Optimisation of Behind the Meter DER Generation Assets within Network Constraints: A Roadmap to Successful DR Program (Project 69)

Work Package-2 Final Report

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Project Lead: A/Prof. Lasantha Meegahapola

Research Team: Prof. Mahdi Jalili

Dr Kazi Hasan

Dr. Richardt Wilkinson

Prof. Brendan McGrath

Dist. Prof. Xinghuo Yu

Prof. Flora Salim

Dr. Mingchen Gu

Dr. Reza Razzaghi

Dr. Hui Song

Dr. Ammar Kamoona

Dr. Moudud Ahmed

Dr. Mohsen Khorasany

Dr. Imran Azim

Mr. Chad Wanninayaka Mudiyanselage

Mr. Kian Keshavarzian

Prepared for: C4NET, AGL, AusNet Services

Contact: A/Prof. Lasantha Meegahapola

Email: *lasantha.meegahapola@rmit.edu.au*

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Executive Summary

Demand response (DR) programs can benefit electricity consumers, distribution network service providers (DNSPs), system operators and the energy market. However, the complexity and characteristics associated with loads connected to customer premises, utilisation of backup generators for DR and the baseline calculation process still require considerable research to optimise and further unlock the capabilities of DR programs. The challenges of DR programs are not limited to technical aspects, since there are several non-technical elements to consider when implementing DR programs, such as regulatory policy compliance. C4NET launched this DR research program to use the research expertise of member universities to solve some of the industry challenges concerning DR schemes and accelerate their deployment in electricity networks. This project is expected to produce potential solutions for some DR challenges associated with commercial and industrial (C&I) customers. The project consists of three work packages, and this project report outlines the summary of work completed under work package 2 (WP2) and recommendations emanating from WP-2.

WP2 investigated the barriers to higher utilisation of backup generators in DR programs, as it is one of the most cost-efficient ways to add flexible capacity to the power grid. Under WP2, the DNSP guidelines for backup generators and their synchronisation with the grid are reviewed, including ways to synchronise them and enable exporting. Simulation studies are conducted to explore the impacts of backup generators on power networks and factors affecting the export limit of backup generators. Three aspects of technical barriers are considered: location-based barriers, network-based barriers, and time-based barriers. WP2 also covers the feasibility study of using biodiesel generators in DR programs.

This study has drawn the following recommendations to increase backup generator utilisation in DR programs.

1) Implementing dynamic export limits (i.e., the export limit varies based on the time of the day) for backup generators, instead of the static export limit, since that can increase the energy export capacity to the network and deliver improved network support and other grid services.

2) Allowing more flexibility for backup generators to select the operating mode between P-V (active power – voltage) and P-Q (active – reactive power) control modes to mitigate network constraints and support the network.

3) Each DNSP has rules and guidelines for generator inter-tripping and synchronisation. Therefore, inter-tripping and technical synchronisation requirements can be standardised to achieve consistency across each DNSP. That will facilitate the process for more C&I customers to carry out projects that will increase their capability to participate in DR programs.

4) Biodiesel blends are available from local Australian producers, and a complete supply chain exits from the manufacturer to the retailer. Furthermore, local generator producers offer generator sets suitable for biodiesel, which helps overcome technical barriers. Therefore, it is feasible to use biodiesel generators as backup generators in Australia, and thus, backup generator owners should be encouraged to use biodiesel to help reduce carbon emissions.

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Acronyms and Terminologies

- **AEMO:** Australian Energy Market Operator
- **AEMC:** Australian Energy Market Commission
- **AER:** Australian Energy Regulator
- **CBD**: Central Business District
- **C&I:** Commercial and Industrial
- **CO:** Carbon Monoxide
- **DER:** Distributed Energy Resources
- **DFA:** Distribution Feeder Automation
- **DNSP:** Distribution Network Service Provider
- **DNP3:** Distributed Network Protocol 3
- **DR:** Demand Response
- **EDC:** Electricity Distribution Code
- **EG:** Embedded Generator
- **EIG:** Electricity Industry Guideline
- **ESR:** Electricity Safety Regulations
- **FEA**: Future Energy Australia
- **GHG**: Greenhouse Gases
- **HC**: Hydrocarbons
- **HMI**: Human-Machine Interface
- **HVO**: Hydrotreated Vegetable Oil
- **IES**: Inverter Energy System
- **LV:** Low Voltage
- **MMOF:** Multi-Mode Optic Fibre
- **MSO:** Model Standing Offer
- **NER:** National Electricity Rules
- **NOx:** Oxides of Nitrogen
- **NVD:** Neutral Voltage Displacement
- **PLC**: Programmable Logic Controller
- **PMG:** Permanent Magnet Generator
- **REFCL:** Rapid Earth Fault Current Limiter
- **RIO:** Remote Input/Output
- **RTU:** Remote Terminal Unit
- **SCADA:** Supervisory Control and Data Acquisition
- **SIR:** Service and Installation Rules
- **SO2:** Sulphur Dioxide
- **TNSP:** Transmission Network Service Provider

- **UE:** United Energy
- **VEDC:** Victorian Electricity Distribution Code
- **VSIR**: Victorian Service Installation and Rules
- **VT:** Voltage Transformer

- **2-phase (90-degree phase rotation):** An obsolete power transfer system where two phases are provided that are 90° out of phase with each other. Since the supply is unbalanced, a return wire with twice the cross-section of phase wires is needed.
- **2-phase (180-degree phase rotation):** An obsolete power transfer system where two phases are provided that are 180° out of phase with each other. Since the supply is balanced, a return wire is not needed.
- **Embedded Generator (EG**): An entity that owns and operates generating units, which are connected within the distribution network and do not have direct access to the transmission network.
- **Micro EG:** If the generation system comprises only inverters and the total inverter capacity (AC nameplate rating) is 200kW or less, it is considered a 'micro' embedded generating unit. Rooftop solar panels and battery systems at residential and commercial premises are typical examples.
- **IES:** Inverter Energy Systems such as solar PV power generation units, wind turbine power generation units and battery storage systems.
- **Non-IES:** Non inverter energy systems such as synchronous or asynchronous generators are typically powered by crude oil engines.
- **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.
- **Long Rural Feeder (**As per VEDC**):** A feeder, which is not a CBD feeder or an urban feeder, with a total length greater than 200 km.
- **Short Rural Feeder (**As per VEDC**):** A feeder, which is not a CBD feeder or an urban feeder, with a total length less than 200 km.
- **Urban Feeder (**As per VEDC**):** A feeder, which is not a CBD feeder, with a load density greater than 0.3 MVA/km.
- **Embedded Generator (EG):** Generating units, which are connected within the distribution network.
- **Generator synchronisation:** The process of connecting generators to the power grid without any /minimum disturbance.
- **Synchronisation Window:** The acceptable limits of the real-world mismatch of generator synchronising quantities.
- **Synchronism Time:** The time to initiate/close synchronising relay.

1. Project Overview

RMIT was engaged by C4NET to provide a roadmap for successful demand response (DR) programs for commercial and industrial (C&I) customers. In response to the C4NET request and in collaboration with AGL, the RMIT team proposed a project with three work packages, which are as follows:

- **Work Package-1:** Machine learning for C&I customers' baseline improvement,
- **Work Package-2:** Unlocking the potential of participation of backup generators in DR,
- **Work Package-3:** Identify tariffs that can incentivise the uptake of batteries.

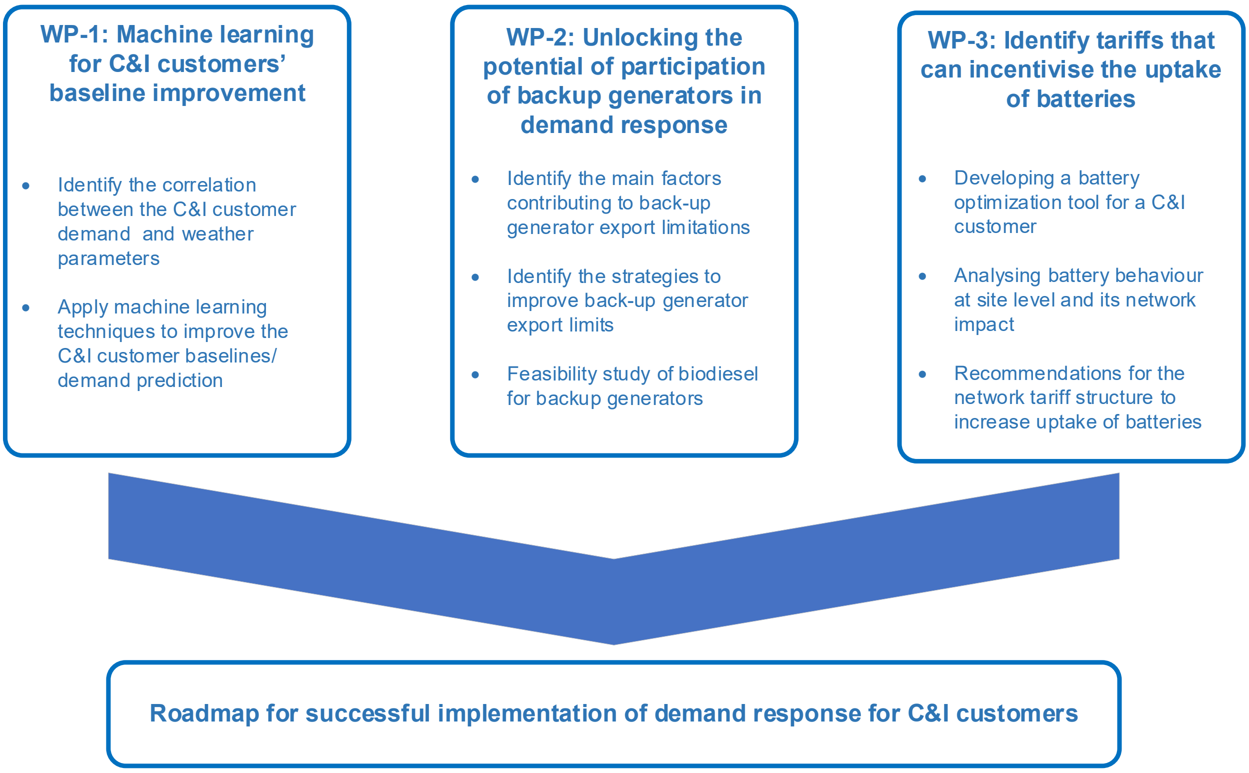


Fig. 1.1. Aims and objectives of project work-packages.

The WP-1 will apply the machine learning techniques to unlock the potential of demand response schemes, in particular focus on improving the baselines used in DR. WP-2 will focus on unlocking the potential of using backup generators and other embedded generators of C&I customers in DR programs. It will also explore possible solutions to overcome the regulatory and technical barriers to using backup generators in DR programs. Lastly, WP-3 will explore the role of network tariffs in DR programs which can incentivise the uptake of batteries.

The project team has engaged with the Victorian distribution network service providers (DNSPs) to understand better the technical and regulatory barriers to deploying backup generators of C&I customers in DR programs, such as water utilities. Moreover, the project team expects to obtain feedback from the Victorian DNSPs on the project outcomes and recommendations.

Finally, this project aims to create a roadmap for successful implementation of DR for C&I customers. It is envisaged that more C&I customers will sign up for the DR programs in the future after implementing recommendations of the project.

2. Scope of Work Package-2

Work Package-2 (WP2) aims to investigate the barriers to use backup generators in the DR programs. Since it is one of the most cost-efficient ways to add flexible capacity to the power grid, for example, adding a peaking plant such as gas-turbine generator would cost millions of dollars and take years to recover the investment.

In brief, this study has undertaken the following research activities:

1. Conducting consultation meetings with the DNSPs in Victoria to understand the various guidelines they apply for back-up/ embedded generator connections,
2. Reviewing DNSP guidelines for backup generator connections,
3. Reviewing backup generator synchronising mechanisms,
4. Identifying the barriers for using backup generators in DR programs,
5. Investigating the impact of backup generator integration on power grids,
6. Investigating the export limit of backup generators,
7. Exploring the impacts of operating modes of backup generators on power grids,
8. Assessing the feasibility of using biodiesel in backup generators,
9. Proposing recommendations for improving participation of C&I customers in DR programs.

The project team used data and power network models from the CSIRO Medium Voltage Feeder Taxonomy Project [1] to characterise the barries to use back-up generators and investigate various strategies to overcome the barriers. The rest of the report is organised as follows:

Chapter 3 explains the methodology utilised in WP2.

Chapter 4 provides summary of the DNSP consultation.

Chapter 5 reviews the DNSP guidelines for backup generator connections.

Chapter 6 reviews the optimal mechanisms and economical ways to synchronise backup generators. This chapter has addressed deliverable 2 "Conducting research on the most economic ways to synchronise backup generators, while meeting regulatory and DNSP requirements".

Chapter 7 investigates the barriers of using backup generators in DR. This chapter has addressed deliverable 1 "Assessing backup generation capacity of C&I customers" and deliverable 3 "Studying barriers for using backup generators in DR". Section 7.5.4 has addressed deliverable 5 "Economic analysis of selected C&I customers".

Chapter 8 addresses deliverable 4 "Feasibility study of using biodiesel for backup generators".

Chapter 9 provides future directions and recommendations.

3. Work Package 2 Methodology

The methodology shown in Fig. 3.1 was followed in WP2 to realise the objectives of the work package.

As the first step, the project team has carried out meeting with the Victorian DNSPs to better understand their guidelines on backup generator connections and participation of C&I customers in demand response programs. Also, the project team has reviewed the literature and the DNSP guidelines and standards on backup generator connections and demand response. Next, the team has investigated the barriers for backup generator participating in demand response, which includes three aspects: location-based barriers, network-based barriers, and time-based barriers. For each barrier, the team has conducted comprehensive simulation studies following DNSP guidelines to investigate the impact of backup generators on power grids. Moreover, the team has carried out the feasibility study of biodiesel generators for demand response, which covers the advantages and barriers of using biodiesel generation. After carefully analysing the simulation results, the project team has proposed several recommendations to mitigate barriers for backup generator participating in demand response schemes. Finally, the project team expects to obtain feedback from DNSPs on project recommendations and discuss the implementation roadmap for recommendations.

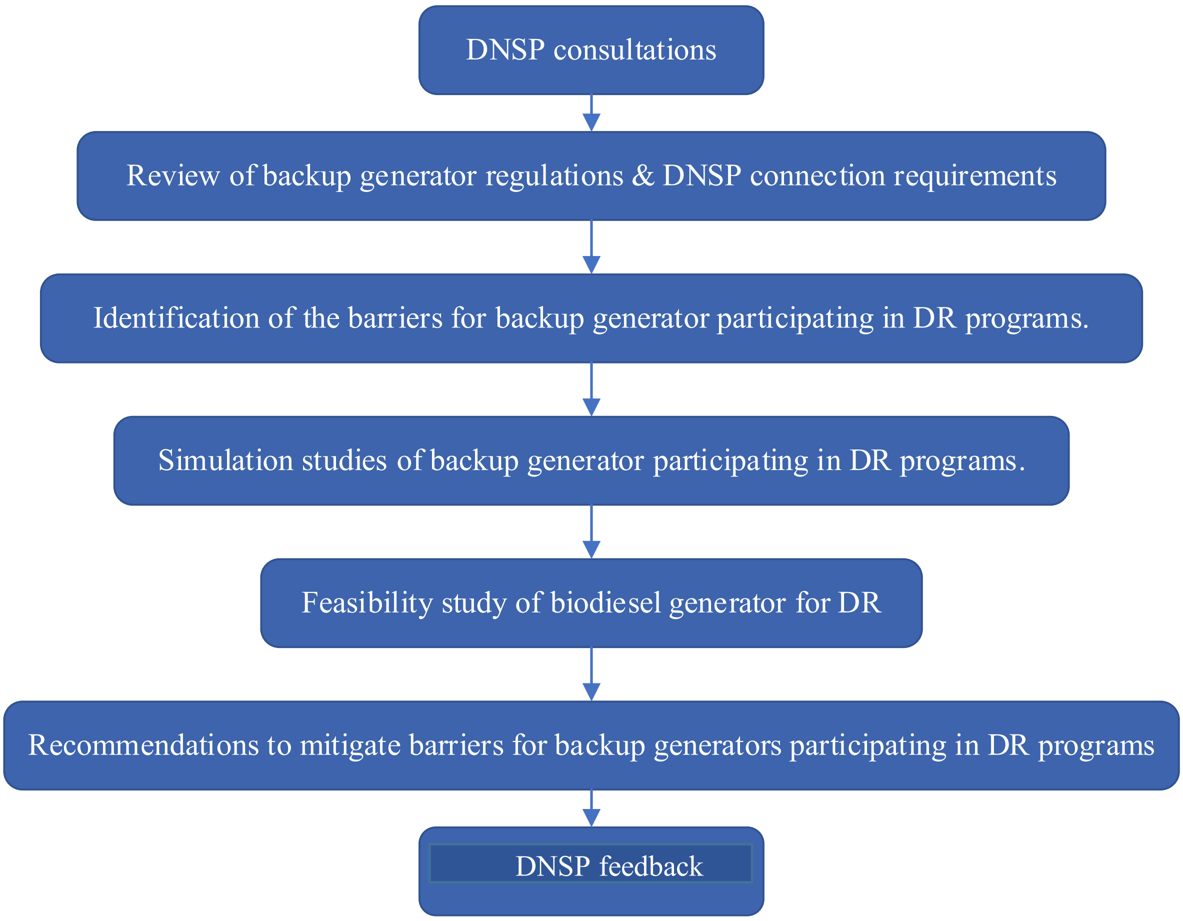


Fig. 3.1. Work package 2 methodology.

4. DNSP Consultations

The project team had four DNSP consultation meetings with AusNet Services, Jemena, Powercor and United Energy. The noteworthy comments from these meetings are summarised below:

Meeting with the AusNet Services Team (Date: 18th November 2021)

1. Embedded generator export limit depends on the network type, and where the embedded generator is situated within the network; for example, the export limits are based on whether the embedded generator units are located in urban, semi-urban or rural feeders.
2. Export limits are determined during the network studies stage and are a function of network topology, asset type, voltage limitations and existing installed embedded generation on the feeder (among other factors).
3. The embedded generation connection guide provides further details regarding embedded generator connections to the AusNet services network: https://www.ausnetservices.com.au/en/Electricity/Connections/Apply-for-Solar-and-Other-Generation

Meeting with the Jemena Team (Date: 7th February 2022)

1. Generally, the connection requirements are the same as if it is a permanent arrangement for backup generators with a 'make-before-break' transfer. Depending on the type, size and synchronisation time with the grid, we may consider exemptions to certain performance standards and modelling requirements. Note that only standby generators with a 'make-before-break' transfer require a connection agreement. For 'break-before-make' transfer, an interlock will break the grid connection supply before connecting the alternative supply.
2. Generally, backup generator export is limited to zero. It will only be allowed as a temporary connection to transfer a customer's supply back to the grid. A parallel generator connection with the distribution network will be limited to a maximum time. A timer shall be installed to disconnect the generator from the distribution network if this time is exceeded in cases where there is a 'make-before-break' transfer.
3. Unless requested by the connection applicant, no evaluation will be done to determine the export limit of the backup generator.
4. The same methodology is used for determining the constraints for backup generators as for other generators with a permanent connection.
5. Jemena follows the national electricity rules (NER) Chapter 5A process for generators (non-IES) less than 5MVA which generally takes up to 65 business days to assess an application and make an offer. The timeframe to be brought online will depend on the extent of the connection works required and the customer's generator work to fully commission the generator. Only standby generators with a 'make-before-break' transfer require a connection agreement.
6. The only communication protocol that can be used with Jemena Host supervisory control and data acquisition (SCADA) is DNP3. A Jemena remote terminal unit (RTU) with Distributed Network Protocol 3 (DNP3) slave connection to SCADA Host at one end and communication

connection to embedded generator RTU/controller at the other end could be looked at, depending upon the application

7. Standby generators are not supposed to connect to the grid beyond a temporary connection timeframe to allow customer's supply to be transferred back to the grid.

Meeting with the Powercor/ United Energy Teams (Date 20-05-2022)

- As soon as a plant is going to export, the Powercor treats that as a generator. The requirements are depending on the capacity of the generation plant,
    - Below 5 MW – Powercor performance standards should be met.
    - Above 5 MW – NER Chapter 2 rules will apply. Generators need to meet the NER technical standards and the AEMO would be involved in the connection process.
- For network augmentation and non-network solutions – invite proponent to come with a fee payable to the demand responder.
- The export capability depends on where the backup generator is connected to the network, network conditions and generator capacity. If there is an embedded generator on the feeder, there may not be enough headroom to allow any more capacity. If it requires network augmentation, then it may not be worth to connect the backup/ embedded generator.
- Also, there is no blanket export limit for backup/ embedded generators – it will depend on network conditions and size of the generator. There is a framework for the connection process. The criteria are consistently applied across all backup/ embedded generator connections; however, Powercor assesses each generator connection case-by-case basis.
- Also, it depends on how weak the network is at the generator connection point – need to adhere to voltage and thermal limits of the feeder, and high fault level limits may also be a constraint (Powercor design limit - 13.1 kA (ultimate capacity) – it is depending on the switchgear, and some may have a lower rating (i.e., old switchgear)). Some limits are from the DNSP code of practice, and some are from asset rating.
- All DNSPs have a similar approach for determining export limits for generators, but different assessment criteria may be applied.
- There are no 'standards' to stipulate how quickly to synchronise. It will depend on the generator size and the impact of the synchronisation activity.
- C&I customers must get an approval from the DNSP on synchronisation period. Make-before-break always synchronise; they may export or stay at zero export.
- Backup generators may export for a minimum number of hours - only use when there is a disruption.
- In break-before-make connection, back-up generators only connect when there is a disruption to the main network. Under break-before-make generation, the interlock prevents from exporting or connecting to the grid.
- In break-before-make, first synchronise with the grid and then export. There is a restriction on how frequent and how often they can export.
- Communication protocol for backup generators is DNP3.
- There is no specific communication protocol requirement for inter-tripping. A range of technologies are recommended.

Powercor/ United Energy Criteria for generator connection

- Preliminary enquiry – export capacity request
- Powercor will respond with available capacity or if an augmentation is required
- Customer to make a decision yes / no – status assessment
- If continuing, Powercor to provide network data- customer must do voltage / thermal studies – to check for any negative impacts
- Next step is to check whether there are no negative impacts for the customer, then to complete a dynamic assessment
- Then a study based on the PSSE model – Powercor will do a study based on standards
- Once all requirements are satisfied, then a connection can be made (e.g., voltage, thermal, fault level study and impact assessment). Power quality assessment includes voltage limits, and flicker etc.
- Commissioning testing will be carried out to ensure agreed performance standards are met.

Meeting with the AusNet Services – (Date 14/07/2022 and via email communications)

- AusNet services assess the generator connections below 5 MW under two categories:
  1. Lower than 1.5MW, customer will need to follow the connection guidelines
  2. Larger than 1.5MW will be assessed by the AusNet team by using guidelines in the following document

  https://www.ausnetservices.com.au/Electricity/Connections/Apply-for-Solar-and-Other-Generation/Large-complex-connections
  https://www.ausnetservices.com.au/en/Electricity/Connections/Apply-for-Solar-and-Other-Generation/Embedded-Generation-Connection-1500-to-5000-kW
- The export limit imposed on the generator depends on the connection type;
  1. Residential/ Commercial/ Industrial solar connections – Export limit up to 5kW per phase or up to 3.5 kW for SWER, and for the inverter energy system (IES) up to 10 kW/phase installed capacity with the basic model standing offer (MSO)
  2. Large solar PV systems (capacity > 30kW) are subjected to AusNet assessment and approval
  3. For community BESS export (for both HV and LV) – Subject to AusNet approval as it depends on the size and LV conductor limitations
     PV/BESS >30 kW subjects to AusNet assessment
- *For generators (non-IES) less than 5MVA, how quickly must the generators be brought online?*
  Depends on the synchronisation technology employed at the backup generator
- *Are there any preferred communication protocols other than "DNP3.0" for SCADA* communication in embedded generators?
  Based on SOP 11-16
  Various communication requirements are currently under consideration/discussion.
- *What are inter-tripping and communication link requirements for back-up generators and how these requirements are determined?* Is there any flexibility on the communication protocol requirements?
  Based on SOP 11-16

4.1. Summary from DNSP consultation meetings

Following conclusions can be drawn from the DNSP consultation meetings.

