Project 4 - Area Hosting Capacity Assessment

Donald and Tarnagulla Microgrid Feasibility Study

Dr Arash Vahidnia

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Outline

- *Project Overview*
- *Microgrid Model Development*
- *Data Analysis*
- *Area Hosting Capacity Assessment – Economics*
- *Area Hosting Capacity Assessment – Reliability*
- *Microgrid Operation Analysis*
- *Hosting Capacity Improvement*

Project Overview

- This project is part of a larger project to assess the feasibility of partial or full microgrid in two regional Victorian towns with supply vulnerabilities. The two load centres have 1034 and 144 predominately residential customers and are supplied through long rural lines with high reliability risks for these communities
- The project particularly assess the hosting capacity of the two proposed sites where various hosting scenarios for self-generation are considered, modelled and analysed.
- The research team explores the project objectives through the following task:

Task Number	Task Name
1	***Developing Representative Microgrid Models and Data Analysis***
2	***Assessing the Area Hosting Capacity***
3	***Analysing the Autonomous and Semi-autonomous Microgrid Operation***
4	***Analysing Hosting Capacity Improvement Scenarios***

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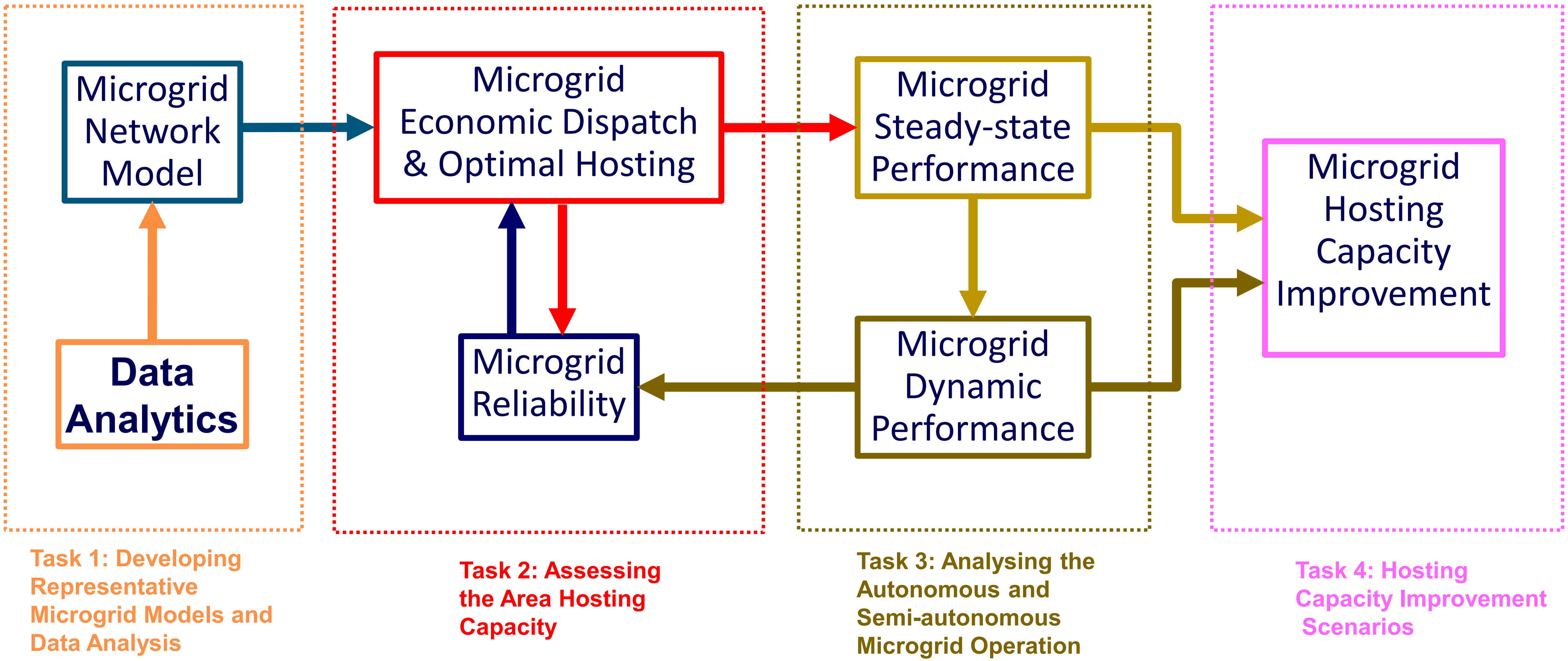
Project Methodology



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Project: 04

Area Hosting Capacity

Donald and Tarnagulla
Microgrid Models

Dr Inam Nutkani

ver.1.0

Donald and Tarnagulla Microgrid Model

This tasks aimed to develop the Donald and Tarnagulla microgrid models suitable for,

- Network hosting capacity assessment & improvement
- Reliability analysis

Representative of town networks	
Voltage Characteristics • MV/LV network voltage • User voltage	Thermal Capacity Feeders/ Transformers

Flexible/Suitable for Planning Studies
Allows creating various integration and operational scenarios of load/DERs Sweeping functions

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Modelling Approach

Incoming Supply Feeders
Charlton to Donald
Maryborough to Tarnagulla
MV Feeders, Line Regulators, Loads

→ Feeders type, lengths, line regulators, and load data from SINCAL

+

Donald & Tarnagulla Microgrid Models

Geographical map/Standards/Reports

PowerCore Data
SINCAL + Substation Loading
Smart meters data

Model component	Data source
MV Network (Feeders)	Cable Type/Lengths from SINCAL model
MV/LV Substations	No and locations from SINCAL/Excel substations list Transformer ratings are estimated from the substation load data
Sub LV Side: Lumped Load + PV + Storage + Synch Gen	Set based on the min and max loading of Substations and SINCAL model
Typical LV Feeders + Nodes (Selected Substations)	Number of feeders, nodes and lengths are estimated from geo maps. Feeders cable type are based on max load /AusNet Standards

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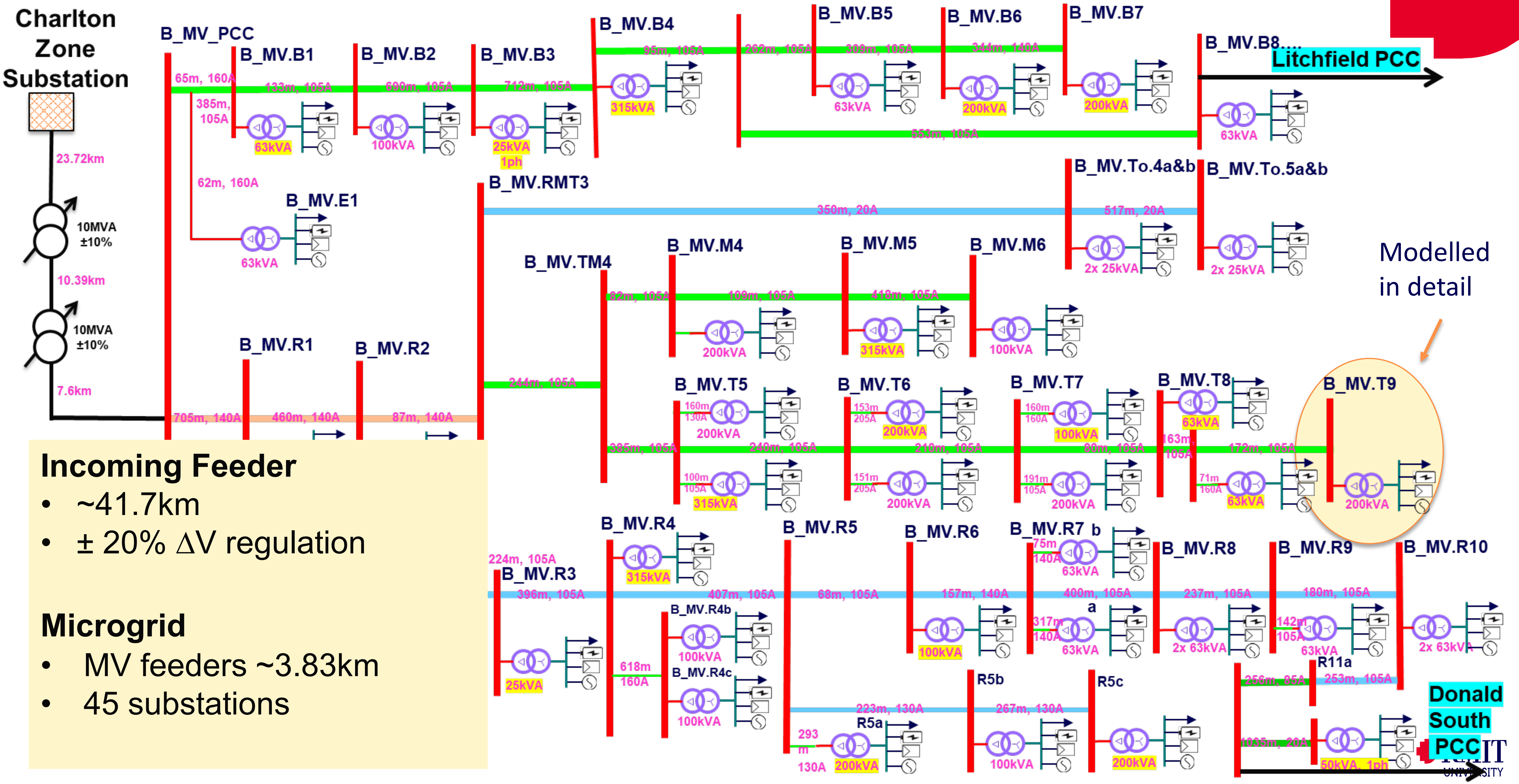
Donald Microgrid – Incoming Feeder + MV Network



Incoming Feeder

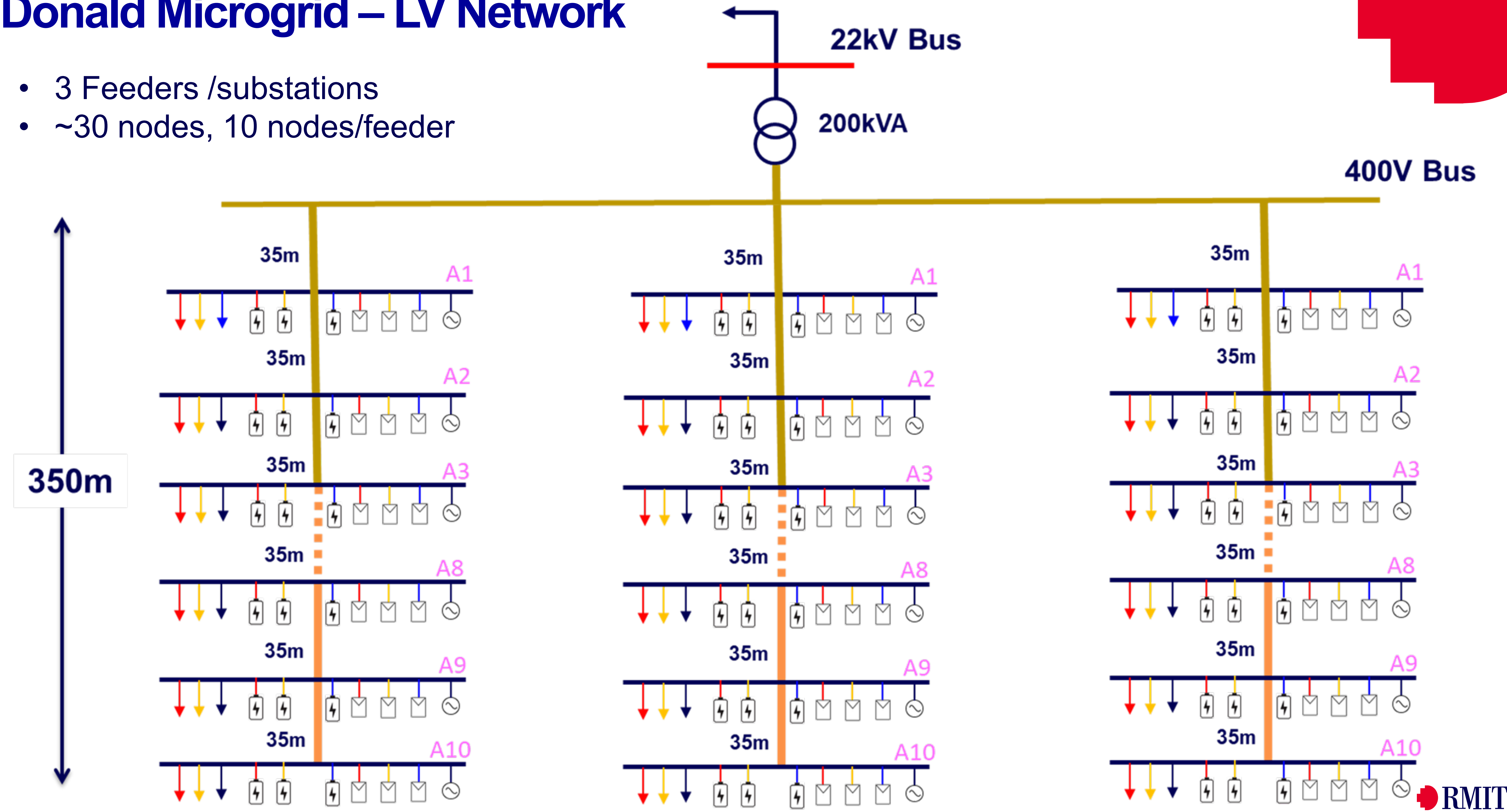
- ~41.7km
- ± 20% ΔV regulation

Microgrid

- MV feeders ~3.83km
- 45 substations

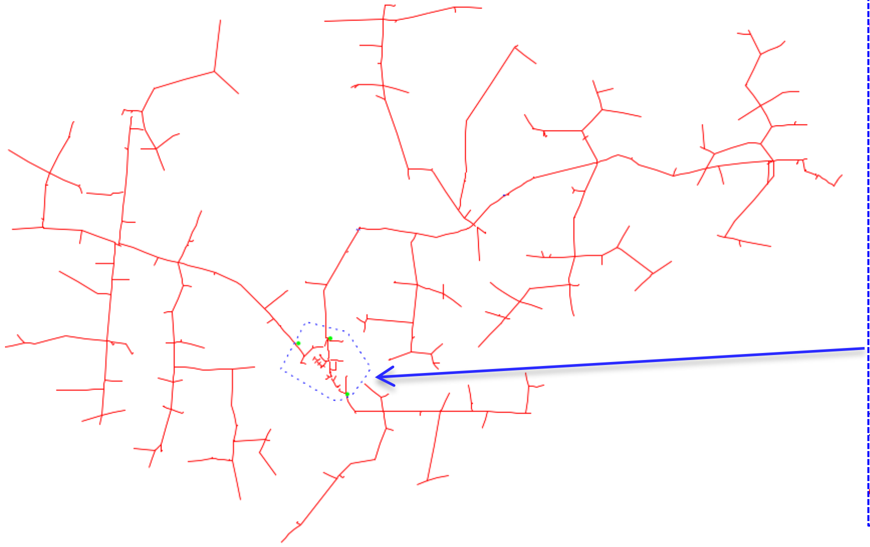
Donald Microgrid – LV Network

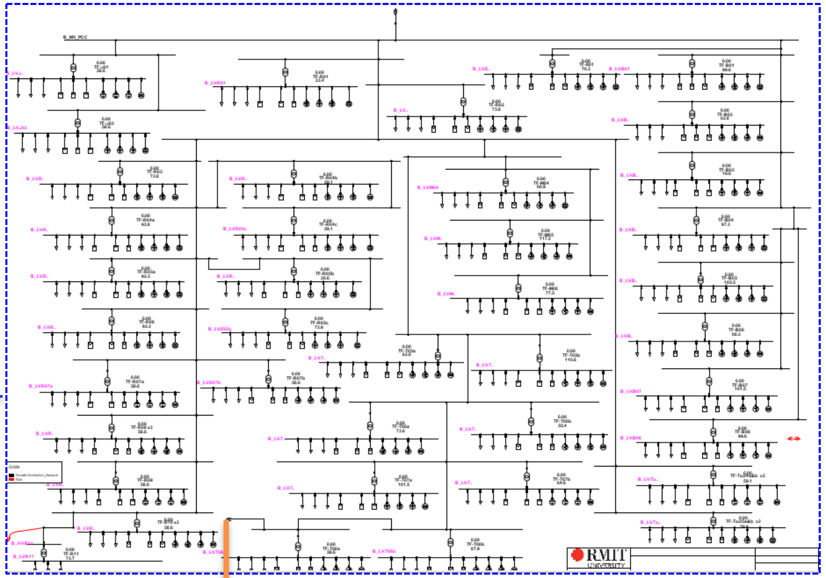
- 3 Feeders /substations
- ~30 nodes, 10 nodes/feeder

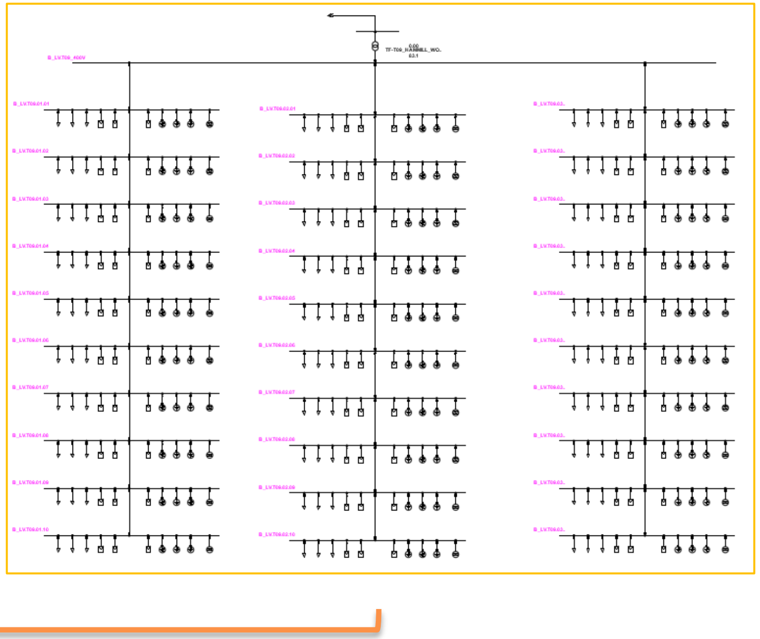


Donald Microgrid Model with Charlton-Donald Supply Feeder

Combined Model





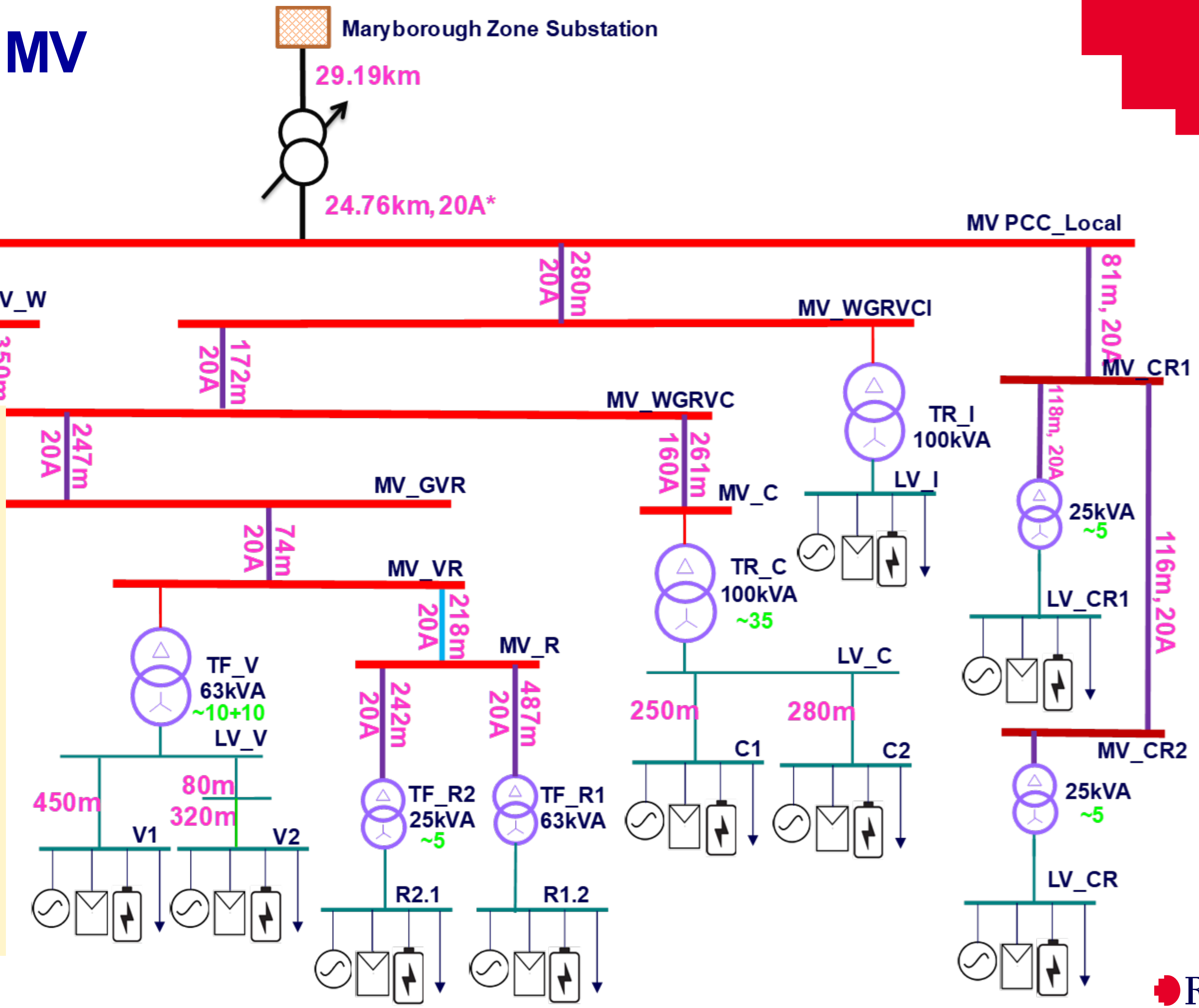


Donald Feeder Model in PF
(imported from SINCAL)

Donald MV Network Model

LV Substation Model - Typical

Tarnagulla Microgrid – MV Network



Incoming Feeder
- ~53.95km
- ± 10% ΔV regulation

Microgrid
- 09 substations
  03 × 25kVA
  04 × 63kVA
  02 × 100kVA
- MV feeders ~1.48km

*Ampacity of immediate supply feeder only

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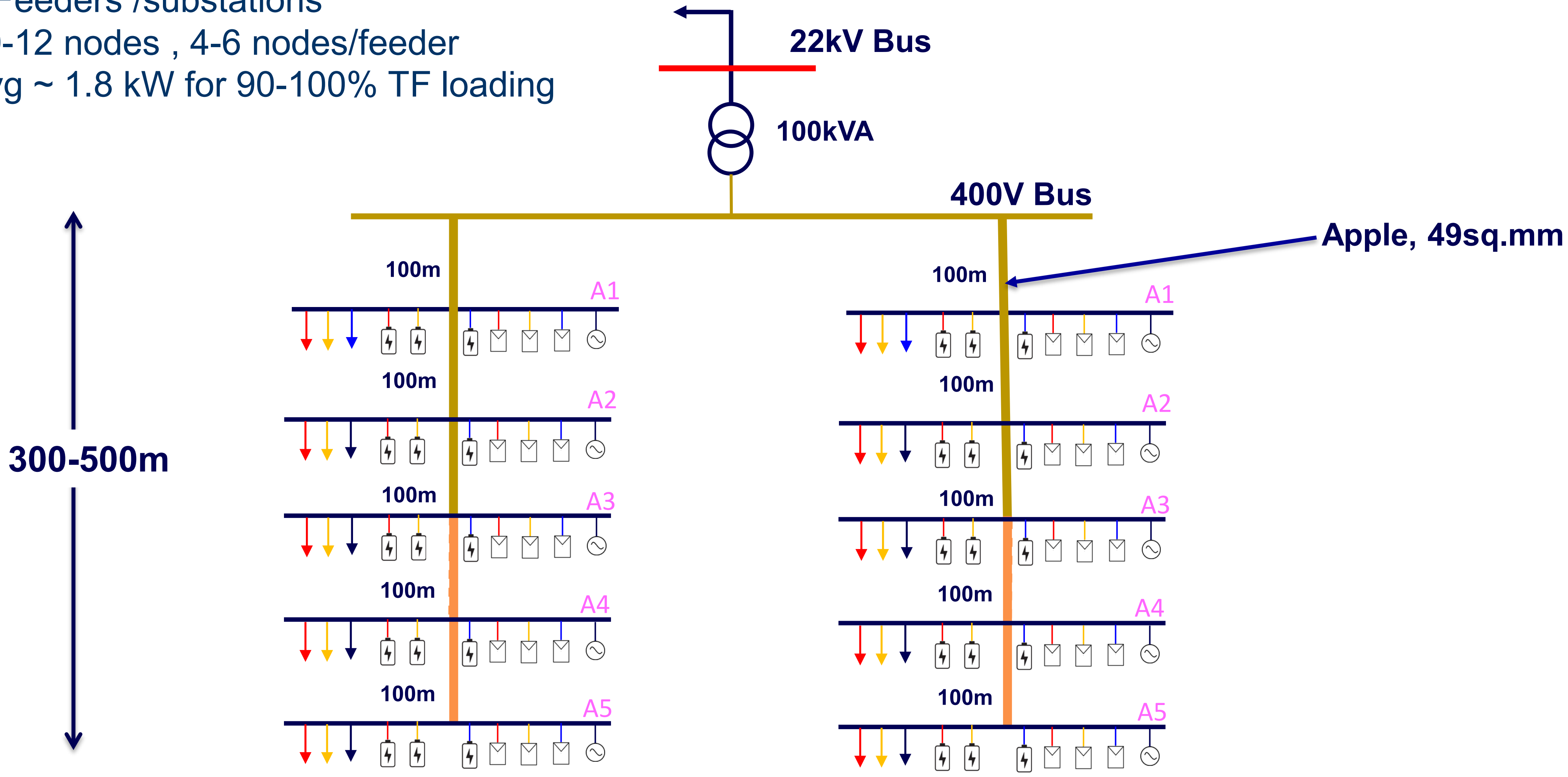
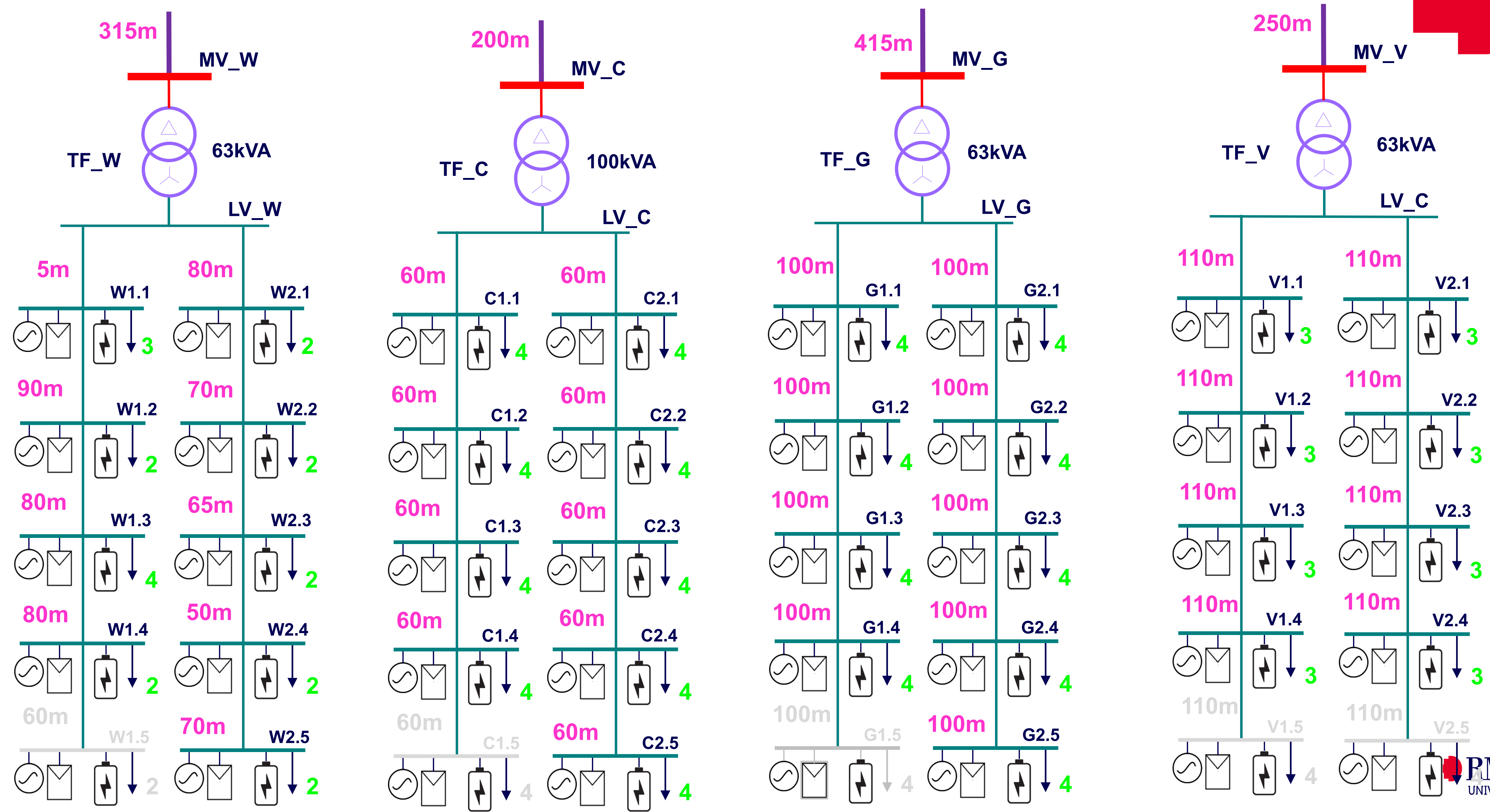
Tarnagulla Microgrid – Typical LV Substation

- 2 Feeders /substations
- 10-12 nodes , 4-6 nodes/feeder
- Avg ~ 1.8 kW for 90-100% TF loading

