battery Inverter Rating (kW/ kVA)

Method-1	Method-2	Method-3
54 kW/ 59 kVA	64 kW/ 70 kVA	179 kW/ 197 kVA

Hosting Capacity Constraint: Within the hosting capacity constraint met for Methods-1 and -2! **< 100 kW**

Battery Pack Energy Capacity: 161 - 538 kWh

Battery Inverter: 54 – 100 kW

Yea Industrial Area

Site Name	Site Address	In Front Meter	Behind the Meter	Host Site Owner	Distribution Substation
Yea Industrial Area	20 NORTH STREET YEA 3717	Y	N	Murrindindi Council	NORTH FRANCIS (200 kVA)

Battery Pack Sizing (Energy Capacity)

Method-1 (Range)	Method-1 (Average)	Method-2 (Range)	Method-2 (Average)	Method-3 (Range)	Method-3 (Average)
84 - 236 kWh	162 kWh	304 – 108 kWh	209 kWh	452 – 163 kWh	312 kWh

Battery Inverter Rating (kW/ kVA)

Method-1	Method-2	Method-3
54 kW/ 59 kVA	70 kW/ 77 kVA	105 kW/ 116 kVA

Hosting Capacity Constraint: Within the hosting capacity constraint for Methods-1, -2 and -3! < 130 kW

Battery Pack Energy Capacity: 162 - 312 kWh

Battery Inverter: 54 – 105 kW