- DNSPs have their own guidelines/ methodologies for generator export limit assessment. However, all DNSPs ensure they comply with the NER, existing voltage standards and thermal limits.
- The generator export limit is depending on the network type and the location of the customer, however there is no time-based assessment done for generators.
- There are no consistent requirements for inter-tripping across the four DNSPs in Victoria and each DNSP provides their own requirements for inter-tripping. In particular, there is no consistent technical specification for communication protocol for inter-tripping. Some DNSPs specify costly fibre optic links while the some DNSPs do not have any specific communication requirement for inter-tripping.
- The differences also relate to the threshold of generator capacity above which inter-tripping is required. This means for example that a large energy user with sites spread across the different DNSPs will face different requirements for different sites. It is not possible at the moment to apply a uniform approach and commercial assessment across all of Victoria.

5. Review of DNSP Guidelines for Backup Generator Connections

Based on the reviewed literature, the guidelines stipulated by DNSPs for back generator / embedded generator connections are based on regional and national framework guidelines defined by regulatory bodies and policy-making organisations. Those organisations can be listed as follows.

AEMO Guidelines: AEMO publishes several guidelines and registration documents that apply to embedded generators in accordance with its obligations under the NER. These documents supplement the NER [2].

National Electricity Rules (NER): Provides the authority to enable AEMO to prepare guidelines that allow a person or class of persons from not requiring registering as a Generator. Such units would need to apply for a registration exemption with AEMO [3].

Electricity Industry Guideline (EIG): Regulates the negotiation of the commercial aspects of connection agreements. It provides no technical performance standards for embedded generators [4].

Australian Energy Regulator (AER): The AER is the regulator of the wholesale electricity and gas markets in Australia. It enforces the rules established by the Australian Energy Market Commission [5].

Electricity Safety Regulations (ESR): According to the electricity safety Act 1998, electricity safety regulations are made and updated to this date [6].

Victorian Electricity Distribution Code (VEDC): Within the Victorian jurisdiction, the VEDC applies different standards in respect of variation in power frequency voltage and voltage unbalance. In all other respects, the NER prevails [7].

Victorian Service Installation and Rules (VSIR): The customer's installation must comply with the VEDC and Victorian Service Installation and Rules (SIRs) [8].

Victoria has five DNSP networks (CitiPower and Powercor, Jemena, AusNet Services, and United Energy). The literature materials published by these DNSPs regarding the integration of embedded non-IES generators / rotating generating systems (< 5MVA) have been reviewed and summarised in Table 5.1.

Table 5.1. Summary of Victorian DNSP requirements for small-scale diesel and renewable generators.

DNSP		**VICTORIA**			
		CitiPower and Powercor [9]	**Jemena** [10]	**AusNet Services** [11]	**United Energy (UE)** [12]
Network Connection Requirements	**Grid Codes**	NER [3], EDC [7]	AEMO [2], NER [3], EIG [4], EDC [7]	NER [3], AER [5]	NER [3], EIG [4], ESR [6], EDC [7], VSIR [8]
	Technical Requirements	-Quality of Supply -Frequency As per AEMO guidelines (50 Hz nominal within allowable limits) The DNSP referred to VEDC standards directly: -Voltage (By DNSP) → -10% < Volt< +13% (LV, t < 1min) → -6% < Volt< +6% (MV, t < 1min) → -10% < Volt< +10% (MV, t < 1min, Rural) -Harmonic voltages (By DNSP) According to AS/NZS 61000.3.6:2001 Australian standards. -Power factor (By Customer) → 0.8 lag<pf < 0.8 lead (< 2MVA) → 0.85 lag<pf < 0.85 lead (> 2MVA)	-Quality of Supply -Voltage operating range →230$V_{ph\text{-}n}$ (1∅) → 216 V <Volt < 253V →400$V_{ph\text{-}ph}$ (3∅) → 376V <Volt < 440V →460$V_{ph\text{-}ph}$ (2∅-180^{0}) → 432 V <Volt < 506V (Rural) →6.6k$V_{ph\text{-}ph}$ (3∅) → 6.2 kV<Volt < 7kV →11k$V_{ph\text{-}ph}$ (3∅) → 10.34 kV<Volt < 11.66kV -Voltage flicker limits → Short Term Perceptibility (P_{st})< 1.0 → Long Term Perceptibility (P_{lt})< 0.8 - LV generators should maintain, → Relative steady state voltage change (dc) < 3% →Maximum relative voltage change (dmax) < 4% -Operating frequency → 49.85Hz< Freq <50.15Hz -Frequency fluctuation tolerance bands and time	-Quality of Supply -Non-IES generation must provide a balanced output across all phases. Phase balance protection may be required. -Preferred protection settings (less than 2 sec) Operating Voltage→ 180V< Volt <260 V Frequency→ 47.5Hz< Freq <52Hz	-Quality of Supply -Preferred protection settings (less than 2 sec) Operating Voltage→ 180V< Volt <260 V Frequency→ 47Hz< Freq <52Hz The DNSP referred to VEDC standards directly: -Voltage (By DNSP) → -10% < Volt< +13% (LV, t < 1min) → -6% < Volt< +6% (MV, t < 1min) → -10% < Volt< +10% (MV, t < 1min, Rural) -Harmonic voltages (By DNSP) According to AS/NZS 61000 series. -Power factor (By Customer) → 0.8 lag<pf < 0.8 lead (< 2MVA) → 0.85 lag<pf < 0.85 lead (> 2MVA) -Harmonic currents from EG (By customer) A table with allowable limits is given under

DNSP		VICTORIA			
		CitiPower and Powercor [9]	**Jemena** [10]	**AusNet Services** [11]	**United Energy (UE)** [12]
		-Harmonic currents from EG (By customer) A table with allowable limits is given under VEDC -Load balance between phases (By Customer) → I_{ph} < 5% of avg I_{ph} (LV) → I_{ph} < 10% of avg I_{ph} (LV, t < 2min) → I_{ph} < 2% of avg I_{ph} (MV) → I_{ph} < 4% of avg I_{ph} (MV, t < 2min) -Magnitude and rate of occurrence of generation fluctuations (By customer) If two or more customers are connected at the same PCC, the maximum voltage fluctuations limit from each customer is in proportion to their respective maximum demand.	→ 49.85Hz < Freq < 50.15Hz (continuous) → 49.75Hz < Freq < 50.25Hz (10 min) → 49 Hz < Freq < 51 Hz (5 min) → 47Hz< Freq <52Hz (2 min) -EG should be disconnected if the rate of change of frequency exceeds ±1Hz/s sustained for 1.0 seconds or more under the minimum access standard of NER. -Power factor limits → 0.75 lag<pf < 0.8 lead (< 1kVA, LV) → 0.8 lag<pf < 0.8 lead (< 1kVA, MV) → 0.8 lag<pf < 0.8 lead (< 2MVA, LV) → 0.85 lag<pf < 0.85 lead (< 2MVA, MV) → 0.85 lag<pf < 0.85 lead (> 2MVA, MV) → 0.9 lag<pf < 0.9 lead (>2MVA, MV)		VEDC -Load balance between phases (By Customer) → I_{ph} < 5% of avg I_{ph} (LV) → I_{ph} < 10% of avg I_{ph} (LV, less than 2 min) → I_{ph} < 2% of avg I_{ph} (MV) → I_{ph} < 4% of avg I_{ph} (MV, less than 2 min) -Magnitude and rate of occurrence of generation fluctuations (By customer) If two or more customers are connected at the same PCC, the maximum voltage fluctuations limit from each customer is in proportion to their respective maximum demand. -Voltage response modes →Fixed power factor control mode →Voltage control mode →Reactive control mode
		-Synchronisation The customer's synchronism check or automatic synchronism (default preference) check is required.	-Synchronisation -For sync generators connected at LV, synchronisation error should be less than 15 electrical degrees before closing the generator circuit breaker. -For mains excited async generators, a speed within ±10% of the	-Synchronisation -A synchronism check is required. -Synchronisation to the grid system can occur at the EG circuit breaker at the point of	-Synchronisation -Synchronisation check: Sync error < ±15 elec. Degrees (deviations will need to be negotiated with UE)

DNSP		VICTORIA			
		CitiPower and Powercor [9]	**Jemena** [10]	**AusNet Services** [11]	**United Energy (UE)** [12]
			synchronous speed is recommended before closing the generator circuit breaker. -For self-excited async generator can be either synchronised like a sync generator (if frequency and voltage can be well controlled) or mains excited async generator.	connection to the grid, and the EG can only be connected once the grid has been stabilised more than 1 minute	
		-Power Export limits -Subject to install capacities -If there is an export limit or intention of export, the customer shall install reverse power protection at the connection point.	-Power Export limits -According to AEMO guidelines, a back generator (< 5MW) is not required to register with AEMO. -Hence, not required to pay participant fees, to have either energy output scheduled or to have their energy generation commercially settled in the market.	-Power Export limits -Not Specified -Egs with export limitations larger than 200 kVA must incorporate reverse power protection incorporating a hard trip setting.	-Power Export limits Up to the maximum rating of the main circuit breaker and the total capacity of less than 5MVA (Three-phase)
		-Requirements based on network type (Urban /Rural) The DNSP referred to VEDC standards directly: -Voltage (By DNSP) →-10% < Volt< +10% (MV, t < 1min, Rural) -The DNSP is required to publish annual information and to include in that information the quality of supply information under a given schedule by VEDC, which includes,	-Requirements based on network type (Urban /Rural) -Voltage operating range →460$V_{ph\text{-}ph}$ (2Ø-180^{0}) → 432 V <Volt < 506V (Rural) -Inverter-connected plants are advocated in rural 460 2-phase systems. -In rural areas, typically, distribution substations are small, and Egs above 10kW may be forced to connect to a dedicated distribution substation and possibly fund the cost of installation.	-Requirements based on network type (Urban /Rural) -Many 22kV rural feeders belonging to AusNet have installed REFCL to detect phase-to-earth faults. Therefore, customers are advised to connect equipment rated at 24.2kV (l-g) to a 22kV supply.	-Requirements based on network type (Urban /Rural) The DNSP referred to VEDC standards directly: -Voltage (By DNSP) →-10% < Volt< +10% (MV, t < 1min, Rural) -The DNSP is required to publish annual information and to include in that information the quality of supply information under a given schedule by VEDC, which includes, → Feeder type (Urban, short rural, long rural)

DNSP		VICTORIA			
		CitiPower and Powercor [9]	**Jemena** [10]	**AusNet Services** [11]	**United Energy (UE)** [12]
		→ Feeder type (Urban, short rural, long rural) → Metred voltages of aggregated 10 minutes averaged data			→ Metred voltages of aggregated 10 minutes averaged data
		-Network and Asset Protection -Interconnection Protection -Non-Export or Export Limited Connection -Neutral Displacement -Protection Coordination	-Network and Asset Protection -Network connection and isolation -Circuit breakers and switches -Protection and metering current and voltage transformers -Ultimate fault levels and plant ratings -Insulation coordination -Surge arresters -Earthing and control of step and touch potentials -General principles for the detection and clearance of all faults -Short circuit faults internal to the generator installation -Power quality protection -Anti-islanding protection -Backup protection -Automatic reclose	-Network and Asset Protection -Installation location of protection measurements -Relays -Protection transformers - protection co-ordination -Phase balance protection -Reverse power protection -Reverse current protection	-Network and Asset Protection -LV non-IES EG Integrated Protection -Backup Protection -Current based protection -Passive Anti-Islanding Protection -Remote Trip Scheme -Special Operational Conditions
		-Other Requirements -Asset Interface Labelling -Earthing of Egs -Fault level contribution -Short circuit withstands -Auto reclose -Reverse phase rotation -Seamless Transfer (or make before break)	-Other Requirements - EG testing, commissioning and maintenance requirements -Revenue metering requirements - Network Ancillary Services - Generator governor control system -Negative and zero sequence injection limits	-Other Requirements -Single line diagram -Distribution network feeder automation (DFA) -Commissioning and testing requirements -Network augmentation -Maintenance -Control systems required	-Other Requirements -Embedded Networks with Embedded LV EG -Cybersecurity -Technical studies -Labelling and Signage -Maximum System Capacity -Generation Control - Network Ancillary Services

DNSP		VICTORIA			
		CitiPower and Powercor [9]	**Jemena** [10]	**AusNet Services** [11]	**United Energy (UE)** [12]
		-Islanding -Customer protection requirements	-Inductive Interference -Network signalling -Generator impact on network capability -Generator fault current contribution	-Rapid earth fault current limiter (REFCL) -Relay and tripping supplies -Earthing requirements -Standby generators and plant (make before break)	-Network Connection and -Isolation -Earthing
	Comm Methods & Protocols	**-**For monitoring of generator status, the DNSP has suggested installing a remote antenna. The antenna cable installation should comply with VSIR. **-**The DNSP has not specified any preferable communication protocols.	-Point to point single-mode fibre optic cables - DNP3.0 Protocol (SCADA Communication)	*Inter-trip* -A secure communications path between DNSP protection devices and the EG units. -Point to point single-mode fibre optic cable -Communication protocol should be complied with IEC 61850 standards. -PTP radio systems are acceptable. *SCADA* -Reliable Licensed or unlicensed radio, microwave link, internet-based communications or other methods may be considered.	**-**Remote monitoring of Egs by customers may be achieved via the use of the LV non-IES EG manufacturer's software applications. **-** A preferable communication protocol is not specified. However, a set of minimum requirements and information to be monitored are given.
	Asset and Infrastructure Requirements	Generation asset should be LV an ad less than 2MW	-Asset modifications with adverse effects need the approval of DNSP. - No changes are permitted to test protection, control, metering, and monitoring systems without consultation with DNSP -The connection agreement is required to nominate a period after which DNSP and the generator are	Generation asset capacity should be less than 5MVA	Generation asset should be LV and less than 5MVA

DNSP		VICTORIA			
		CitiPower and Powercor [9]	**Jemena** [10]	**AusNet Services** [11]	**United Energy (UE)** [12]
			to co-operate in the testing of protection systems -Within three months of any subsequent testing, the generator must update the information in relevant databases -Each registered generator must maintain records for 7 years, setting out details of all technical performance tests and monitoring conducted and is making this available to AEMO or the DNSP on request		
Network Connection Obligations	**DNSP Obligations**	To comply with regional and national frameworks accordingly when establishing its stands and requirement for EG installations	To comply with regional and national frameworks accordingly when establishing its stands and requirement for EG installations	To comply with regional and national frameworks accordingly when establishing its stands and requirement for EG installations	To comply with regional and national frameworks accordingly when establishing its stands and requirement for EG installations
	C&I Customer Obligations	-To comply with the technical requirements as well as relevant national standards, industry codes, legislation, and regulations.	-To comply with the technical requirements as well as relevant national standards, industry codes, legislation, and regulations.	-To comply with the technical requirements as well as relevant national standards, industry codes, legislation, and regulations.	-To comply with the technical requirements as well as relevant national standards, industry codes, legislation, and regulations. -In the event of inconsistency, legislation and regulations shall prevail, followed by the technical requirements, followed by national standards and industry codes -Not to connect additional LV EG units, make modifications or install additional LV EG units, including energy storage systems, without prior written agreement from UE

DNSP		VICTORIA			
		CitiPower and Powercor [9]	**Jemena** [10]	**AusNet Services** [11]	**United Energy (UE)** [12]
					- To comply with the UE's connection agreement -To meet the requirements in the design, installation, operation and maintenance of the LV EG system.
Network Connection Process to Facilitate More Participation	**Barrier Factors**	-Not specify directly among reviewed documents.	-Some of Egs may have to enter into a contract with the DNSP, and violation of those contracts could result in financial penalties. -Planned outages and network faults could put Egs out of service while incurring a loss of revenue. -According to NER guidelines, an EG may have to compensate a DNSP when there is a harmful financial impact by dispatching the EG on the operation of another generator.	-Not specify directly among reviewed documents.	-UE does not permit a non-IES installation to operate in parallel with the network for single-phase and two-phase connections.
	Encouraging Factors	-Parallel of operations of Egs with the network at the connection point	-Ability to participate in the ancillary services market -Opportunities of non-network solutions for increasing capacity constraints in networks, such as opportunities for installing more Egs, are to be published to encourage more participation. -Parallel of operations of Egs with the network at the connection point. -Ability to use the network as an exercise load for standby generators. -In the range around 1MW, there is recognition of the need to relax guidelines further to allow participation of standby plant on an intermittent basis.	-Generators less than 1 MVA can connect to the distribution network and operate in sync with the grid without a formal agreement with AusNet Services.	-Not specify directly among reviewed documents.

According to "Annual Benchmarking Report Electricity distribution network service providers 2021," [13] Australian DNSPs with the highest asset values are given in Table 5.2.

Table 5.2. Australian DNSPs with highest asset values.

DNSP	State	Total Assets ($m)
Ausgrid (AGD)	NSW & ACT	1,094.9
Ergon Energy (ERG)	QLD	655.0
Energex (ENX)	QLD	645.7
Essential Energy (ESS)	NSW	612.2
SA Power Networks (SAP)	SA	432.7
Endeavour Energy (END)	NSW	425.7
AusNet (AND)	VIC	348.9
Powercor (PCR)	VIC	305.9
United Energy (UED)	VIC	225.3
CitiPower (CIT)	VIC	158.0
TasNetworks (TND)	TAS	154.3
Jemena (JEN)	VIC	123.4
Evoenergy (EVO)	NSW & ACT	103.0
Western Power	WA	Not given

In the continuation of the DNSP guideline review study, the largest DNSP from each state (except Vitoria) was selected to review and summarise on backup generator connection requirements.

Table 5.3. Summary of other Australian DNSPs requirements for small-scale diesel and renewable generators.

DNSP		NSW ACT	QLD	SA	TAS	WA
		Ausgrid	**Ergon Energy and Energex**	**SA Power Networks**	**TasNetworks**	**Western Power**
Network Connection Requirements	**Grid Codes**	NER [6], EDC [7], NSWSIR [14]	NER [6], EDC [7], AEMO [8], EIG [9]	NER [6], EDC [7], AEMO [8]	NER [6], EDC [7], AEMO [8]	NER [6], EDC [7], AEMO [8]
	Technical Requirements	-Quality of Supply -Preferred protection settings (Delay 2s) Voltage→ 180V< Volt <265 V Frequency→ 47Hz< Freq <52Hz -LV Steady State Settings Operating Voltage→ 216V< Volt <253 V - For Ausgrid's low voltage network, the compatibility level for negative sequence voltage is 3%.	-Quality of Supply -Operating Voltage IEC 60255-127 Functional requirements for over/under voltage protection Vphase-to-neutral = 230 V +10% / -6%. Vnom-max as per AS/NZS 4777.2 shall be set at 258 V. -Operating Frequency IEC 60255-181 Functional requirements for frequency protection. Frequency→47Hz< Freq <52Hz	-Quality of Supply -Preferred protection settings (Delay 0.4s) Voltage→ +10% or -6% from nominal Frequency→ +4% or -6% of nominal frequency (50Hz) -ROCOF ± 4Hz/s for 250ms ± 3Hz/s for 1s -Total harmonic distortion & harmonics According to AS/NZS 61000.4.7	-Quality of Supply -Passive Anti Islanding Protection Setting -Under freq → 47Hz (1s delay) -Over freq → 52Hz (0.1s delay) -Under volt→90% (20s delay) -Under volt→75% (1s delay) -Over volt→115%(3s delay) -Over volt→130%(0.1s delay)	-Quality of Supply -The user shall be responsible for ensuring that the maximum voltage rise within the Premises complies with AS/NZS 4777.1 -Power Quality response modes according to AS/NZS 4777.2 -Volt-var mode 205V→30% (var/rated VA %) 220V→0% (var/rated VA %) 235V→0% (var/rated VA %)

DNSP		NSW / ACT	QLD	SA	TAS	WA
		Ausgrid	Ergon Energy and Energex	SA Power Networks	TasNetworks	Western Power
		- Limit both alternating and direct voltage differences between neutral and earth to less than 10 Volts steady-state (ten-minute average) at the connection point. -Harmonic voltages (By DNSP) According to AS/NZS 61000.2.2 Australian standards. -Power factor restrictions, According to NER Chapter 5 S5.2.5.1	-Power factor (By Customer) power factor at the Connection Point of greater than 0.8 lagging and not leading unless otherwise agreed to in writing by the DNSP. -Harmonic Voltage from EG Harmonic voltage limits permitted to be injected into the Distribution System at the Network Coupling Point shall be as agreed with the DNSP and specified in the Connection Contract. -Harmonic currents from EG Harmonic current emission limits shall be allocated following IEEE 519.		-Harmonic injection limits According to access standards defined in S5.2.5.2 of the NER, AS/NZS 61000.3.6:2001 and guidelines published by Standards Australia.	255V→40% (var/rated VA %) -Volt-watt mode 250V→30% (var/rated VA %) 260V→30% (var/rated VA %) -Power rate limit only requires soft ramp-up to be applied to connection ramp up power rate limit shall be: $W_{Gra+=}$16.67% of rated power per minute -The maximum voltage rise from the connection point shall not exceed 1%.

DNSP		NSW / ACT	QLD	SA	TAS	WA
		Ausgrid	Ergon Energy and Energex	SA Power Networks	TasNetworks	Western Power
		-Synchronisation - A synchronism check is required. -Synchronisation conditions should be fulfilled and wait at least 1 min to be connected to the grid. -Asynchronous machines do not require synchronising facilities.	**-Synchronisation** - A synchronism check is required. -Synchronisation conditions should be fulfilled and wait at least 1 min to be connected to the grid.	**-Synchronisation** - A synchronism check is required. -automatic synchronising facilities must be installed at the circuit breaker -Synchronisation must produce voltage variations less than ± 3% of the prevailing network voltage at the network connection point and comply with the assigned flicker levels -Gen cap (<500kW)→ $\Delta\phi<20^0 + \Delta V<10V + \Delta f<0.3Hz$ -Gen cap (<1500kW)→ $\Delta\phi<15^0 + \Delta V<5V + \Delta f<0.2Hz$ -Gen cap (<500kW)→ $\Delta\phi<10^0 + \Delta V<3V + \Delta f<0.1Hz$	**-Synchronisation** - A synchronism check is required. -EG rotating asynchronous generators do not require synchronisation facilities	**-Synchronisation** - Embedded Generators that are not an AS/NZS 4777 compliant inverter used for backup power shall not be connected on the grid side of a basic EG system as defined by this technical requirement document.

DNSP		NSW / ACT	QLD	SA	TAS	WA
		Ausgrid	**Ergon Energy and Energex**	**SA Power Networks**	**TasNetworks**	**Western Power**
				-Asynchronous generating systems, including inverters, do not require the installation of synchronising facilities		
		-Power Export limits -Subject to install capacities	**-Power Export limits** -Subject to install capacities and aggregate system capacity for standard Fixed EG Connections are, For LV EG IES ≤ 30 kVA fixed connection →10 kVA per phase For LV EG IES > 30 kVA and ≤ 200 kVA fixed connection →200 kVA For LV EG IES > 200 kVA fixed connection →1,500 kVA	**-Power Export limits** -Low Voltage Systems Only up to 1.5MW via a dedicated transformer, with a 400V connection point. -11kV via an existing shared 11kV Distribution Network, with a 11kV connection point. -33kV via an existing shared 33kV Distribution Network; with a 33kV connection point. -66kV via a dedicated 66kV line.	**-Power Export limits** -Subject to install capacities -Partial export EG should be exported up to the agreed export threshold.	**-Power Export limits** -The specified maximum capacities and export limits are determined based on Western Power standard network designs

DNSP		NSW ACT	QLD	SA	TAS	WA
		Ausgrid	**Ergon Energy and Energex**	**SA Power Networks**	**TasNetworks**	**Western Power**
			For LV EG rotating machines fixed connection →1,500 kVA -Export limits shall be interpreted as "soft" and meet the definition of soft Export limits in clause 3.4.8 of AS/NZS 4777.1.			
		-Requirements based on network type (Urban /Rural) -Vector Shift (VS) for IES greater than 200kVA and Rotating machines 8 degrees (strong/urban network) 12 degrees (weak/rural network)	**-Requirements based on network type (Urban /Rural)** Not specified.	**-Requirements based on network type (Urban /Rural)** Not specified.	**-Requirements based on network type (Urban /Rural)** Not specified.	**-Requirements based on network type (Urban /Rural)** Typically, small semi-rural lots, rural lots, and larger properties outside of the metropolitan area and outside of country city centres. The small network nominal voltage is 240 V single-phase (line to neutral), and 480 V split phase (line to line). Include any of the following:

DNSP		NSW / ACT	QLD	SA	TAS	WA
		Ausgrid	Ergon Energy and Energex	SA Power Networks	TasNetworks	Western Power
						i. LV distribution transformers less than 60 kVA. ii. Single-phase 240 V LV networks; and iii. Split phase 240/480V LV networks.