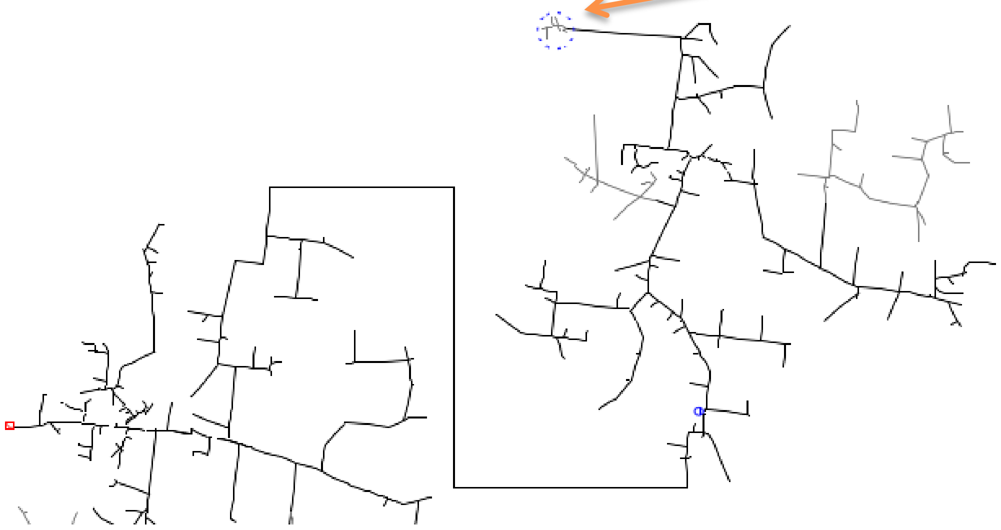


Tarnagulla Microgrid – LV Substations

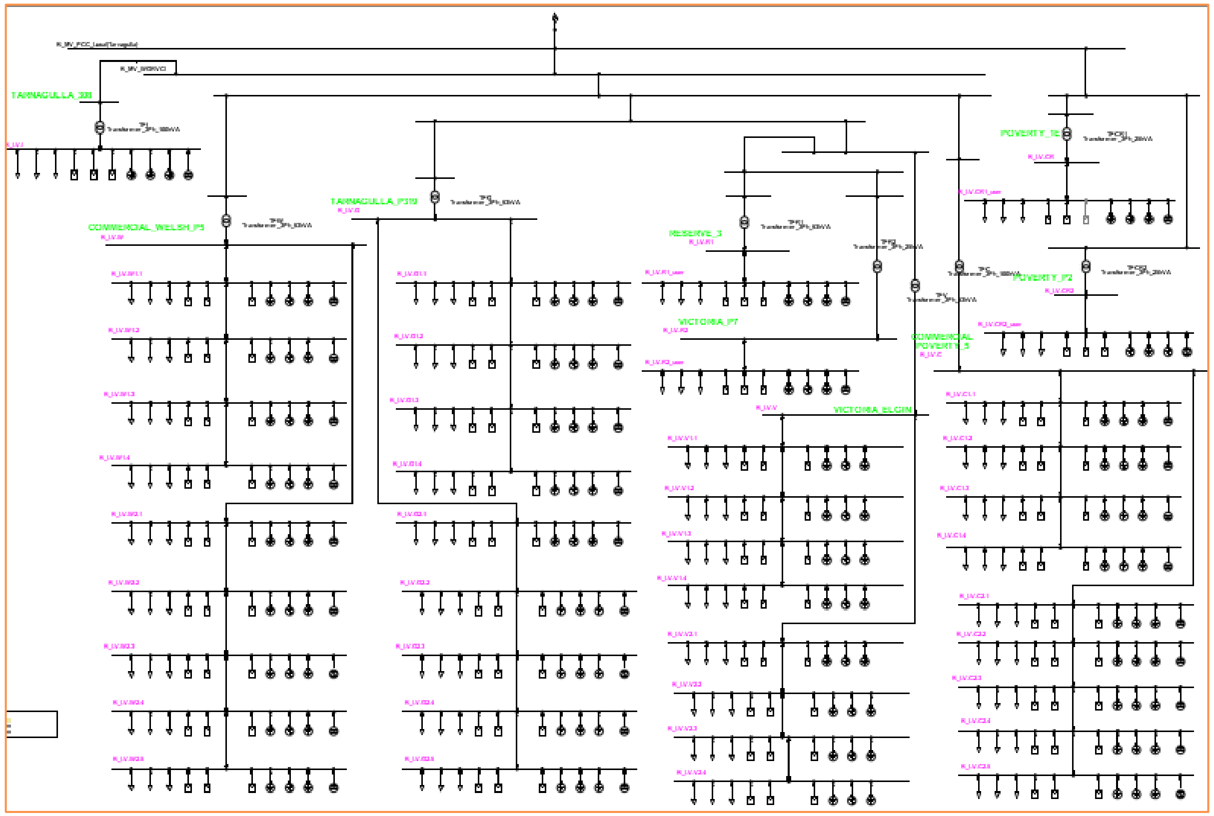


Tarnagulla Microgrid Model with Maryborough Supply Feeder

Combined Model



Tarnagulla Feeder Model in PF
(imported from SINCAL)



Tarnagulla MV and LV Network Model

Donald and Tarnagulla Microgrid Models – Summary

Features:

- The supply incoming feeders are part of the network to capture the feeder dynamics – i.e., voltage regulation, voltage drop and rise with load change!
- Model includes all the substations in the towns. MV feeders' (type/lengths) are modelled using data in the SINCAL model.
- Solar PV + Battery + Synch Gen: Included at all substations to create various integration and operational scenarios

Assumptions:

- Transformers kVA capacities are estimated - based on max demand & SINCAL model load data
- LV feeders are typical – estimated based the load data

Donald and Tarnagulla Microgrid Models – Summary

- The models are suitable for **steady-state** and **dynamic simulation studies** such as load flow, sweep/quasi dynamic analysis, and reliability analysis

- The model are used in project Task #2, #3, and #4 for network hosting capacity assessment and improvement and reliability analysis.

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Project: 04

Area Hosting Capacity

Data Analysis

Dr Hui Song

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Data investigated and clustering method

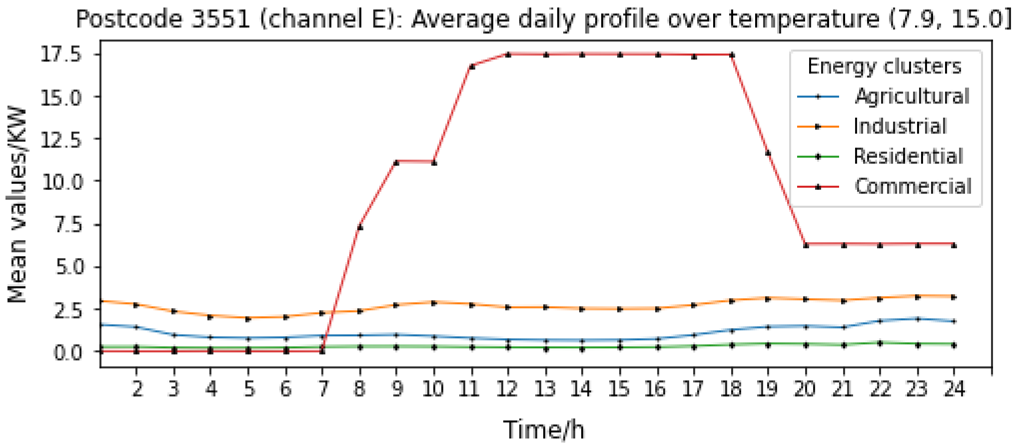
- # instances over postcode 3480: 399279
- # instances over postcode 3551: 53219
- Granularity: 30 mins

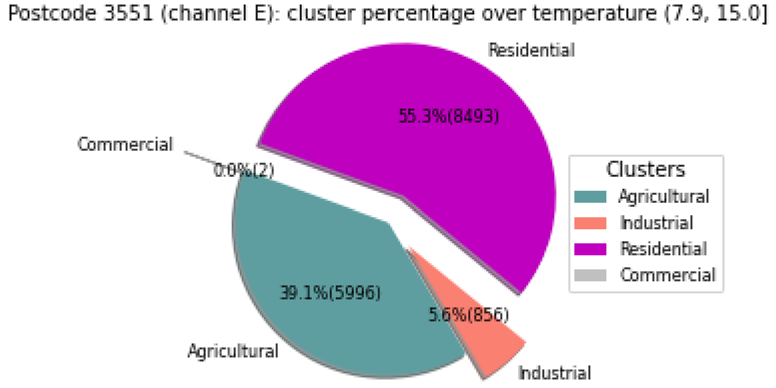
postcode	channel	# instances
3480	B	60346
	E	338933
3551	B	10476
	E	42743

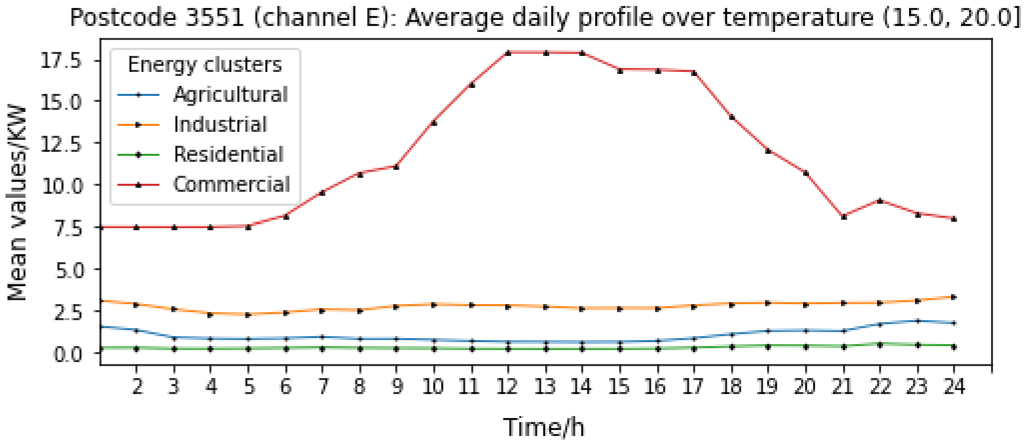
- Clustering method: *kmeans*
- # clusters over all instances: 4
- Pie chart: percentage (counts: number of instances)
- # clusters over residential for postcode 3551: 2
- # clusters over residential for postcode 3480: 3

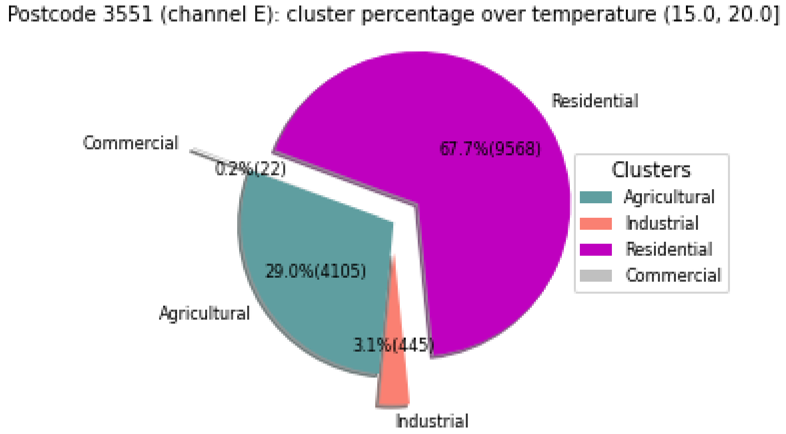
Visualization over postcode 3551: channel E

- # clusters: 4
- Pie chart: percentage (counts)



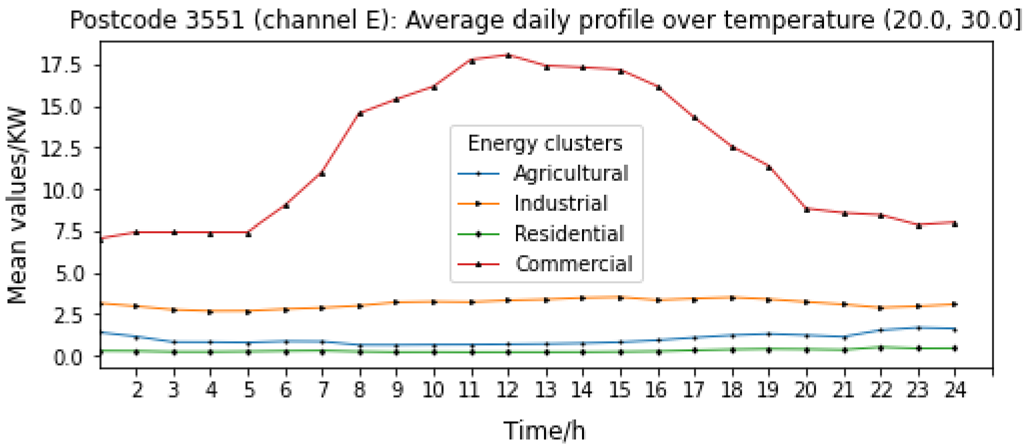


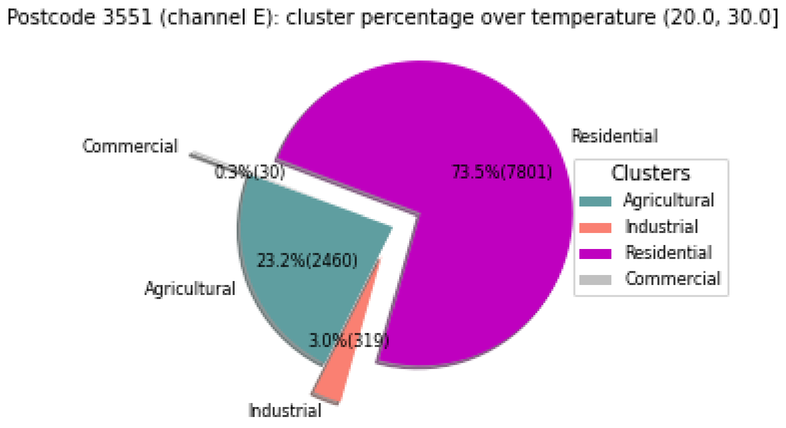


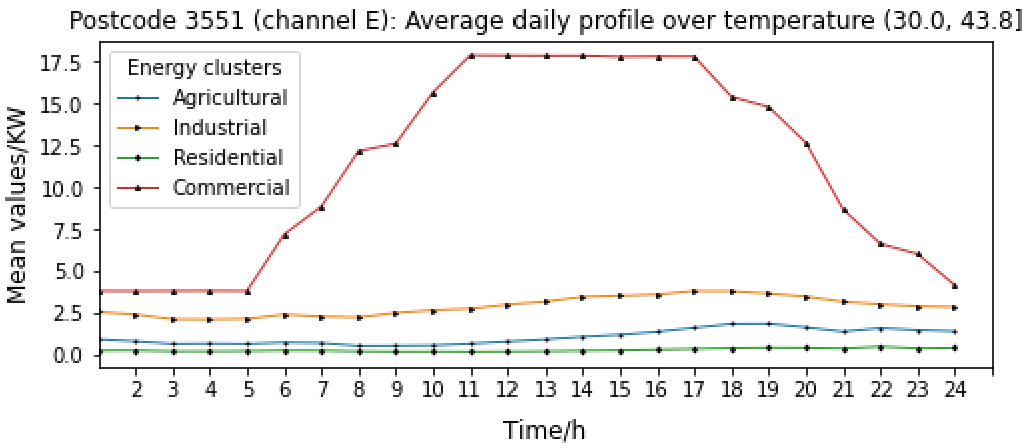


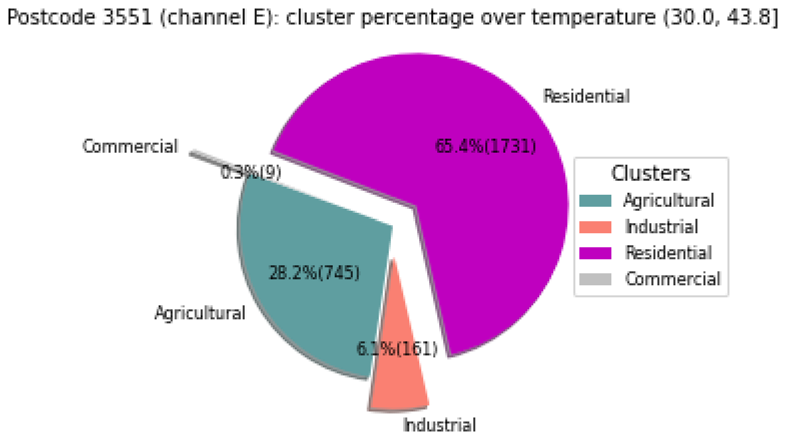
Visualization over postcode 3551: channel E

- # clusters: 4
- Pie chart: percentage (counts)



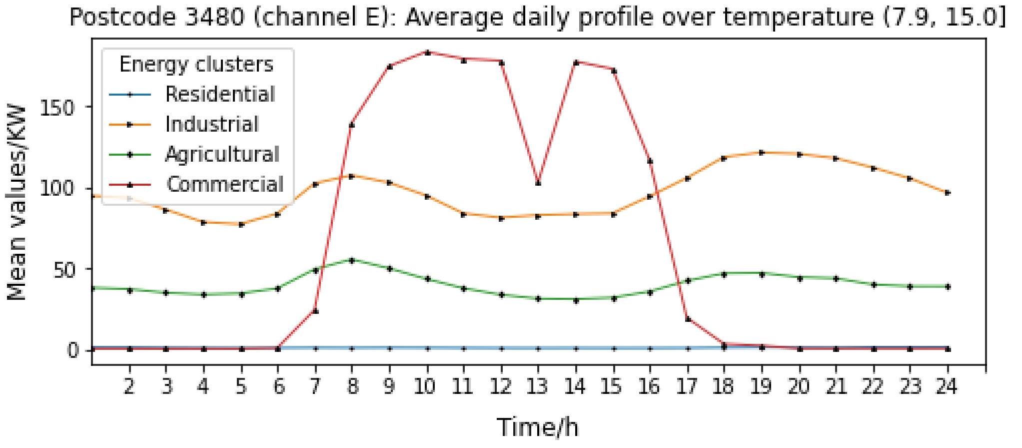


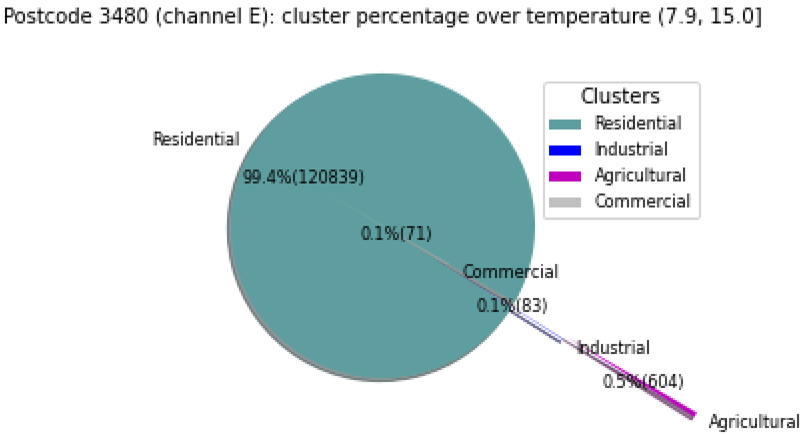


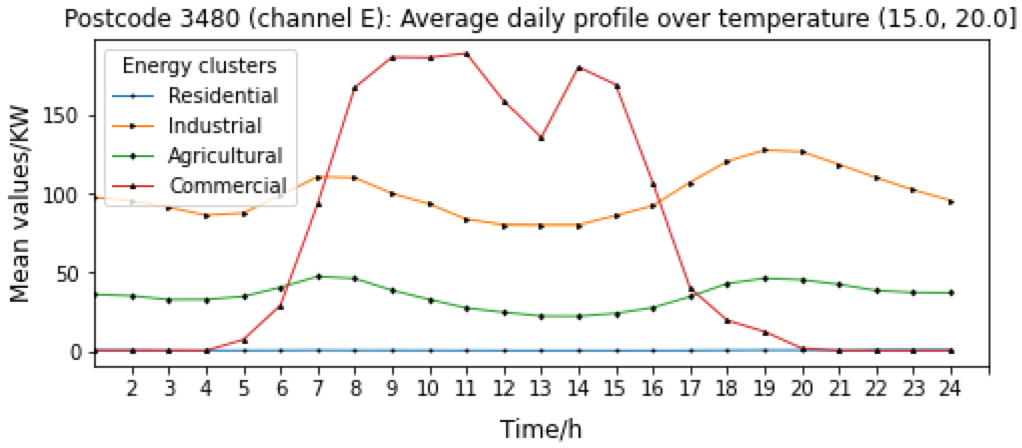


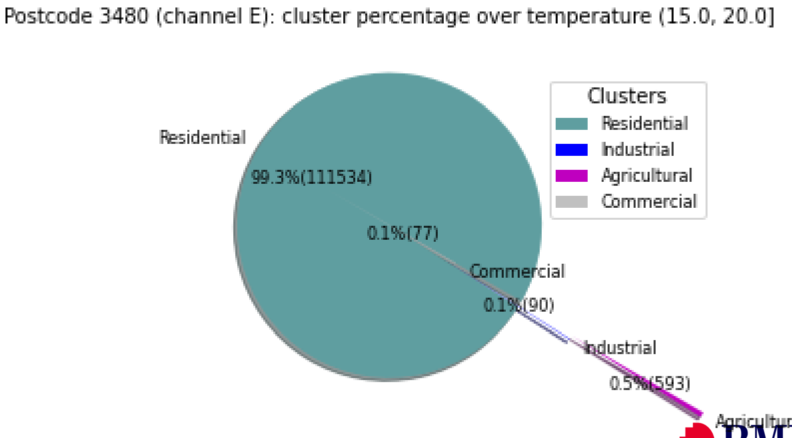
Visualization over postcode 3480: channel E

- # clusters: 4
- Pie chart: percentage (counts)









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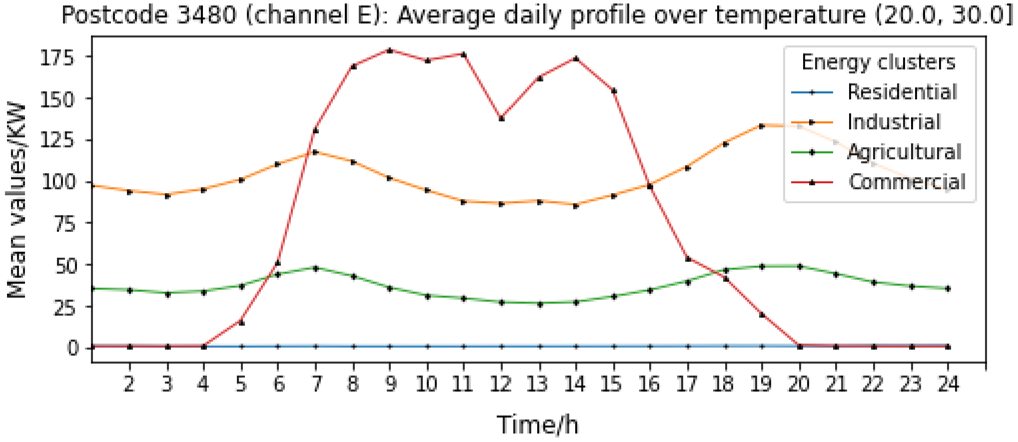
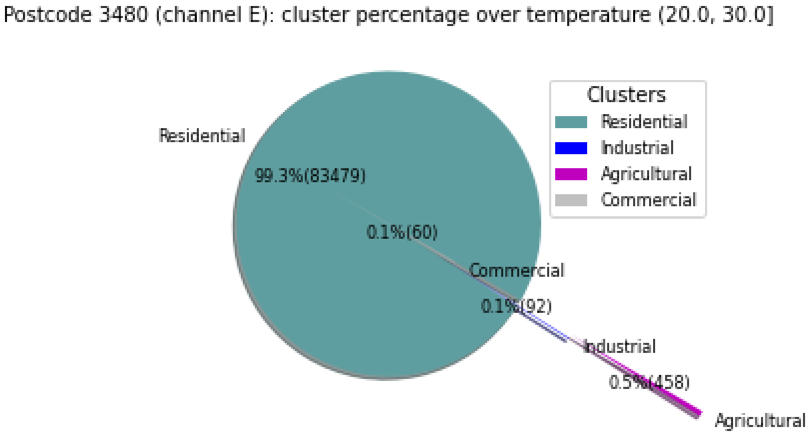
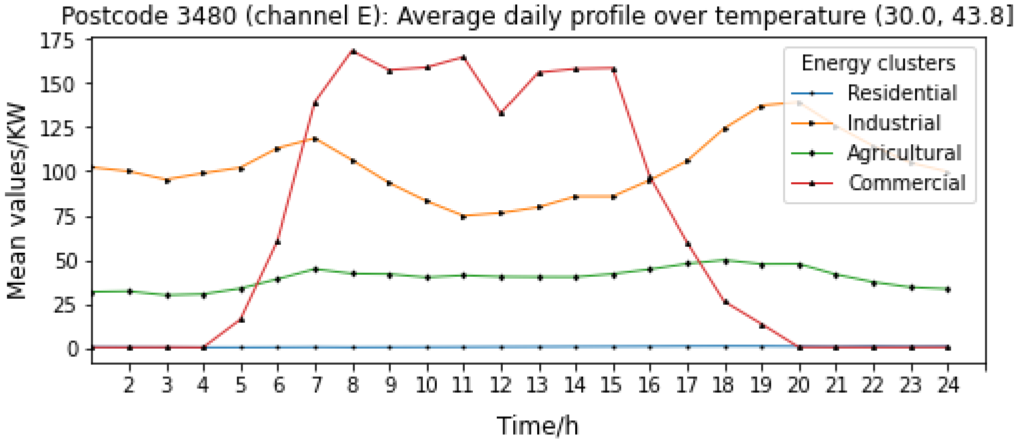
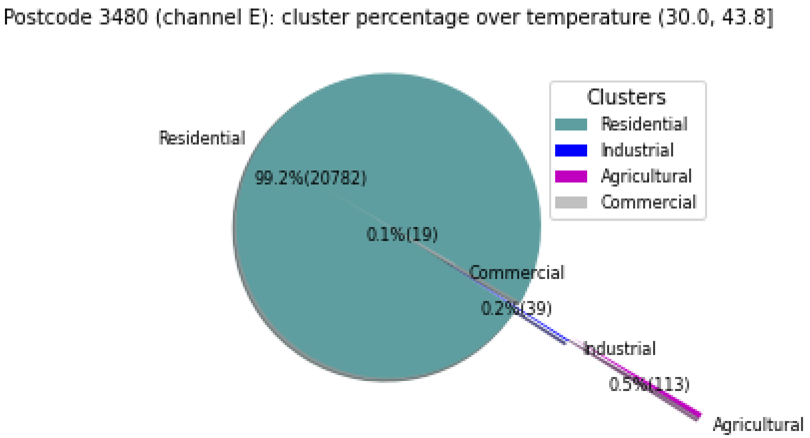
Visualization over postcode 3480: channel E

- # clusters: 4
- Pie chart: percentage (counts)







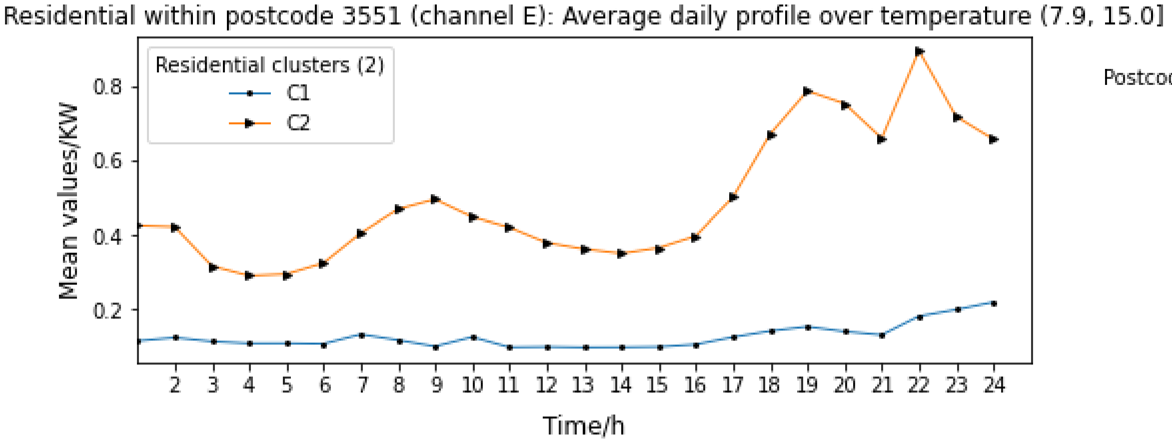


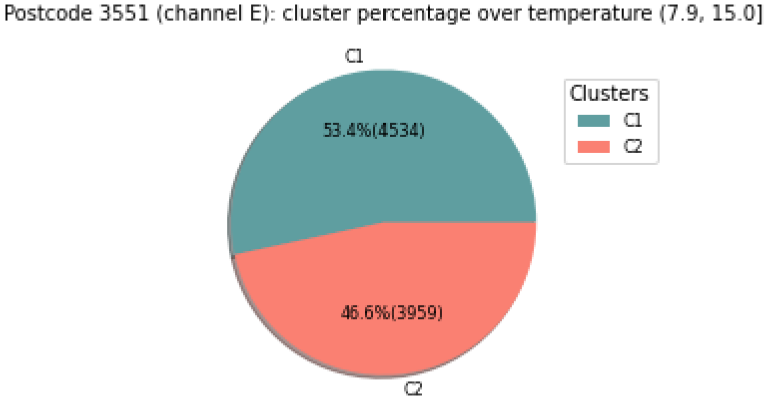
Clustering over Residential – Postcode 3551

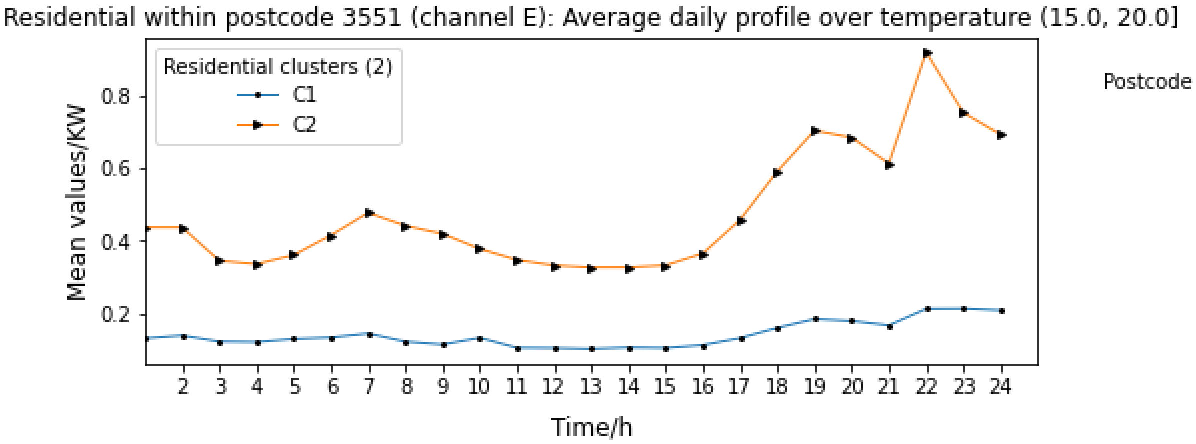
Channel: E

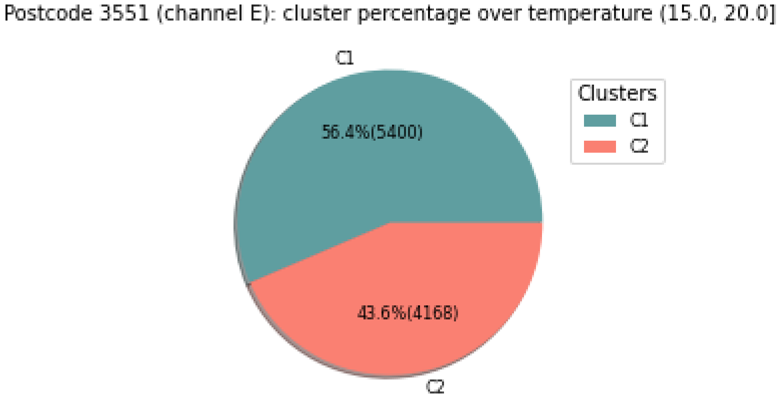
 # clusters: 2 (C1, C2)

Pie chart: percentage (counts)