DNSP		NSW / ACT	QLD	SA	TAS	WA
		Ausgrid	**Ergon Energy and Energex**	**SA Power Networks**	**TasNetworks**	**Western Power**
		-Network and Asset Protection -Design Approval -Commissioning -Inspections and compliance auditing -Primary Anti-islanding testing	**-Network and Asset Protection** -Grid reverse power protection -Phase balance protection -Overcurrent and earth fault protection -Passive Anti-islanding Protection -Inter-tripping -Power Limit protection -Standards compliance -Neutral Voltage Displacement (NVD) protection	**-Network and Asset Protection** - Anti-Islanding - Synchronising Facilities - Over-Current and Earth Fault - Feeder/Line Protection - Voltage Unbalance - Circuit Breaker Fail -Protection Equipment Requirements	**-Network and Asset Protection** - General -Protection system design philosophy - Protection operating speed - Inverter integrated protection - Central protection -Generator connection and disconnection -Automatic reclose	**-Network and Asset Protection** - Inverter integrated protection - Central protection - Interlocking
		-Other Requirements -Earthing	**-Other Requirements** -Metering -Cybersecurity	**-Other Requirements** -Revenue Metering	**-Other Requirements** -Cybersecurity -Earthing	**-Other Requirements** Cybersecurity

DNSP		NSW ACT	QLD	SA	TAS	WA
		Ausgrid	**Ergon Energy and Energex**	**SA Power Networks**	**TasNetworks**	**Western Power**
		-Mixed embedded generator systems -Centralised backup protection -Existing embedded generators	-Testing and commissioning	-Generator (Equipment) Earthing -Pre-Connection Offline Testing and Commissioning		Metering labelling and signage
	Comm Methods & Protocols	Not specified	Where wireless communication is used following criteria should be met. -have a supervised wireless communications link -have a communication delay that does not exceed 0.5 seconds. -disconnect the Fixed EG System from the distribution System for any loss of communications longer than 5 seconds.	**For Rotating Machines-Non-Export** →SCADA (Basic) **-**Serial DNP3 protocol for SCADA interface between EG programmable logic controller (PLC) and remote terminal unit (RTU) -Physical layer delivery can potentially be via a screened copper RS-232 serial communication cable (<15m) -'Multi-Mode Optic Fibre' (MMOF) in RS-232 serial communication Protocol (>15m)	for remote monitoring SCADA system DNP 3.0 communication protocol is preferred. The preferred communications medium is point-to-point fibre optic for all protection, control, and remote monitoring. Where the implementation of fibre is excessively expensive or impractical, it may be appropriate for another communications medium to be used.	Not specified

DNSP		NSW / ACT	QLD	SA	TAS	WA
		Ausgrid	Ergon Energy and Energex	SA Power Networks	TasNetworks	Western Power
				For Rotating Machines- Export →SCADA (Inter-trip) - Ethernet DNP3 protocol for SCADA interface between EG PLC and RTU -Ethernet SCADA interface compliant with IEEE 802.3 standard - physical layer delivery method shall notionally be via a 'Multi-Mode Optic Fibre' (MMOF)		
Network Connection Obligations	**DNSP Obligations**	To comply with regional and national frameworks accordingly when establishing its own stands and requirement for EG installations **Ausgrid takes particular interest in any connection which** → supplies any item of equipment that is rated at greater than 75A	To comply with regional and national frameworks accordingly when establishing its own stands and requirement for EG installations	To comply with regional and national frameworks accordingly when establishing its own stands and requirement for EG installations	To comply with regional and national frameworks accordingly when establishing its own stands and requirement for EG installations	To comply with regional and national frameworks accordingly when establishing its own stands and requirement for EG installations

DNSP		NSW ACT	QLD	SA	TAS	WA
		Ausgrid	Ergon Energy and Energex	SA Power Networks	TasNetworks	Western Power
		→ contains a total of 100kW or more of variable speed drives or other inverters (including embedded generation) → takes a fluctuating load (e.g., Lifts, welders, pumps, cranes, x-ray, MRI or similar type medical equipment) → is supplied at voltages greater than 1000V **as they pose the greatest risk to the network and other customers**				

According to the published literature, international DNSP guidelines for generator connections have been reviewed and summarised below. The IEEE 1547 standards and German standards (BDEW-2008) on the interconnection of generators to the power grid were reviewed in [15]. The Italian standards, Spanish standards, and USA standards on generator connections with the power grid were reviewed in [16].

Table 5.4. Summary of international requirements for small-scale diesel and renewable generators.

Country		IEEE 1547	German standards (BDEW-2008)	Italian Standards	Spanish Standards	USA Standards
Network Connection Requirements	**Reference**	[15]	[15]	[16]	[16]	[16]
	Technical Requirements Comm Methods & Protocols	**-Quality of Supply** **Operating Voltages and Protection settings** V< 50% → 0.16s delay 50% <V< 88% →2s delay 88%<V< 110% → Continue Op 110%<V< 120% → 1s delay V>120% →0.16s delay **Operating Frequency and Protection settings** -2% <Δf< 1% →0.133s delay **Current Harmonics and Inter-harmonics** standard refers to the values from in IEEE 519 -A 0.5% of rated output current as the maximum DC injection allowed	**-Quality of Supply** **Operating Voltages and Protection settings** 10% <V< 100% →2.7s delay 100%<V< 130% → 0.1s delay **Operating Frequency and Protection settings** -5% <Δf< 3% →0.2s delay **Current Harmonics and Inter-harmonics** refer to the German version of the IEC 61000 Electromagnetic Compatibility standards	**-Quality of Supply** **Operating Voltages and Protection settings** V < 80% → 0.2s delay V > 120% → 0.1s delay **Operating Frequency** 49Hz <f< 51 Hz **Power Factor** CosØ ≥0.9 **Harmonics** CEI EN 61000-3-2 or CEI EN 61000-3-12 **Long-term flickers** CEI EN 61000-3-3 or CEI EN 61000-3-11	**-Quality of Supply** **Operating Voltages and Protection settings** V < 85% → 1.5s delay V > 110% → 1.5s delay **Operating Frequency** 48Hz >f→ 0.5s delay f > 51 Hz→ 0.5s delay **Power Factor** CosØ ≥0.8 (Sync gen) CosØ ≥0.86 (Sync gen) **Harmonics** UNE EN 61000-3-2 or UNE EN 61000-3-12 or UNE EN 61000-3-4 **Long-term flickers** CEI EN 61000-3-3 or CEI EN 61000-3-11	**-Quality of Supply** **Operating Voltages and Protection settings** V < 50% → 0.16s delay V < 88% → 2s delay V > 110% → 1s delay V > 120% → 0.16s delay **Operating Frequency** 59.3Hz >f→ 0.16s delay f > 60.5 Hz→ 0.16s delay **Power Factor** CosØ ≥0.85 (Sync gen) CosØ ≥0.86 (Sync gen) **Harmonics** TDD →5% **Long-term flickers** CEI EN 61000-3-3 or CEI EN 61000-3-11
		-Synchronisation Reconnection Standards Normal voltage and frequency for 5 minutes	**-Synchronisation Reconnection Standards** At least 95% nominal voltage between 47.5 Hz and 51.5 Hz delay to allow for switching operations	**-Synchronisation**	**-Synchronisation** **For synchronous machines** **Voltage difference** $\Delta V<\pm8\%V_{rated}$ **Frequency difference** Δf<±0.1Hz	**-Synchronisation** **≤500kVA** $\Delta V<\pm10\%V_{rated}$ Δf<±0.3Hz $\Delta\varphi<\pm20^0$ **≤1500kVA:** ΔV<±5%Vrated

Country		IEEE 1547	German standards (BDEW-2008)	Italian Standards	Spanish Standards	USA Standards
					Phase angle difference $\Delta\varphi<\pm10^0$ **-For Induction machines** Speed must be in-between 90% to 100% of synchronous speed	$\Delta f<\pm0.2Hz$ $\Delta\varphi<\pm15^0$ **≥1500kVA** $\Delta V<\pm3\%V_{rated}$ $\Delta f<\pm0.1Hz$ $\Delta\varphi<\pm10^0$ **-For Induction machines** Voltage deviation must be $\Delta V<5\%$Vrated
		-Network and Asset Protection **Islanding protection** Cease to energise within 2 seconds of the formation of the island	**-Network and Asset Protection** **Islanding protection** Network operator may have special requirements	**-Network and Asset Protection** **Protection devices** -Automatic disconnection switch with intrinsic security -Voltage supervision must be an externa device	**-Network and Asset Protection** **Protection devices** -Automatic disconnection switch with intrinsic security -Anti-islanding according to UNE EN 50438	**-Network and Asset Protection** **Protection devices** -Automatic disconnection switch with intrinsic security -Anti-islanding protection required (delay 0.2s)

6. Review on Optimal Mechanisms and Economical Ways to Synchronise Backup Generators

Generally, backup generators used by C&I customers are alternators (< 5MVA) coupled with diesel engines. Within the range of 100 kVA to 4000 kVA, typical diesel-powered generators use a *3-phase LV **synchronous AC generator** separately excited by a Permanent Magnet Generator (PMG)* [17], [18].

The synchronisation requirements given by Victorian DNSPs for embedded generators (LV) are as follows. The generators with the intentions of participation in DNSPs' networks must follow the guidelines outlined in Table 6.1.

Table 6.1. Victorian DNSPs' regulation on embedded generator synchronisation.

CitiPower and Powercor [9]	**Jemena** [10]	**AusNet Services** [11]	**United Energy** [12]
The customer's **synchronism check** or automatic synchronism (default preference) check is required.	-For sync generators connected at LV, **synchronisation error** should be less than 15 electrical degrees before closing the generator circuit breaker. -For mains excited async generators, a speed within ±10% of the synchronous speed is recommended before closing the generator circuit breaker. -For self-excited async generator can be either synchronised like a sync generator (if frequency and voltage can be well controlled) or mains excited async generator.	-A synchronism check is required. -Synchronisation to the grid system can occur at the EG circuit breaker at the point of connection to the grid -The EG can only be connected once the grid has been stabilised more than 1 minute	- Synchronisation check: Sync error < ±15 elec degrees (Deviations will need to be negotiated with UE)

As per the regulatory requirements by Victorian DNSPs, a synchronism check should be carried out prior to connecting to the grid. For LV synchronous AC generators, the synchronised error should be less than 15 electrical degrees [10], [12].

6.1. Review of Generator Synchronisation

Academic and technical materials published on synchronisation methods and technologies have been reviewed and summarised in this section. This review intends to identify and compare existing and researched technologies of generator synchronisation on a cost-effective and reliability basis.

Art of Generator Synchronising – Research Article (2017) [19]

- This paper discusses the background synchronisation concept.
- **Synchronisation** is defined as matching certain parameters of a power supply (generator) to the network to which the generator is being connected. Those parameters are as follows.
    - Power frequency
    - Voltage magnitude
    - Voltage phase sequence
    - Voltage phase angles
    - Voltage waveform
- The term "**synchronisation window**" describes the acceptable limits of the real-world mismatch of synchronising quantities. Defining this synchronisation window is essential for steering the voltage amplitude, frequency, and phase angle of an oncoming generator through manual methods or an automatic synchroniser (25A). It is also essential for setting a sync-check (25) protective relay to monitor conditions and allow connection of the two systems.
- An older, less-precise method employed a phase-angle/time approach where a **sync-check relay** issued a close to the intertie circuit breaker within the window but without matching phases. This method did not take into account the dynamic, variable nature of the slip frequency (the difference in generator speed, and thus the difference in frequency), which is set by the speed controller.
- The **sync-check** function in the purest definition refers only to live-line/live-bus closing (when two sources are active). For dead-bus and deadline closing, a switch is included for the supervisory sync-check relay that bypasses the sync-check function by shorting across the sync-check relay output contacts (also known as "voltage monitor").

6.2. Synchronisation Methods

- **Manual Synchronisation** [19]**:** This is performed by power-plant operating personnel. When the phasors are within the synchronisation window, an operator closes the intertie circuit breaker to connect the generator to the load bus. This type of synchronising scheme is simple and economical. Typical metering devices for the process are as follows:
    - Synchroscope
    - Indicating lamps
    - Bus and generator frequency meters for matching frequency
    - Bus and generator ac voltmeters for matching voltage.

Two main schemes are "dark-lamp" synchronising and "bright-lamp" synchronising.

- **Assisted-Manual Synchronisation** [19]**:** Adding a supervisory relay, known as a sync-check (25) relay, to the manual synchronisation process assists with proper synchronisation. The supervisory relay enforces a synchronisation window for safe conditions
- **Automatic Synchronisation** [19]**:** This is introduced to avoid costly equipment damage resulting from improper synchronisation with the previous two methods. The automatic synchroniser (25A) monitors voltage, frequency, and phase angle; issues correction signals to a generator governor to achieve matching of the voltage and frequency; and then provides an output contact to close the circuit breaker. Under emergency outage conditions, a dedicated automatic synchroniser should be used for each generator. This allows the generators to be parallel to each other and to the main bus as quickly as possible. Larger slip frequencies allow synchronisation to be accomplished faster, but there is more system disturbance, and the following consideration should be weighted to make a decision.
    - How quickly must the generator be brought online?
    - How critical is the generator?
    - How expensive is repair or replacement of the generator versus the cost of possible outage (down) times?

Fundamentals and Advancements in Generator Synchronising Systems – Research Article (2012) [20]

- This paper presents how this technology can simplify synchronising circuits to reduce cost, improve reliability, and easily accomplish complete integration, automation, and remote control of the system.
- Protective-relay-grade microprocessor devices can significantly improve manual and automatic synchronising systems.
- Complete galvanic isolation between circuits is possible. Signals can be wired to isolated VT and I/O terminals on the microprocessor-based devices and selected in logic. Remote I/O modules with fibre-optic links can allow an automatic synchroniser to be located near remote breakers—eliminating long VT circuit runs.
- Enhanced visualisation of the synchronising process using a computer-based soft synchroscope that provides the operator with better information can make it easier to correctly synchronise the unit every time.

6.3. Synchronising System Components [20]

Synchronism-Check Relays: This supervises both manual and automatic synchronising operations. Most synchronism-check relays check that the angle is inside a ± angle window and stays there for a time period. Microprocessor-based synchronism-check elements are capable of measuring slip directly and calculating the slip-compensated advanced angle and adjusting their characteristics to assert permissive trip at the advanced angle instead of the edge of the angle window. A microprocessor-based synchronism-check element with a slip-compensated advanced angle function can be used to initiate closing similar to the feature in an automatic synchroniser.

Voltage Relays: voltage relays are used to supervise the close command. Used to supervise live generator/dead-bus close, generator, and bus voltage magnitude. All of these voltage supervision functions are typically included in a microprocessor-based synchronism-check element.

Dead-Bus Close Permissive: Used to prevent a faulty synchronisation caused by a blown bus VT fuse.

6.4. Comparison between Synchronisation Methods [20]

Table 6.2 provides a comparison of the qualities of different synchronisation methods.

Table 6.2. Comparison of synchronisation methods.

Synchronisation Method	Capital Cost	O&M Cost	Accuracy	Reliability/ Redundancy
Manual System	Low	High	Low	Low
Assisted-Manual System	High	High	Medium	Medium
Automatic with backup manual system	Medium	Medium	High	High
Fully automatic (primary and secondary both) system	High	Low	High	High

6.5. Advanced Technologies Introduced for Synchronisation [20]

- **Advanced microprocessor-based automatic synchroniser** with six isolated and independent single-phase voltage sensing inputs → Eliminate Voltage Signal Switching.
- **Synchrophasor-Based Synchroscope** → Fully eliminate hard-wired voltage and control signal switching circuits and allow complete computer human-machine interface (HMI) integration.
- **Synchrophasor data concentrator software** → Enables streaming of synchrophasor data in real-time and analyse it in a software interface.
- **Fibre-optic data links** → Operator can monitor and control the generator and breaker from a remote location with a minimum sensor reading delay.
- **High performance, relay-to-relay logic communication** in the A25A device→ allow it to be located close to the synchronising breaker with control signals sent back to the governor and exciter via fibre-optic links.

- **Remote I/O (RIO) Functionality** The automatic synchroniser can be connected to a remote I/O module to read control signals remotely. IEC 61850 GOOSE (Generic Object-Oriented Substation Event) messaging over an Ethernet network can also be used with this platform.
- **High-Current Interrupting Contacts** To prevent automatic synchroniser from arcs caused while pulsing the governor and exciter.
- Detailed sequence-of-events and oscillography **recording functions.**
- **Slow Synchronising Breaker Protection.**

Synchrophasor Broadcast Over Internet Protocol for Distributed Generator Synchronisation (2010) [21]

- This research investigates the effectiveness of synchronising a distributed generator (diesel 50kVA) via an Internet protocol (UDP/IGMP) communication link which has high latency compared to conventional analogue wired communication.
- The diesel generator was held in synchronism with the all-Ireland power system using a remote reference signal at a wind farm site located approximately 100 km away.
- The research proposes a latency tolerant algorithm by extrapolating transmitted data to replace lost data packets during the communication period to adhere to this latency issue.
- Results were presented which show that, with an enhanced governor and phase controller, a load disturbance of 10 kW (25%) can be endured while holding the phase difference within ±60 degree.

Automatic Synchronisation Unit for The Parallel Operation of Synchronous Generators (2009) [22]

- This paper presents a microcontroller (PIC16F877) based automatic synchronisation unit.
- The micro-controller has been programmed with an algorithm to read the measurement signals (phase voltages, phase sequence, frequency of the supply, etc.) and calculate synchronism time (i.e., the time to initiate/close synchronising relay).
- The algorithm consists of subroutines to determine synchronising voltage, phase sequence and frequency based on measured data. Based on the outcomes of these subroutines, the algorithm then calculates the synchronism time.
- The main qualities of this synchronisation method are that it is cost-effective, simple, reliable, independent of extra measurement tools, and easy to use.

6.6. Inter-tripping Communication Requirements

Inter-tripping is the process of tripping a generator according to a remote-control signal. Inter-tripping is also a protection mechanism of the generator to avoid damage during unintended operating conditions.

Ausgrid embedded generation guideline section 7.7.5 indicates, “Inter-tripping and communications between Ausgrid and the generator facility shall be provided over dedicated dark fibre cores” [23].

According to the Jemena embedded generation guideline section 5.3.11 DNSP preferred communication methods and protocols, “Communications links may be required for protection (such as remote trips or differential protection) or for SCADA monitoring and control. The preferred communications medium is point-to-point single mode fibre optic cable for all protection, control and remote monitoring. Where existing infrastructure using copper communication cables is available this can also be utilised, however copper cables shall not be used where new communication links are to be installed” [10].

Ausnet embedded generation guideline section 4.5.3 “communication links are required at power stations” presents: “If a protection study can demonstrate that duplicated protection and control requirement is not required between the generator and the zone substation, single path of optical fibre cable may be considered. Otherwise, protection and control requirements should be duplicated through two separate and independent optical fibre cables with diverse routes between the generator and zone substation. Sufficient cores should be provided in each optical cable for protection, control, and communication functions” [24].

According to CitiPower/Powercor’s document section 6.16 “Communication requirements”, point-to-point radio or fibre optic cable can be used for communication. Fibre optic cable is the preferred method of communication for all communication links [25]. The preferred communication methods by each DNSP for inter-tripping are summarised in Table 6.3.

Table 6.3. Summary of DNSPs’ preferred inter-tripping communication methods.

DNSP	Preferred inter-tripping communication
Ausgrid	Dedicated dark fibre cores
Jemena	Point-to-point single mode fibre optic cable
Ausnet	Single path of optical fibre cable
CitiPower/Powercor	Point-to-point radio or fibre optic cable

According to the Table 6.3, fibre optic is the preferred solution for inter-tripping communication systems across each DNSP, but some DNSPs allow other technologies as well.

Wireless communication can be another solution. The wireless communication latency, considering 5G as an example, is 0.022s, and 0.35s for 4G communication [26]. While the communication latency of optical fibre is 5 μs/km [27]. The optical to electrical conversion time is 2953 ps [28], which is negligible. Thus, fibre optic has lower communication latency. However, in some protection scenarios, such as under voltage and under frequency, the tripping time can be 2s [29]. In this case, the communication latency has a negligible effect.

7. Investigation of Technical Barriers for Using Backup Generators in Demand Response

7.1. Simulation Methodology

In this chapter, the barriers to backup generator utilisation in demand response schemes are investigated using simulation studies. Three types of barriers are investigated here: 1) network barriers, 2) location-based barriers, and 3) time-based barriers. Load-flow studies are carried out to explore the barriers regarding network and backup generator location. Time-based barriers are investigated with quasi-dynamic simulations and short-circuit calculations to identify the export limit of the backup generators. The simulation studies are summarised in Fig. 7.1.

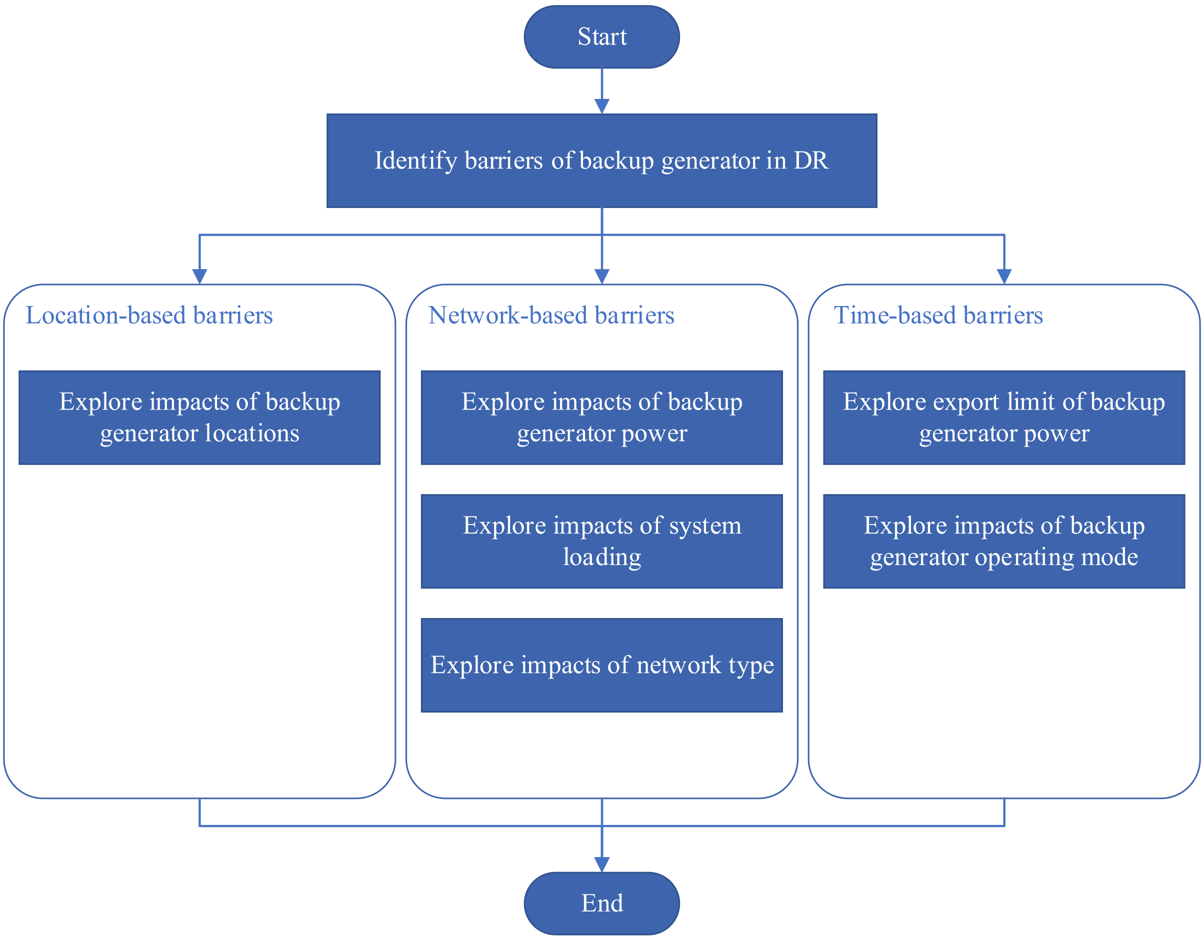


Fig. 7.1. The simulation methodology.

7.2. Identification of Barriers

7.2.1. Location-based barriers

Location-based barriers focus on the location of backup generators. Backup generators can be installed at any location in the distribution feeder. A backup generator can have different impact on the network based on its location in the feeder. In this study, the project team has selected three representative locations (i.e., the beginning of the feeder (upstream of the grid), the middle of the feeder, and the end of the feeder (downstream of the grid)) to investigate the influence of backup generator location on the power network.

7.2.2. Network-based barriers

Network-based barriers cover the influences caused by the network properties including the network type, system loading, and backup generator power. For network type, we selected urban and short rural networks and compare their performances under multiple scenarios. Power networks under full load and half load are also examined with backup generator connection. Multiple backup generator power levels (i.e., 10%, 20% and 50% of network capacity) are compared and integrated with other scenarios for cross comparisons.

7.2.3. Time-based barriers

Time-based barriers are related to the export limit and operating modes of backup generators. Factors such as voltage limit, thermal limit, and short-circuit current limit are considered for the time-variant export limit calculation for backup generators. The performance of backup generators with two operating modes, P-V control and P-Q control, are investigated and compared with one-day quasi-dynamic simulations.

7.3. Representative Power Network Used in This Study

7.3.1. Medium voltage feeder taxonomy project

The network models provided in the CSIRO Medium Voltage Feeder Taxonomy Project [1], [30] are used as representative network models in this study. The Medium Voltage Feeder Taxonomy Project provides 19 networks across central business district (CBD), urban, short rural and long rural areas. The networks include typical elements of the Australian distribution network, i.e., residential, commercial, agricultural, industrial, mining loads.

Among the networks, four clusters are selected considering the following aspects: (1) covering both short rural and urban areas; (2) covering both commercial and industrial customers; (3) covering both NSW and VIC locations; (4) with a smaller number of busbars for ease of analysis and simulation. Therefore, the following four clusters are selected and listed in the sequence of size from small to large: (1) Urban-NSW1 (cluster 14); (2) Urban-NSW2 (cluster 15), (3) Urban-VIC (cluster 12); (4) Short rural-NSW (cluster 8). The details of these clusters are provided in this section.

7.3.2. Urban-NSW1 (Cluster 14)

Urban-NSW1 (cluster 14) is an 11kV network located in NSW with medium/high density residential customers and few commercial customers, as shown in Fig. 7.2. The total length of the feeder including underground and overhead cables is 3.4 km. The basic information of Urban-NSW1 network is presented in Table 7.1.

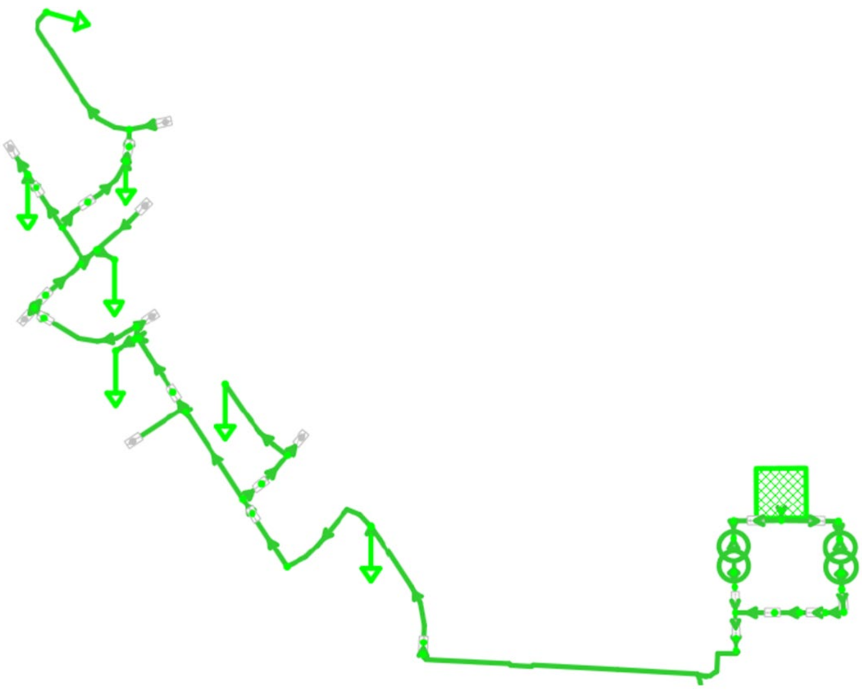


Fig. 7.2. Urban-NSW1 network.

Table 7.1. Urban-NSW1 network.

No. of loads	7
No. of buses	57
No. of lines	55
Total active power (MW)	0.926
Total reactive power (MVar)	0.448
Total rated capacity (MVA)	1.029

7.3.3. Urban-NSW2 (Cluster 15)

Urban-NSW2 (cluster 15) is a 11kV network located in NSW with industrial customers, as shown in Fig. 7.3. The total length of the feeder including underground and overhead cables is 4.9 km. The basic information of Urban-NSW2 network is presented in Table 7.2.

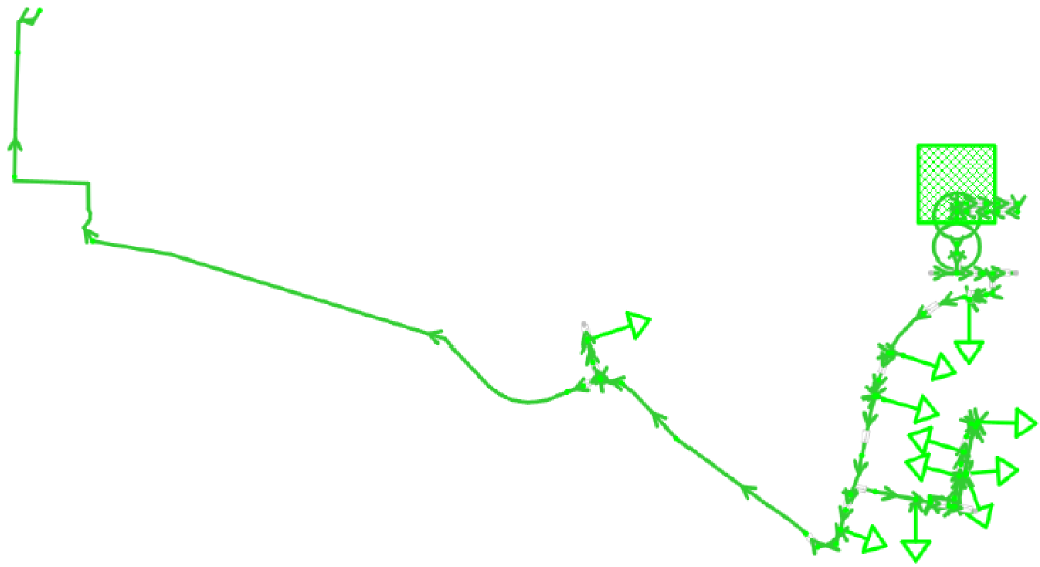


Fig. 7.3. Urban-NSW2 network.

Table 7.2. Urban-NSW2 network.

No. of loads	11
No. of buses	90
No. of lines	89
Total active power (MW)	1.458
Total reactive power (MVar)	0.706
Total rated capacity (MVA)	1.620

7.3.4. Urban-VIC (Cluster 12)

Urban-VIC (cluster 12) is a 22kV network located in VIC with medium density residential customers and few commercial customers, as shown in Fig. 7.4. The total length of the feeder including underground and overhead cables is 9.6 km. The basic information of Urban-VIC network is presented in Table 7.3.

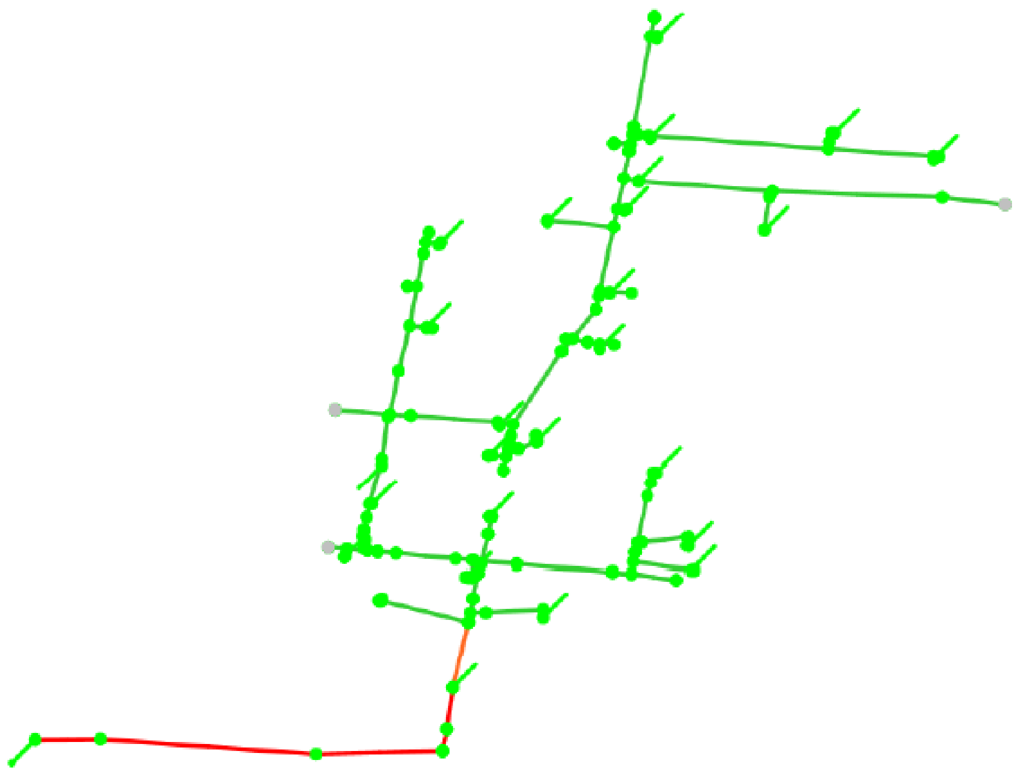


Fig. 7.4. Urban-VIC network.

Table 7.3. Urban-VIC network.

No. of loads	26
No. of buses	191
No. of lines	187
Total active power (MW)	12.001
Total reactive power (MVar)	5.812
Total rated capacity (MVA)	13.333

7.3.5. Short rural-NSW (Cluster 8)

Short rural-NSW (cluster 8) is a 11kV network located in NSW with principally residential customers and some commercial customers, as shown in Fig. 7.5. The total length of the feeder including underground and overhead cables is 16.7 km. The basic information of Short rural-NSW network is presented in Table 7.4.

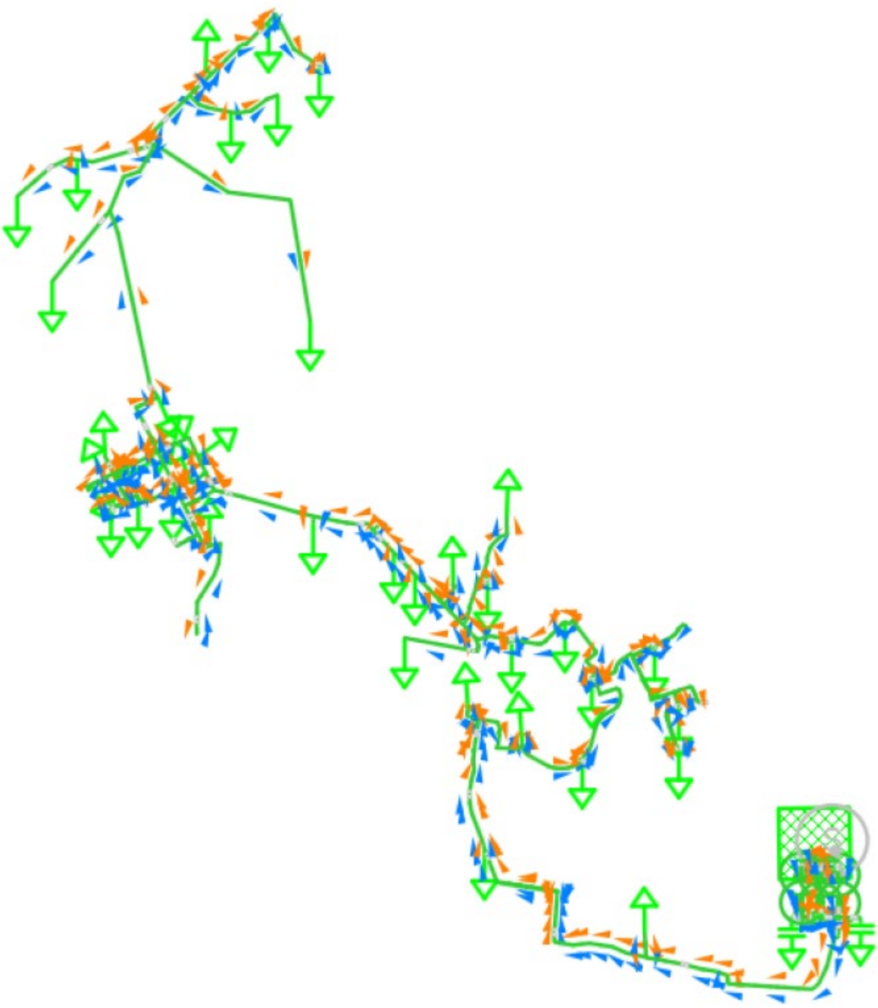


Fig. 7.5. Short rural-NSW network.

Table 7.4. Short rural-NSW network.

No. of loads	39
No. of buses	263
No. of lines	263
Total active power (MW)	5.367
Total reactive power (MVar)	2.599
Total rated capacity (MVA)	5.963

7.4. Impacts of Backup Generator Integration on the Power Grid

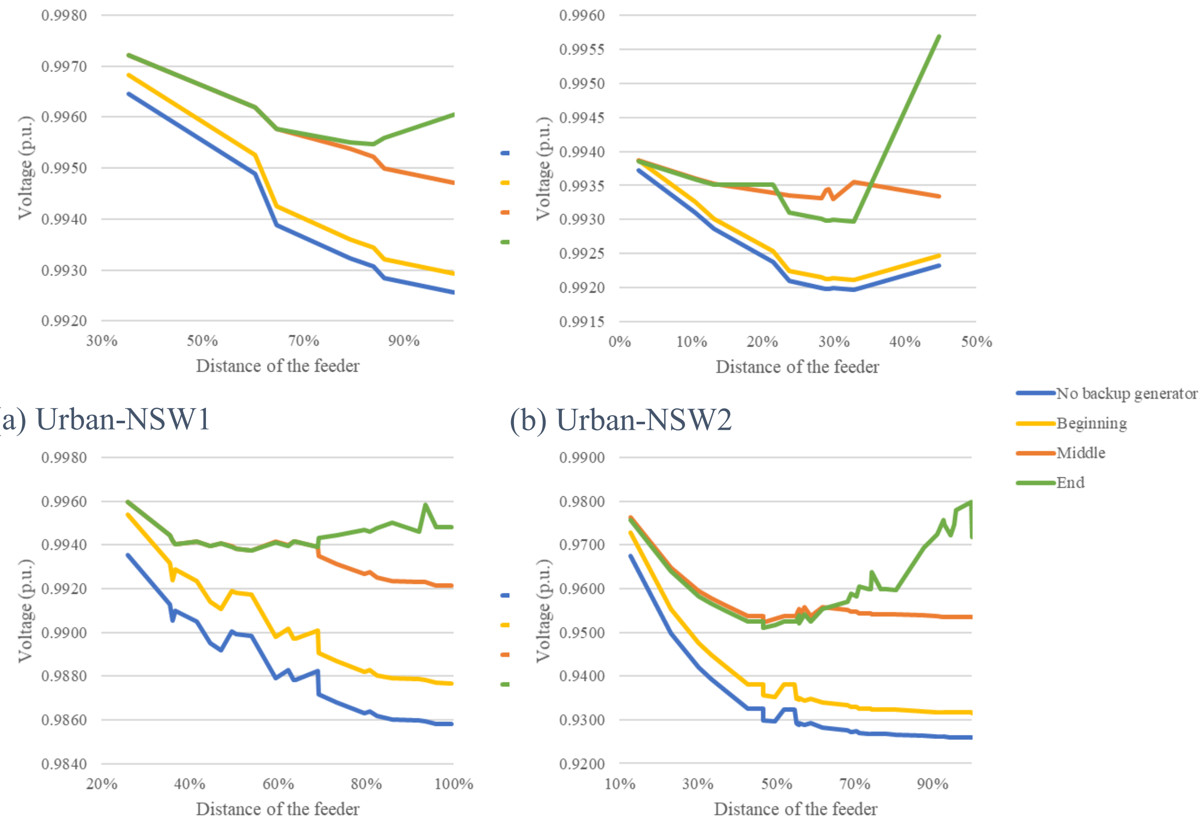
7.4.1. Impact of backup generator location

Three backup generator locations are investigated in this section, i.e., the beginning of the feeder, the middle of the feeder, and the end of the feeder. The power output of the backup generator is 50% of the total load in the feeder. The voltage of the terminals with loads along the feeder from upstream to downstream is presented in Fig. 7.6.

The voltage profiles of cluster Urban-NSW1 indicates that if there is no backup generator, the terminal voltage decreases from upstream to downstream. When the backup generator is connected to the beginning of the feeder, the voltage performance of the network is similar to the situation that no backup generator is connected. When the backup generator is connected at the middle of the feeder, the voltage profile has improved, i.e., the voltage drop has reduced. If the backup generator is connected at the end of the feeder, the terminal voltage can be improved further, especially at the end of the feeder (near the backup generator). The voltage increase around the end of the feeder indicates that the power output of the backup generator is higher than the load demand at the downstream of the feeder, and the power flow is reversed (from downstream to upstream) at the downstream of the feeder.

For other clusters Urban-NSW1, Urban-VIC and Short rural-NSW, the voltage profiles show similar performance as Urban-NSW1. Irregularities can be observed in the voltage profiles because the terminals are listed in a sequence based on the distance from the substation, which is different from the original network topology as a tree.

Therefore, the location of the backup generator has impact on the network voltage profile. The installation of backup generator can help reduce the voltage drop along the feeder. Moreover, when the backup generator is connected at the end of the feeder, the improvement is more significant than other locations.



(a) Urban-NSW1 (b) Urban-NSW2

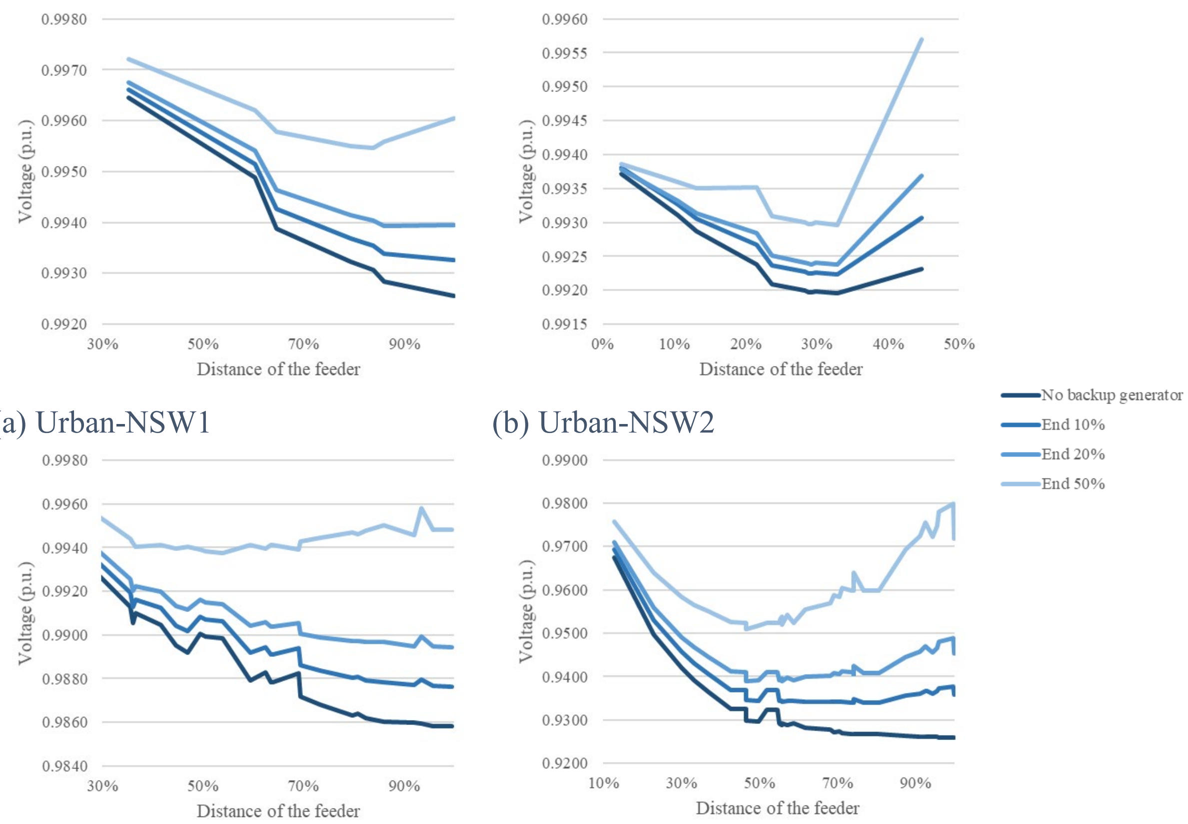
(c) Urban-VIC (d) Short rural-NSW

Fig. 7.6. Terminal voltage with different backup generator locations.

7.4.2. Impact of backup generator power export

The impact of backup generator power export is investigated by comparing voltage profiles under different backup generator power outputs such as 10%, 20% and 50% of the rated load in the network. To show the significance of each scenario, the backup generator is connected at the end of the feeder. The voltage profiles of the four networks are shown in Fig. 7.7.

It can be noticed that the voltage support provided by the backup generator not only increases the voltage of the terminals around the backup generator but also enhances the voltage of the entire feeder. Moreover, with the increase of backup generator power output, the voltage profile along the feeder increases more significantly. The voltage profiles of the Urban-NSW2 and Short rural-NSW show that if the large loads in the network are located at the upstream or middle of the feeder, then with a backup generator connected at the end of the feeder is generating 50% of the total rated load. Thus, the voltage at the end of the feeder can be higher than upstream terminals.



(a) Urban-NSW1 (b) Urban-NSW2

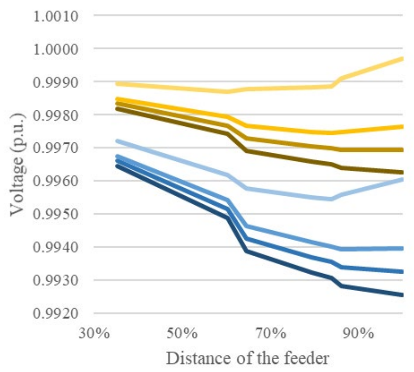
(c) Urban-VIC (d) Short rural-NSW

Fig. 7.7. Terminal voltage with different backup generator power.