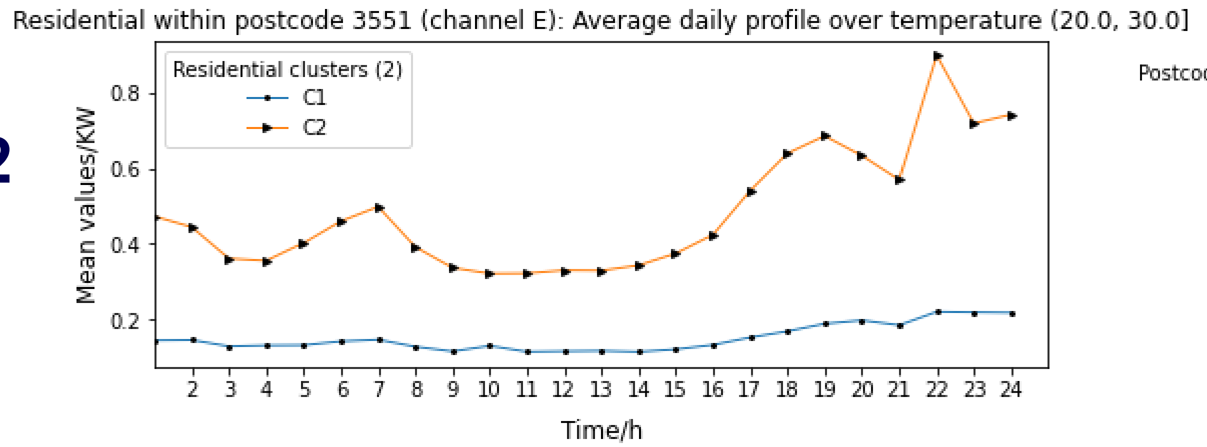


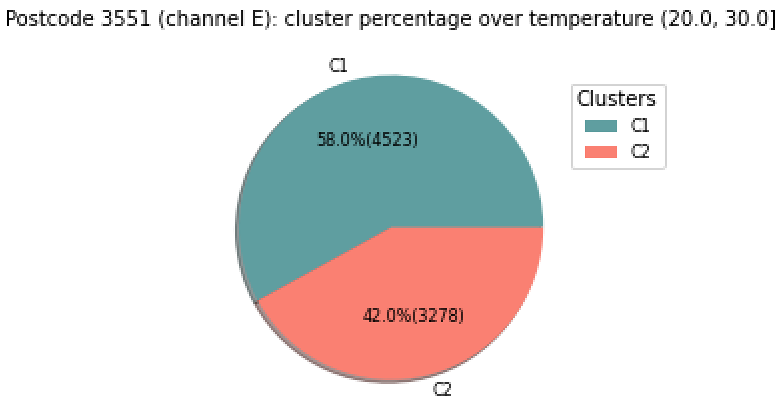
Clustering over Residential – Postcode 3551

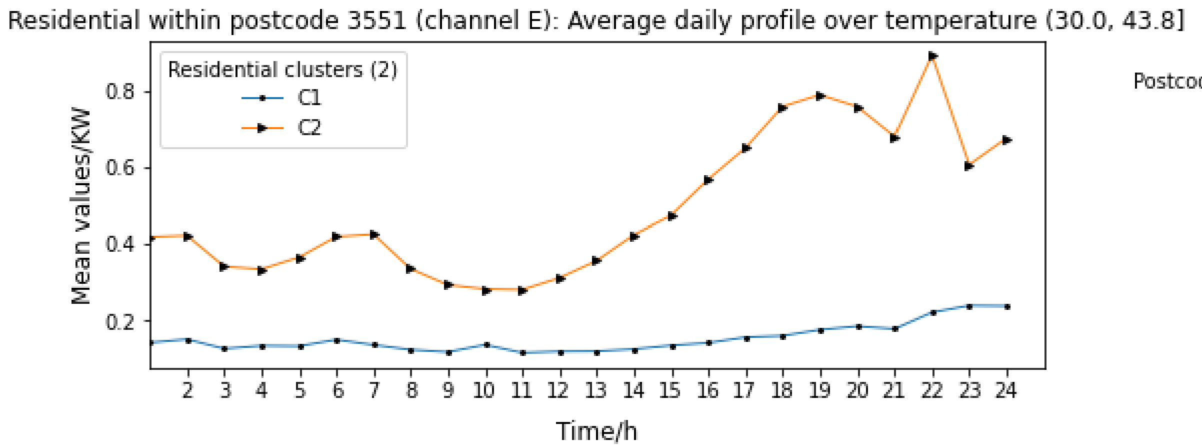
Channel: E

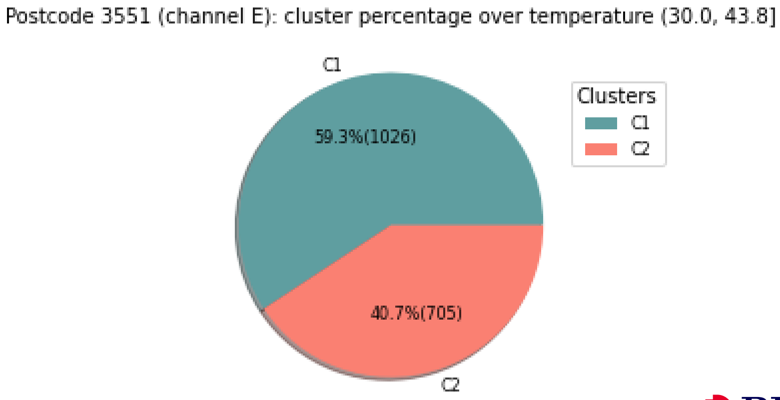
 # clusters: 2 (C1, C2)

Pie chart: percentage (counts)









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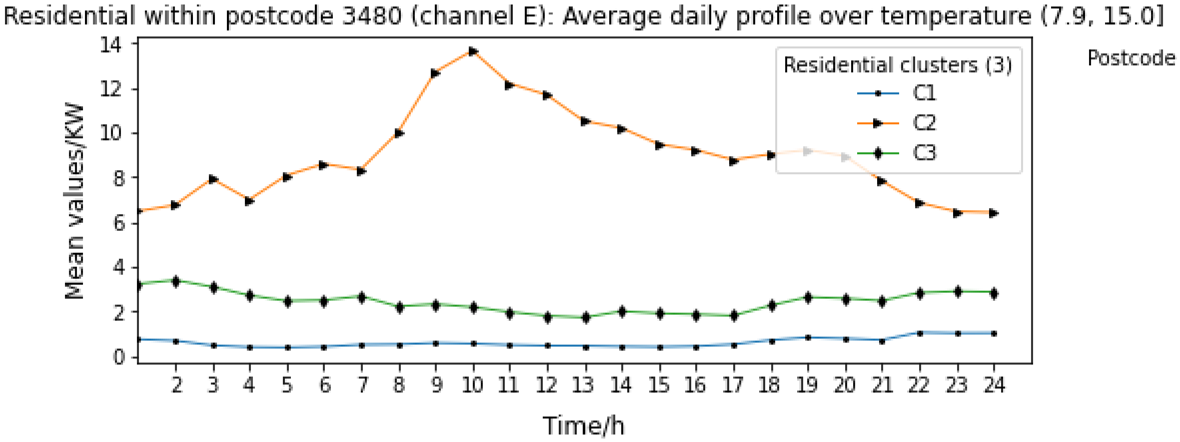
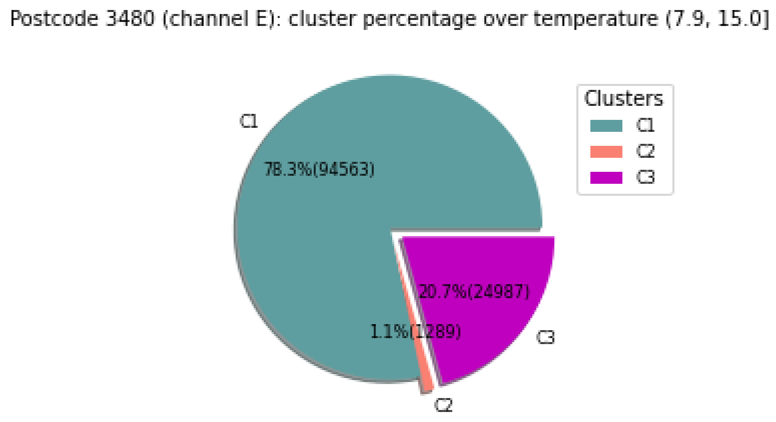
Clustering over Residential – Postcode 3840

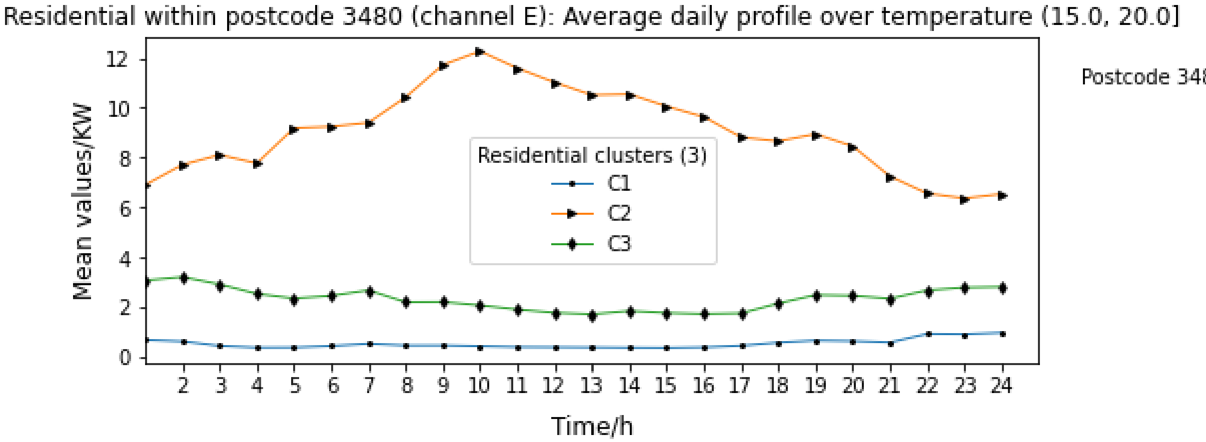
Channel: E

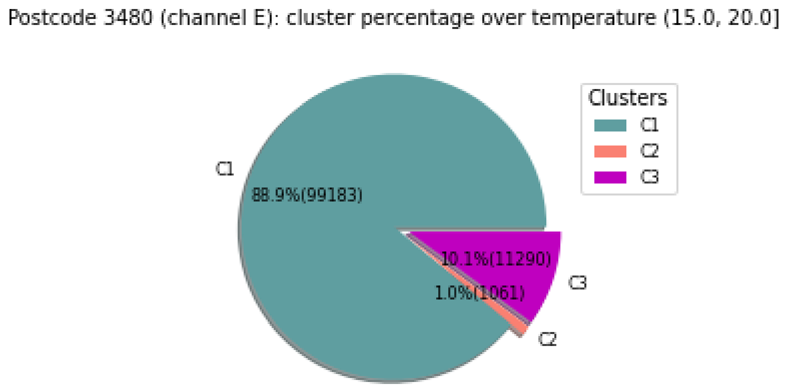
 # clusters: 3 (C1, C2, C3)

Pie chart: percentage (counts)







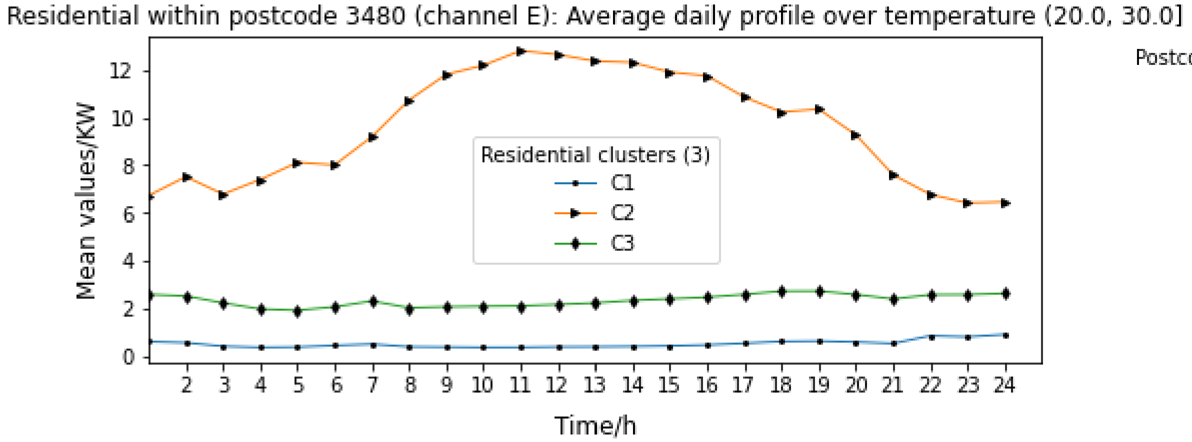


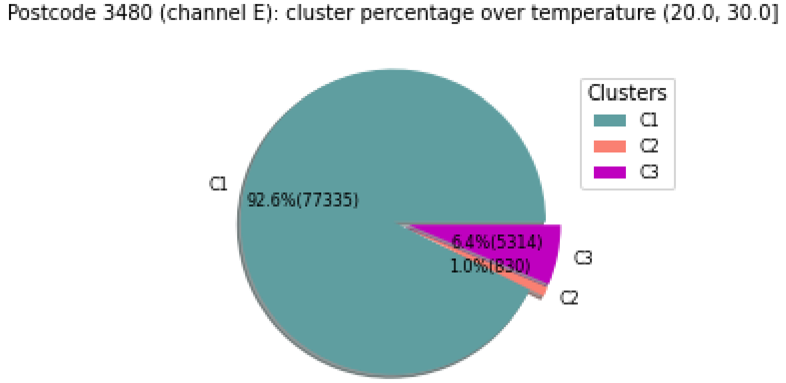
Clustering over Residential – Postcode 3840

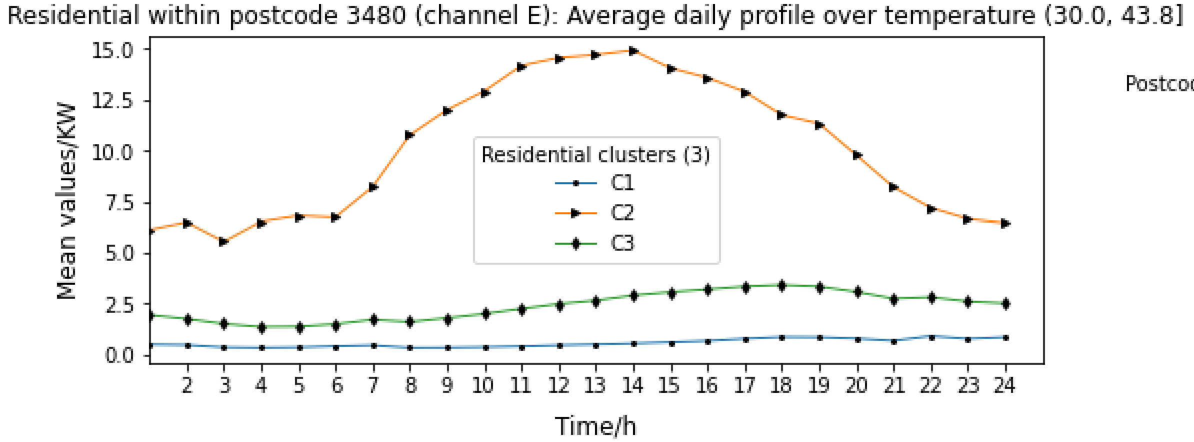
Channel: E

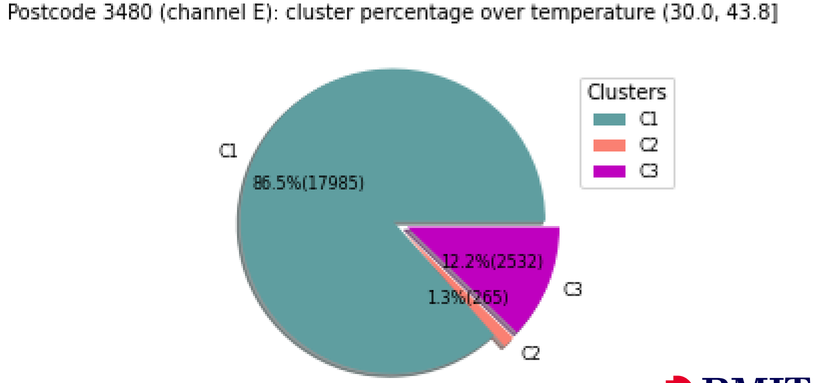
 # clusters: 3 (C1, C2, C3)

Pie chart: percentage (counts)









Project: 04

Area Hosting Capacity

Donald & Tarnagulla Microgrid Control for Economic Operation

Dr Manoj Datta

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Methodology

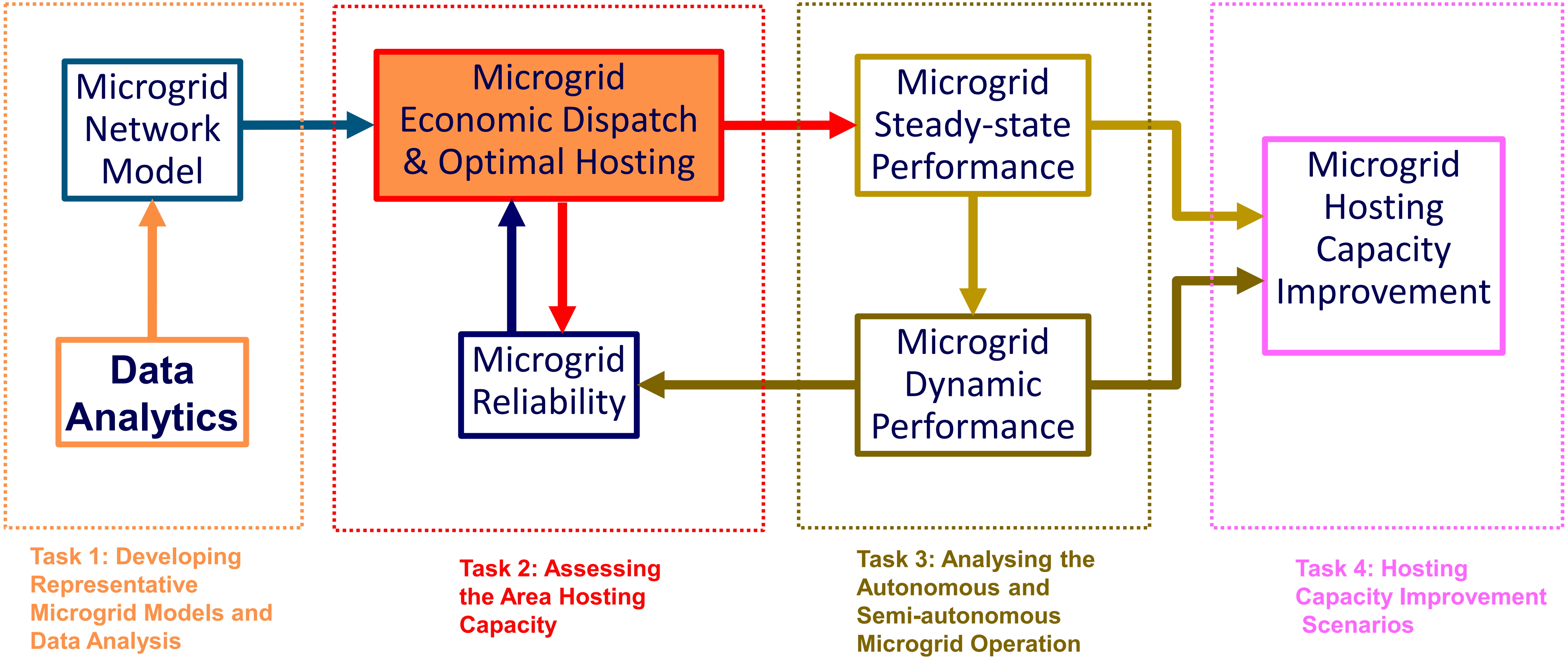

Figure 1 : Project Methodology

Optimal Hosting Capacity Analysis Tool

- HOMER Pro is a professional microgrid design and optimisation tool which is first developed by the National Renewable Energy Laboratory (NREL) and Department of Energy (DOE), the USA, in 1993.
- Although various professional tools and customised mathematical algorithms have been proposed for microgrid planning and hosting capacity assessment in the coming years, HOMER Pro remains the most widely used tool for microgrid design and optimal sizing due to its adequate mathematical modelling and optimisation algorithms.
- In this task, the HOMER Pro is used to find optimal component sizing and hosting capacity assessment of Donald and Tarnagulla microgrids to ensure economical operation and control and system reliability.

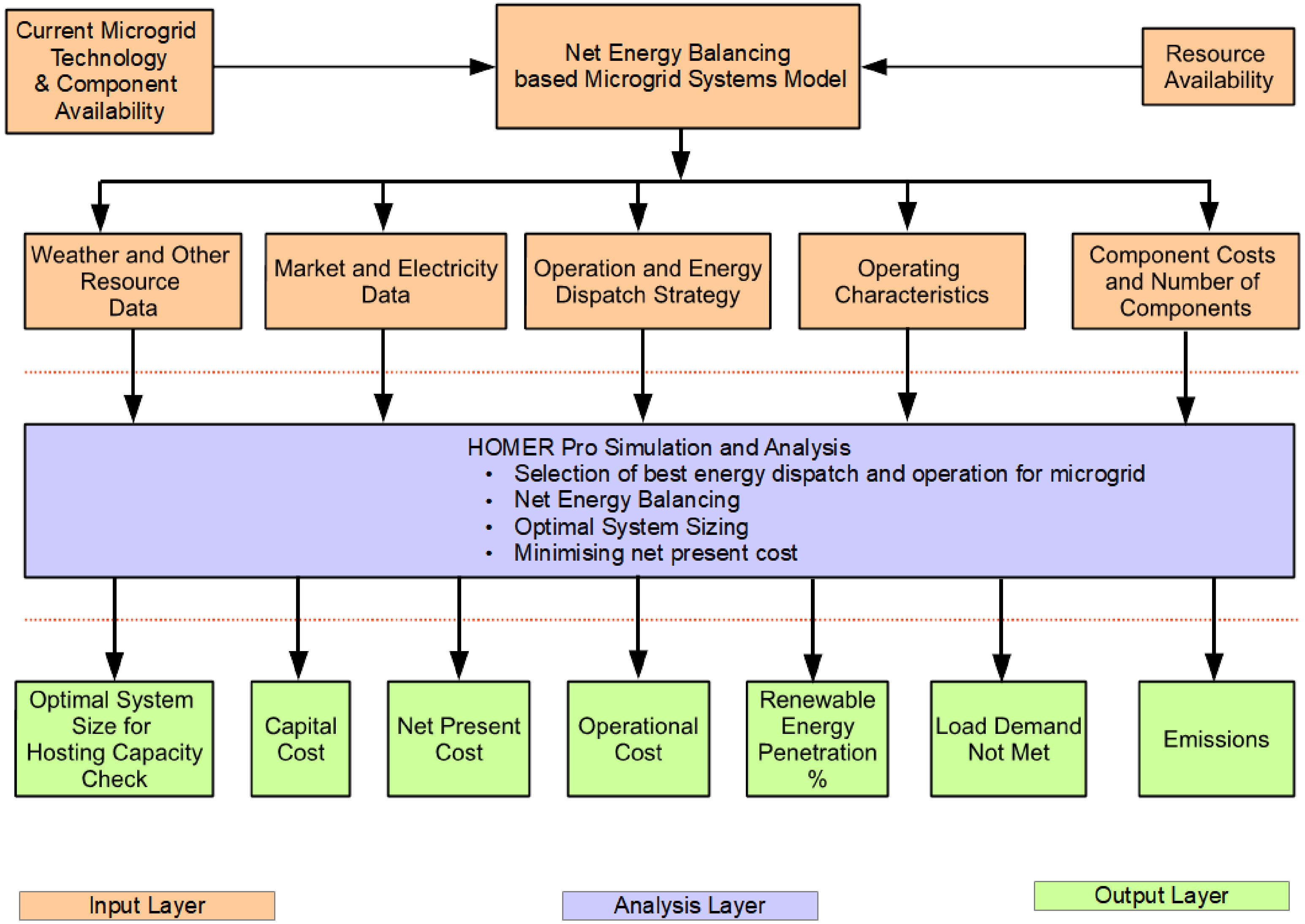

Figure 2: Simple block diagram of HOMER Pro analysis for microgrid hosting capacity calculations.

Task 2: Assessing the Area Hosting Capacity

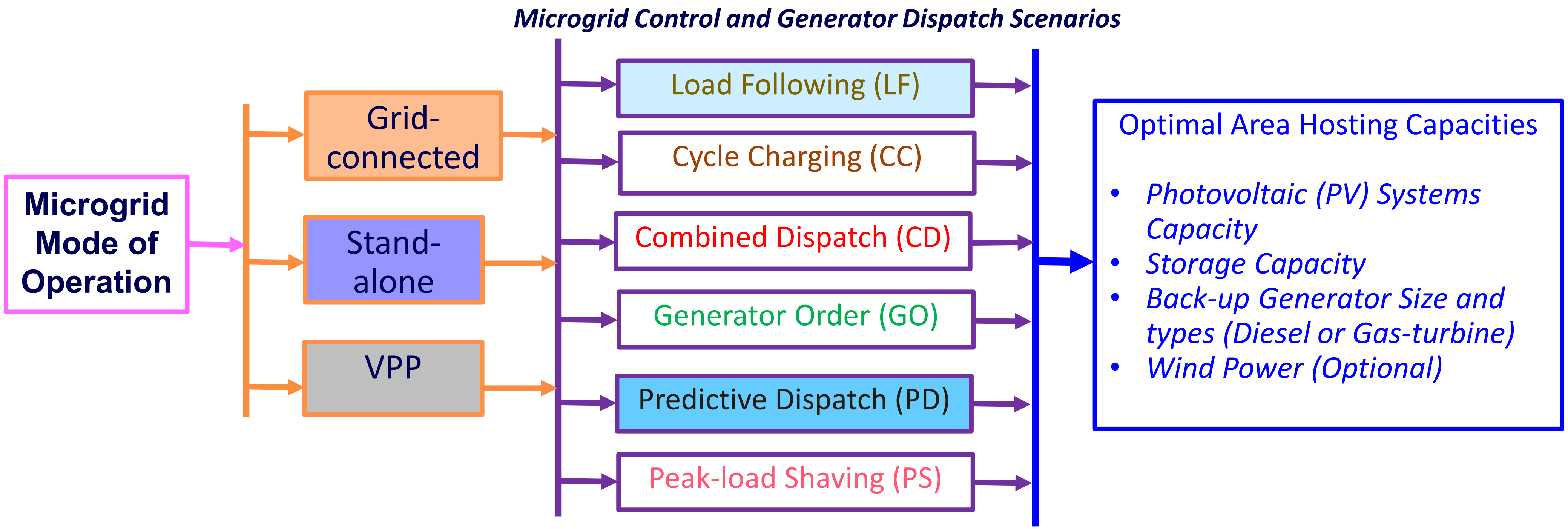

Figure 3: Microgrid Operation Scenarios

A microgrid controller is essentially the brain of a microgrid. It makes important decisions such as how the daily demand for energy is met, how and when the battery storage is used, and if the back-up generator needs to be turned on. Over time, microgrid controllers have become sophisticated and complex, even responding in real time to price signals from a utility.

LF: whenever a generator operates, it produces only enough power to meet the primary load. Lower-priority objectives such as charging the storage bank or serving the deferrable load are left to the renewable power sources. The generator can still ramp up and sell power to the grid if it is economically advantageous.

CD: In every timestep, the CD decides which is the cheapest decision to make for energy and generator dispatch: LF or CC

GO: Under the GO, energy dispatch follows a defined order of generator combinations, and uses the first combination in the list that meets the Operating Capacity. The GO only supports systems with generators, PVs, wind turbines, a converter and/or storage components and will not work in the grid-connected mode.

PS: PS dispatch strategy makes decisions in each time step that determine how to use the microgrid's components for demand charge reduction and energy arbitrage while serving the electric load.

CC: whenever a generator needs to serve the primary load, it operates at full output power. Surplus electrical power production goes toward the lower-priority objectives such as, in order of decreasing priority: serving the deferrable load or charging the storage bank.

PD: the dispatch algorithm knows the upcoming electrical load demand, as well as the coming PV and wind resource availability. It will often produce results with lower system operating costs compared to the other dispatch strategies. This dispatch strategy has 48-hour foresight and uses this knowledge to operate the batteries in an economical way. It will approximate modern systems that use forecasting to improve performance.