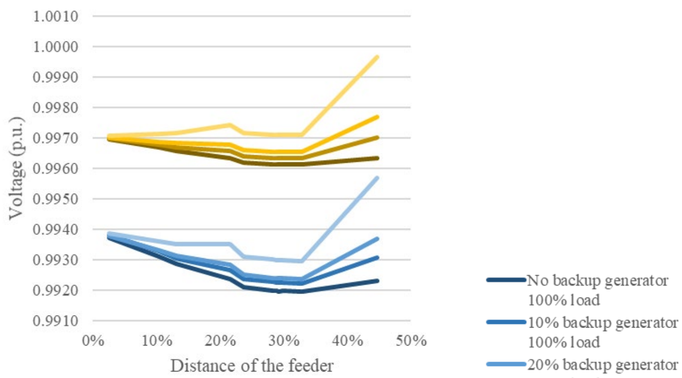
7.4.3. Impact of system loading

In this section, a comparison between different system loading is conducted, as shown in Fig. 7.8. The power of each load in the system are set to be: (1) 100% of the rated load (blue lines), and (2) 50% of the rated load (yellow lines). The backup generator is connected at the end of the feeder, and the backup generator power output is increased in steps, such as 10%, 20% and 50% of the total rated load in the network.

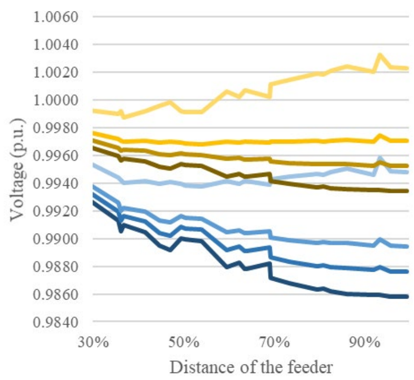
According to voltage profiles in Fig. 7.8, the yellow lines are above the blue lines. Therefore, when the system loading is lower (i.e., 50% of rated load), the voltage profile is higher, i.e., the voltage drop is lower. The reason is that per-length voltage drop reduces due to decrease in current flow in the feeder under low loading conditions. Moreover, with the same backup generator, the voltage increases by the same amount as the system loading varies. For example, in the Urban-NSW1 network, the backup generator generating 50% of the total rated load, and that can improve its terminal voltage from 0.9926 p.u. to 0.9960 p.u. (0.0034 p.u. increment) under 100% system loading. While under 50% system loading, the backup generator generating 50% of the total rated load can improve its terminal voltage from 0.9963 p.u. to 0.9997 p.u. (0.0034 p.u. increment).



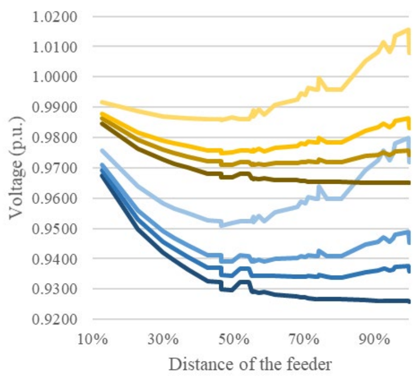
(a) Urban-NSW1



(b) Urban-NSW2



(c) Urban-VIC



(d) Short rural-NSW

Fig. 7.8. Terminal voltage with different system loading.

7.5. Investigation of Dynamic Export Limits in Different Scenarios

The power output of backup generator is limited due to multiple reasons: (1) the physical power limitation of the generator, (2) the limitation of the voltage in the network, (3) the thermal limitation of cables in the network and (4) the limitation of the short-circuit current in the network. In this section, the limitations relating to the network are explored. The physical power limitation of the generator is not considered here.

In this section, quasi-dynamic simulations are conducted to investigate the export limit of the backup generator constrained by voltage and thermal limits. Short-circuit analysis is conducted to examine whether the short-circuit current limit has reached once a backup generator is connected to the network.

In the quasi-dynamic simulations, the power profiles of each load hours are required. In the Medium Voltage Feeder Taxonomy Project, the 62-day power profiles for loads in Urban-NSW1 are provided. Both power consumption and solar power generation are included in the load power profile, and both are time-variant values. Therefore, the net power of the load can be positive or negative. Positive value indicates the power consumption is more than the solar power generation at a given time instance, while the negative value means the solar power generation is more than the power consumption. For example, the net power profile of one load in the Urban-NSW1 network is shown in Fig. 7.9.

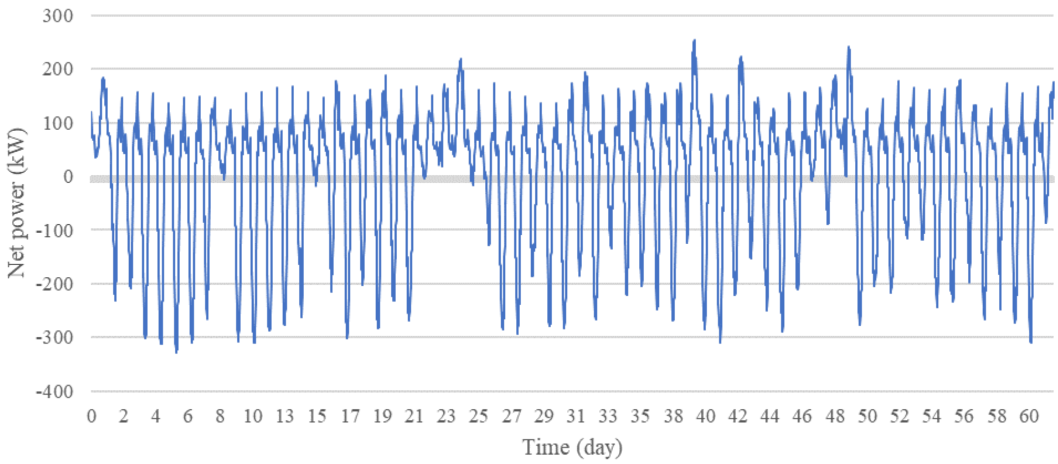


Fig. 7.9. Net power profile of one load in Urban-NSW1 network.

Since load profiles are not provided for networks Urban-NSW2, Urban-VIC and Short rural-NSW in the Medium Voltage Feeder Taxonomy Project, the following steps have been followed to add load profiles to these networks:

(1) For each load in network Urban-NSW1, divide each load value in the load profile by the rated power of the feeder. Thus, a time-variant scaling factor can be obtained for each load.
(2) Since networks Urban-NSW2, Urban-VIC and Short rural-NSW have more loads than network Urban-NSW1, randomly assign scaling factor profiles obtained from network Urban-NSW1 to loads in these networks.
(3) Reduce the load profiles of networks Urban-NSW2, Urban-VIC and Short rural-NSW by applying another scaling factor K to ensure the voltage and thermal limit are not violated under normal operating conditions.

The scaling factor K manipulates the load profile to suit the network characteristics of each network (e.g., Urban-NSW2, Urban-VIC and Short rural-NSW) considered in the study.

7.5.1. Voltage limit

According to the IEC Standard 61000.3.100, the voltage of the busbars in a MV network (11 kV or 22 kV) should be maintained in the range of 0.9 to 1.06 p.u. under steady-state conditions.

The Medium Voltage Feeder Taxonomy Project provides load profiles of 62 days with a time resolution of 30 minutes. First, the quasi-dynamic simulations are conducted for 62 days. Then, we analysed the simulation results and find the dates that the maximum and minimum busbar voltage are reached. Next, on these two selected dates, the backup generator is connected at the end of the feeder, and the busbar voltages are examined. If all busbar voltages are within limits, the backup generator power is increased. The export limit of the backup generator is the export power when any of the busbars exceeds the voltage limit. The data preparation procedure described above is presented in Fig. 7.10.

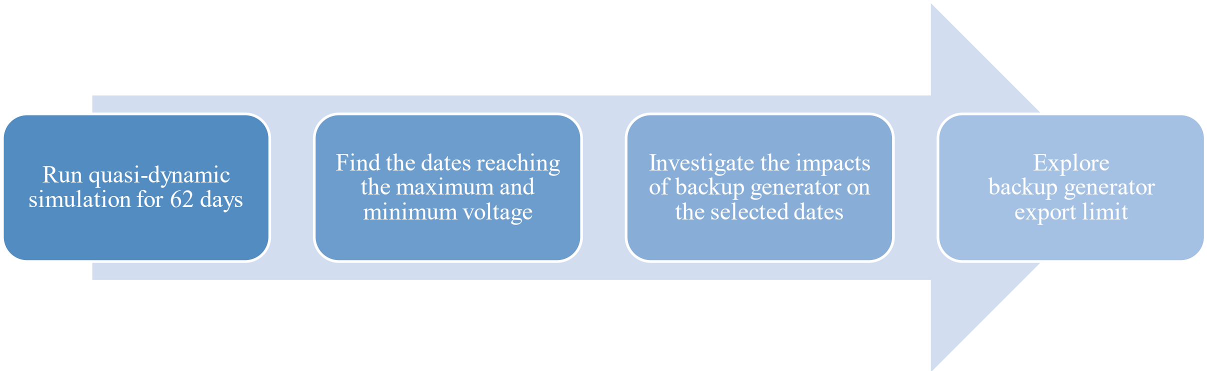


Fig. 7.10. Data preparation procedure.

Consider Urban-NSW1 network as an example. The scaling factor *K* is 2 for this network. According to the quasi-dynamic simulation results for 62 days, the highest busbar voltage is achieved on day 6. The profiles of each load are presented in Fig. 7.11. The highest voltage is achieved at terminal 17 (at the end of the feeder). The voltage profile of terminal 17 is presented in Fig. 7.12, where the highest voltage is 1.013 p.u. at 11:30.

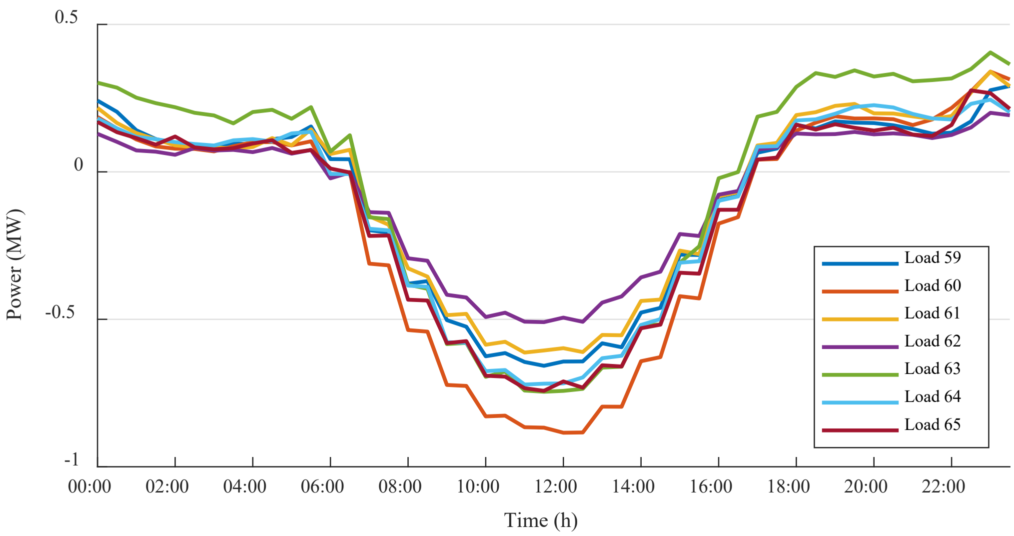


Fig. 7.11. Load profiles of Urban-NSW1 network on day 6.

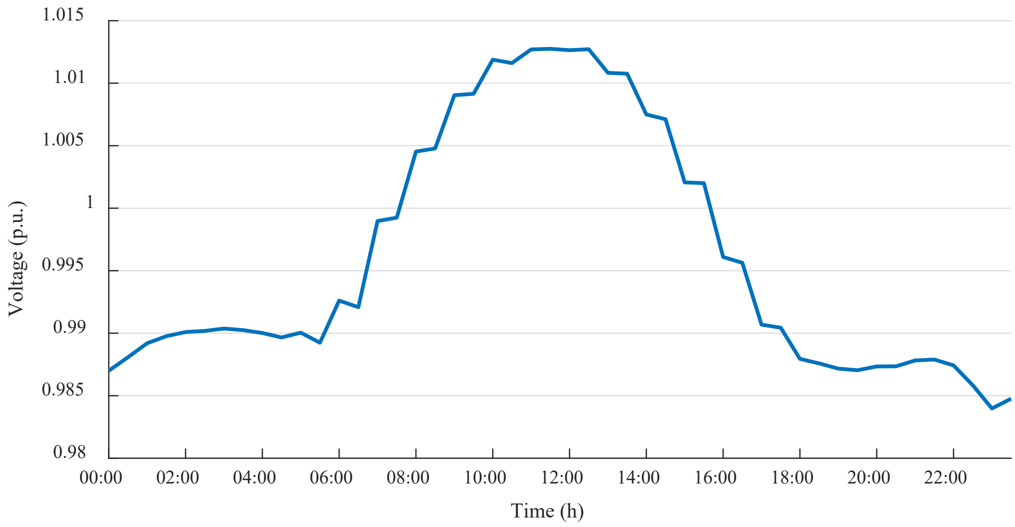


Fig. 7.12. Voltage profile of terminal 17 on day 6.

On day 6, the dynamic export limit of backup generator based on voltage limit is illustrated in Fig. 7.13. Around 12:00 when the solar power is high, the export limit is 8 MW, and the export limit increases to 11.5 MW during night-time.

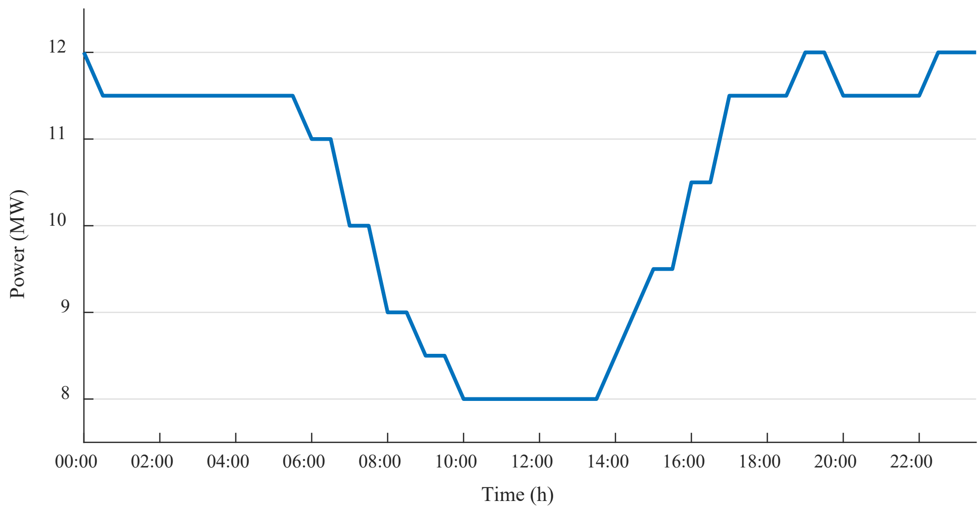


Fig. 7.13. The dynamic export limit of a backup generator on day 6 based on the voltage limit.

According to the quasi-dynamic simulation results for 62 days, the lowest busbar voltage was recorded on day 49. The profiles of each load on day 49 are presented in Fig. 7.14. The lowest voltage was recorded at terminal 17 (at the end of the feeder). The voltage profile of terminal 17 is presented in Fig. 7.15, where the lowest voltage is 0.977 p.u. at 18:00.

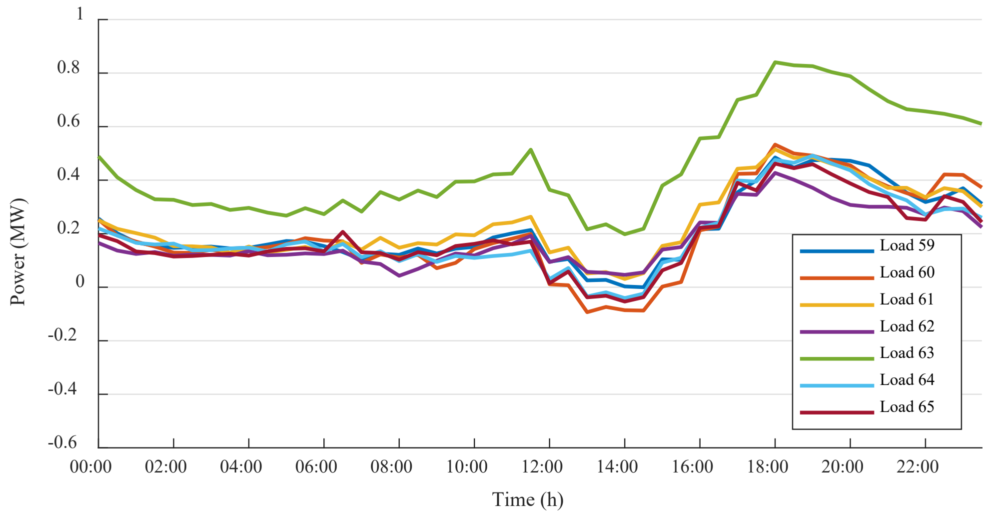


Fig. 7.14. Load profiles of Urban-NSW1 network on day 49.

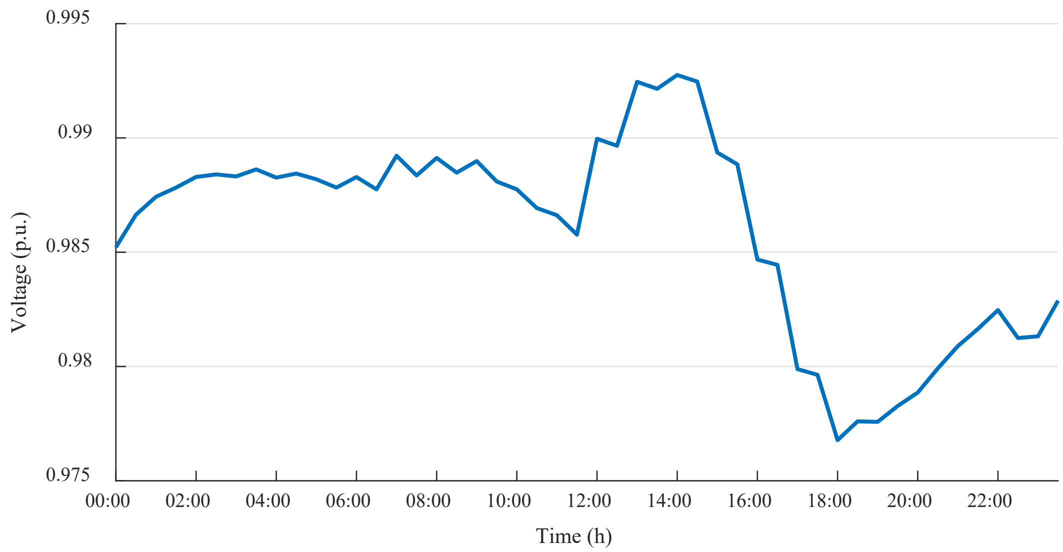


Fig. 7.15. Voltage profile of terminal 17 on day 49.

On day 49, the dynamic export limit of backup generator based on voltage limit is illustrated in Fig. 7.16. During peak load hours (around 18:00), the export limit of backup generator can go high as 13 - 13.5 MW. In off-peak hours (around 14:00), the export limit has reduced to 11 MW.

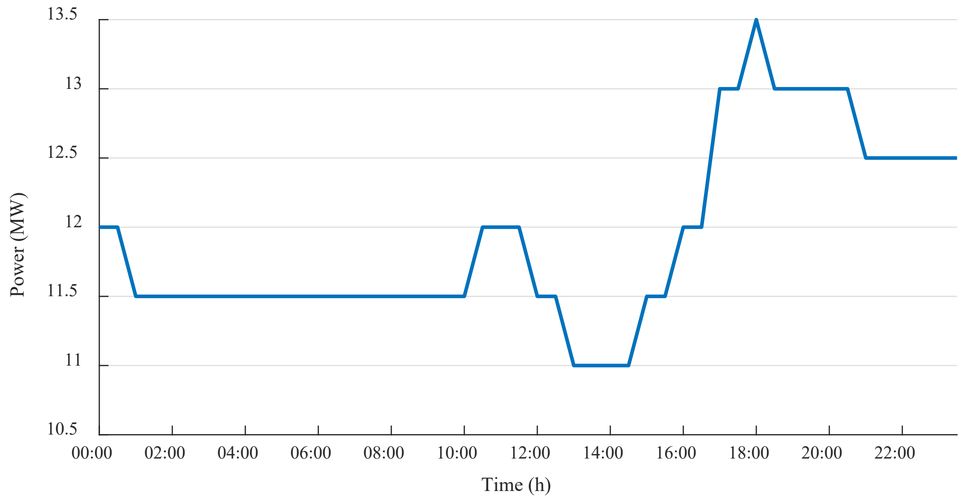


Fig. 7.16. The dynamic export limit of backup generator on day 49 based on voltage limit.

By comparing the dynamic export limit on day 6 and day 49, it can be noticed that the limit on day 6 is lower, which means the power output range for the backup generator is narrower. Since day 6 is the day with the highest terminal voltage, less power output is allowed to be exported from the backup generator to maintain the network voltage within limits. Therefore, the dynamic export limit calculated on day 6 should be followed to ensure the voltage stays within limits on any day. Dynamic export limits for only day 6 are presented for other networks.

Urban-NSW2 network has a scaling factor K of 1.5. The maximum terminal voltage is recorded on day 6 at terminal 28. The dynamic export limit of the backup generator based on the voltage limit of day 6 is presented in Fig. 7.17, which varies between 16 MW to 17.5 MW.

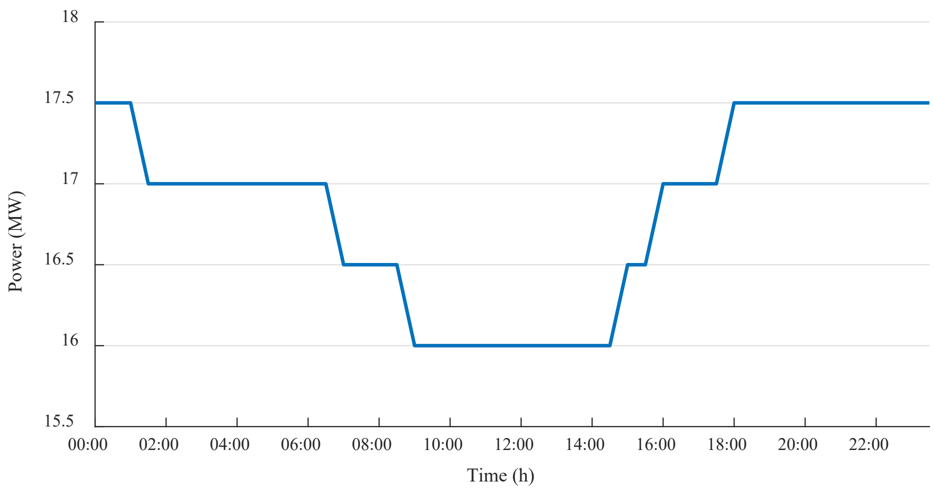


Fig. 7.17. The dynamic export limit of backup generator in Urban-NSW2 network.

Urban-VIC network has a scaling factor K of 0.3. The maximum terminal voltage is achieved on day 6 at terminal 29. The dynamic export limit of the backup generator based on voltage limit of day 6 is presented in Fig. 7.18. The export limit varies between 19 MW (143% of the rated network capacity 13.333 MVA) to 26.5 MW (199% of the rated network capacity 13.333 MVA).

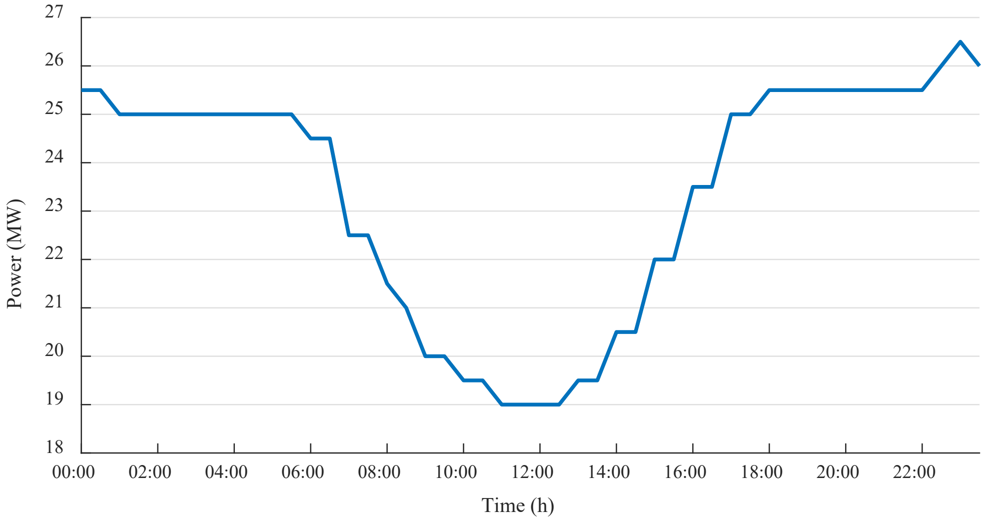


Fig. 7.18. The dynamic export limit of backup generator in Urban-VIC network.

Short rural-NSW network has a scaling factor K of 0.3. The maximum terminal voltage is achieved on day 6 at terminal 43. The dynamic export limit of the backup generator based on the voltage limit of day 6 is presented in Fig. 7.19. The export limit varies between 2 MW (34% of the rated network capacity 5.963 MVA) to 4.5 MW (75% of the rated network capacity 5.963 MVA).

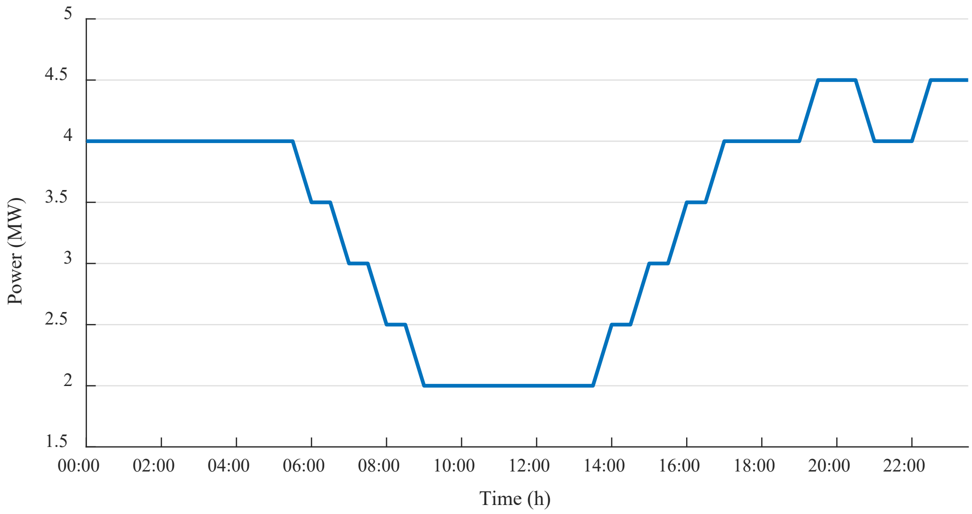


Fig. 7.19. The dynamic export limit of backup generator in Short rural-NSW network.

7.5.2. Thermal limit

Thermal limit defines the limitation due to the network's thermal capacity of lines and transformers. The loading of each line and transformer in the network should be lower than 100% to avoid damage to any equipment. For the representative networks used in this study, the line loading limit is achieved earlier than the transformer loading limit when increasing the backup generator power output. Therefore, here, export limits of backup generators are calculated according to the network's maximum line loading and maintained it should be maintained below 100% loading at every time.

For Urban-NSW1 network, the maximum line loading is achieved on day 6 at line 16 (scaling factor K is 2). The loading of line 16 is presented in Fig. 7.20, and the maximum loading is 87% at noon. The line loading is lower during evenings.

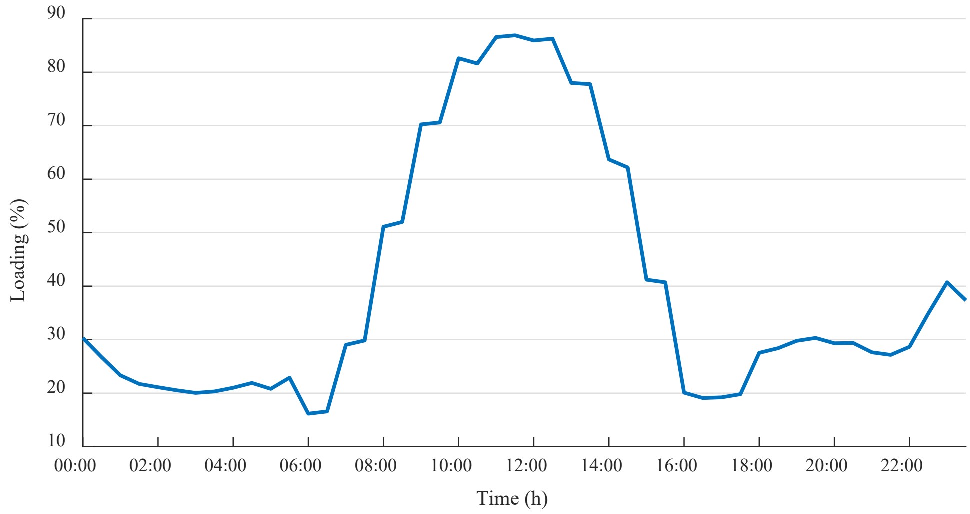


Fig. 7.20. The loading of line 16 on day 6.

The dynamic export limit of the backup generator located at the end of the network is shown in Fig. 7.21. At noon when line loading is higher, the export limit of the backup generator is relatively lower (1.5 MW, 146% of the rated network capacity, 1.029 MVA) to avoid exceeding the thermal limit. At night, the output power of the backup generator can increase up to 4.5 MW.

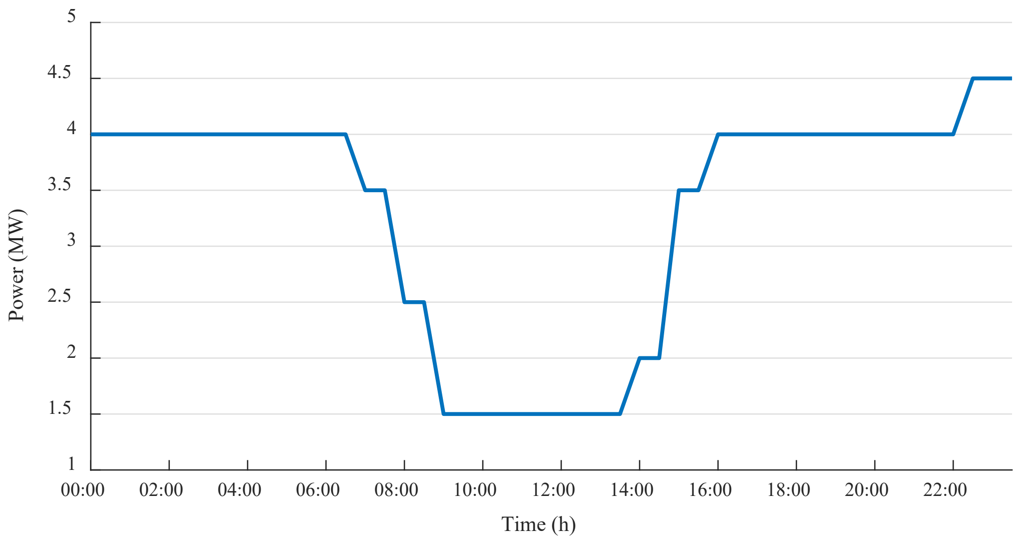


Fig. 7.21. The dynamic export limit of the backup generator based on thermal limit.

Similar results can be seen with the Urban-NSW2, Urban-VIC and Short rural- NSW networks. The dynamic export limits on day 6 based on the thermal limit are shown in Fig. 7.22 - Fig. 7.24. The export limits reach their lowest point around 12:00, since the solar power generation is higher than the load and the net load is negative (i.e., exporting power to the network). The network load is high at night, and the backup generator can export more power to support the network voltage. For the Urban-NSW2 network, the export limit varies between 1.5 MW (93% of the rated network capacity 1.620 MVA) to 6 MW (370% of the rated network capacity 1.620 MVA). For the Urban-VIC network, the export limit varies between 2.5 MW (19% of the rated network capacity 13.333 MVA) to 12 MW (90% of the rated network capacity 13.333 MVA). For the Short rural-NSW network, the export limit varies between 0.5 MW (8% of the rated network capacity 5.963 MVA) to 4 MW (67% of the rated network capacity 5.963 MVA).

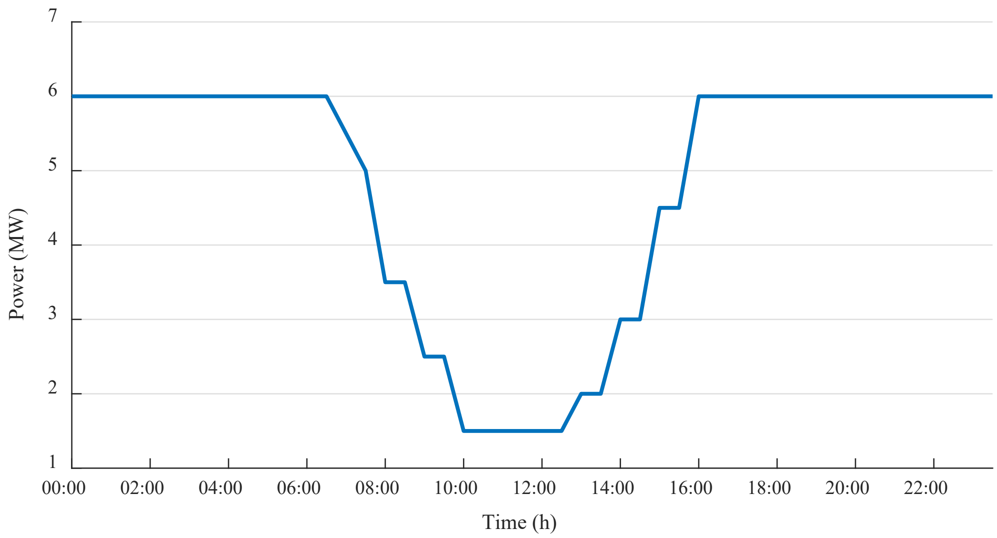


Fig. 7.22. The dynamic export limit of the backup generator in Urban-NSW2 network.

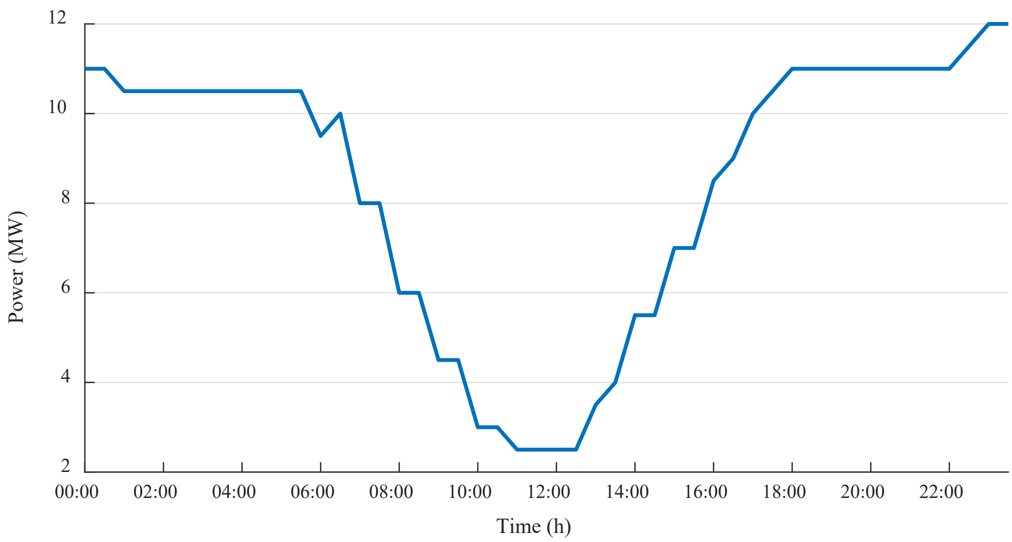


Fig. 7.23. The dynamic export limit of the backup generator in Urban-VIC network.

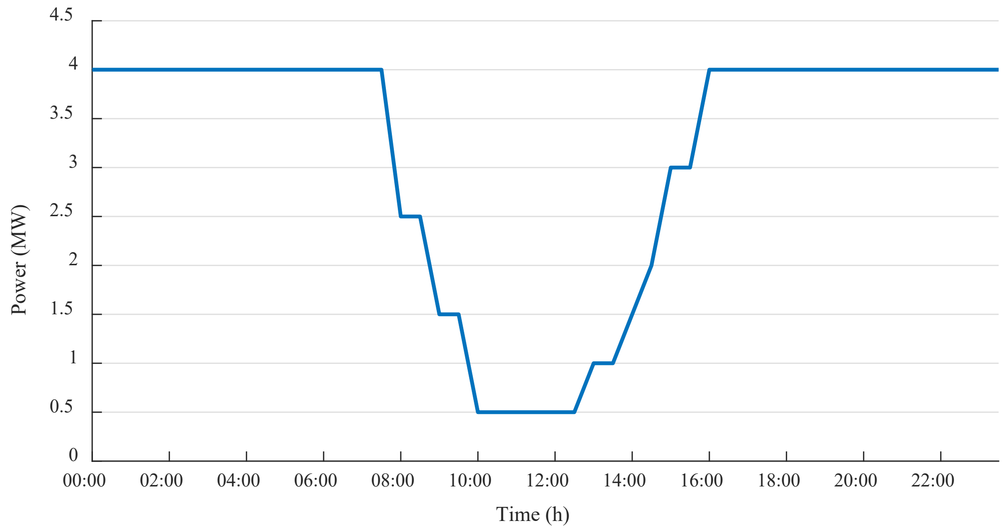


Fig. 7.24. The dynamic export limit of the backup generator in Short rural-NSW network.

7.5.3. Short-circuit current limit

The power grid equipment (e.g., switchgear) are typically designed to withstand a specific short-circuit current level. The fault-level or short-circuit capacity is calculated by (1), where $V_{nominal}$ is the nominal voltage (kV) of the network and I_f is the short-circuit current (kA).

$$Fault\ level\ (\text{MVA}) = \sqrt{3}V_{nominal}.I_f \tag{7.1}$$

According to the distribution and transmission codes [10], [31], the maximum fault levels and short-circuit levels under each voltage level are listed in Table 7.5. Since the test networks used in this study are 22 kV and 11 kV, they have short-circuit levels of 13.1 kA and 18.4 kA, respectively.

Table 7.5. The maximum fault levels and short-circuit levels under each voltage level.

Voltage Level	System Fault Level	Short Circuit Level
220 kV (TNSP)	15,000 MVA	40.0 kA
66 kV (TNSP&DNSP)	2,500 MVA	21.9 kA
22 kV	500 MVA	13.1 kA
11 kV	350 MVA	18.4 kA
230 V, 400 V, 460 V	36 MVA	50 kA
Residential 400 V	7 MVA	0 kA (phase to phase)
Residential 230 V, 460 V	1.4 MVA	6 kA (phase to ground)

CUMMINS C1675D5 generator model has been used in this study and its specifications are listed in Table 7.6.

Table 7.6. The details of CUMMINS C1675D5 generator model.

Generator Set	CUMMINS C1675D5
Capacity	1675 kVA, 1340 kW
Engine	CUMMINS KTA50-G3
Alternator	CUMMINS P735B
Frequency	50 Hz
Voltage	380-440V
Alternator rating	1400 kVA

According to the datasheet of the generator model, the generator parameters are listed in Table 7.7

Table 7.7. The CUMMINS C1675D5 generator parameters.

Main stator resistance	0.0016 Ω/phase at 22°C star connected
WR² inertia	32.7498 kgm^2 (1 bearing)
Voltage (star)	400/231 V
Base rating for reactance values	1400 kVA
Xd d-axis reactance	3.26 p.u.
X'd d-axis transient reactance	0.2 p.u.
X''d d-axis sub- transient reactance	0.15 p.u.
Xq q-axis reactance	2.1 p.u.
X''q q-axis sub- transient reactance	0.29 p.u.
Xl leakage reactance	0.04 p.u.
X2 negative sequence reactance	0.21 p.u.
X0 zero sequence reactance	0.03 p.u.
T'd, T'q transient time constant	0.13 s
T''d, T''q sub-transient time constant	0.01 s

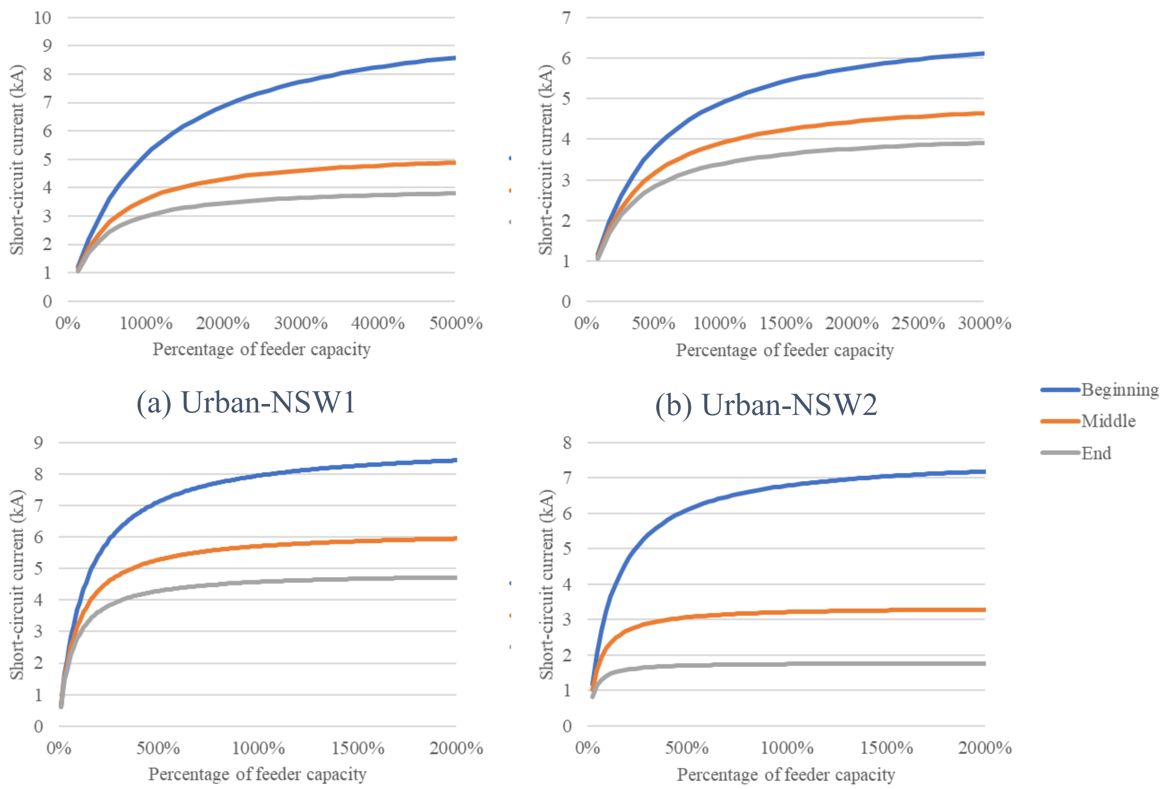
Using the generator parameters listed in Table 7.7, a short-circuit analysis is conducted to explore whether the backup generator will cause a higher short-circuit current beyond the maximum stipulated limit. The short-circuit analysis results for the Urban-NSW1 network are presented in Table 7.8

When there is only one generator connected at the beginning of the feeder, the short-circuit current caused by the short-circuit event happening at the generator terminal is 1.218 kA. If the generator is located at the middle of the feeder and the end of the feeder, the short-circuit currents are 1.11 kA and 1.059 kA, respectively. By comparing with the short-circuit current limit (18.4 kA for 11 kV network), the short-circuit current in Urban-NSW network is much lower than the limit when one backup generator is connected. If the number of backup generator is increased by connecting more generators in parallel, the short-circuit current increases. For example, when the backup generator is connected at the end of the feeder, the short-circuit current is 1.059 kA for one generator, 1.705 kA for two generators and 2.131 kA for three generators. It can be noticed that the increase of short-circuit current is nonlinear, and the increment reduces with the increase of generator capacity.

Table 7.8. Results of short-circuit analysis with network Urban-NSW1.

Number. of paralleled generators	Rated capacity (MVA)	Percentage of feeder capacity	Short-circuit current (kA)		
			Location of backup generator		
			Beginning	Middle	End
1	1.4	136%	1.218	1.114	1.059
2	2.8	272%	2.181	1.862	1.705
3	4.2	408%	2.961	2.393	2.131

If the number of generators is increased further, the short-circuit current values are plotted in Fig. 7.25 (a). It can be observed that even if the capacity of backup generator is 50 times of the total feeder capacity, which is much higher than the required capacity for demand response, the short-circuit current limit is not exceeded. Similar trend can be seen for Urban-NSW2, Urban-VIC and Short rural-NSW networks as shown in Fig. 7.25 (b), (c) and (d), respectively. Therefore, the short-circuit current limit will not influence the export limit of the backup generator.



(a) Urban-NSW1 (b) Urban-NSW2

(c) Urban-VIC (d) Short rural-NSW

Fig. 7.25. Short-circuit current with increase of backup generator capacity.

7.5.4. Dynamic export limit of a backup generator

According to the simulation results and above analysis, the dynamic export limits of backup generators in the representative networks are mainly constrained by the voltage limit and the thermal limit. The power ranges of the dynamic export limit for each network are summarised in Table 7.9. The dynamic export limit calculated with the thermal limit is lower than the export limits calculated with the voltage limit. Therefore, to avoid exceeding the thermal limit of cables in the network, the dynamic export limit calculated with the thermal limit should be followed.

Table 7.9. Range of dynamic export limit of backup generators.

Power range	Urban-NSW1	Urban-NSW2	Urban-VIC	Short rural-NSW
Voltage limit	8-12 MW	16-17.5 MW	19-26.5 MW	2-4.5 MW
Thermal limit	1.5-4.5 MW	1.5-6 MW	2.5-12 MW	0.5-4 MW

If the export limit of a backup generator is a static value, the static value can should be the lowest value of the dynamic export limit in a day. For example, for the backup generator in the Urban-NSW1 network, the static export limit should be no more than 1.5 MW. Otherwise, the thermal limit will be exceeded at noon. A comparison between the static export limit and dynamic export limits is presented in Table 7.10. In the table, the energy generated by the backup generator under tow limitations are calculated. It is obvious that by applying dynamic export limit, the backup generator can export more energy to the network, and the improvement is more than 100%.

Table 7.10. Generated energy of backup generator under different limits.

Generated energy	Urban-NSW1	Urban-NSW2	Urban-VIC	Short rural-NSW
Static limit	36.00 MWh	36.00 MWh	60.00 MWh	12.00 MWh
Dynamic limit	79.75 MWh	115.25 MWh	202.25 MWh	75.25 MWh
Improvement	122%	220%	237%	527%

7.6. Flexibility of Operating Modes

Backup generators can operate under different operating modes to control the active and reactive power output. In this section, two commonly used operating modes are investigated and compared their demand response performance.

7.6.1. P-V control mode

Under P-V control mode, the active power output and terminal voltage of the backup generator are directly controlled. The terminal voltage and output current are measured, and the output active power can be calculated. The active power and terminal voltage are required for the generator controller to regulate the current on d and q axes and reach the active power and terminal voltage setpoints. Consider the Urban-NSW1 network as an example. The scaling factor K is still 2. The backup generator is located at the end of the network. The load profiles of day 6 (the day with the highest voltage) are used. The setpoints of active power and terminal voltages are 1 MW and 1 p.u., respectively. The active and reactive power of the backup generator is plotted in Fig. 7.26.

The active power remains the same at 1 MW. The reactive power is time variant as it is regulated to control the terminal voltage. The terminal voltage is presented in Fig. 7.27. It is clear that the terminal voltage is maintained 1 p.u. in P-V control mode. If there is no backup generator providing voltage control, the terminal voltage is time-variant as shown in orange in Fig. 7.27. Under P-V control, the highest loading is 115%, which happens at line 16, as shown in Fig. 7.28.