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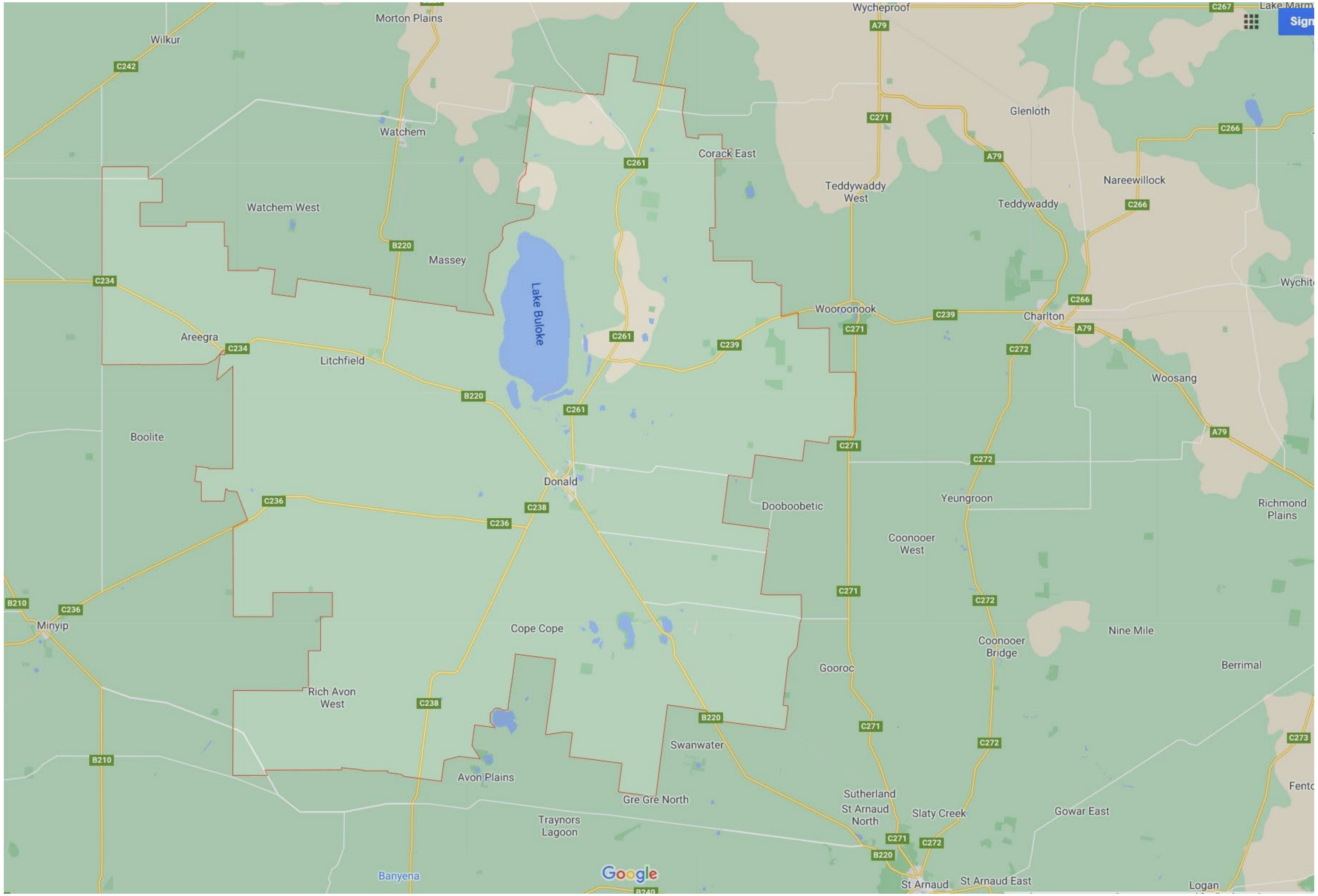
Donald Town (3480): Area to be considered



Postcode	Suburb
3480	AREEGRA, VIC
3480	CARRON, VIC
3480	COPE COPE, VIC
3480	CORACK, VIC
3480	CORACK EAST, VIC
3480	DONALD, VIC
3480	GIL GIL, VIC
3480	JEFFCOTT, VIC
3480	JEFFCOTT NORTH, VIC
3480	LAEN, VIC
3480	LAEN EAST, VIC
3480	LAEN NORTH, VIC
3480	LAWLER, VIC
3480	LITCHFIELD, VIC
3480	RICH AVON, VIC
3480	RICH AVON EAST, VIC
3480	RICH AVON WEST, VIC
3480	SWANWATER WEST, VIC

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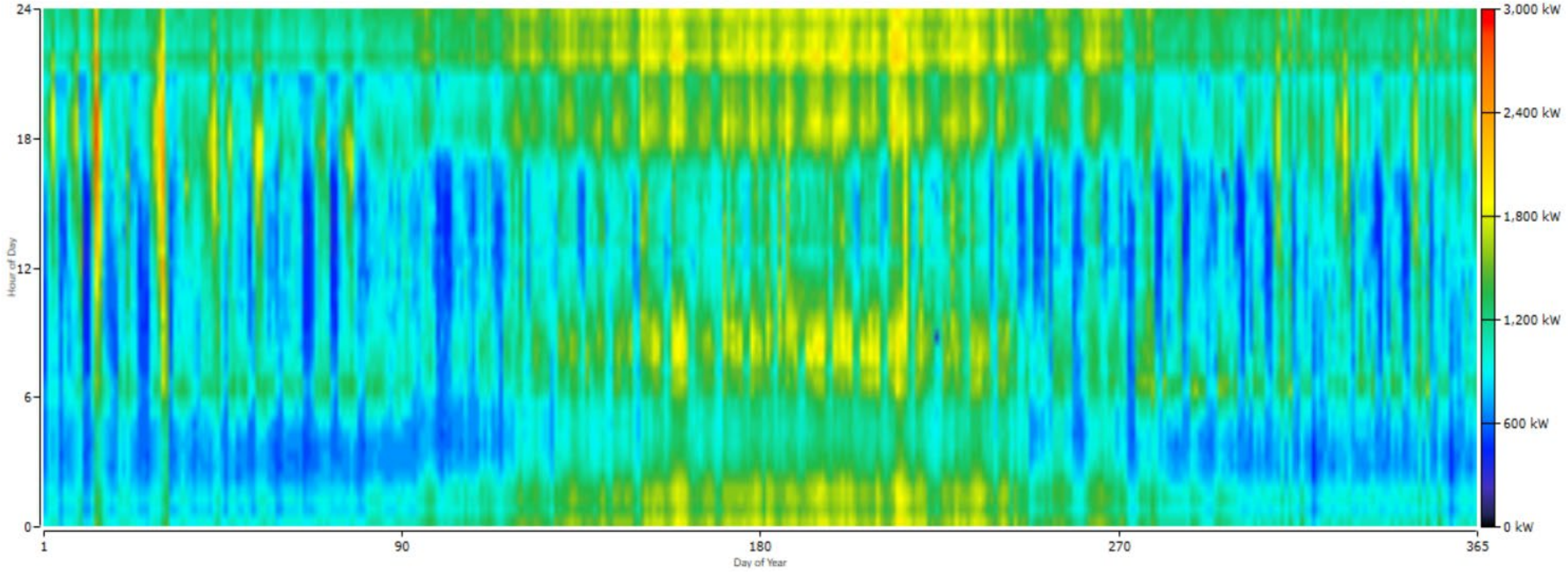
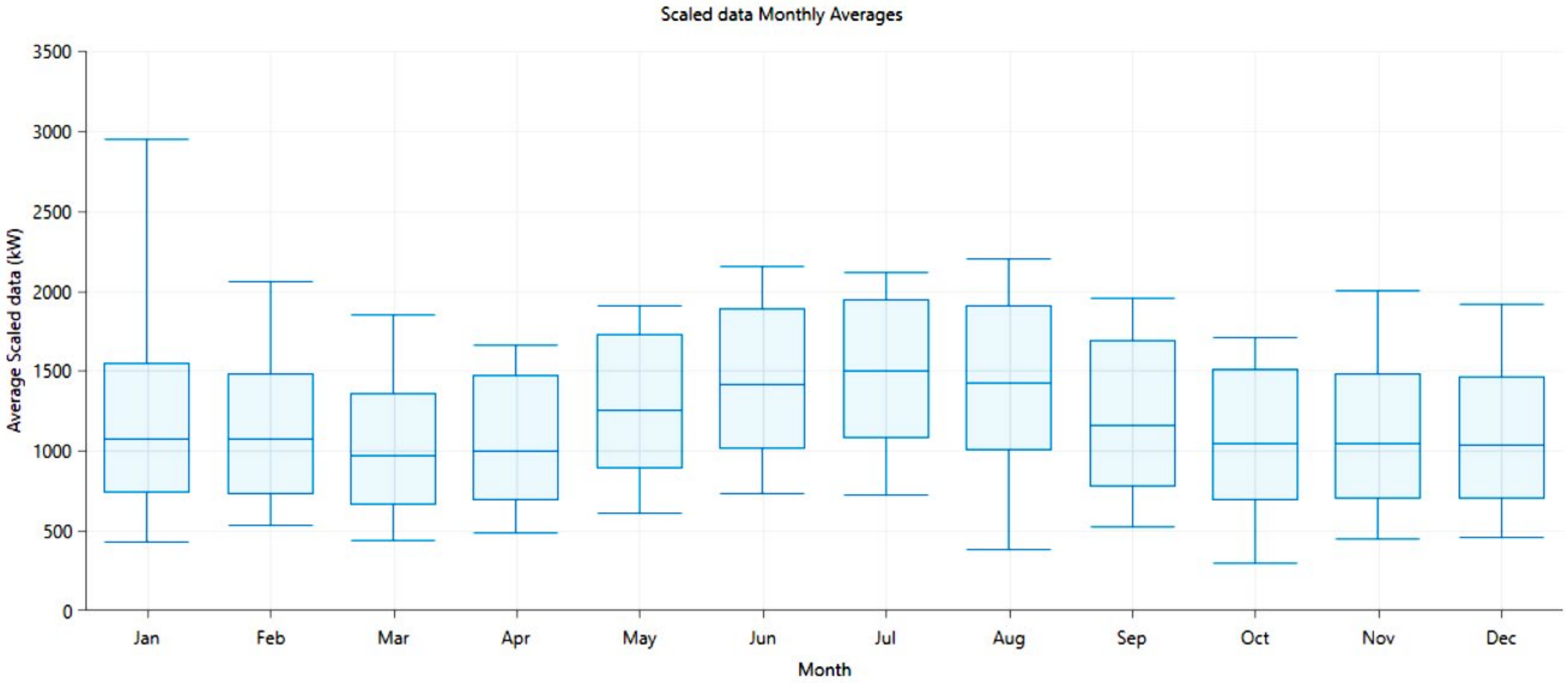
Donald Town: Smart Meter Data- Yearly Consumption (Aggregated)





Total Customer/Smart Meter Data Nodes: **1092** (Approximate)

Peak Load Month in 2020: **July**

Metric	Baseline
Average (kWh/day)	**28,128**
Average (kW)	**1,172**
Peak (kW)	**2,949.6**
Load Factor	**0.4**

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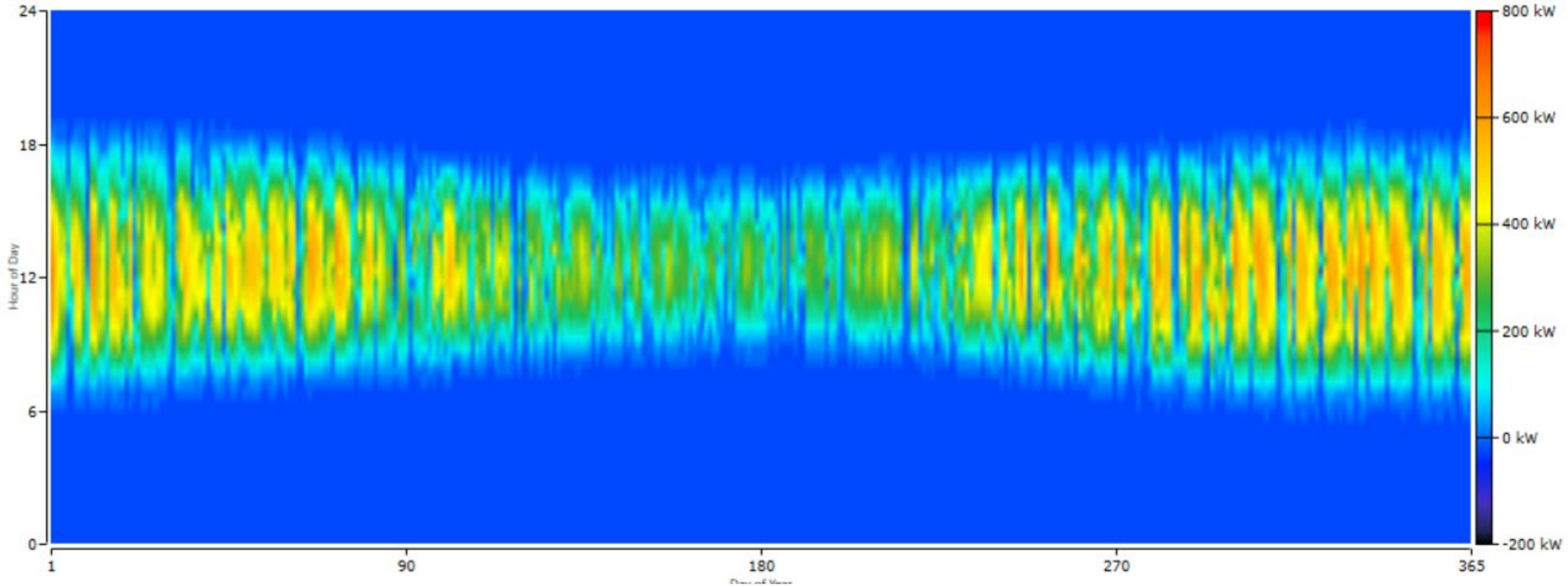
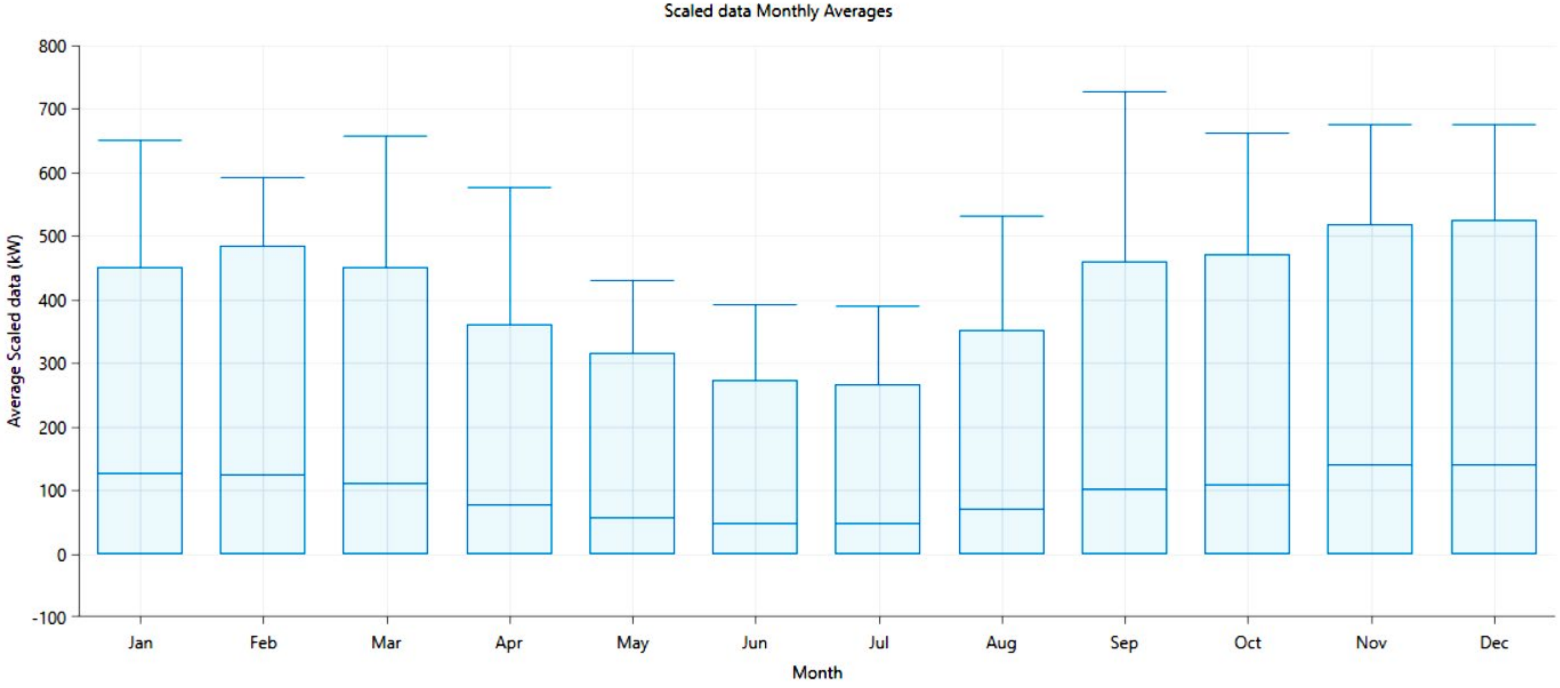
Donald Town: Smart Meter Data- Present Yearly Generation





Total Customers with DER: **201** (Approximately)

Mostly Roof-top PVs.

Some customers may have battery energy storage.

Peak Generation Month in 2020: **December**

Metric	Baseline
Average (kWh/day)	2332.8
Average (kW)	97.2
Peak (kW)	728.65

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Donald Town Microgrid: Hosting Capacities

Table : Stand-alone, VPP, and Grid-connected operation of Donald Town Microgrid and Area Hosting Capacities

Operation Mode	Energy Dispatch Strategy	PV Hosting Capacity (kW)	Storage Hosting Capacity (kWh)	Storage Converter Size (kW)	Back-up Generator Size (kW)
Grid-connected	Load Following *Time of Use Tariff* *Dispatch Algorithm has no advance knowledge of grid outages*	**3078**	**1015**	**641**	1000 (Small)
VPP (grid-connected)	Predictive + Load Following *Forecasted load + Forecasted generation* *Time of Use Tariff* *Dispatch Algorithm has no advance knowledge of grid outages*	**3507**	**7049**	**1716**	2800 (Large) 1800 (Medium) 1000 (Small)
Stand-Alone/Islanded	Load Following	**3216**	**4627**	**1639**	2800 (Large)

Data Input:

Data Input:

- 30 minutes resolution load data of 2020 supplied by Powercor
- 30 minutes resolution present generation data of 2020 supplied by Powercor
- Actual Solar Irradiance data collected from NASA surface metrology
- Actual Wind Speed (NASA surface metrology)
- Actual Temperature (NASA surface metrology)
- GloBird Energy Time of Use electricity pricing
- Incoming feeder reliability data supplied by Powercor

- **PV Unit:** Generic Flat Plate PV; Rated Capacity:1 kW; NOCT-47^{0}C; Efficiency: 13%; Temperature Co-efficient: -0.5
- **Storage (Battery Unit):** Generic 1 kWh Li-Ion; Nominal Voltage: 6V; Nominal Ah: 167; Max. Charge Current: 167 A; Max. Discharge Current: 500 A; Roundtrip Efficiency: 90%
- **Converter Unit for Battery:** 1 kW Generic bi-directional converter; Inverter/rectifier efficiency: 95%
- **Alternative Storage (Hydrogen Unit):** UNSW LAVO, 40 kWh hydrogen storage, Nominal Voltage: 48V; Nominal Ah: 833; Max. Charge Current: 833 A; Max. Discharge Current: 833 A; Roundtrip Efficiency: 95%;
- **Converter Unit for Hydrogen: 5** kW Generic bi-directional converter; Inverter/rectifier efficiency: 95%
- **Back-up Generator Unit (Diesel)**: Caterpillar CAT-3500 kVA (2800 kW)/ 50 HZ/1500 RPM Prime Power; Caterpillar CAT-C3516B Prime (1825 kW)/ 50 HZ Prime Power; Caterpillar CAT-C32 Prime (910 kW)/ 50 HZ Prime Power
- **Alternative Back-up Generator Unit (Biodiesel B20):** GFC SG550A-550 kVA (440 kW)/500 kVA (400 kW), 50 Hz; GFC HSW-305 T5 330 KVA (264 kW)/300 kVA (240 kW), 50 Hz; GFC HFW-160 T5 175 kVA (140 kW)/ 160 kVA(128 kW), 50 Hz

Detail time-domain simulation are performed and results are available for all the weather data, aggregated load, PV generation, battery charging/discharging, grid power exchange, and diesel power generation (data resolution: 1 hour, year: 2020)

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Donald Town Microgrid: Hosting Capacity Analysis

Table : Comparison of Grid-connected and VPP operations of Donald Town Microgrid

Operation Mode	PV Hosting Capacity (kW)	Storage Hosting Capacity (kWh)	Storage Converter Size (kW)	Back-up Generator Size (kW)	Cost of Energy (COE)	Initial Capital cost	Renewable Energy Fraction	**Grid Reliability** Mean outage frequency/year = 7 Mean Repair Time = 0.5 hour	**Grid Reliability** Mean outage frequency/year = 14 Mean Repair Time = 1 hour	**Grid Reliability** Mean outage frequency/year = 14 Mean Repair Time = 2 hour
Grid-connected	**3078**	**1015**	**641**	1000 (Small)	$0.164	$ 8.75 M	36.9%	Can handle	**Cannot handle. Small % of load unmet**	**Cannot handle. Small % of load unmet**
VPP (grid-connected)	**3507**	**7049**	**1716**	1000 (Small)	$0.206	$13.2 M	42.2%	Can handle	Can handle	Can handle

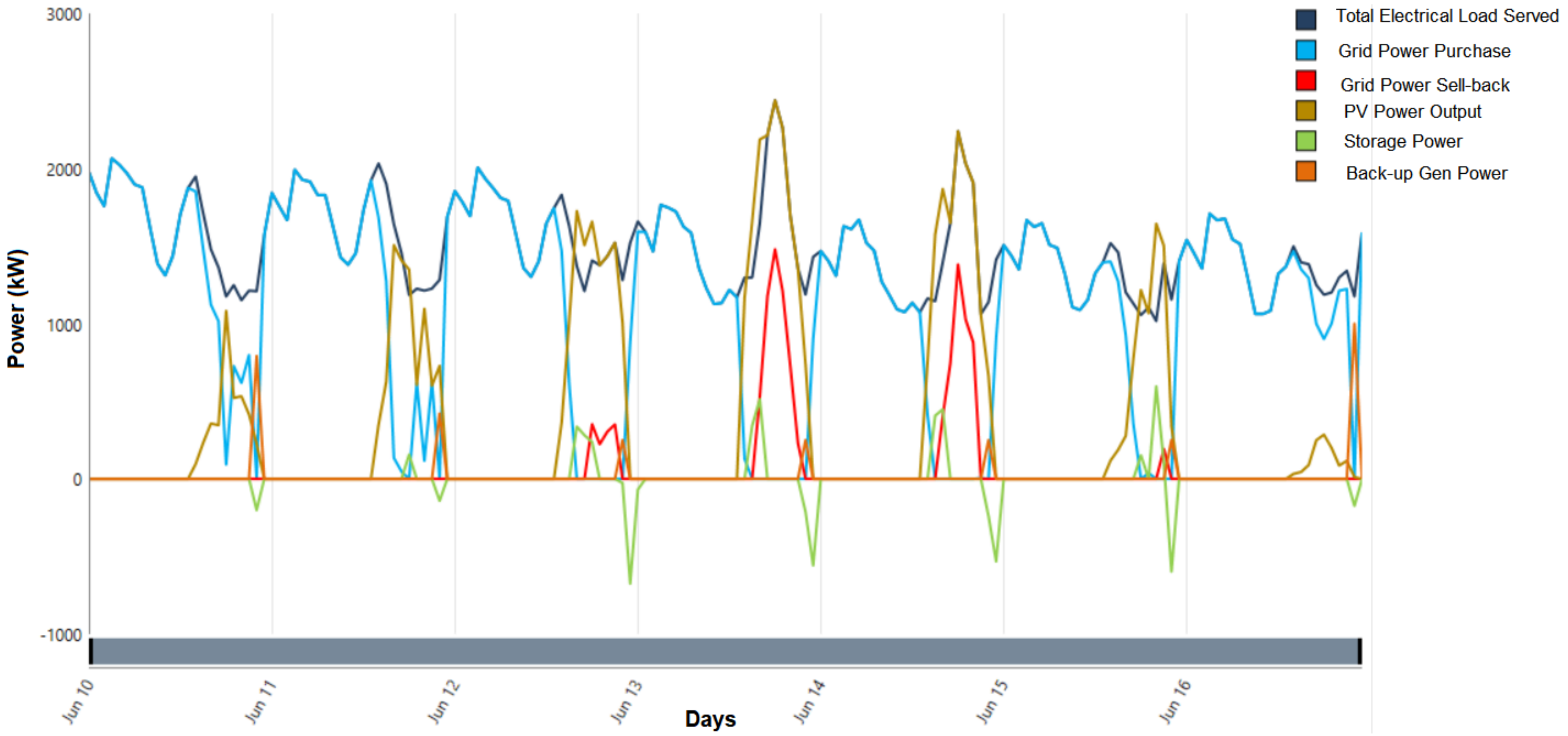
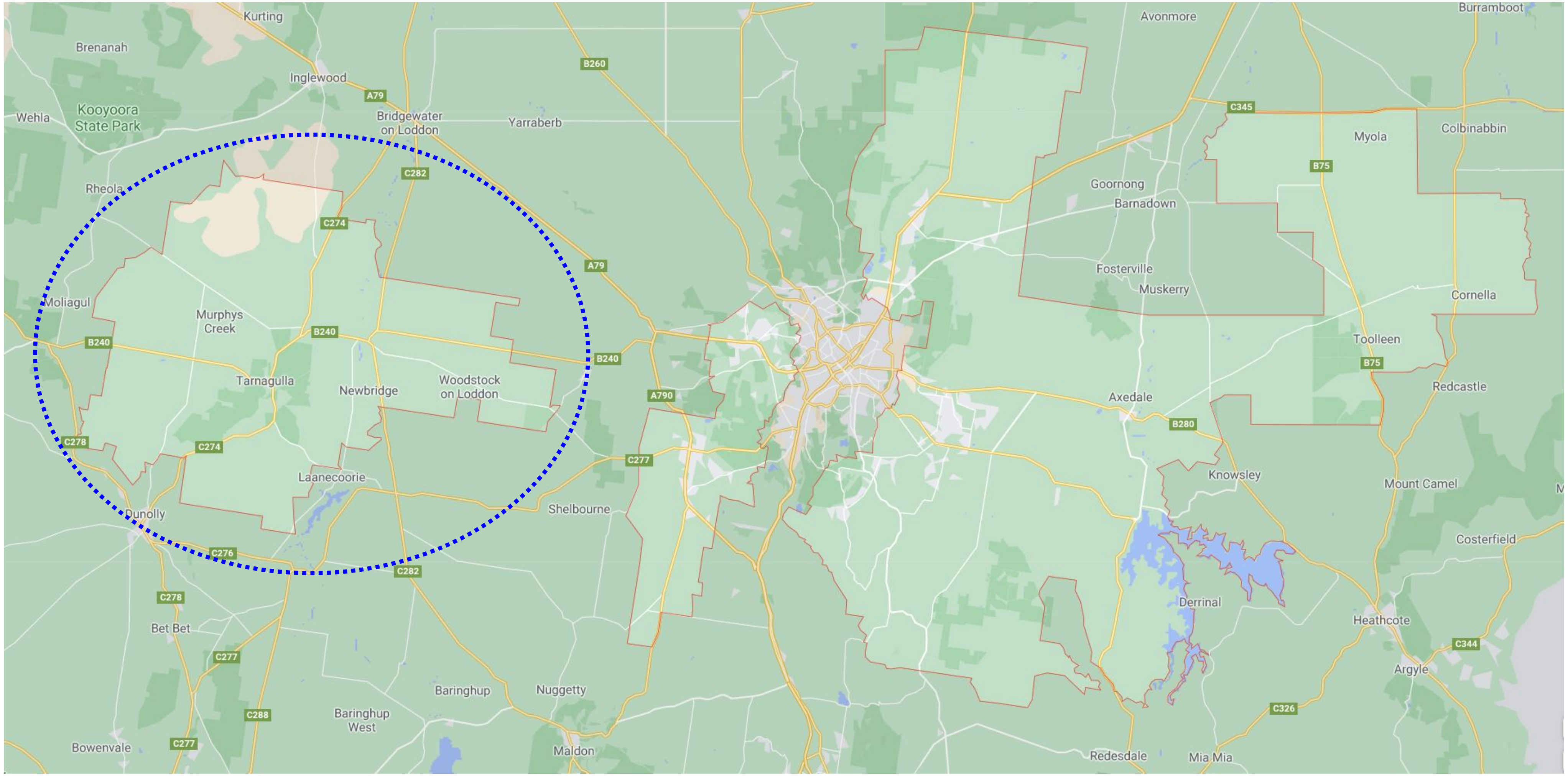


Figure 4: Time-domain simulation of energy balancing under grid connected mode (Donald Town Microgrid)

Tarnagulla Town (3551): Area to be considered



Postcode	Suburb
3551	ARNOLD, VIC
3551	ARNOLD WEST, VIC
3551	LLANELLY, VIC
3551	MURPHYS CREEK, VIC
3551	NEWBRIDGE, VIC
3551	PAINSWICK, VIC
3551	TARNAGULLA, VIC
3551	WAANYRRA, VIC
3551	WOODSTOCK ON LODDON, VIC

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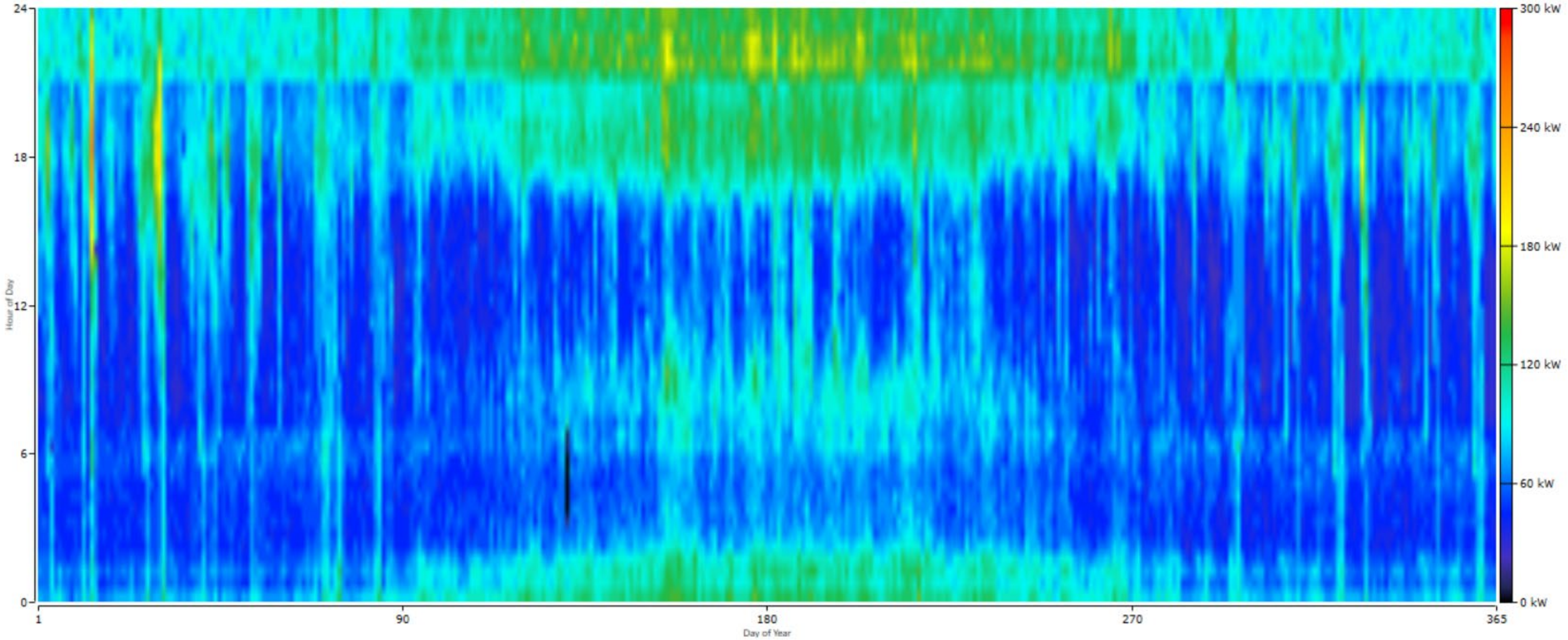
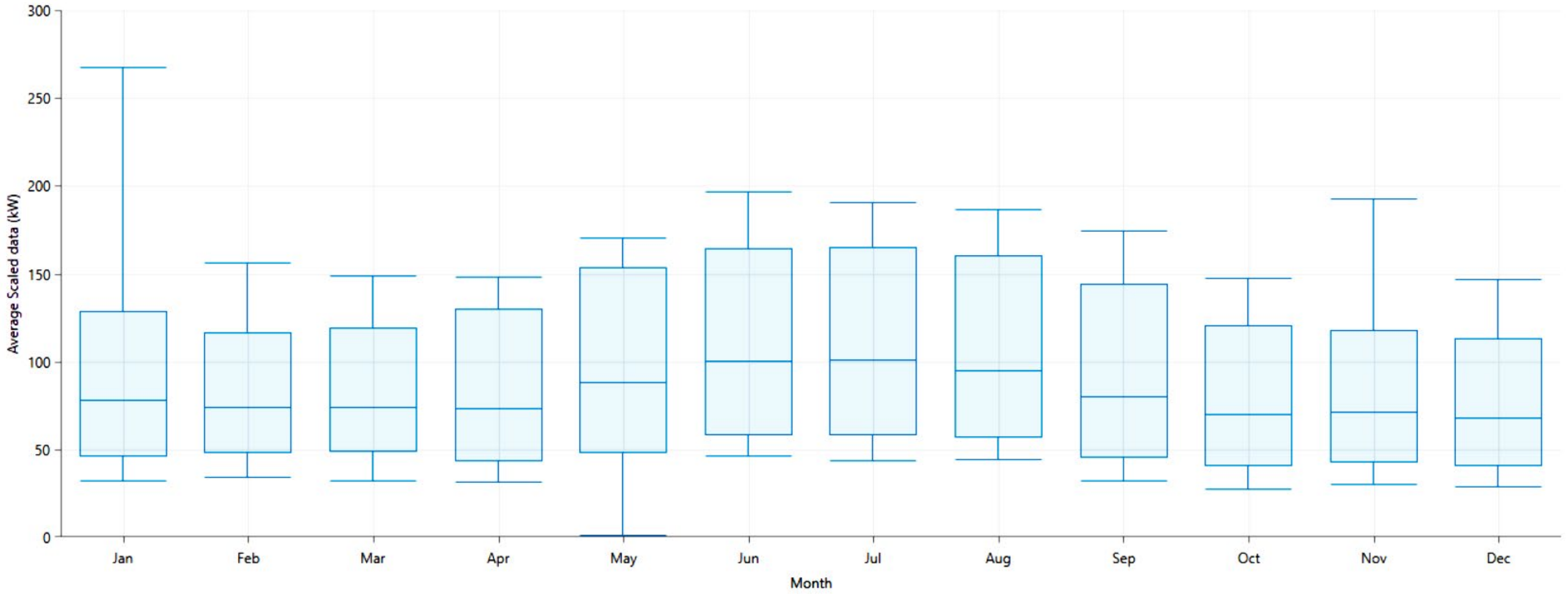
Tarnagulla Town: Smart Meter Data- Yearly Consumption (Aggregated)



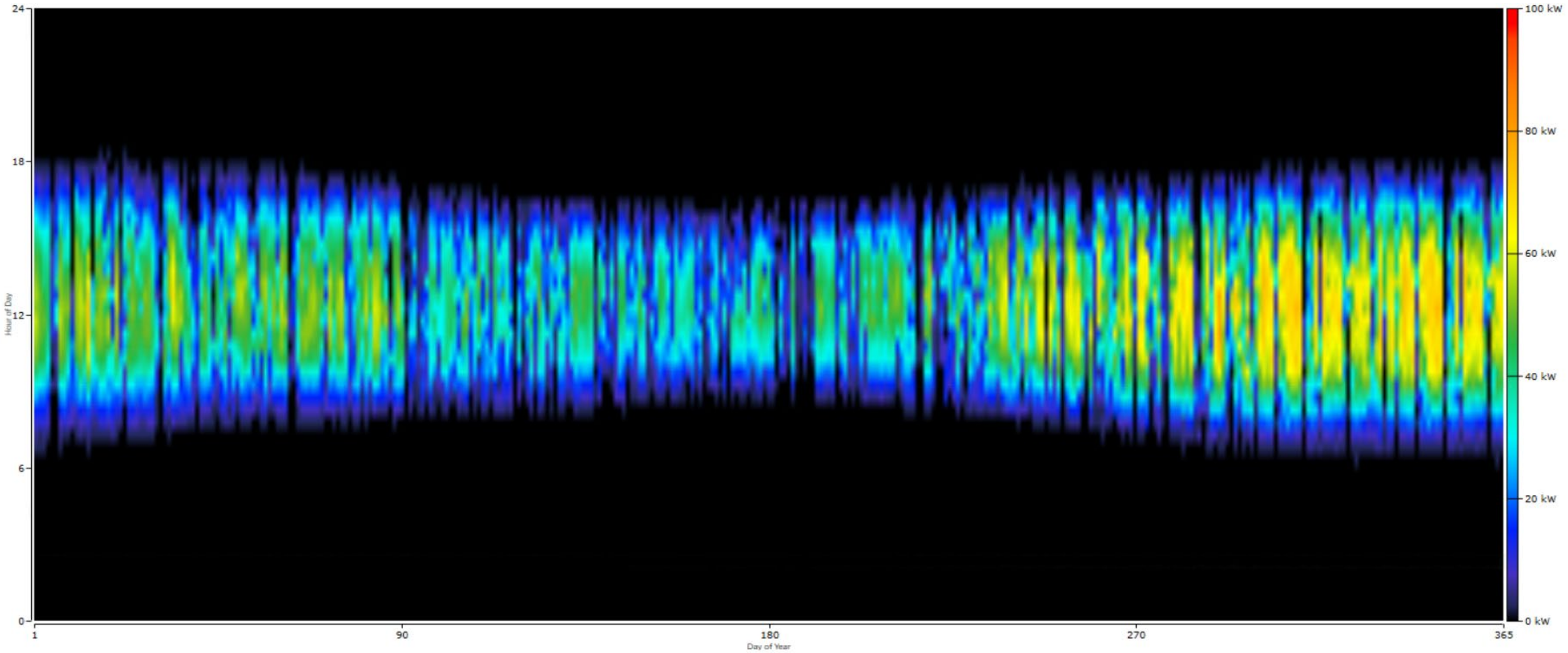


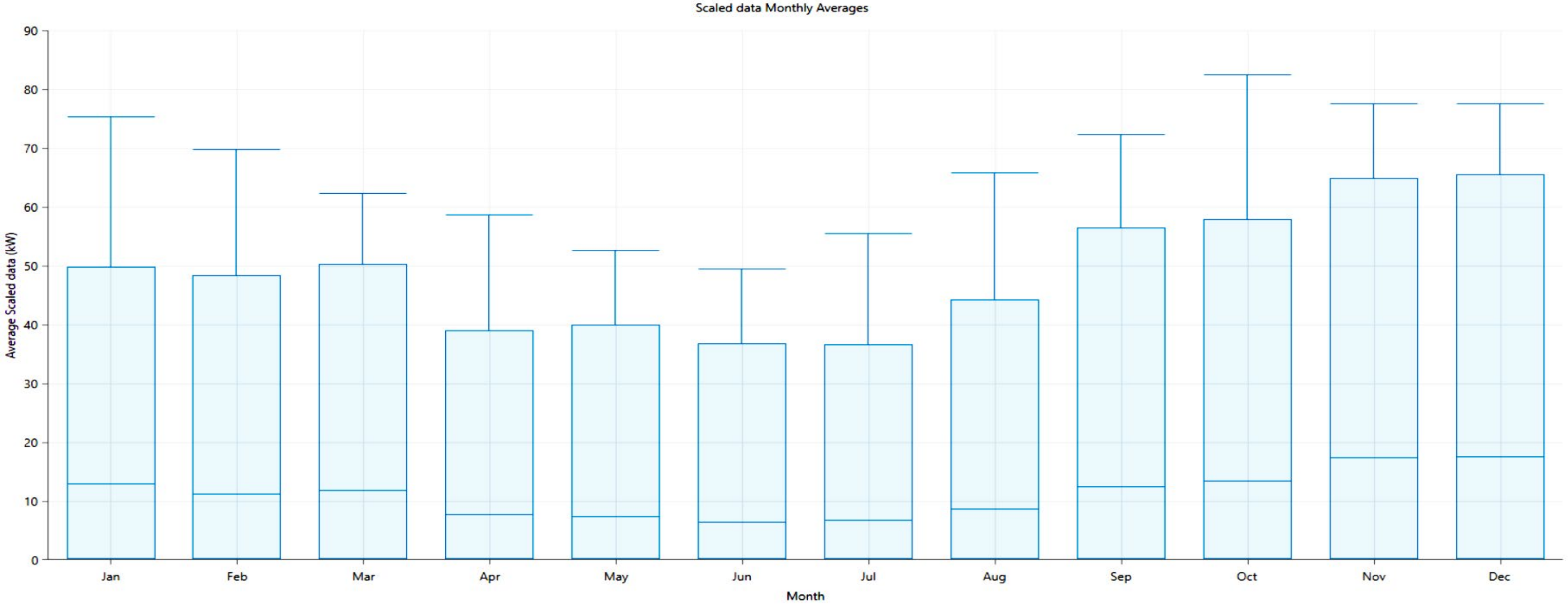
Total Customer/Smart Meter Data Nodes: **151** (Approximate)

Peak Load Month in 2020: **July**

Metric	Baseline
Average (kWh/day)	1,947.5
Average (kW)	81.15
Peak (kW)	267.48
Load Factor	0.3

Tarnagulla Town: Smart Meter Data- Yearly Generation (Aggregated)





Total Customers with DER: **34** (Approximately)

Mostly Roof-top PVs.

Some customers with a very small battery energy storage.

Peak Generation Month in 2020: **December**

Metric	**Baseline**
Average (kWh/day)	**266.26**
Average (kW)	**11.09**
Peak (kW)	**82.5**

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Tarnagulla Town Microgrid: Hosting Capacities

Table: Stand-alone and VPP operation of Tarnagulla Town Microgrid and Area Hosting Capacities

Operation Mode	Dispatch Strategy	PV Hosting Capacity (kW)	Storage Capacity (kWh)	Storage Converter (kW)	Back-up Generator Size (kW)
Grid-connected	Load Following *Time of Use Tariff* *Dispatch Algorithm has no advance knowledge of outages*	**115**	**75**	**23**	120 (Small)
VPP (grid-connected)	Predictive + Load Following *Forecasted load +Forecasted generation* *Time of Use Tariff* *Dispatch Algorithm has no advance knowledge of outages*	**155**	**192**	**111**	320 (Large) 240 (Medium) 120 (Small)
Stand-Alone/Islanded	Load Following	**131**	**148**	**101**	320 (Large)

Data Input:

- 30 minutes resolution load data of 2020 supplied by Powercor
- 30 minutes resolution present generation data of 2020 supplied by Powercor
- Actual Solar Irradiance data collected from NASA surface metrology
- Actual Wind Speed (NASA surface metrology)
- Actual Temperature (NASA surface metrology)
- GloBird Energy Time of Use electricity pricing
- Incoming feeder reliability data supplied by Powercor

- **PV Unit:** Generic Flat Plate PV; Rated Capacity:1 kW; NOCT-47^{0}C; Efficiency: 13%; Temperature Co-efficient: -0.5
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- **Converter Unit for Hydrogen: 5** kW Generic bi-directional converter; Inverter/rectifier efficiency: 95%
- **Back-up Generator Unit (Diesel)**: Caterpillar CAT-C13 Prime (365 kW)/ 50 HZ Prime Power, Caterpillar CAT-C9 Prime (275 kW)/ 50 HZ Prime Power, Caterpillar CAT-150kVA (120 kW)/50 Hz prime power
- **Alternative Back-up Generator Unit (Biodiesel B20):** GFC SG550A-550 kVA (440 kW)/500 kVA (400 kW), 50 Hz; GFC HSW-305 T5 330 KVA (264 kW)/300 kVA (240 kW), 50 Hz; GFC HFW-160 T5 175 kVA (140 kW)/ 160 kVA(128 kW), 50 Hz

Detail time-domain simulations are performed and results are available for all the weather data, aggregated load, PV generation, battery charging/discharging, grid power exchange, and diesel power generation (data resolution: 1 hour, year: 2020)

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Optimal Hosting Capacity Assessment Summary

- From the time series results of net energy balancing, it has been found that the optimally sized microgrid can meet the electric load demand reliably and continuously under different operation scenarios.

- Grid-connected operation of microgrid under load following dispatch strategy provides the most cost-effective design of microgrid. However; if the incoming utility feeder's reliability is somewhat less than the standard requirements, the energy security will be compromised unless a large backup generator or large-capacity storage system is present.

- Grid connected operation of microgrid under virtual power plant (VPP) and load following dispatch strategy provides the ideal design. However, the initial capital cost will be significant and can be recovered within a couple of years.

- VPP operation provides the best energy security. However; if significant forecasting errors are present in the load and generation forecasting, an intelligent energy management solution will be necessary.

- These optimally sized microgrid components are used as the base-case scenario for the microgrid's steady-state and quasi-dynamic operation simulations and are found to be acceptable under distribution voltage limits.

Project: 04

Area Hosting Capacity

Task 2

Donald Microgrids Reliability Analysis

Dr Kazi Hasan
Dr Manoj Datta
Dr Moudud Ahmed

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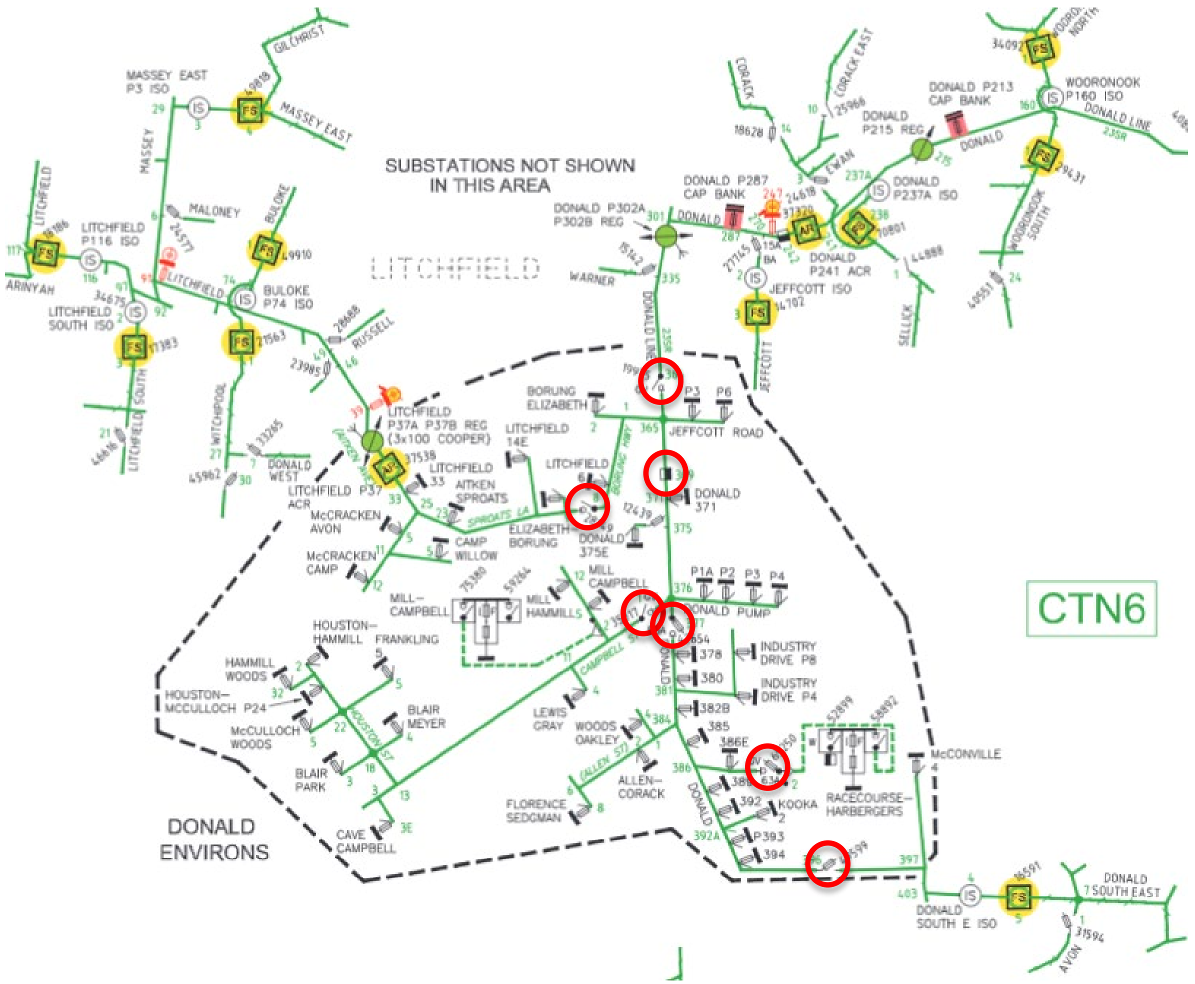
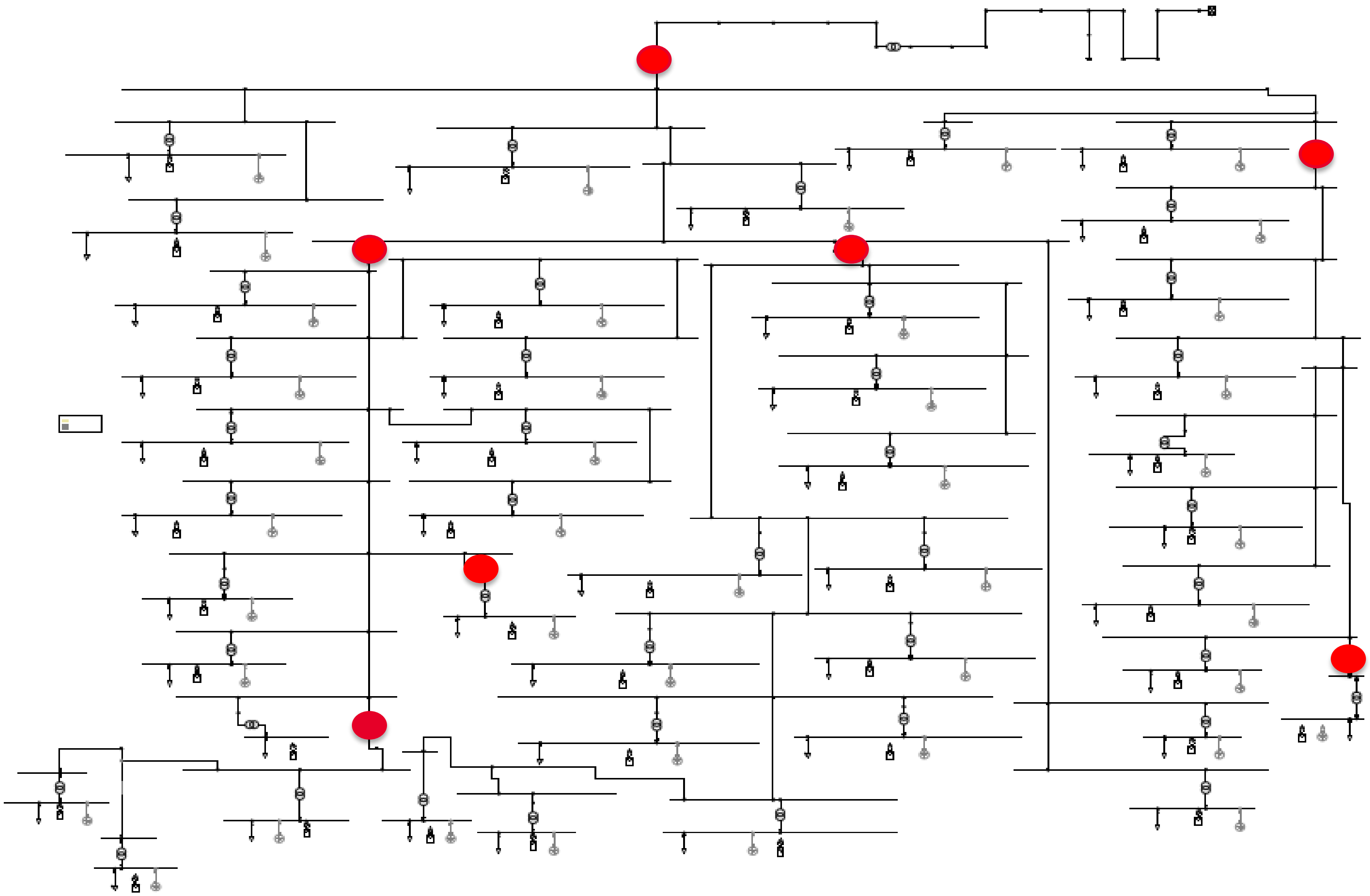
Contents

- **Reliability model** of the microgrid with protection devices.
- Calculation of major system reliability indices: **SAIDI, SAIFI, ENS**.
- Reliability indices for **grid-connected vs. islanded systems**.
- **Grid-connected** system reliability with respect to **PV hosting capacity**.
- **Islanded microgrid** reliability with respect to **PV hosting capacity**.

Donald Network for Reliability Model (with protection devices)



Donald Network for Reliability Model (with protection devices)



Circuit breakers

Assumptions and Input Reliability Parameters

Model Simplification Approach

- ✓ Litchfield PCC is replaced by a transformer and a load
- ✓ Donald south is replaced by a transformer and a load
- ✓ Typical LV sub-station is replaced by a transformer and a load
- ✓ One customer is equal to 5 kW load

Input Reliability data		
CB at 22 kV feeder	Time to actuate switch	30 min
	CB fails to open	5%
CB at secondary side of transformer	Time to actuate switch	1 min
Terminal 22 kV	Forced Outage rate	0.0104 1/a
	Forced Outage Expectancy	0.208 h/a
	Forced Outage Duration	20 h
	Failure frequency	1.99094
Terminal 0.4 kV	Repair duration	1.914055
22 kV overhead lines	Failure frequency	0.177 1/(_a*km)
	Repair duration	10 h
	Transient fault frequency	12.5053
Solar-PV	Failure rate	0.2487
	Repair duration	40 h
Battery	Failure rate	0.2487
	Repair duration	40 h

Reliability Index Definition

SAIDI: **System Average Interruption Duration Index**, in units of [h/C/a], indicates the total duration of interruption for the average customer during the period in the calculation. It is commonly measured in customer minutes or customer hours of interruption.

$$SAIDI = \frac{\sum ACIT_i * C_i}{\sum C_i} \text{ h/C/a}$$

$ACIT$: Average customer interruption time
C_i: The number of customers supplied by load point i
C: The number of customers

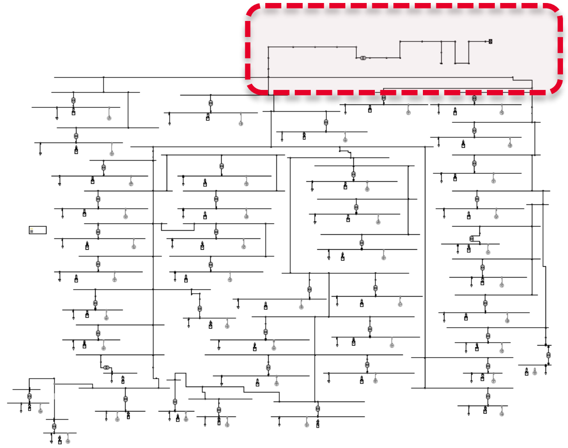
SAIFI: **System Average Interruption Frequency Index**, in units of [1 /C/a], indicates how often the average customer experiences a sustained interruption during the period specified in the calculation.

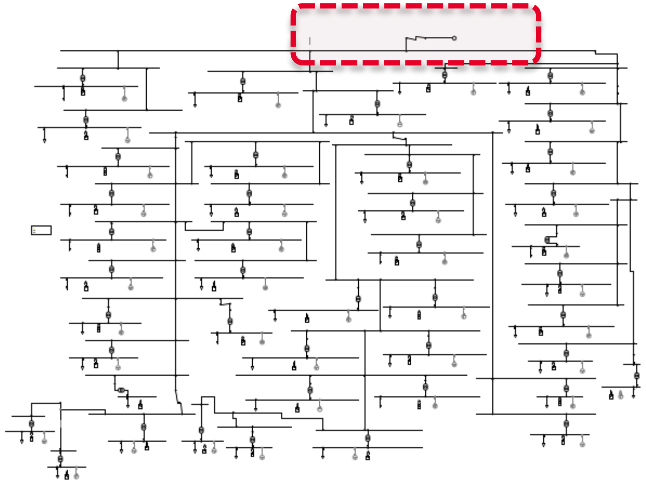
$$SAIFI = \frac{\sum ACIF_i * C_i}{\sum C_i} \text{ 1/C/a}$$

$ACIF$: Average customer interruption frequency
C_i: The number of customers supplied by load point i
C: The number of customers

ENS: **Energy Not Supplied**, in units of [MWh/a], is the total amount of energy on average not delivered to the system loads.

Grid-connected vs. islanded mode reliability





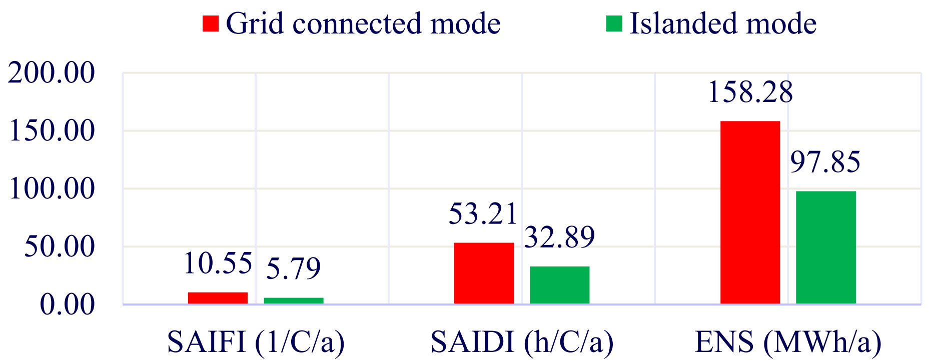


Figure: Donald area reliability indices in grid-connected and islanded mode.

Lower value means higher reliability

- The SAIDI, SAIFI, and ENS have been decreased by 45%, 38%, and 38% respectively, in the islanded mode.
- Due to the low reliability of the incoming supply feeder, the system reliability will improve in the islanded mode (subject to enough available local generation).

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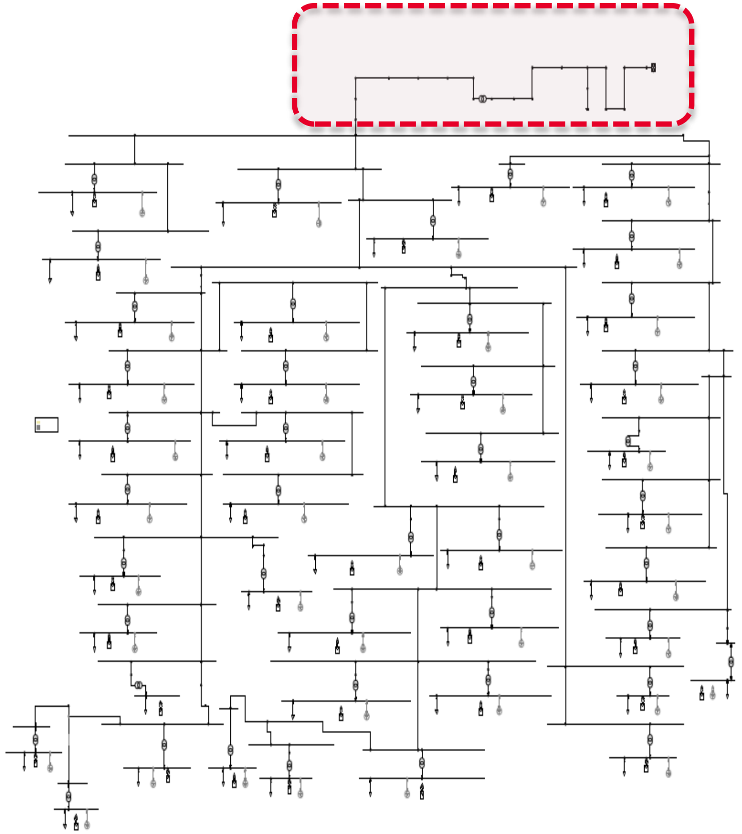
Grid-connected mode: reliability w.r.t. PV hosting capacity



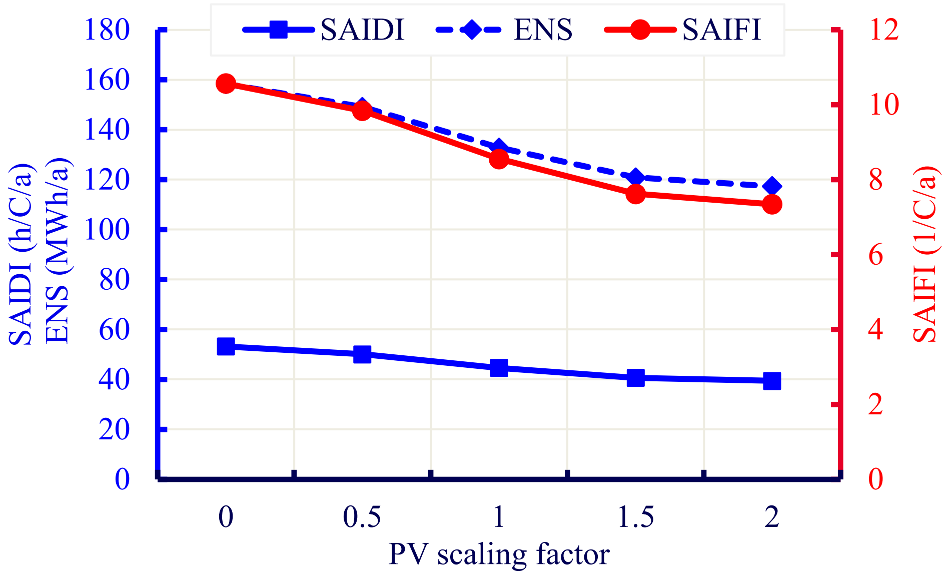


Figure: Donald area reliability indices in grid-connected mode w.r.t. PV hosting capacity.

- SAIDI, SAIFI and ENS is decreased proportionately with higher % of PV penetration.

Lower value means higher reliability

$$Change\ in\ Reliability = \frac{\Delta\ Reliability}{\Delta\ PV\ capacity}$$

Average SAIFI change factor -1.8
Average SAIDI change factor -7.5
Average ENS change factor -22.4

1 unit (100%) increase in PV will decrease the SAIFI by 1.8 unit.

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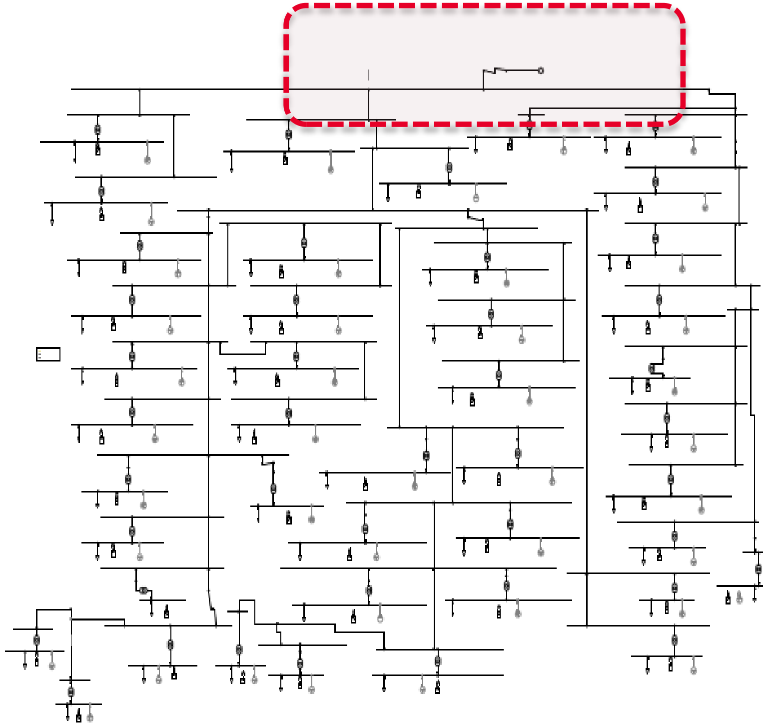
Islanded mode: reliability w.r.t. PV hosting capacity



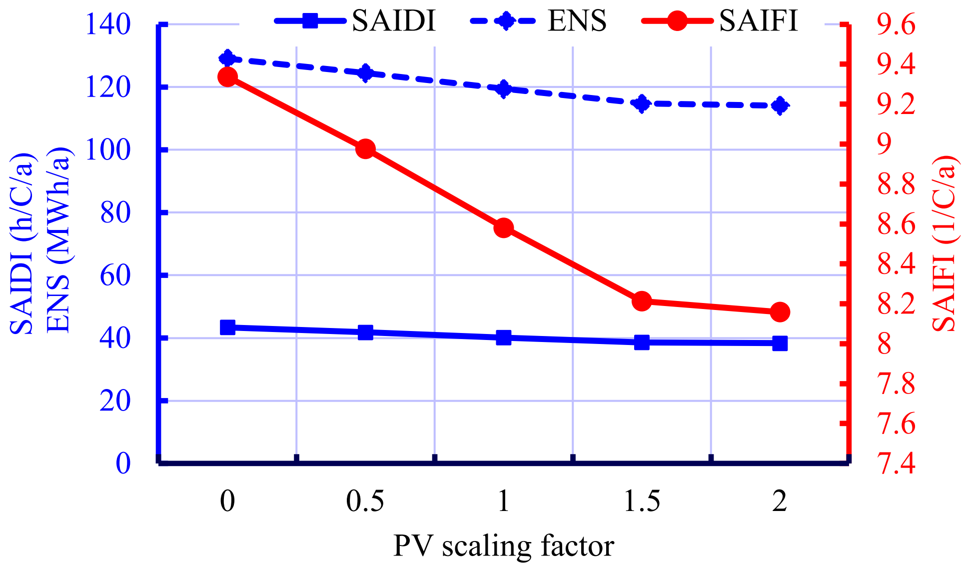


Figure: Donald area reliability indices in islanded mode w.r.t. PV hosting capacity.