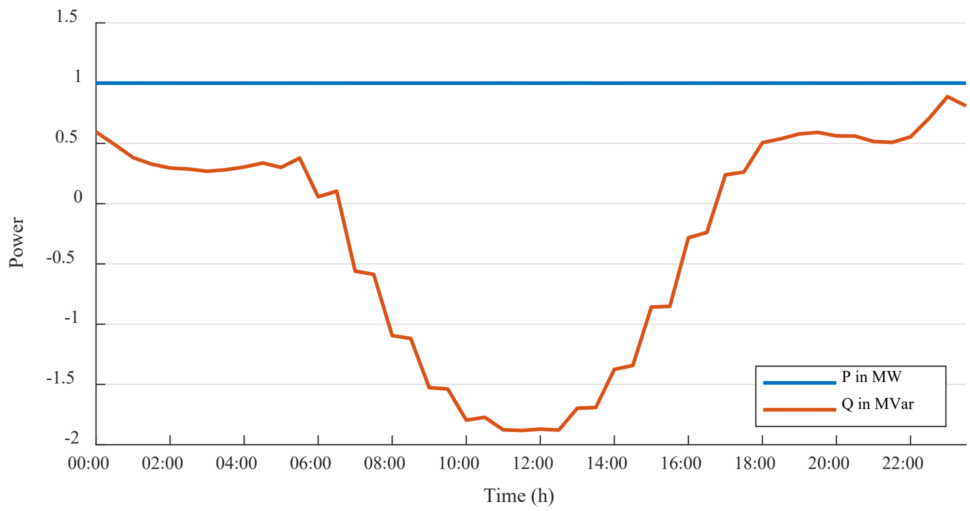


Fig. 7.26. The active and reactive power under P-V control.

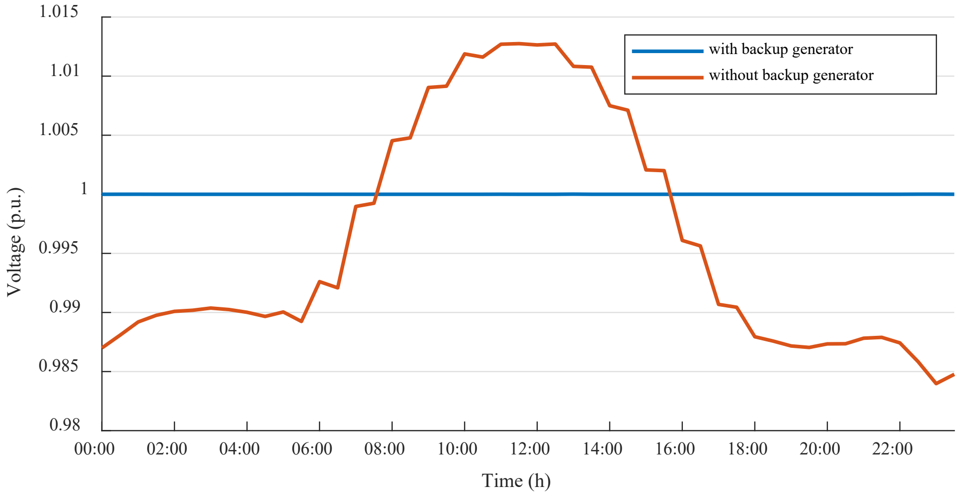


Fig. 7.27. The terminal voltage under P-V control.

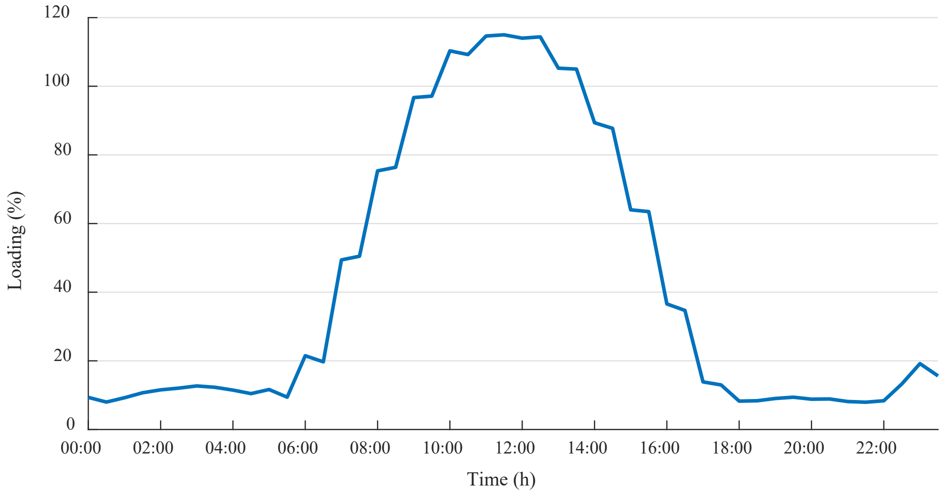


Fig. 7.28. The line loading under P-V control.

7.6.2. P-Q control mode

Parameters of the Urban-NSW1 network when the backup generator is operating at the P-Q control mode are presented in Fig. 7.29 - Fig. 7.31. Similar to the P-V control case, the scaling factor *K* is 2. The backup generator is located at the end of the network. The load profiles of day 6 (the day with the highest voltage) are used for the analysis. The setpoints of active power and reactive power are 1 MW and 0 MVar, respectively. Therefore, the active and reactive power output of the backup generator are constant. The terminal voltage with the backup generator is time-variant and is higher than the voltage without the backup generator. In this case, the highest line loading is 104%, and it occurs in line 16.

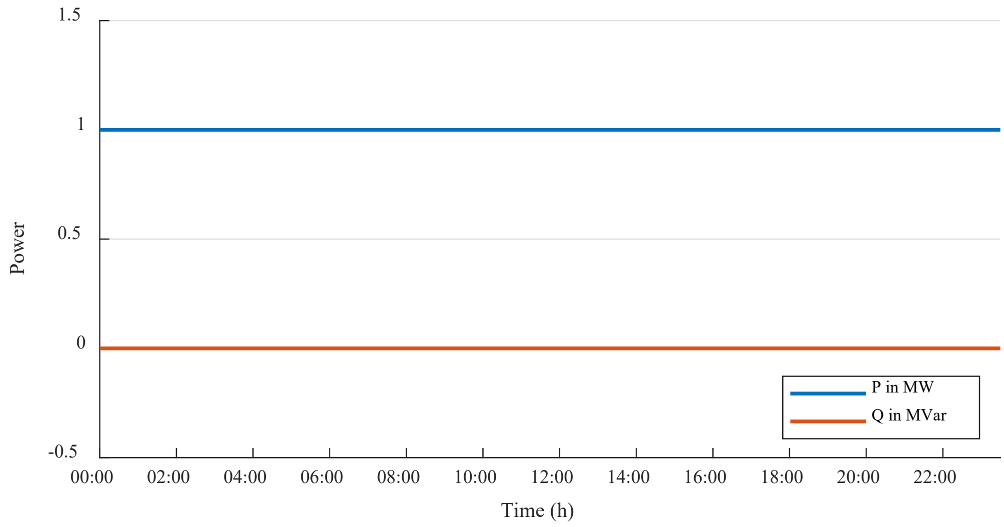


Fig. 7.29. The active and reactive power under P-Q control.

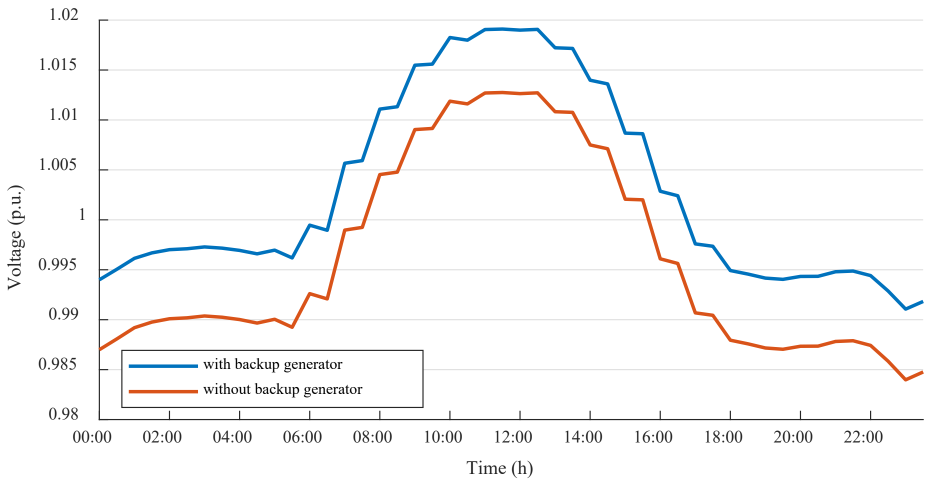


Fig. 7.30. The terminal voltage under P-Q control.

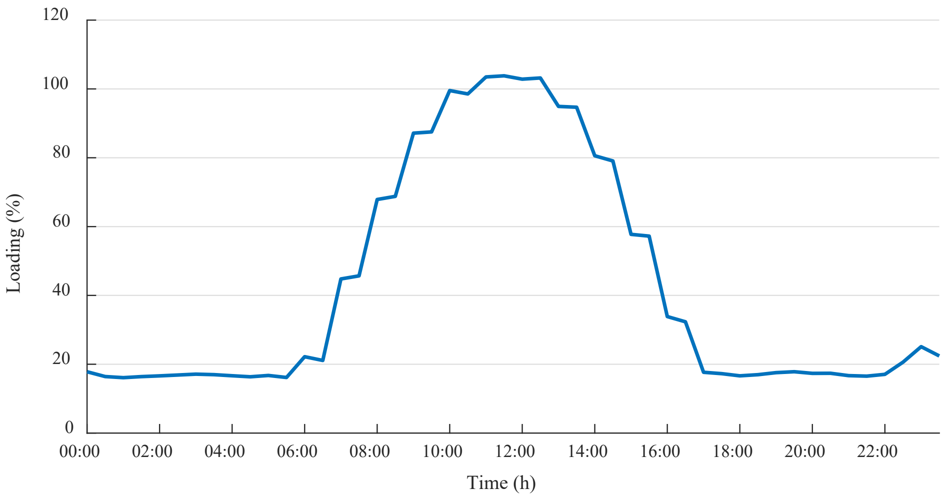


Fig. 7.31. The line loading under P-Q control.

7.6.3. Summary of operating modes

The results for each representative networks are listed in Table 7.11. For all networks, the setpoints are P=1 MW, V= 1.0 p.u. for P-V control; P=1 MW, Q = 0 MVar for P-Q control. Since the reactive power and the terminal voltage are time-variant in P-V control and P-Q control, respectively, their maximum values are listed as well. It can be observed that the maximum line loading in the network is higher with P-V control compared with the P-Q control strategy.

Table 7.11. Summary of simulation results under different operating modes.

Operating mode	Parameters	Urban-NSW1	Urban-NSW2	Urban-VIC	Short rural-NSW
P-V control	**Maximum reactive power**	1.88 MVar	0.64 MVar	3.87 MVar	1.85 MVar
	Maximum line loading	115%	95%	93%	118%
P-Q control	**Maximum terminal voltage**	1.02 p.u.	1.00 p.u.	1.01 p.u.	1.04 p.u.
	Maximum line loading	104%	93%	86%	105%

In summary, with P-V control: (1) the terminal voltage of the backup generator is accurately controlled at a constant value, (2) the maximum line loading in the network is increased; while with P-Q control: (1) active and reactive power output of the backup generator are accurately controlled, (2) with constant P and Q setpoints, the terminal voltage is time-variant.

8. Feasibility Study of Using Biodiesel for Backup Generators

As part of the study biodiesel was examined as an alternative fuel to the standard fossil fuel of diesel. The following are the key advantages identified.

8.1. Advantages of Biodiesel Generators

Biodiesel is manufactured from vegetable oils, animal fats, or recycled restaurant grease. Unlike the fossil fuel, biodiesel is a renewable and biodegradable fuel, which is the most obvious advantage of using biodiesel. Biodiesel can be used in its pure form while more commonly, biodiesel is used in a blended form. Biodiesel is typically categorised based on the percentage of pure biodiesel in the biodiesel blend. For example, a blend of diesel and pure biodiesel with up to 5% or 20% of biodiesel is called B5 or B20, respectively. The other advantages of biodiesel generators over diesel generators are: (1) emission reduction and (2) operation efficiency improvement.

8.1.1. Emission reduction

Existing studies reveal that the use of biodiesel in diesel engines results in a decrease in the emissions of hydrocarbons (HC), carbon monoxide (CO), particulate matter (PM) emissions and sulphur dioxide (SO_2) [32]. Since biodiesel can be produced from various types of vegetable oils and tallows, the emission performance varies with different sources. Research conducted with polanga seed oil shows that the CO2 emissions can be reduced by 40% with B20 and B100 biodiesel, and 35% reduction on smoke emission is observed with B60 biodiesel [33]. Soybean based B20 biodiesel is investigated in [34], and the results show 10.1%, 21.1% and 11.0% reduction of PM, HC, and CO_2 emissions, respectively, compared with diesel.

Note that the emission of nitrogen oxide (NOx) increases because of the oxygen content in the biodiesel [32]. Moreover, emissions from biodiesel generators depend on the start-of-injection timing and engine air mixing technology. Inappropriate start-of-injection timing and air mixing may result in higher emissions [35], [36].

8.1.2. Operation efficiency improvement

Reference [36] investigated the steady-state fuel efficiency of 50 kVA generators with biodiesel and diesel. The comparison results provided in this study are presented in Fig. 8.1. It is claimed that the efficiency of biodiesel is lower under low load and is related to the start-of-injection timing. Under high load, the efficiency of biodiesel is also lower than biodiesel as biodiesel has lower energy density, and the maximum fuel injection is constrained. When the loading of the generator is between 40% and 74%, the efficiency of biodiesel is higher than diesel.

Since the performance of biodiesel is related to the generator, the efficiency of biodiesel diesel generators can be improved if the generator is specifically designed for biodiesel applications. Generally, biodiesel can achieve comparable, or indeed higher, efficiency with respect to fossil diesel generators [36].

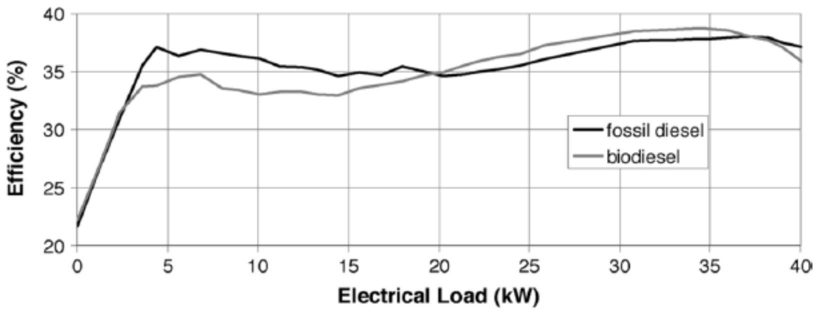


Fig. 8.1. Efficiency of biodiesel and fossil diesel versus the electrical load [36].

8.2. Technical Barriers to Biodiesel Generation

Biodiesel has different physical characteristics than fossil diesel. Cloud point and pour point are the two important parameters to describe the fuel state under low temperatures. If the temperature is lower than the cloud point, the crystals are visible, and the fuel becomes cloudy. If the temperature is below the pour point, the fuel becomes semi-solid, and its fluidity is reduced [37].

The cloud and pour points of different biodiesel types are presented in Table 8.1. It can be noticed that the cloud point and pour point for different biodiesels are different. Since biodiesel can have a combination of sources, the cloud and pour points of biodiesel are in a range. The cloud and pour points of diesel are -4 °C and -18 °C, respectively [38]. By comparing the cloud and pour points of biodiesel and diesel, it can be observed that biodiesel has a higher pour point. Thus, the fluidity of biodiesel is lower than diesel in cold weather. Therefore, the operation environment of biodiesel generators is more critical than diesel generators, and extra equipment may be required in cold weather.

Table 8.1. Cloud point and pour point of biodiesels [37].

Biodiesel type	Cloud point (°C)	Pour point (°C)
Sunflower	−3	−6
Soybean	2	−2
Peanut	5	–
Rapeseed	−2	−9
Palm	13	11
Mahua	–	6
Jatropha	–	6
Karanja	–	7
Rice bran	9	−2
Croton	−4	−9
Oleander	12	3
Neem	9	2
Pungam	6	–
Sesame	−6	−14
Pumpkin	−2	−8
Canola	–	−8

8.3. Supply-Chain of Biodiesel

8.3.1. Biodiesel availability in Australia

Biodiesel is available in Australia. Multiple producers produce biodiesel locally in Australia. Biodiesel Industries in Australia produce biodiesel with cooking oils. It has been in operation since 2003. The production capacity is 20 million litres per annum [39].

Macquarie Oil produces biodiesel via poppy oil [40]. Ecofuel is another company producing biodiesel. In their current key project MP Biodiesel Project, Ecofuel uses canola oil and canola meal in biodiesel production. Initial fuel production will be approximately 1,000,000 litres per annum, which will increase to 2,000,000 litres per annum in the future [41].

Biodiesel produced by Ashoil in WA is sold under contract to Rio Tinto Iron Ore for use in their drill and blast operations [42]. The biodiesel production facility of Ecotech has been in operation since May 2006. It can produce up to 30 million litres, and a second facility can increase the production to 75 million litres [43].

One of the largest biodiesel production plants is Barnawatha BDI biodiesel plant of Just Biodiesel Pty Ltd, which was formed in 2018. The Barnawartha plant can produce up to 50 million litres of biodiesel annually, including B5, B20 and B100 fuels [44].

The biodiesel producers are summarised in Table 8.2 according to [45].

Table 8.2. Biofuels production facilities available in Australia [45].

Biofuel plant	Location	Owner (*BAA member)	Capacity (ML/year)	Feedstocks
ARFuels Barnawartha	Barnawartha, VIC	Australian Renewable Fuels*	60	Tallow, used cooking oil
ARFuels Largs Bay	Largs Bay, SA	Australian Renewable Fuels*	45	Tallow, used cooking oil
ARFuels picton	Picton, WA	Australian Renewable Fuels*	45	Tallow, used cooking oil
ASHOIL	Tom Price, WA	Ashburton Aboriginal Corporation*	Unknown	Used cooking oil
Biodiesel industries	Rutherford, NSW	Biodiesel Industries Australia Pty Ltd*	20	Used cooking oil, vegetable oil
EcoFuels Australia	Echuca, VIC	EcoFuels Australia Pty Ltd.	1.5	Canola oil
EcoTech BioDiesel	Narangba, QLD	Gull Group*	30	Tallow, used cooking oil
Macquarie oil	Cressy, TAS	Macquarie Oil Co.	15	Poppy oil and waste vegetable oil
Neutral fuels	Dandenong, VIC	Neutral Fuels (Melbourne) Pty Ltd	Unknown	Used cooking oil
Territory biofuels	Darwin, NT	Territory Biofuels Ltd.	140	Refined, palm oil, tallow, waste oil

Since back-up generators are deployed only for small number of hours to provide DR, the current production capacity is adequate to cater the biodiesel demand for back-up generators.

8.3.2. Biodiesel supply chain in Australia

The major elements in the biofuel supply chain are: (1) farms, (2) storage facilities, (3) biorefinery plants, (4) blending facilities, (5) retail outlets, and (6) transportation [46]. Biodiesel farms are listed in the previous section, such as ARFuels, ASHOIL, EcoFuels Australia, EcoTech Biodiesel, etc.

The major bulk storage facilities in Australia are Ampol, BP Australia, Viva Energy and Chevron Australia [47]. Ampol provides biodiesel suitable for cold weather [48]. BP Australia provides diesel blends with up to 5% biodiesel [49] as well as commercial customer services. Viva energy is actively engaged in the biodiesel industry. It has storage facilities and blending facilities. Viva energy is also the primary distribution partner of the Just Biodiesel Pty Ltd [50], [51].

Australia has biorefinery plants in Queensland developed by Oceania Biofuels. This biorefinery plant can produce more than 350 million litres of biofuel annually [52]. Future Energy Australia (FEA) also developed its renewable diesel biorefinery project at Narrogin with support from the Western Australian government [53].

Caltex is Australia's leading company providing biodiesel blends. It blends and distributes varieties of biodiesel blends [54]. Bioworks supply B20, B100 biodiesel and custom blends [55]. Biodiesel is available from the major fuel retailers in Australia, e.g., Ampol, Mobil [56], BP [49], Caltex, and Shell [57]. Mobil fuels are available in Mobil stations and 7-eleven stations. BP and Shell sell biodiesel blends up to 5%. Refuelling Solutions [58] and Viva energy are large fuel transportation service providers. They are the main distribution partner of the biodiesel farm Just Biodiesel Pty Ltd [59]. Bioworks also delivers biodiesel blends [55].

Therefore, Australia has a strong supply chain to produce, store and distribute biodiesel blends to consumers.

8.4. Methods to Overcome Operating Limitations

The following are several methods that could be adopted to facilitate the usage of biodiesel as a fuel for demand response and the general running of backup generators.

8.4.1. Preheating

According to the discussion above, biodiesel has a higher pour point than fossil diesel. Therefore, preheating equipment is required to ensure the operation of biodiesel generators in a cold climate [36], [60]. Reference [61] uses a heat exchanger to preheat palm oil-based biodiesel using the heat from the exhaust gasses. It shows that preheated palm oil-based biodiesel can achieve better performance and emission characteristics than diesel fuel.

8.4.2. Adjusting engine timing

Biodiesel generator has higher NOx emissions, which may require adjustments to engine timing [32]. It is emphasised in [62] that the fuel injection system is crucial to reduce engine emissions and to reduce fuel consumption. It is recommended that the injection timing should be retarded to reduce NOx emissions.

8.4.3. Procurement and utilisation of biodiesel ready generators

Preheating and adjusting engine timing are some measures to use biodiesel in diesel generators. There are also a variety of generator sets designed for biodiesel fuels, which consider biodiesel's characteristics. By purchasing such generators energy users can benefit from using biodiesel with limited impacts. For example, local generator producer Cummins provides a series of engine models that supports B20, while B5 can be used for all Cummins diesel engine models [63].

8.4.4. Hydrotreated vegetable oil

Hydrotreated vegetable oil (HVO) is a new generation of renewable fuel and a new form of biodiesel. It is produced from waste vegetable oils and other feedstocks by hydrogenation and hydrocracking processes. HVO can reduce carbon emissions by up to 90% compared with fossil fuels. With a different purifying process from biodiesel production, HVO has similar chemical properties to fossil-based diesel. Therefore, compared with biodiesels, HVO is more compatible with other fuels. Also, HVO can achieve better combustion, better cold start, and reduced emissions levels. HVO can perform well under cold conditions down to -32 °C as well. [64] Thus, HVO can be an alternative to biodiesel.

8.5. GHG Emissions from Biodiesel

Using biodiesel as a neat fuel or blended with conventional diesel will result in significant emission reduction. For example, biodiesel can reduce carbon emissions between 40 - 78% [65] compared with conventional diesel. Fig. 8.2 illustrates the greenhouse gases (GHG) emissions from several biodiesel types (e.g., Soy biodiesel, Canola biodiesel, and Tallow biodiesel) and conventional diesel. The GHG emission from baseline conventional diesel is 94.4 g CO2e/MJ, while the soy biodiesel total GHG emission is 29.52 g CO2e/MJ, which is 68.7% lower than the baseline conventional diesel. Moreover, all three biodiesel types can reduce GHG emissions between 64.88 - 73.7 g CO2e/MJ compared with conventional diesel [65].