- SAIDI, SAIFI and ENS is decreased with higher % of PV penetration.

Lower value means higher reliability

$$Change\ in\ Reliability = \frac{\Delta\ Reliability}{\Delta\ PV\ capacity}$$

Average SAIFI change factor -0.72
Average SAIDI change factor -3.00
Average ENS change factor -8.95

1 unit (100%) increase in PV will decrease the SAIFI by 0.72 unit.

Network reliability index: SAIDI

Table 5: Jurisdictional SAIDI Standards[36]

Region	Utility Company	CBD	Urban	Rural Short	Rural Long
ACT	ActewAGL	-	40	40	40
New South Wales	Ausgrid (Energy Australia)	45	80	300	700
	Endeavour (Integral) Energy	-	80	300	none
	Essential (Country) Energy	-	125	300	700
Queensland	Ergon Energy	-	149	424	964
	Energex	15	106	218	-
SA	ETSA Utilities	25	115	240 - 450	240 - 450
Tasmania	Aurora Energy	60	120	480	600
	CitiPower	11	22	-	-
	JEN	-	68	153	153
Victoria	Powercor	-	82	115	234
	SP AusNet	-	102	209	257
	United Energy	-	55	99	99
NT	Power and Water Corporation	-	-	-	-
WA	Western Power	30	160	290	290

Feeder (length/location) reliability significantly affect the overall power supply reliability

S. Hesmondhalgh, W. Zarakas and T. Brown, "Approaches to setting electric distribution reliability standards and outcomes," The Brattle Group, London, 2012

Summary and Conclusions

- Standard **reliability indices** (SAIDI, SAIFI and ENS) have been calculated for **grid connected** mode and **islanded mode –** with multiple levels of **PV hosting capacity**.

- System reliability is **increased** in **islanded mode** compared to **grid connected** mode.

    - The **SAIDI, SAIFI, and ENS** have been decreased by **45%, 38%, and 38%** respectively, in the islanded mode. (provided that there is enough local generation)

- SAIDI, SAIFI, and ENS are **decreased** (i.e. system reliability is increased) with the higher **PV hosting capacity.**

    - Grid connected mode reliability is increased more (1.8 unit SAIDI drop) compared to islanded mode (0.72 unit SAIDI drop) with the increased PV hosting capacity.

Project: 04

Area Hosting Capacity

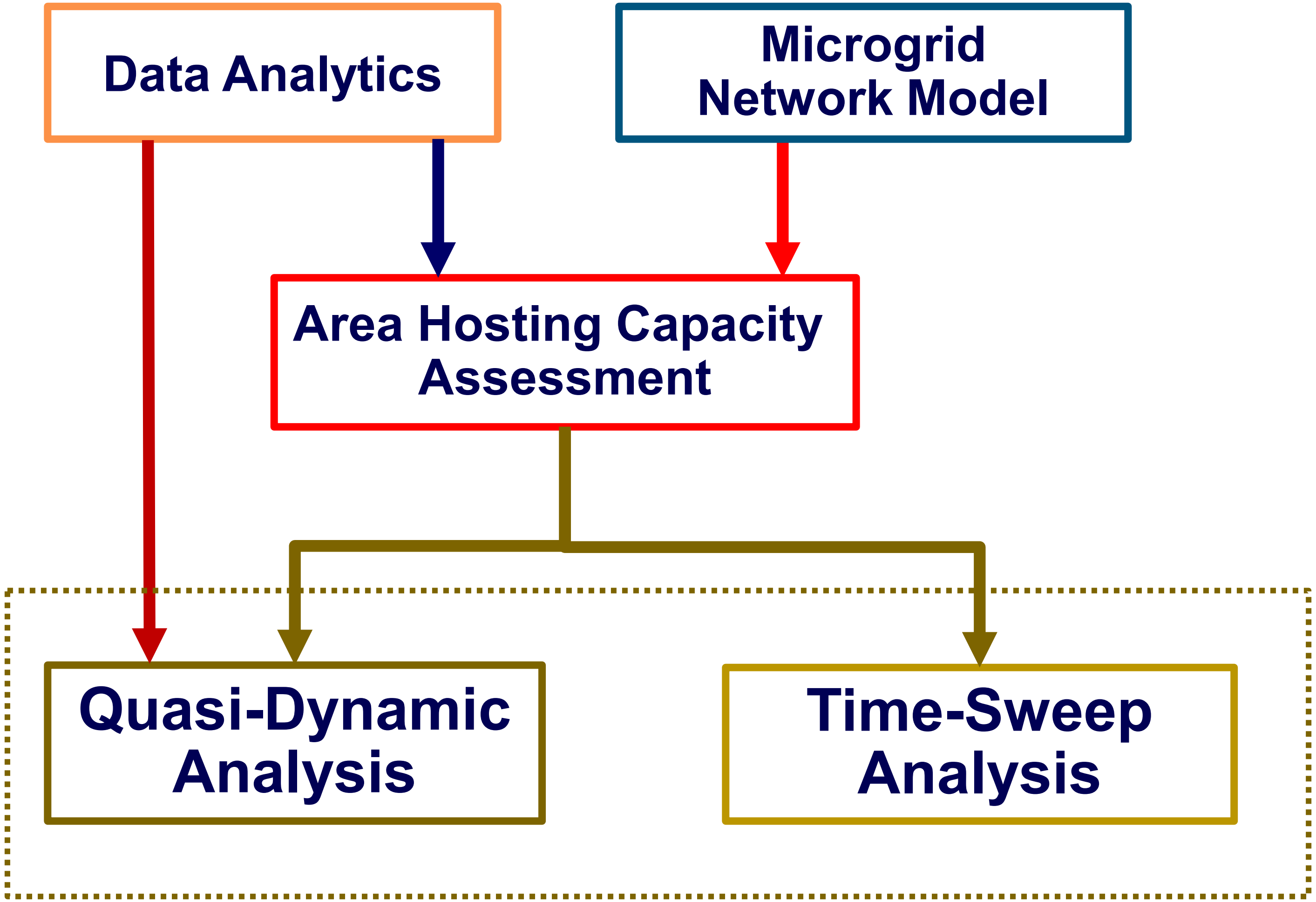
Donald & Tarnagulla Microgrid Operation Analysis

Dr Arash Vahidnia

RMIT UNIVERSITY

ver.1.0

Methodology



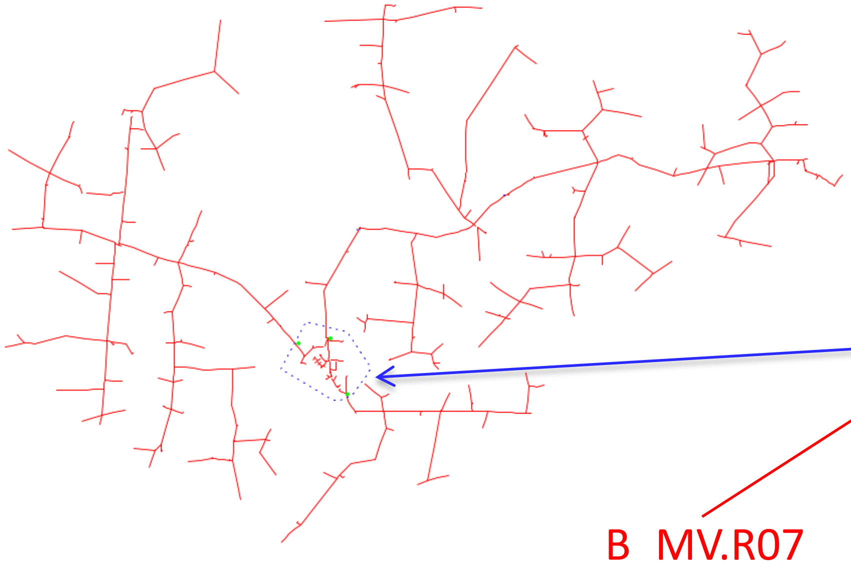
Task 3: Analysing the Autonomous and Semi-autonomous Microgrid Operation

Donald Time Sweep Scenarios

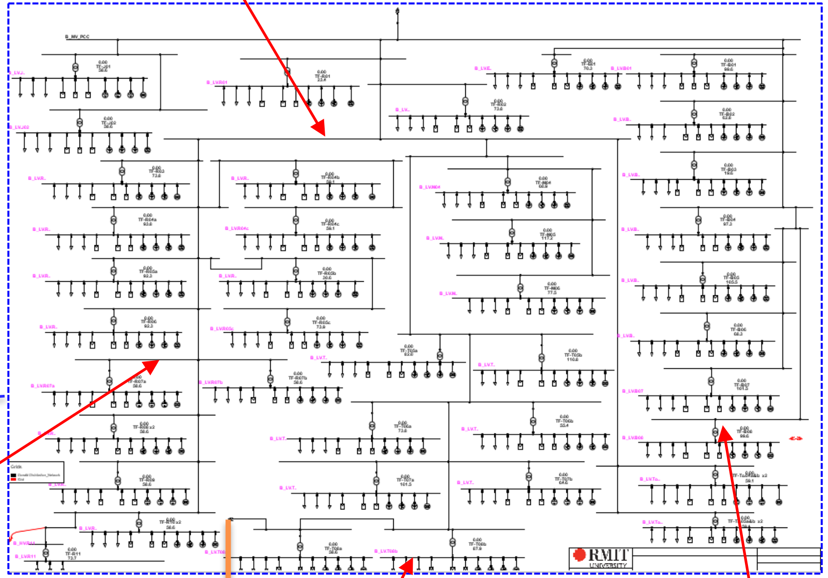
Integration Scenario	Total Load (KW)	Load Variation	Total PV (KW)	PV Variation	Total Battery Inveter (KW)	Battery Variation	Backup Generator
1	2949.6	0-130%	0		0		
2	2949.6		3216	0-130%	0		
3	2949.6		0		1639 (c)	0-130%	
4	2949.6		0		1639 (d)	0-130%	
5	1172		3216	0-130%	0		
6	1172		3216	0-130%	1639 (c)		
7	1172		3216	0-130%	1639 (d)		
8	2949.6		3216	0-130%	1639 (c)		
9	2949.6		3216	0-130%	1639 (d)		
10	2949.6		3507	0-130%	1716 (c)		
11	2949.6		3507	0-130%	1716 (d)		
12	1172		3507	0-130%	1716 (c)		
13	1172		3507	0-130%	1716 (d)		
14	2949.6		3507	0-130%	4516 (d)		
15	2949.6	0-130%	0		0		2800 kW
16	2949.6		3216	0-130%	0		2800 kW
17	2949.6		3216	0-130%	1639 (c)		2800 kW
18	2949.6		3216	0-130%	1639 (d)		2800 kW

Donald Network Model with Charlton-Donald Supply Feeder

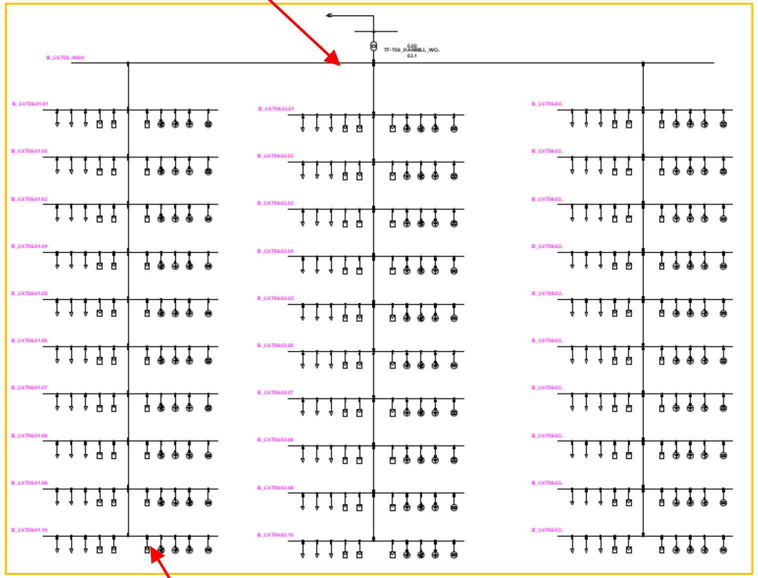
Combined Model



Donald Feeder Model in PF
(imported from SINCAL)



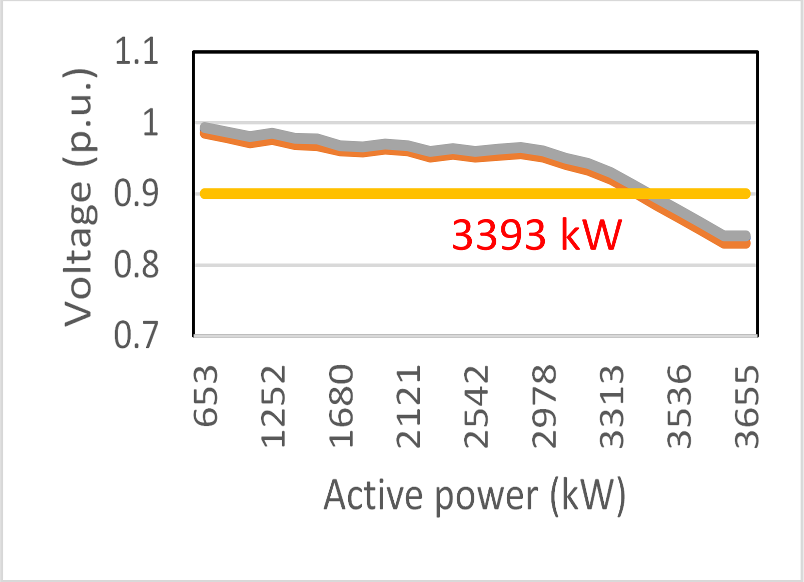
Donald MV Network Model

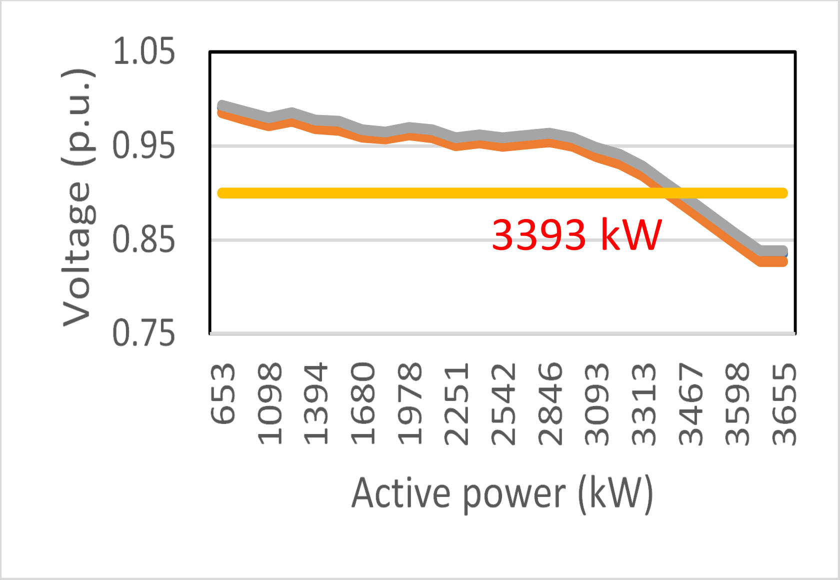


LV Substation Model - Typical

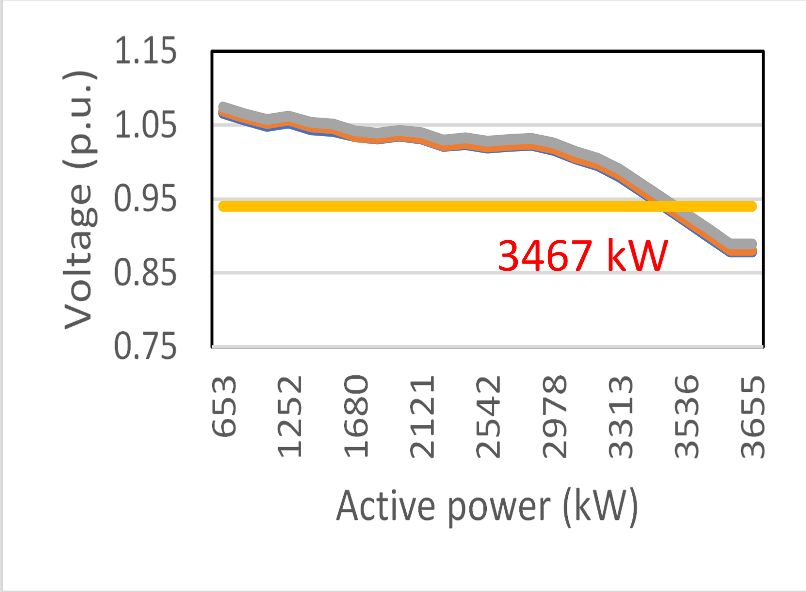
Donald Town Microgrid: Hosting Capacities

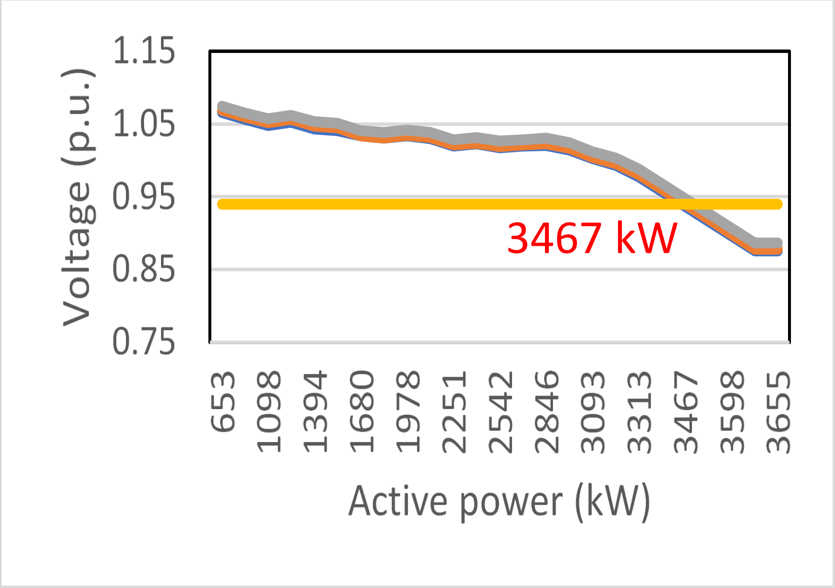
MV





LV





Metric	**Magnitude**	**Variation**
Load (kW) at 0.85 pf	**2949.6**	**0-130%**
PV (kW)	**0**	
Battery (kW)	**0**	
Base Case		**1**

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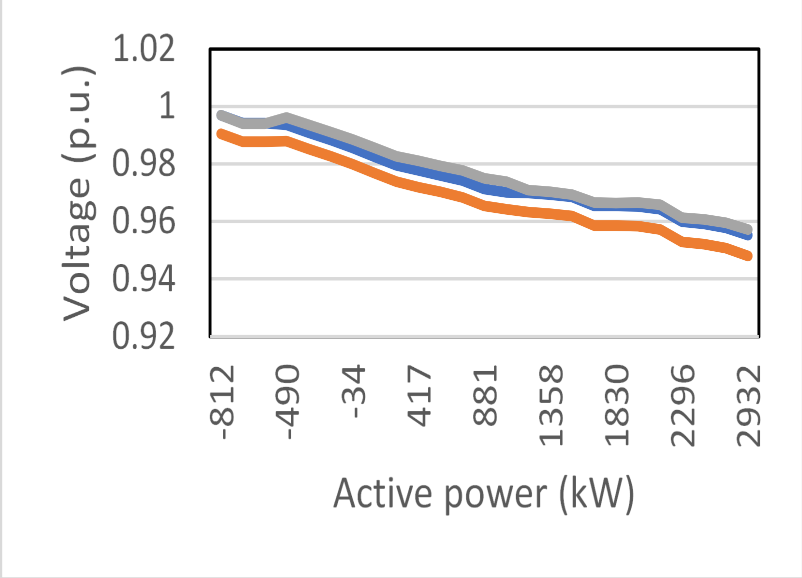
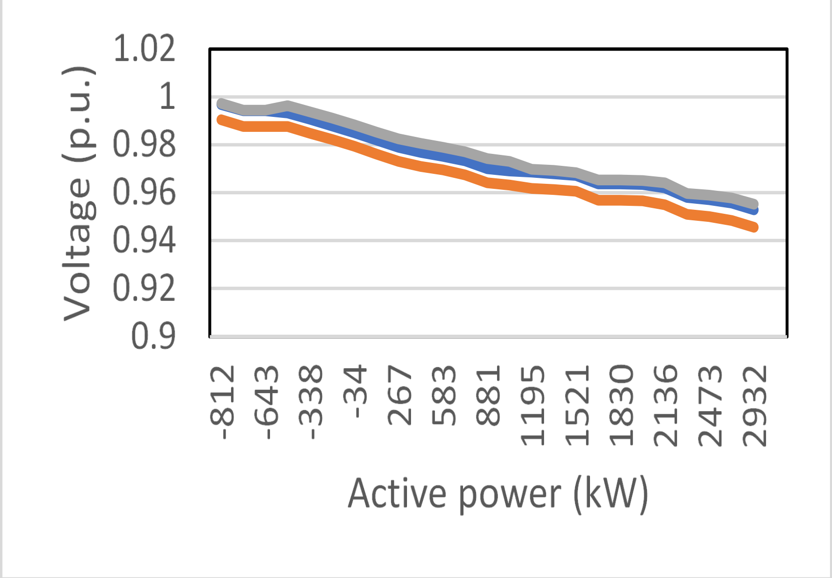
Donald Town Microgrid: Hosting Capacities

MV





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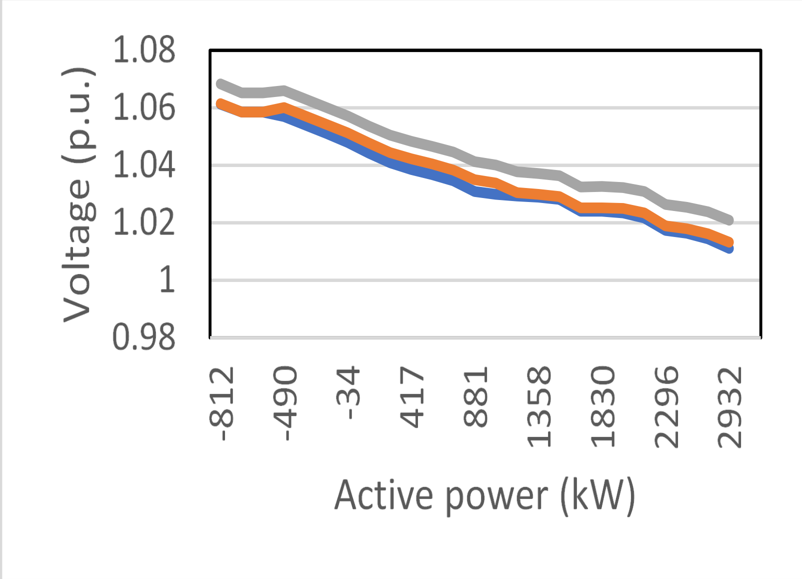
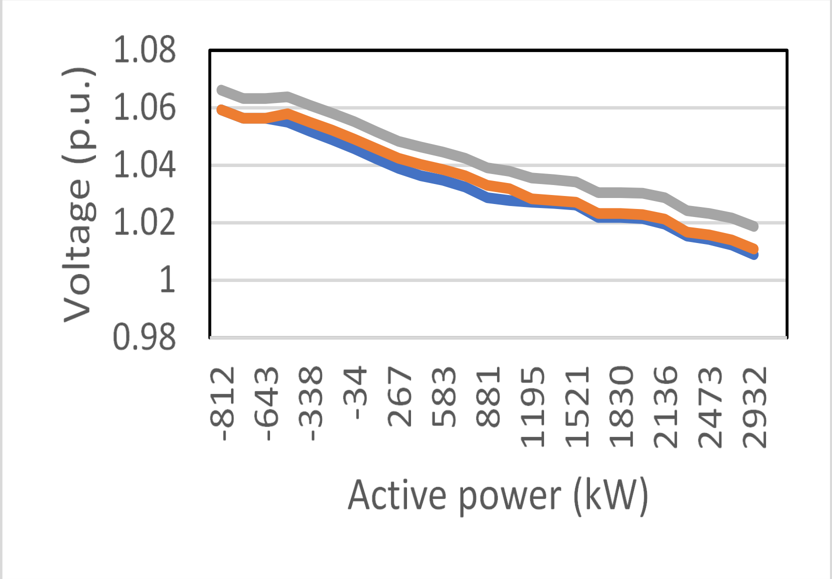
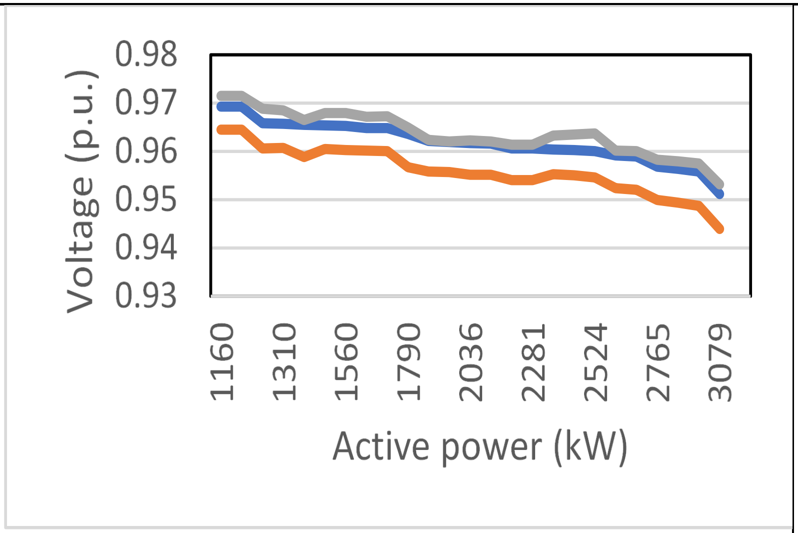


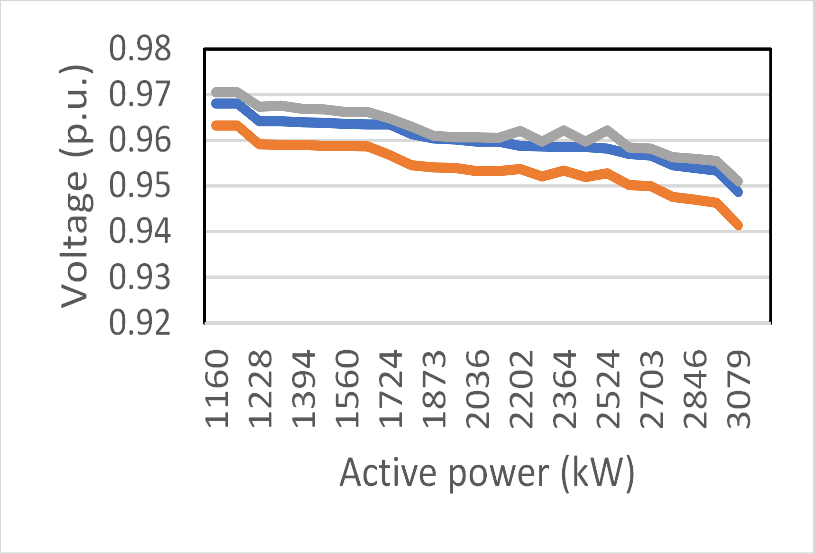


Metric	Magnitude	Variation
Load (kW)	2949.6	
PV (kW)	3216	0-130%
Battery (kW)	0	
Base Case		2

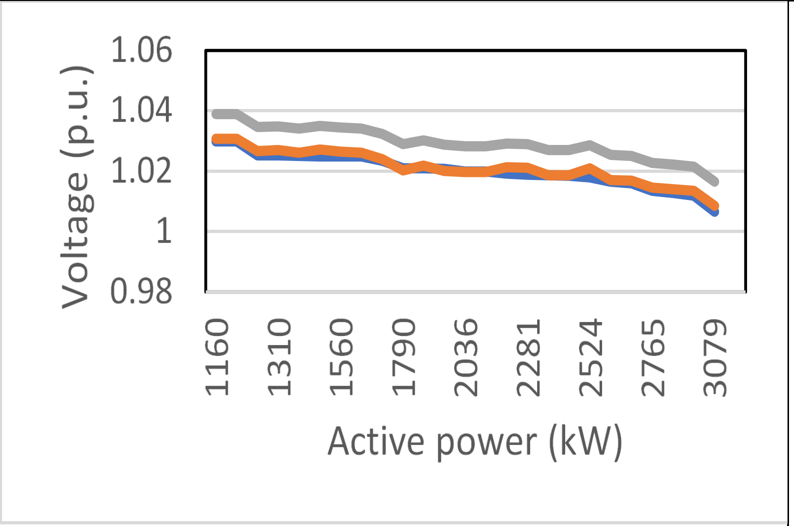
Donald Town Microgrid: Hosting Capacities

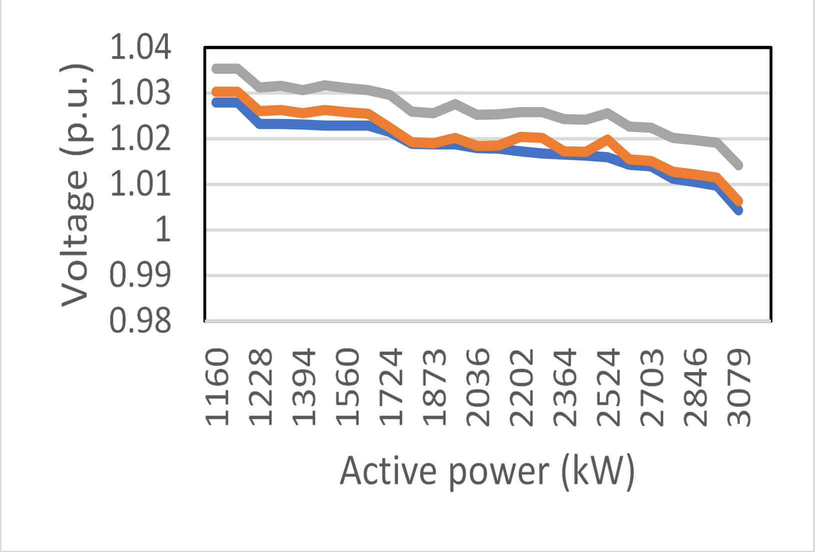
MV





LV

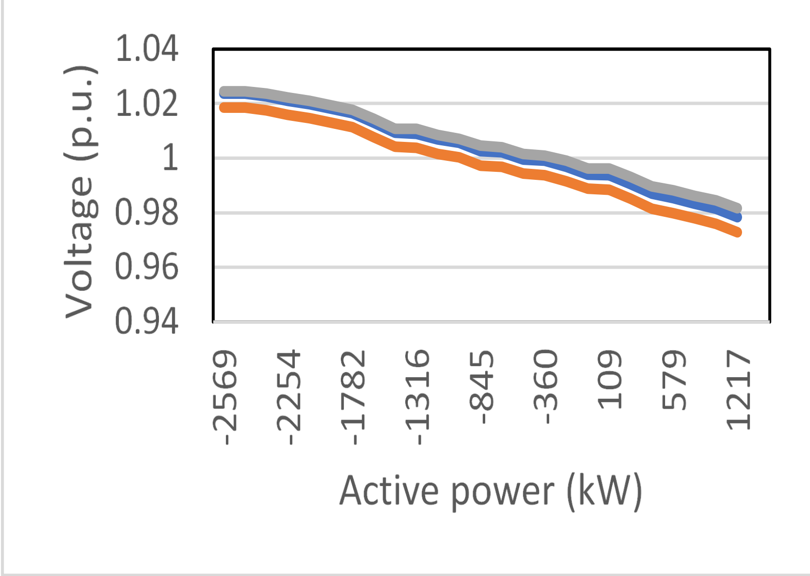


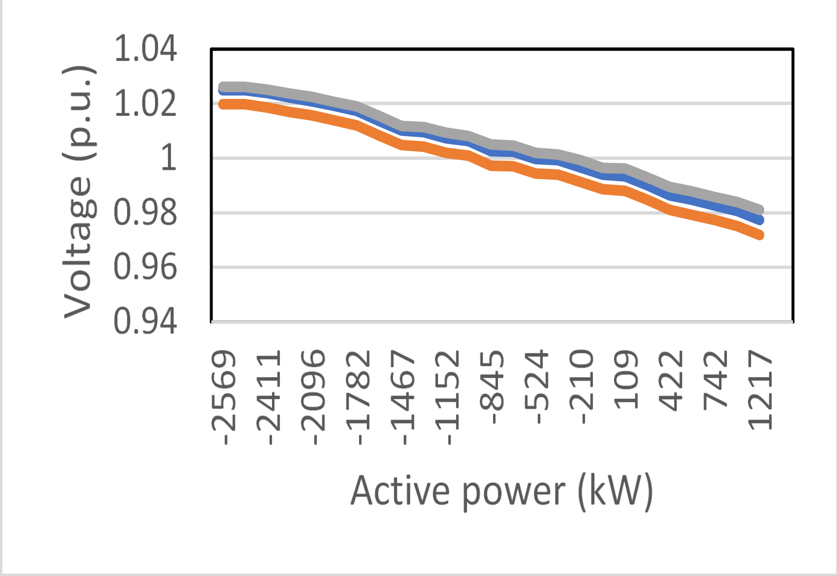


Metric	Magnitude	Variation
Load (kW)	2949.6	
PV (kW)	0	
Battery (kW)	1639 (d)	0-130%
Base Case		4

Donald Town Microgrid: Hosting Capacities

MV





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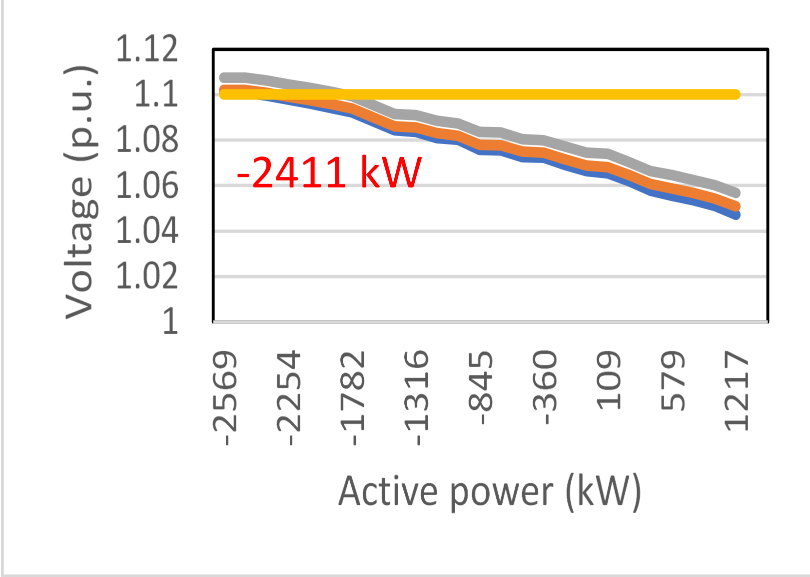
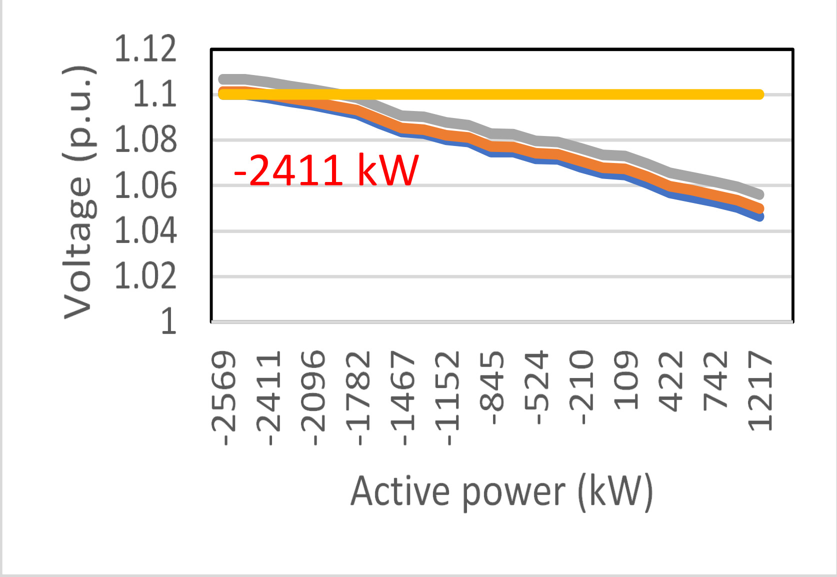
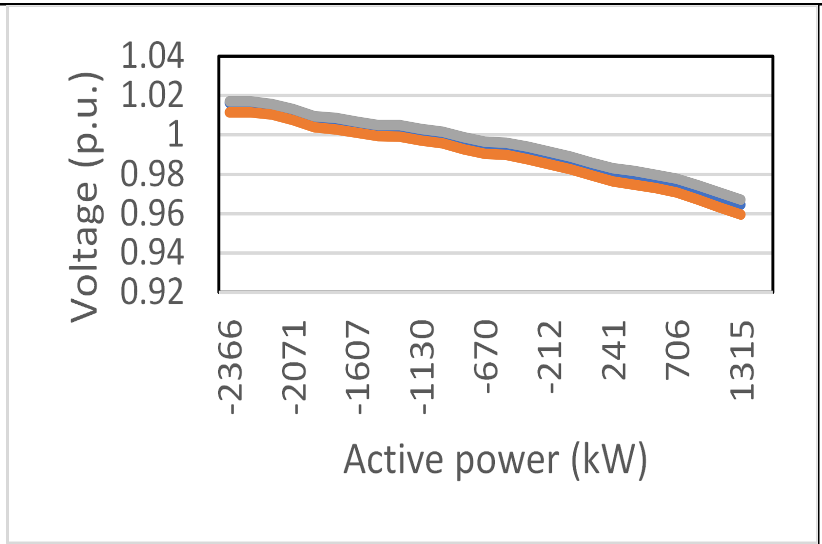


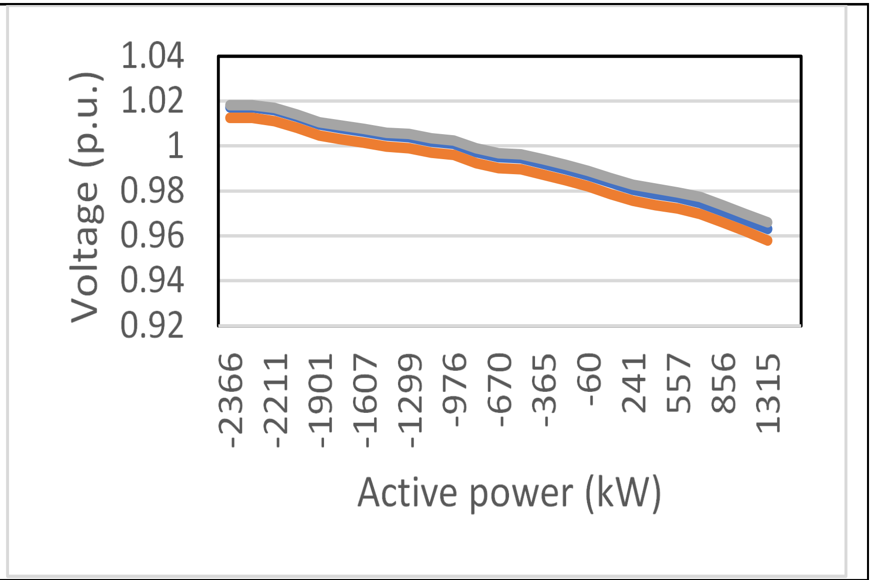


Metric	Magnitude	Variation
Load (kW)	1172	
PV (kW)	3216	0-130
Battery (kW)		
Base Case		5

Donald Town Microgrid: Hosting Capacities

MV





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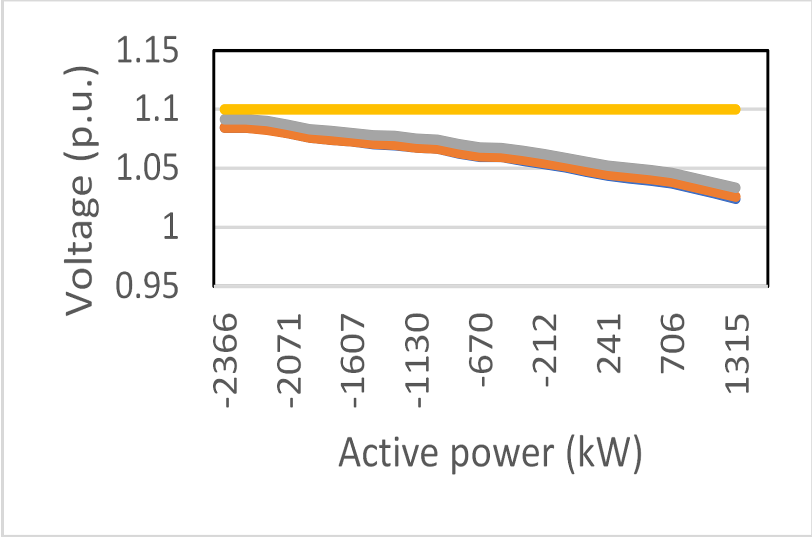
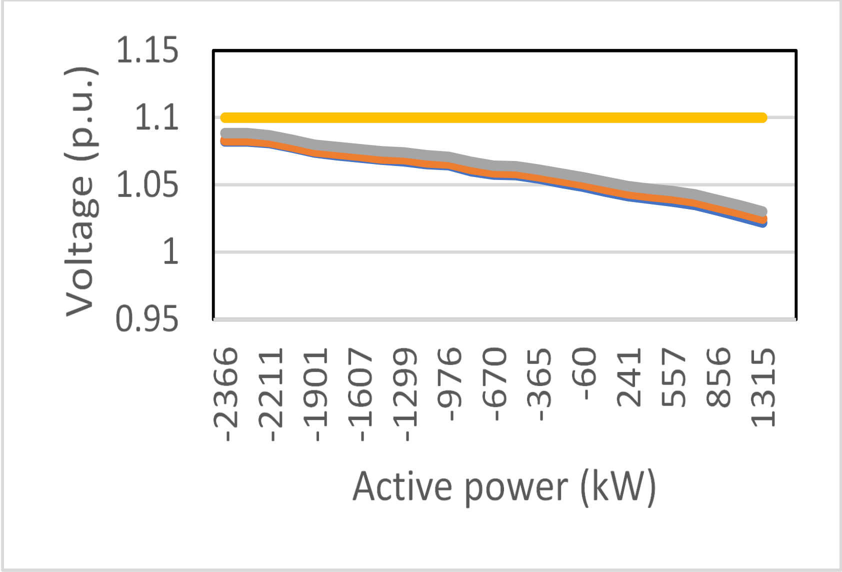
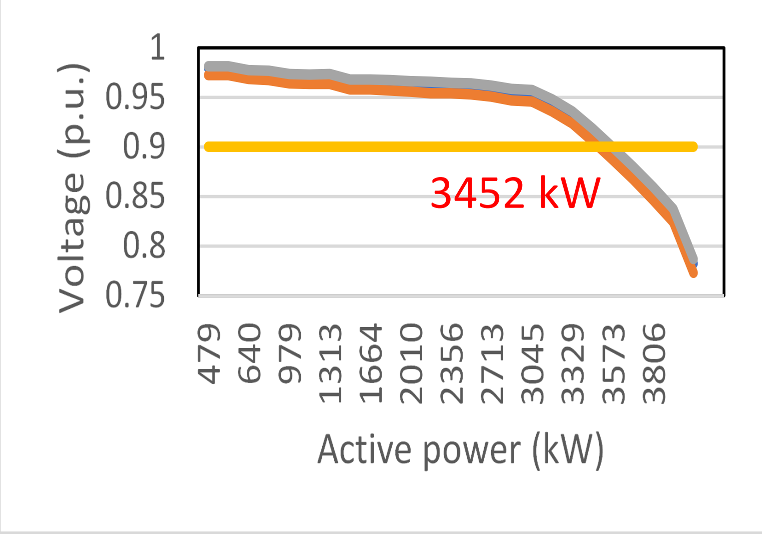


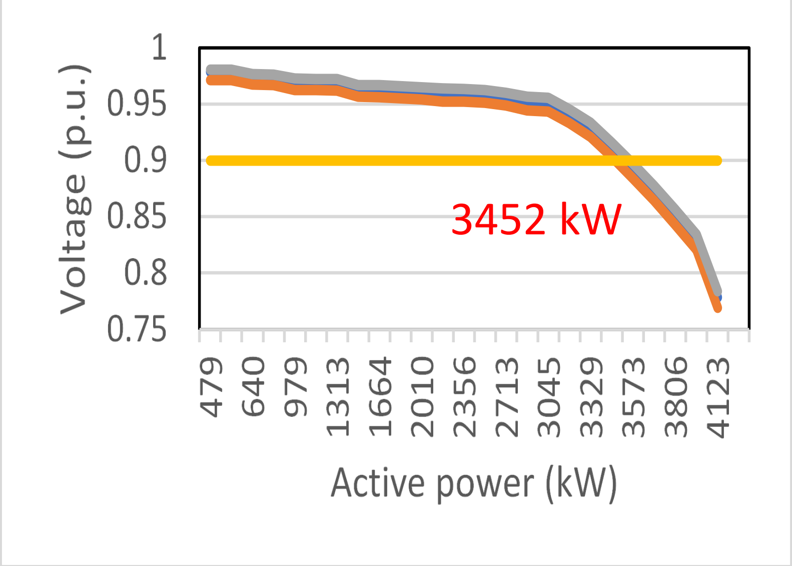


Metric	Magnitude	Variation
Load (kW)	**2946**	
PV (kW)	**3216**	**0-130%**
Battery (kW)	**1639 (d)**	
Case		**9**

Donald Town Microgrid: Hosting Capacities

MV





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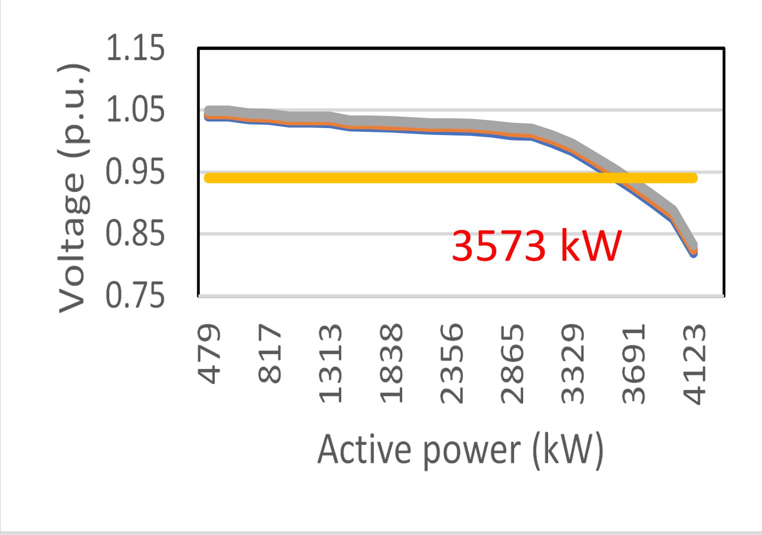

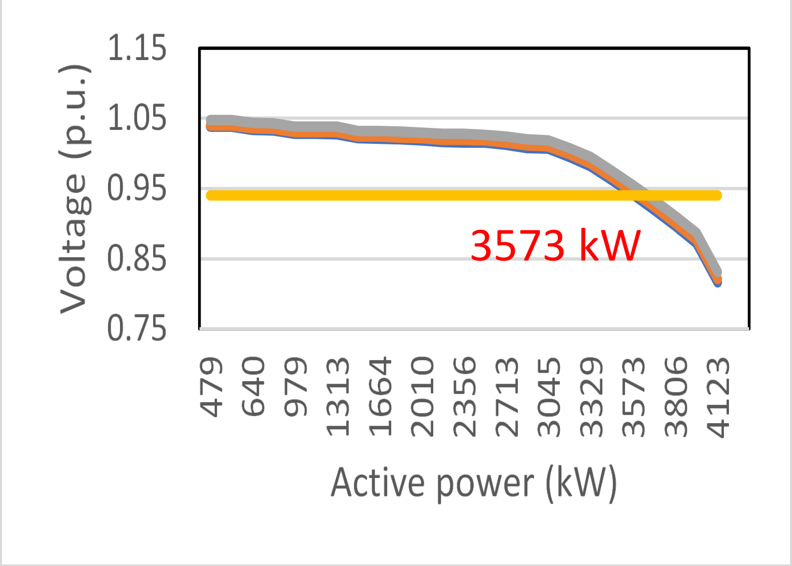

Metric	Magnitude	Variation
Load (kW) at 0.85 pf	**2946.6**	
PV (kW)	**3507**	**0-130%**
Battery (kW)	**1716 (c)**	
Case		**10**

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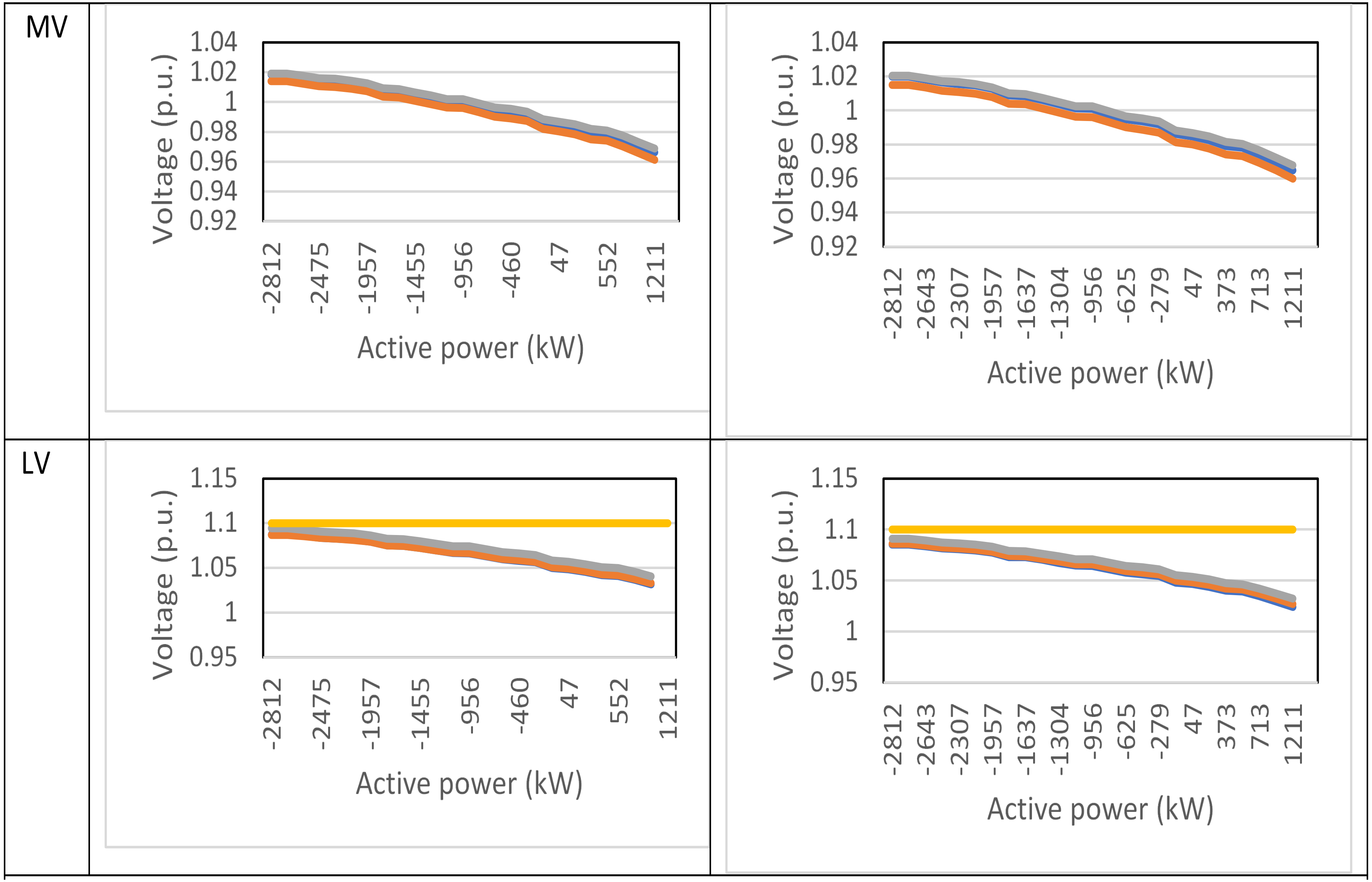
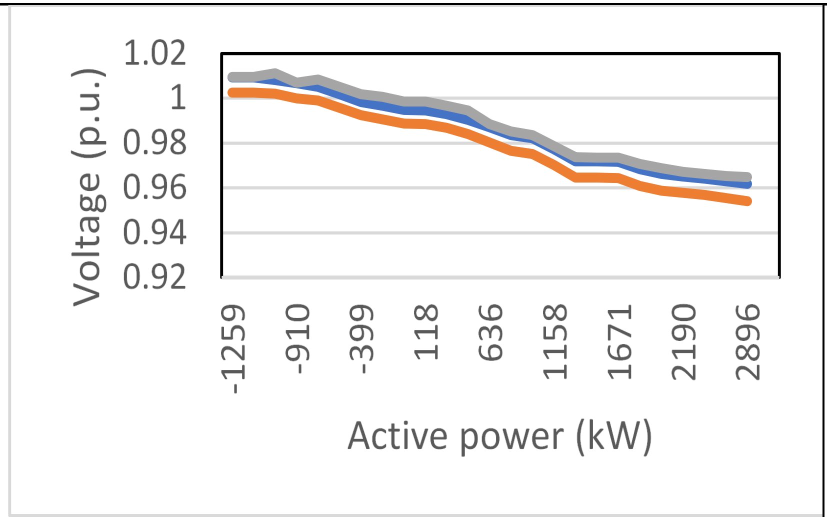
Donald Town Microgrid: Hosting Capacities

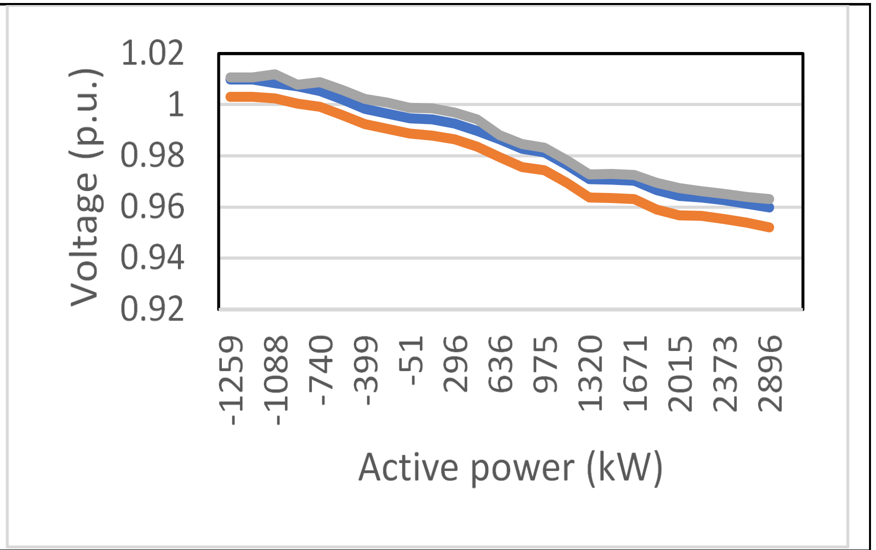


Metric	Magnitude	Variation
Load (kW) at 0.85 pf	**1172**	
PV (kW)	**3507**	**0-130%**
Battery (kW)	**1716 (d)**	
Case		**11**

Donald Town Microgrid: Hosting Capacities

MV





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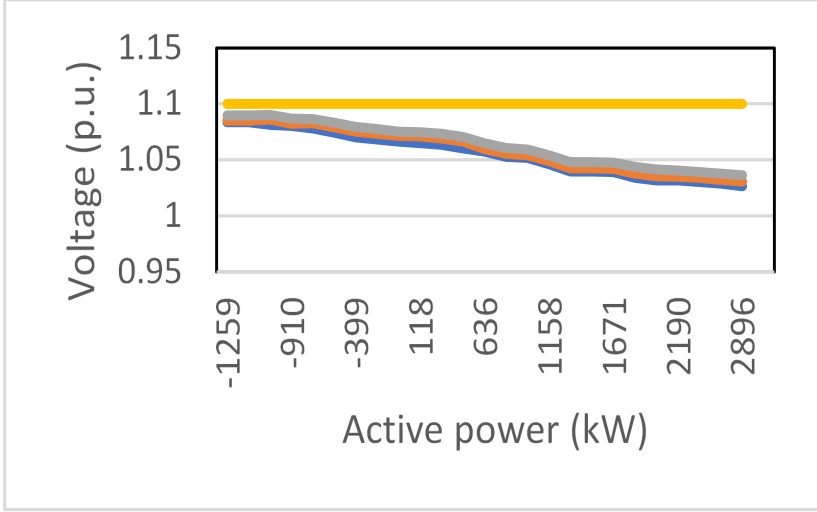
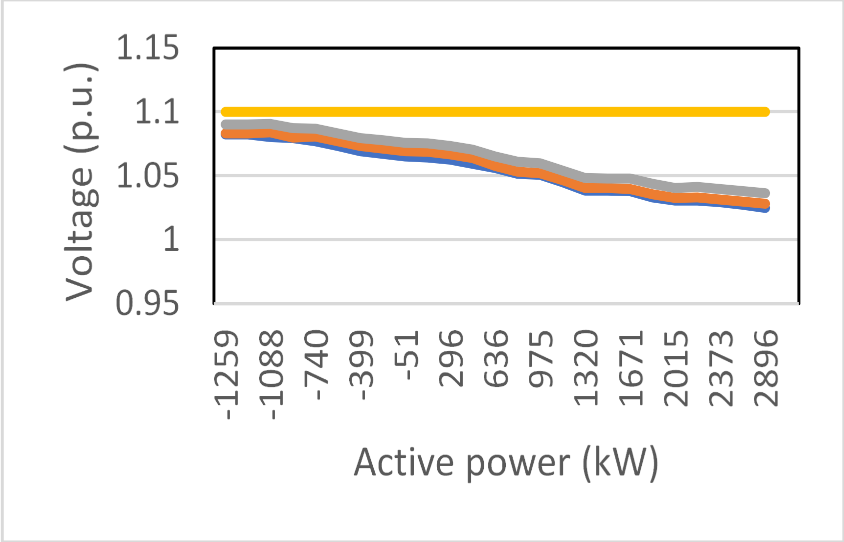
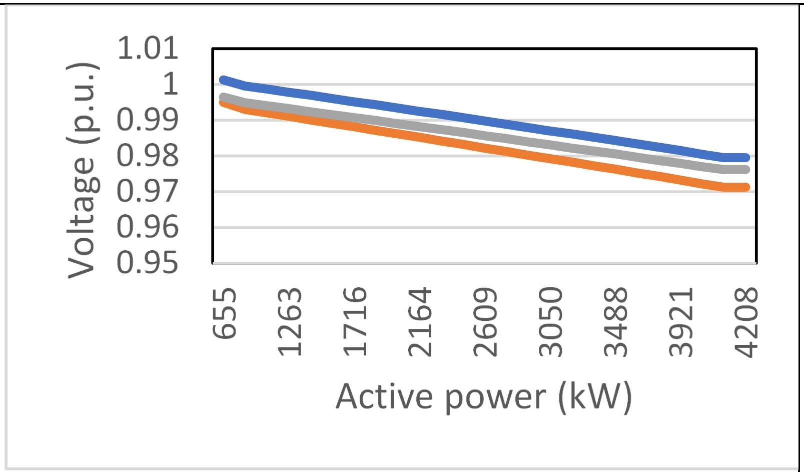


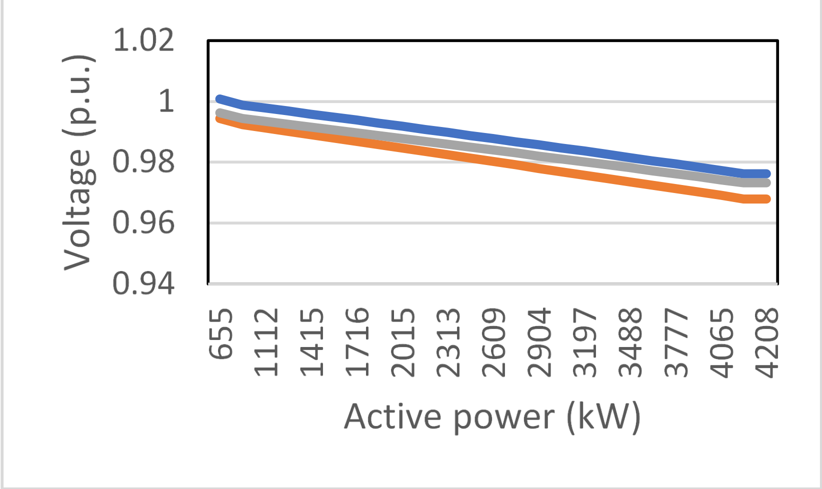


Metric	Magnitude	Variation
Load (kW) at 0.85 pf	**1172**	
PV (kW)	**3507**	**0-130%**
Battery (kW)	**1716 (c)**	
Case		**12**