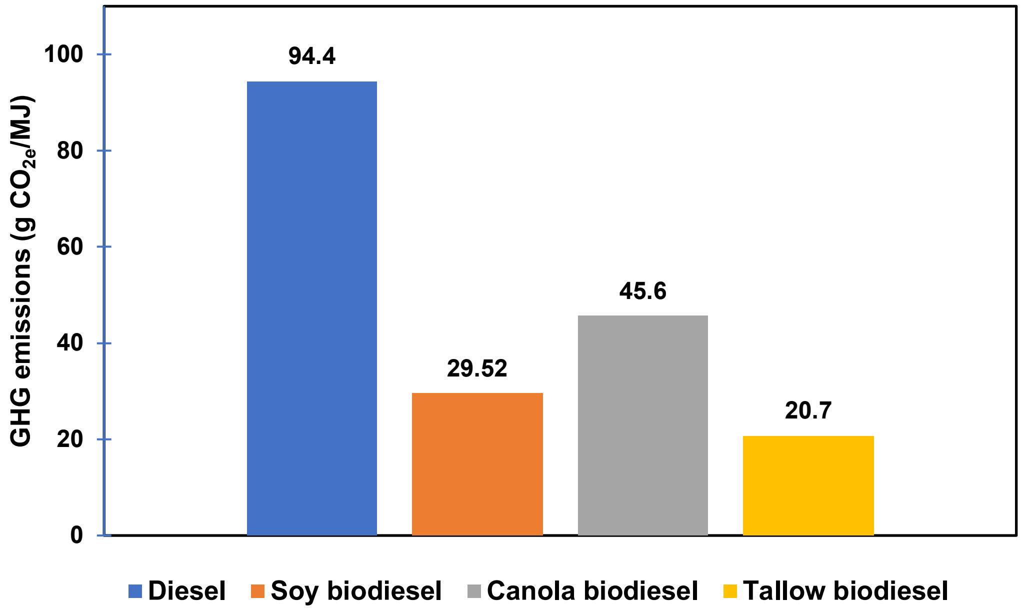
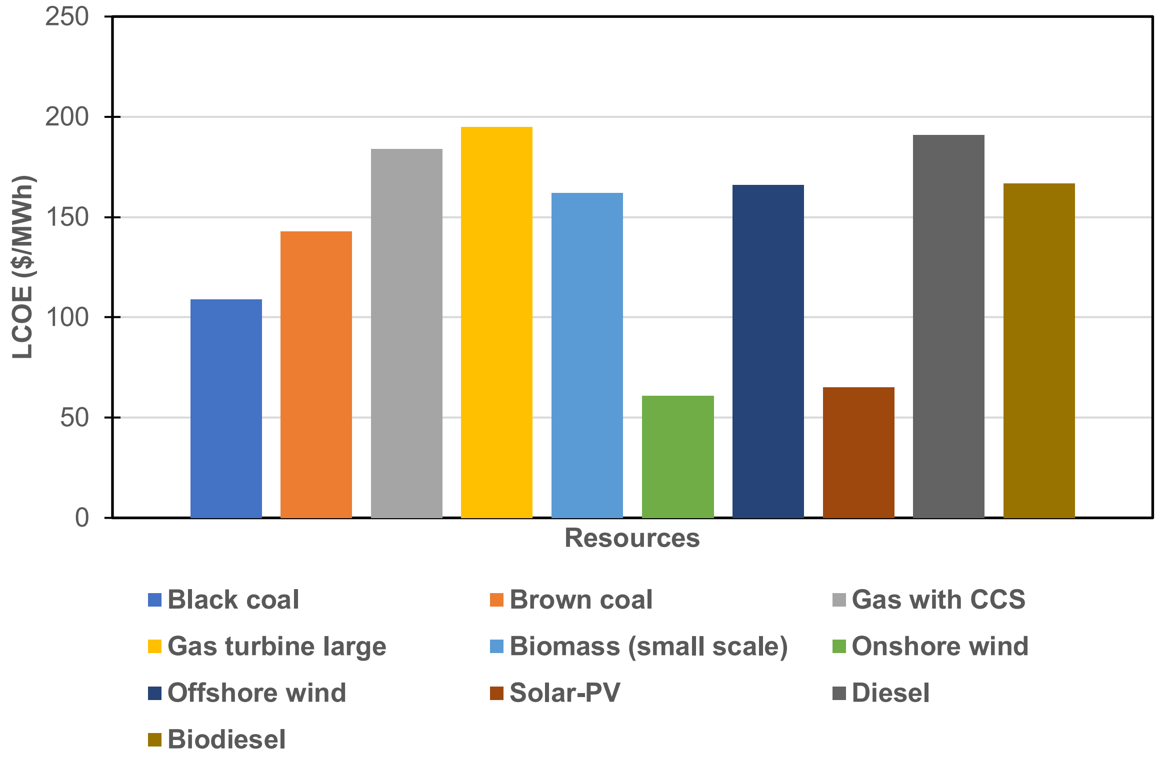


Fig. 8.2. Overall GHG emissions of conventional diesel and several biodiesel types [65].

8.6. Economics of Biodiesel - Levelised Cost of Electricity

Investment in electricity generation sources requires an assessment of the economic competitiveness of generation technologies and that is determined as part of the system modelling process. The investment decision is determined by a parameter called the levelised cost of electricity (LCOE). The LCOE refers to the cost of generating electricity by a given system, including all costs over its lifetime, such as initial investment, operations and maintenance, fuel cost, and capital cost. Fig. 8.3 illustrates the LCOE for several generation sources in the NEM. The LOCE for black coal, brown coal, gas with carbon capture and storage (CCS), large gas turbine, biomass, onshore wind, offshore wind and solar-PV are taken from the CSIRO Gen. Cost Report [66]. The LOCE of diesel and biodiesel were estimated from [67] and [68], as they were not available in the CSIRO Gen. Cost Report or any other reliable source.



*Based on the 2021 LCOE high values in CSIRO Gen. Cost Report [66].

Fig. 8.3. The LCOE for different generation sources.

It can be seen from Fig. 8.3 that the LCOE for biodiesel is comparable with the majority of other generation technologies (e.g. coal and gas turbines) in the NEM. More importantly, the LCOE for biodiesel is less than the conventional diesel.

9. Future Directions and Recommendations

9.1. Recommendations on Improvement of Export Limit of Backup Generators

The study has found that a backup generator located at the end of the network can achieve better performance in supporting the network voltage. The voltage along the network feeder also increases with the increase of backup generator power injection. While under different network loading conditions, the voltage enhancement achieved by the backup generator remains the same under the same level of power generation. The voltage limit and thermal limit of the power network mainly constrain the export limit of backup generators. Moreover, according to the study, the short-circuit current limit does not act as a barrier for backup generator connection to medium voltage networks.

Based on the simulation studies, two recommendations can be made to increase backup generator utilisation in demand response programs:

(1) Specify dynamic export limits to backup generators instead of the static export limit.

According to the results in Section 7.5.4, a backup generator with a dynamic export limit can generate 1 to 5 times more energy than with a static export limit. Since backup generators with a static export limit must follow the minimum export limit determined at the peak generation hours (around midday), they cannot export extra power during off-peak hours. While with dynamic export limits, backup generators are allowed to generate less power during peak generation hours and more power during off-peak hours. For example, in the evening hours (around 7 pm), the power network demand is typically high and solar farms do not generate or generate a small amount of power. During this period, backup generators can generate more power to support the power network if the voltage and thermal limits are not exceeded. Thus, the energy generated by backup generators can be maximised, thereby increasing the DR capacity. This will maximise revenue to the DR participant and benefit the grid.

(2) Allow more flexibility to backup generators for selecting the operating mode best suited to the network and the plant.

As summarised in Section 7.6.3, the advantages and disadvantages of the two operating modes, P-V control and P-Q control are: **(a) with P-V control**: (1) the terminal voltage of the backup generator can be accurately controlled at a specific value, (2) the maximum line loading can be increased; **(b) with P-Q control**: (1) active and reactive power output of the backup generator can be accurately controlled, (2) with constant P and Q setpoints, the terminal voltage will vary depending on the overall network condition. Therefore, there is no single operating mode to satisfy all conditions. In this case, if the backup generator can select the suitable operating mode according to its capability and network requirements, the benefit to the power network and C&I customers can be maximised.

9.2. Recommendations on Inter-tripping and Synchronisation

Each DNSP has their own rules and guidelines on generator inter-tripping and synchronisation. Therefore, inter-tripping and synchronisation requirements can be standardised to achieve consistency across each DNSP. A more uniform process and set of requirements will facilitate the application process and allow for a more rapid adoption of new technical solutions. More specifically, it is recommended to stipulate a technical specification for communication protocols associated with inter-tripping instead of a technology mandate. The expected outcome is to encourage more C&I customers to initiate projects to synchronise their generators and enable exporting. This will increase their capacity to participate in DR programs.

9.3. Recommendations on Biodiesel

Based on the investigations conducted in Chapter 8, biodiesel blends are available from local Australian producers. A complete supply chain of biodiesel is available from production to retail. Moreover, local generator producers provide generator sets that are suitable for biodiesel, which overcomes its technical barriers. Therefore, it is technically feasible to use biodiesel generators as backup generators in Australia. Furthermore, due to low GHG emissions, utilisation of biodiesel in diesel-based backup generators would further help achieve the emission reduction targets.

10. References

[1] A. Berry, T. Moore, J. Ward, S. Lindsay, K. Proctor, and T. Mitchell, "National Feeder Taxonomy: Describing a Representative Feeder Set for Australian Electricity Distribution Networks," CSIRO, Newcastle, 2013.

[2] Australian Energy Market Operator (AEMO), "Transmission and Distribution in the NEM - Process Overview: Stage 3 Application." [Online]. Available: https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/participate-in-the-market/network-connections/transmission-and-distribution-in-the-nem/stage-3-application.

[3] Australian Energy Market Commission (AEMC), "National electricity rules version 177." [Online]. Available: https://energy-rules.aemc.gov.au/ner/367.

[4] Essential Services Commission, "Electricity Industry Guideline No.15 Issue 1." [Online]. Available: https://www.esc.vic.gov.au/sites/default/files/documents/a9e6e27a-e286-403a-9f94-ec3b5e10e1f9.pdf.

[5] Australian Energy Regulator, "Information for electricity consumers in embedded networks." [Online]. Available: https://www.aer.gov.au/consumers/information-for-electricity-consumers-in-embedded-networks.

[6] Austlii, "Electricity Safety (General) Regulations 2019." [Online]. Available: http://www.austlii.edu.au/cgi-bin/viewdb/au/legis/vic/consol_reg/esr2019373/.

[7] Essential Services Commission, "Electricity Distribution Code version 12." [Online]. Available: https://www.esc.vic.gov.au/sites/default/files/documents/Electricity-Distribution-Code-version-12-20210101.pdf.

[8] Victorian Service and Installation Rules Management Committee, "Victorian Electricity Distributors Service & Installation Rules 2014 with Incorporating Amendments 2017(A1) and 2019(A2)." [Online]. Available: http://www.victoriansir.org.au/site/DefaultSite/filesystem/documents/SIR%202014%20with%20Amendment%202%20-%20July%202019.pdf.

[9] Powercor, "Customer Guidelines for Low Voltage Connected Embedded Generation." [Online]. Available: https://media.powercor.com.au/wp-content/uploads/2018/11/30122510/customer-gl-for-lv-connected-eg-v8-final-22112018.pdf.

[10] Jemena, "Embedded Generation Guidelines." [Online]. Available: https://jemena.com.au/getattachment/25d5d563-1087-4619-ac93-ff2148c6e07a/Embedded-Generation-Guidelines-(1).aspx.

[11] Ausnet Services, "Protection Requirements of Embedded Generators < 5 MVA (LV + HV up to 22kV)." [Online]. Available: https://www.ausnetservices.com.au/-/media/Files/AusNet/New-Connections/Solar-Connections/Large-Solar/SOP-11-16-V3---Protection-Requirements-for-Embedded-Generators.ashx?la=en.

[12] Unitedenergy, "Low Voltage Embedded Generation Network Access Standard." [Online]. Available: https://www.unitedenergy.com.au/wp-content/uploads/2021/02/UE-ST-2008.2-LV-EG-Network-Access-Standard.pdf.

[13] Australian Energy Regulator, "2021 Annual Benchmarking Report - Electricity distribution network service provider." [Online]. Available: https://www.aer.gov.au/networks-pipelines/guidelines-schemes-models-reviews/annual-benchmarking-reports-2021.

[14] NSW Climate and Energy Action, "NSW Service and Installation Rules." [Online]. Available: https://www.energy.nsw.gov.au/sites/default/files/2022-08/2018_07_NSW_ServiceAndInstallationRulesOfNSW_underlined.pdf.

[15] L. Schwartfeger, D. Santos-Martin, A. Wood, N. Watson, and A. Miller, “Review of Distributed Generation Interconnection Standards,” *EEA Conference & Exhibition*, Auckland, New Zealand, Jun. 2019, pp. 18–20.

[16] S. Ingo, “Study about International Standards for the connection of Small Distributed Generators to the power grid,” *Internationale Zusammenarbeit (GIZ) GmbH.*

[17] Cummins Inc., “Below 600 kVA | Cummins Inc.” [Online]. Available: https://www.cummins.com/generators/below-600-kva.

[18] Cummins Inc., “Above 600 kVA | Cummins Inc.” [Online]. Available: https://www.cummins.com/generators/above-600-kva.

[19] R.C. Schaefer, “Art of Generator Synchronizing,” *IEEE Trans. on Ind. Applicat.*, vol. 53, no. 1, pp. 751–757, Jan. 2017, doi: 10.1109/TIA.2016.2602215.

[20] M. J. Thompson, “Fundamentals and advancements in generator synchronizing systems,” in *2012 65th Annual Conference for Protective Relay Engineers*, College Station, TX, USA, Apr. 2012, pp. 203–214. doi: 10.1109/CPRE.2012.6201234.

[21] R. J. Best, D. J. Morrow, D. M. Laverty, and P. A. Crossley, “Synchrophasor Broadcast Over Internet Protocol for Distributed Generator Synchronization,” *IEEE Trans. Power Delivery*, vol. 25, no. 4, pp. 2835–2841, Oct. 2010, doi: 10.1109/TPWRD.2010.2044666.

[22] E. Bekiroglu and A. Bayrak, “Automatic synchronization unit for the parallel operation of synchronous generators,” *IEEE EUROCON 2009*, St. Petersburg, Russia, May 2009, pp. 766–771. doi: 10.1109/EURCON.2009.5167720.

[23] Ausgrid, “Embedded generation.” [Online]. Available: https://www.ausgrid.com.au/-/media/Documents/Technical-Documentation/NS/NS194.pdf.

[24] Ausnet, “Guidelines for the Connection of Embedded Generators of 5 MW or Greater.” [Online]. Available: https://www.ausnetservices.com.au/-/media/project/ausnet/corporate-website/files/solar/5000kw-or-greater/embedded-generation-guidelines-sop-33-05_issue-5---nov-2022.pdf.

[25] Powercor, “High Voltage Distribution Connected Embedded Generation.” [Online]. Available: https://media.powercor.com.au/wp-content/uploads/2019/09/23142527/Customer-Guidelines-High-Voltage-Distribution-Connected-Embedded-Gener....pdf.

[26] S. Sharma, A. Biswas, B. K. Kaushik, and V. K. Sachan, Eds., *Recent trends in communication and electronics: proceedings of the International Conference on Recent Trends in Communication and Electronics (ICCE-2020), Ghaziabad, India, 28-29 November, 2020*. Leiden, The Netherlands: CRC Press, 2021.

[27] C. Joseph, “Latency in optical fiber systems.” [Online]. Available: https://www.commscope.com/globalassets/digizuite/2799-latency-in-optical-fiber-systems-wp-111432-en.pdf?r=1.

[28] H. Z. Peek, T. J. Pinkert, P. P. M. Jansweijer, and J.C. J. Koelemeij, “Measurement of optical to electrical and electrical to optical delays with ps-level uncertainty,” *Opt. Express*, vol. 26, no. 11, p. 14650, May 2018, doi: 10.1364/OE.26.014650.

[29] United Energy, “High Voltage Embedded Generation Network Access Standard.” [Online]. Available: https://media.unitedenergy.com.au/factsheets/UE-ST-2008.3-HV-EG-Network-Access-Standard-v1.pdf.

[30] E.L. Oliver, and C. Perfumo, “Technical report: Load and solar modelling for the NFTS feeders Part of the Virtual Power Station 2,” *CSIRO*, Newcastle, 2015.

[31] AEMC, “National Electricity Rules S5.2.8.” [Online]. Available: https://energy-rules.aemc.gov.au/ner/175/24642.

[32] Y.C. Sharma, B. Singh, and S.N. Upadhyay, “Advancements in development and characterization of biodiesel: A review,” *Fuel*, vol. 87, no. 12, pp. 2355–2373, Sep. 2008, doi: 10.1016/j.fuel.2008.01.014.

[33] P. K. Sahoo, L. M. Das, M. K. G. Babu, and S.N. Naik, “Biodiesel development from high acid value polanga seed oil and performance evaluation in a CI engine,” *Fuel*, vol. 86, no. 3, pp. 448–454, Feb. 2007, doi: 10.1016/j.fuel.2006.07.025.

[34] A. Demirbas and S. Karslioglu, “Biodiesel Production Facilities from Vegetable Oils and Animal Fats,” *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, vol. 29, no. 2, pp. 133–141, Feb. 2007, doi: 10.1080/009083190951320.

[35] P. K. Srivastava and M. Verma, “Methyl ester of karanja oil as an alternative renewable source energy,” *Fuel*, vol. 87, no. 8–9, pp. 1673–1677, Jul. 2008, doi: 10.1016/j.fuel.2007.08.018.

[36] R. J. Best, J. M. Kennedy, D. J. Morrow, and B. Fox, “Steady-State and Transient Performance of Biodiesel-Fueled Compression-Ignition-Based Electrical Generation,” *IEEE Trans. Sustain. Energy*, p. 5598540, Jan. 2010, doi: 10.1109/TSTE.2010.2085458.

[37] R. Mythili, P. Venkatachalam, P. Subramanian, and D. Uma, “Production characterization and efficiency of biodiesel: a review: Production characterization and efficiency of biodiesel: a review,” *Int. J. Energy Res.*, vol. 38, no. 10, pp. 1233–1259, Aug. 2014, doi: 10.1002/er.3165.

[38] A.H. Saeedi Dehaghani and R. Rahimi, “An experimental study of diesel fuel cloud and pour point reduction using different additives,” *Petroleum*, vol. 5, no. 4, pp. 413–416, Dec. 2019, doi: 10.1016/j.petlm.2018.06.005.

[39] Bioenergy Australia, “BIODIESEL INDUSTRIES AUSTRALIA.” Accessed: Dec. 31, 2022. [Online]. Available: https://www.bioenergyaustralia.org.au/join-us/biodiesel-industries-australia.

[40] Macquarie Oil Co, “Poppy oil.” [Online]. Available: https://macquarieoils.com.au/poppy/poppy-oil/.

[41] Ecofuels Australia, “Intergrated Agricultural solutions.” [Online]. Available: https://www.ecofuels.com.au/biofuels.html.

[42] Ashoil Pty Lttd., “Biodiesel.” [Online]. Available: https://ashburton.net.au/enterprise/ashoil-pty-ltd/.

[43] Ecotech Biodiesel, “The power behind change.” [Online]. Available: https://www.ecotechbiodiesel.com/company.

[44] ABC News, “Barnawartha biodiesel plant bounces back to life, as industry calls for more government support.” [Online]. Available: https://www.abc.net.au/news/2019-07-17/biodiesel-bounces-back-as-barnawartha-plant-reopens/11318966.

[45] A. K. Azad, M. G. Rasul, M. M. K. Khan, S. C. Sharma, and M. A. Hazrat, “Prospect of biofuels as an alternative transport fuel in Australia,” *Renewable and Sustainable Energy Reviews*, vol. 43, pp. 331–351, Mar. 2015, doi: 10.1016/j.rser.2014.11.047.

[46] I. Awudu and J. Zhang, “Uncertainties and sustainability concepts in biofuel supply chain management: A review,” *Renewable and Sustainable Energy Reviews*, vol. 16, no. 2, pp. 1359–1368, Feb. 2012, doi: 10.1016/j.rser.2011.10.016.

[47] IBIS World, “Biggest companies in the Bulk Fuel Storage industry in Australia.” [Online]. Available: https://www.ibisworld.com/au/industry/bulk-fuel-storage/5349/.

[48] AMPOL, “Biofuels.” [Online]. Available: https://www.ampol.com.au/your-vehicle/petrols-and-diesels/biofuels.

[49] BP Australia, “Diesel blend with biodiesel.” [Online]. Available: https://www.bp.com/en_au/australia/home/products-services/fuels/diesel/diesel-blend-biodiesel.html.

[50] Viva Energy Australia, “Shell Fuels.” [Online]. Available: https://www.vivaenergy.com.au/motorists/shell-fuels.

[51] Viva Energy Australia, “Viva Energy joins Bioenergy Australia.” [Online]. Available: https://www.vivaenergy.com.au/media/news/2020/viva-energy-joins-bioenergy-australia.

[52] Queensland Government, “New $500 million biorefinery planned for Gladstone.” [Online]. Available: https://statements.qld.gov.au/statements/94951.

[53] Upstream Energyexplored, “First commercial-scale renewable diesel biorefinery project in Australia secures funding.” [Online]. Available: https://www.upstreamonline.com/energy-transition/first-commercial-scale-renewable-diesel-biorefinery-project-in-australia-secures-funding/2-1-1201588.

[54] Bioenergy Australia, “Liquid biofuel.” [Online]. Available: https://www.bioenergyaustralia.org.au/resources/liquid-biofuel/#:~:text=Caltex%20is%20Australia's%20leading%20supplier,variants%20of%20bioethanol%20and%20biodiesel.

[55] Bioworks, “Biodiesel Supply.” [Online]. Available: https://www.bioworks.com.au/BioDiesel-Supply.shtml.

[56] Mobil, “Mobil Fuels FAQs.” [Online]. Available: https://www.mobil.com.au/en-au/our-fuels/faqs.

[57] Shell, “Shell Diesel and Adblue.” [Online]. Available: https://www.shell.com.au/motorists/shell-fuels/shell-diesel-and-adblue.html#:~:text=Shell%20Biodiesel%20may%20contain%20up,that%20run%20on%20conventional%20diesel.

[58] Refuelling Solutions, “Refuelling Solutions - Australia’s First Choice for Over 30 Years.” [Online]. Available: https://www.rfs.com.au/fuel-solutions/future-fuels.

[59] Just biodiesel, “Just biodiesel.” [Online]. Available: https://justbiodiesel.com.au/.

[60] S. Nagaraja, K. Sooryaprakash, and R. Sudhakaran, “Investigate the Effect of Compression Ratio Over the Performance and Emission Characteristics of Variable Compression Ratio Engine Fueled with Preheated Palm Oil - Diesel Blends,” *Procedia Earth and Planetary Science*, vol. 11, pp. 393–401, 2015, doi: 10.1016/j.proeps.2015.06.038.

[61] S. S. Prabu, M. A. Asokan, S. Prathiba, S. Ahmed, and G. Puthean, “Effect of additives on performance, combustion and emission behavior of preheated palm oil/diesel blends in DI diesel engine,” *Renewable Energy*, vol. 122, pp. 196–205, Jul. 2018, doi: 10.1016/j.renene.2018.01.068.

[62] B. Kegl, “Biodiesel usage at low temperature,” *Fuel*, vol. 87, no. 7, pp. 1306–1317, Jun. 2008, doi: 10.1016/j.fuel.2007.06.023.

[63] Cummins, “Biodiesel questions and answers.” [Online]. Available: https://www.cummins.com/engines/biodiesel-faqs.

[64] Kohler, “Renewable fuels - the reliable and risk-free source of sustainable mission-critical power.” [Online]. Available: https://hvo.kohlerpower.com/wp-content/uploads/sites/4/2022/06/KPGH2A-HVO-eBook-FINAL-ENG-1.pdf.

[65] R. Chen, Z. Qin, J. Han, M. Wang, F. Taheripour, W. Tyner, D. O'Connor, and J. Duffield, “Life cycle energy and greenhouse gas emission effects of biodiesel in the United States with induced

land use change impacts," *Bioresource Technology*, vol. 251, pp. 249-258, March 2018, doi: 10.1016/j.biortech.2017.12.031.

[66] P. Graham, J. Hayward, J. Foster, and L. Havas, "GenCost 2021-22: Final report," CSIRO, 2022. [Online]. Available: https://doi.org/10.25919/mb22-c107.

[67] M. M. Fawzy, V. Kazulis, I. Veidenbergs, D. Blumberga, "Levelized cost of energy analysis of co-firing solid, liquid and gaseous fuel," Energy Procedia, vol. 128, pp. 202–207, 2017.

[68] Lazard, "Lazard's levelized cost of energy analysis—version 11.0," 2017. [Online]. Available: https://www.lazard.com/media/451905/lazards-levelized-cost-of-energy-version-150-vf.pdf.