Donald Town Microgrid: Hosting Capacities

MV





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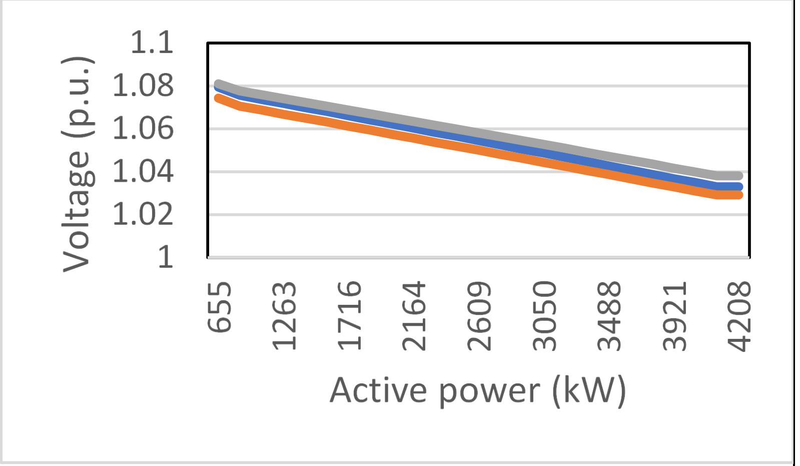
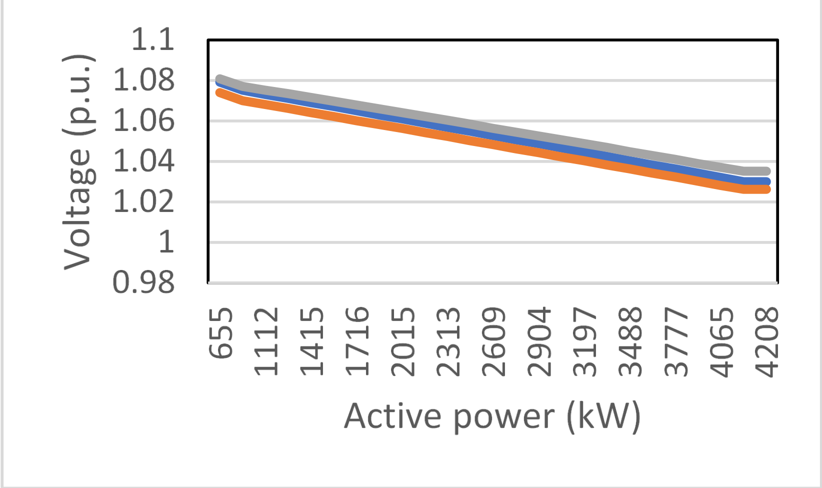


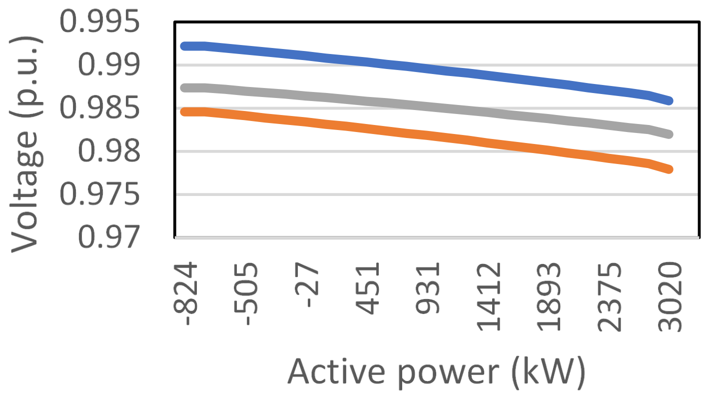


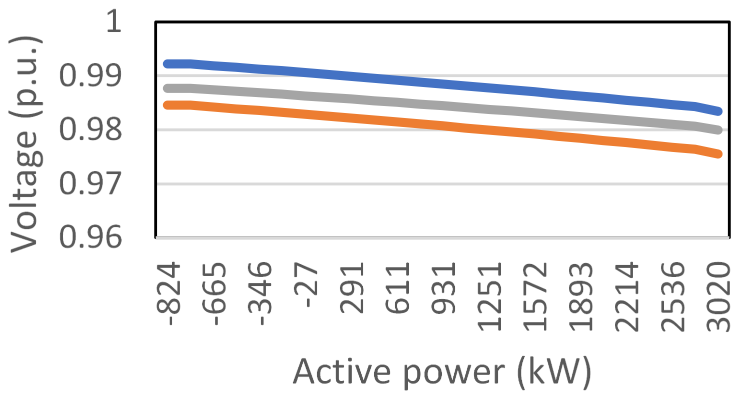
Backup generator 2800 kW

Metric	Magnitude	Variation
Load (kW) at 0.85 pf	**2949.6**	**0-130%**
PV (kW)		
Battery (kW)		
Case		**15**

Donald Town Microgrid: Hosting Capacities

MV





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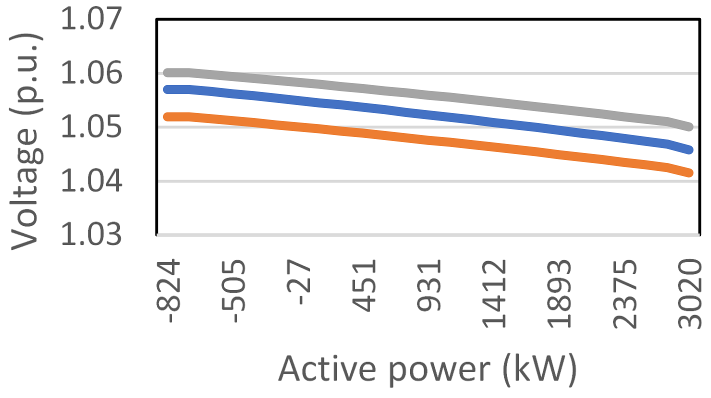
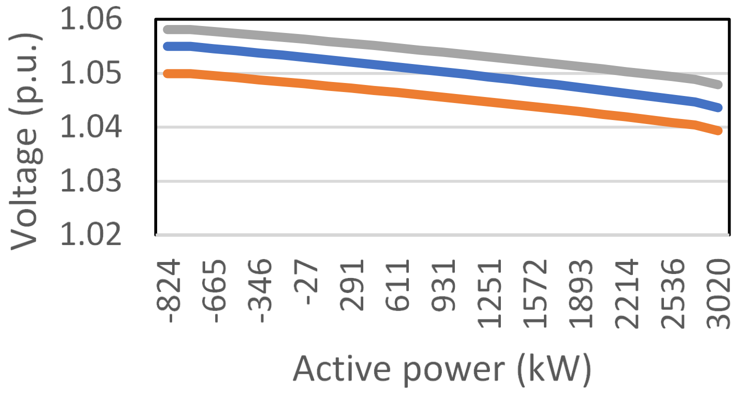


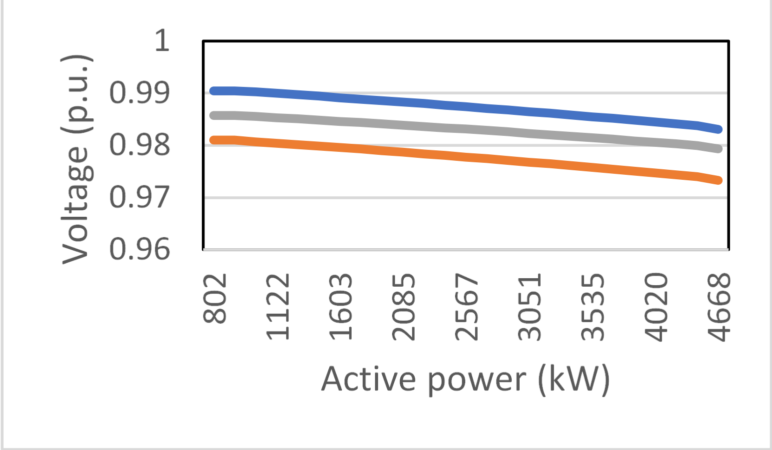


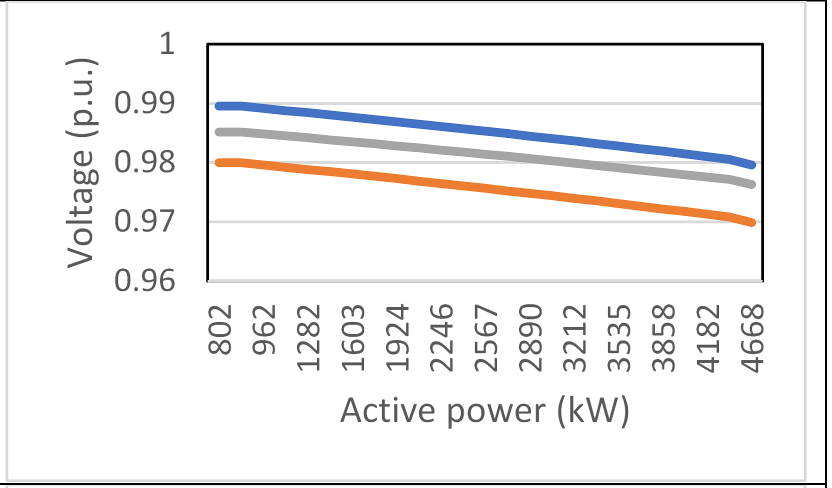
Backup generator 2800 kW

Metric	Magnitude	Variation
Load (kW) at 0.85 pf	2949.6	
PV (kW)	3216	0-130%
Battery (kW)		
Case		16

Donald Town Microgrid: Hosting Capacities

MV





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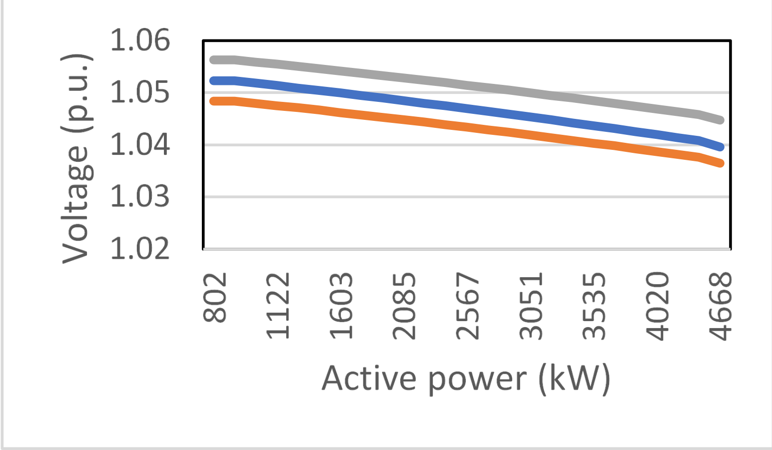
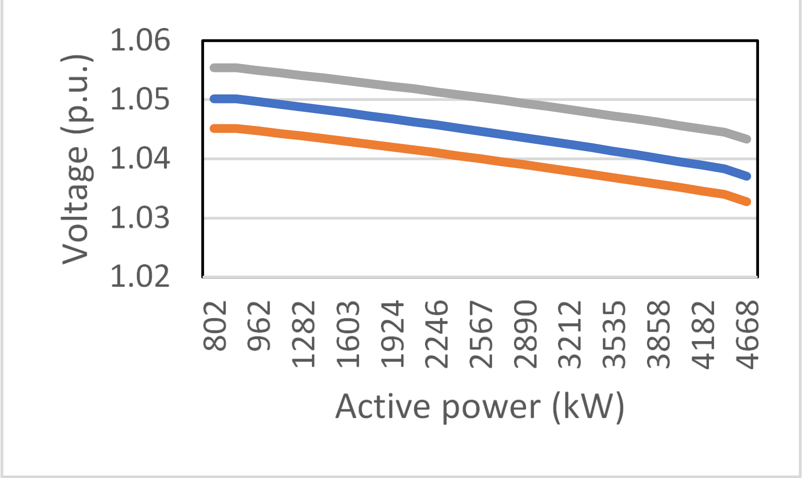
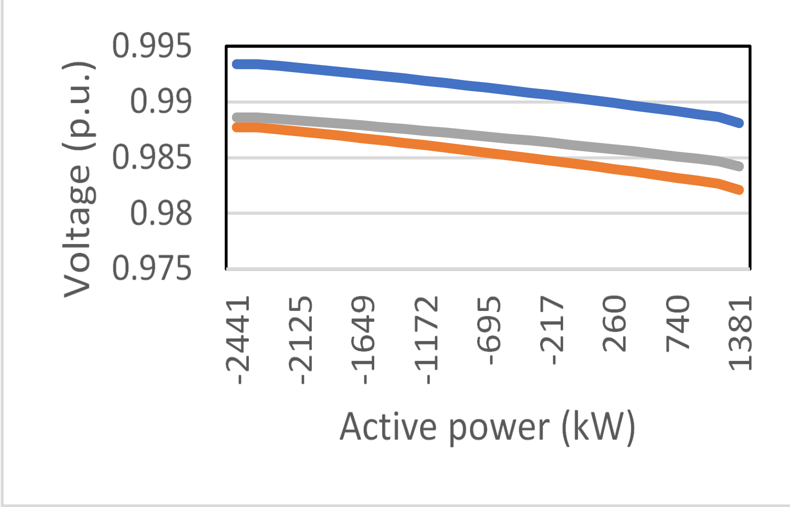
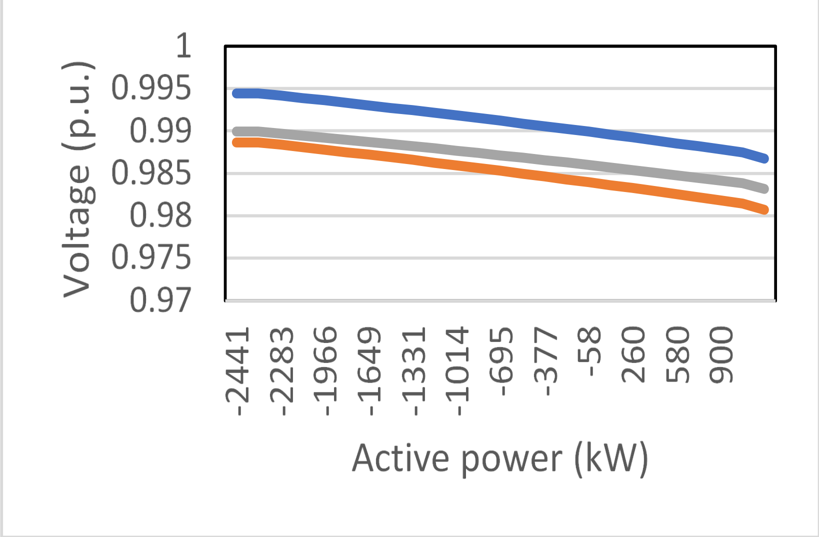
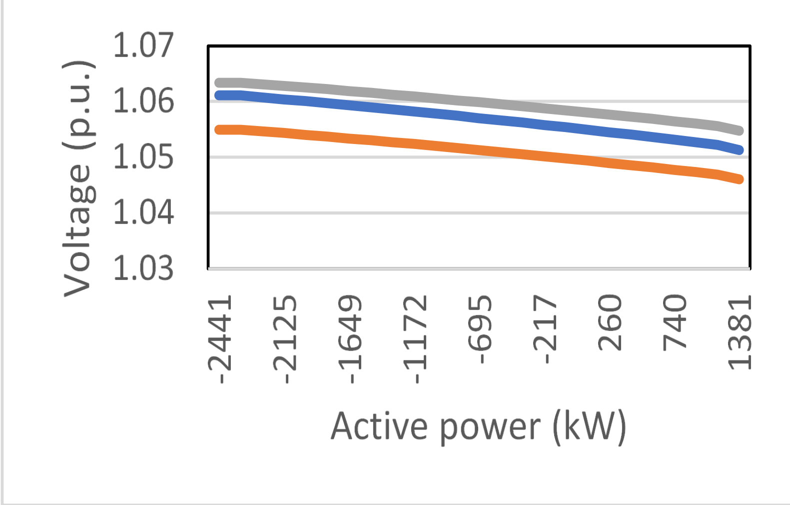
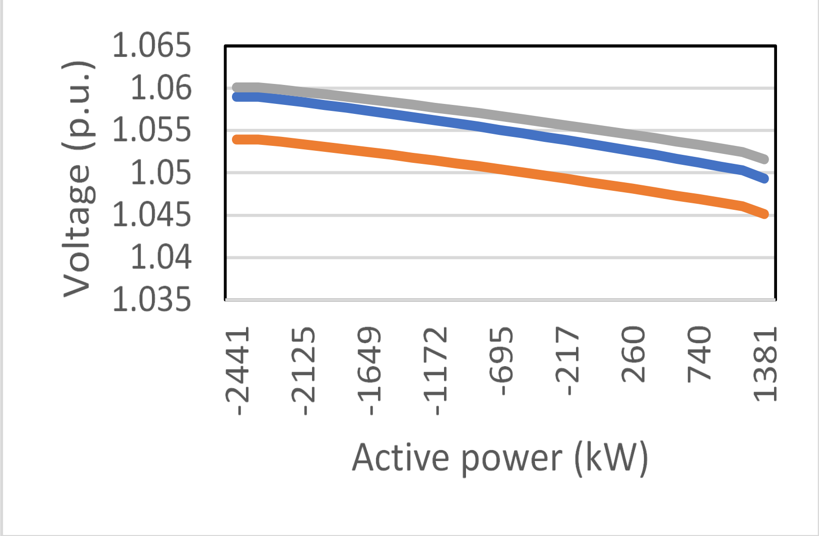




Backup generator 2800 kW

Metric	Magnitude	Variation
Load (kW) at 0.85 pf	**2949.6**	
PV (kW)	**3216**	**0-130%**
Battery (kW)	**1639 (c)**	
Case		**17**

Donald Town Microgrid: Hosting Capacities

MV		
LV		

Backup generator 2800 kW

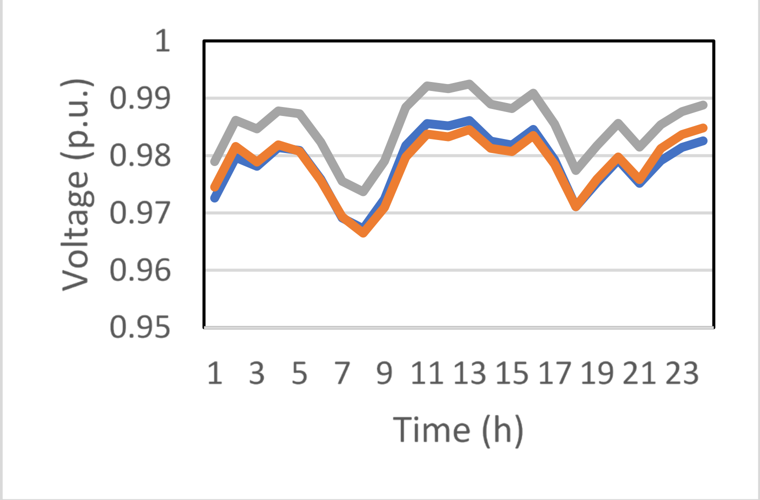
Metric	Magnitude	Variation
Load (kW) at 0.85 pf	**2949.6**	
PV (kW)	**3216**	**0-130%**
Battery (kW)	**1639 (d)**	
Case		**18**

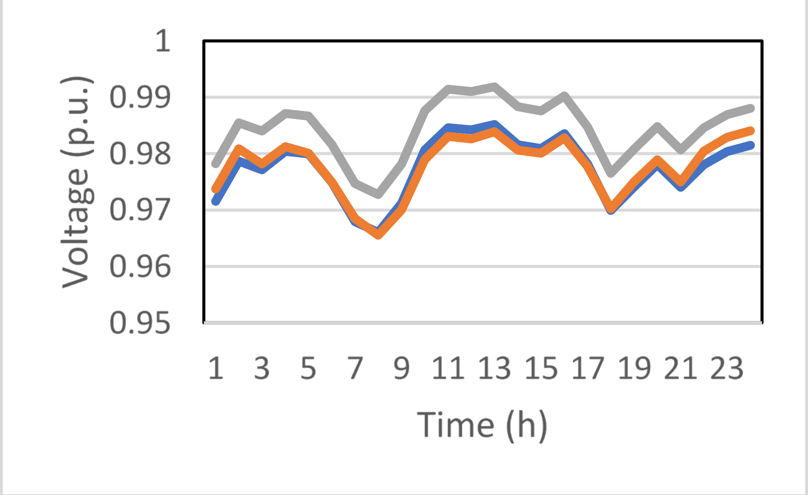
Donald Quasi–Dynamic Scenarios

Operational Scenario	Maximum Load (KW)	Maximum PV (KW)	Maximum Battery Inveter (KW)	Temperature Zone
1	1172	0	0	15 degrees
2	1172	3216	0	15 degrees
3	1172	3216	1639 (c & d)	15 degrees
4	2949.6	0	0	15 degrees
5	2949.6	3216	0	15 degrees
6	2949.6	3216	1639 (c & d)	15 degrees
7	1172	0	0	40 degrees
8	1172	3216	0	40 degrees
9	1172	3216	1639 (c & d)	40 degrees
10	2949.6	0	0	40 degrees
11	2949.6	3216	0	40 degrees
12	2949.6	3216	1639 (c & d)	40 degrees

Donald Town Microgrid: Quasi-dynamic Simulations

MV





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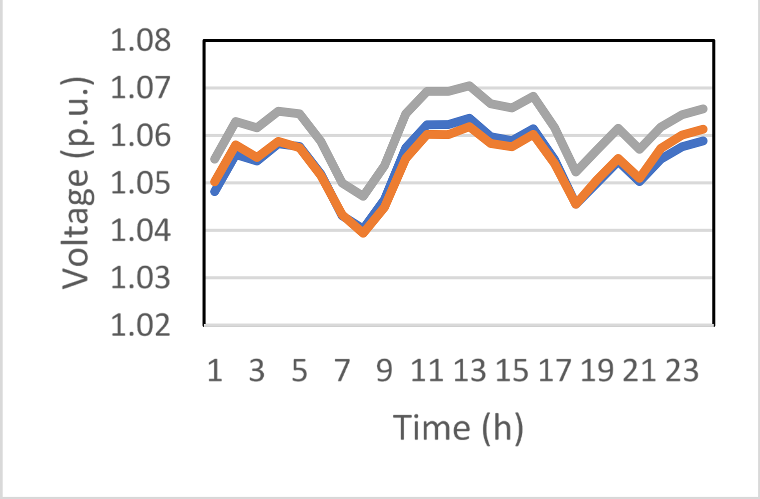
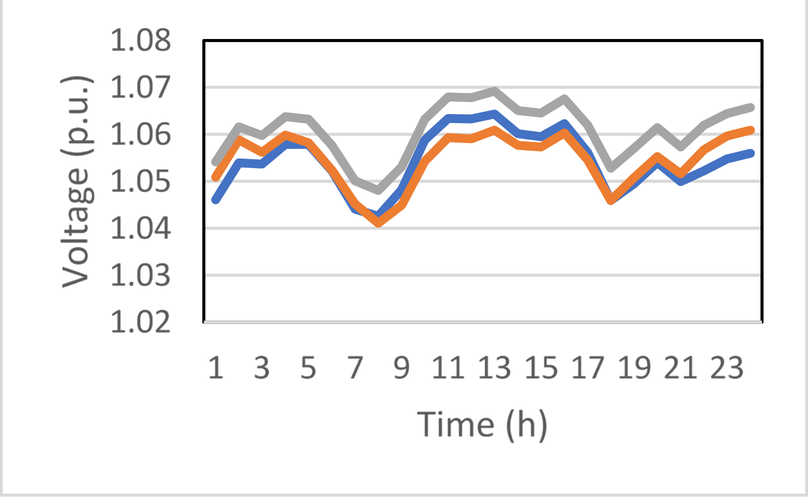
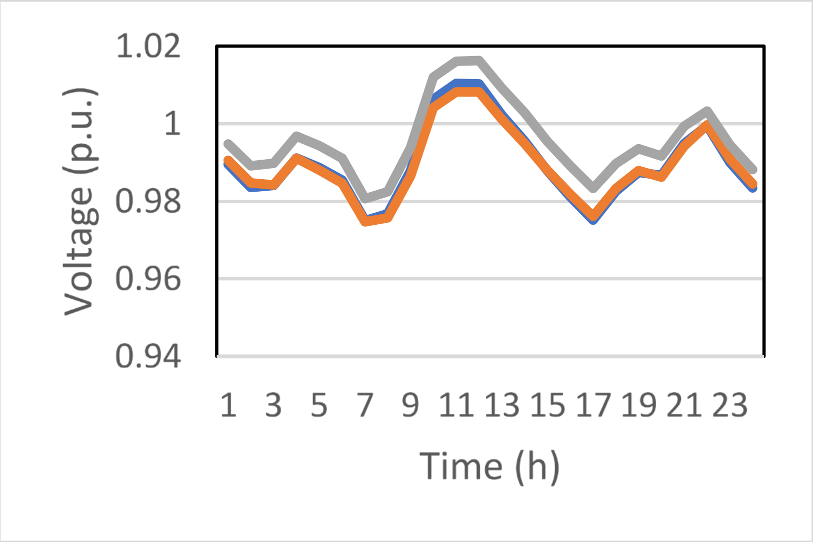
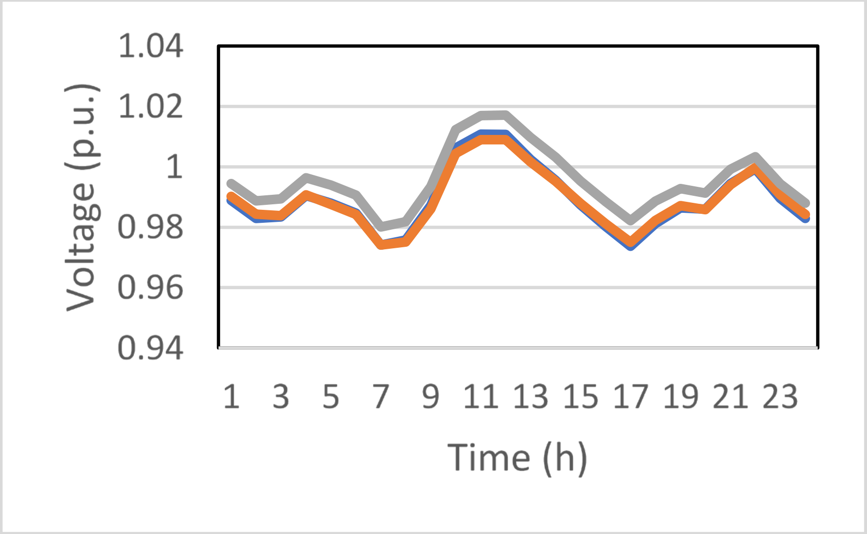
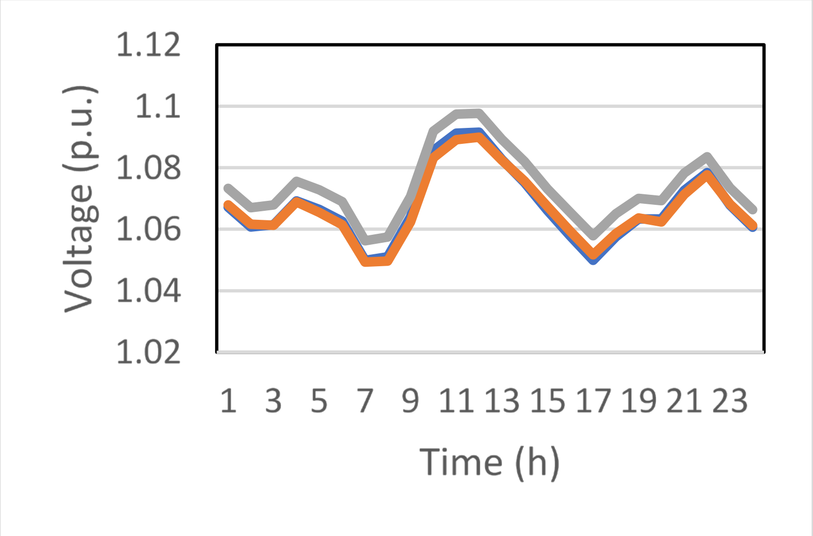
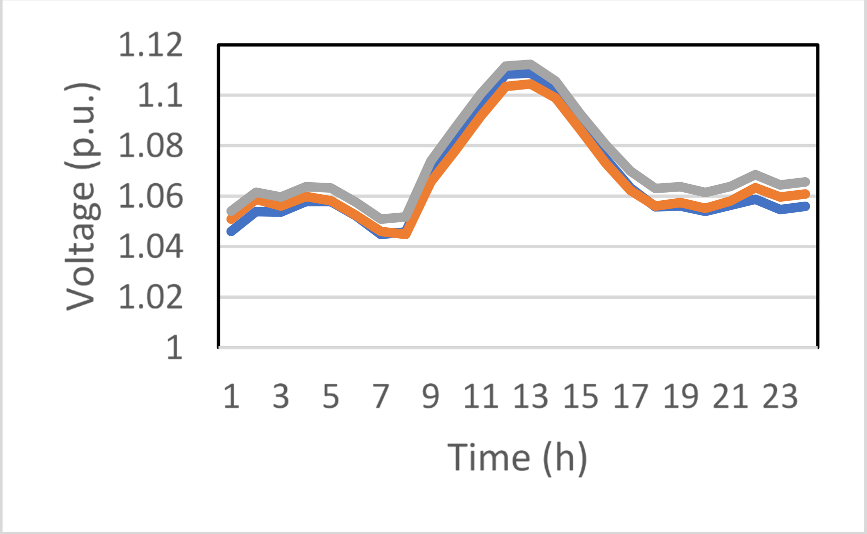




Load	1172 kW
PV	0
BB	0
Temp	15 deg

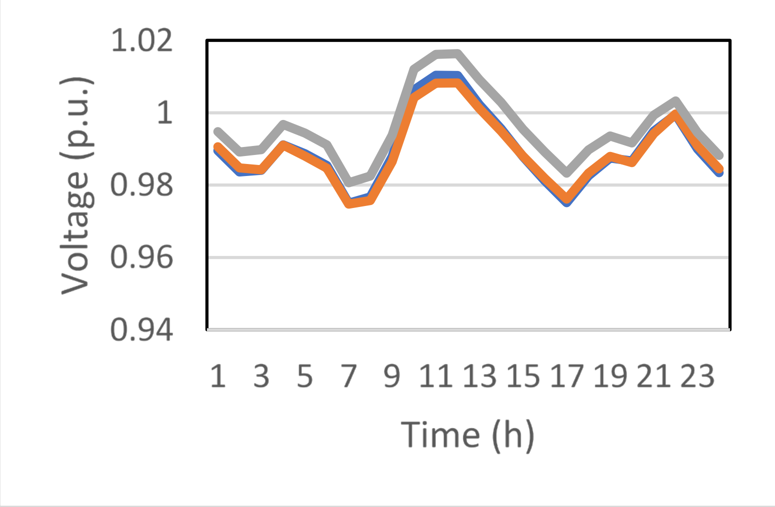
Donald Town Microgrid: Quasi-dynamic Simulations

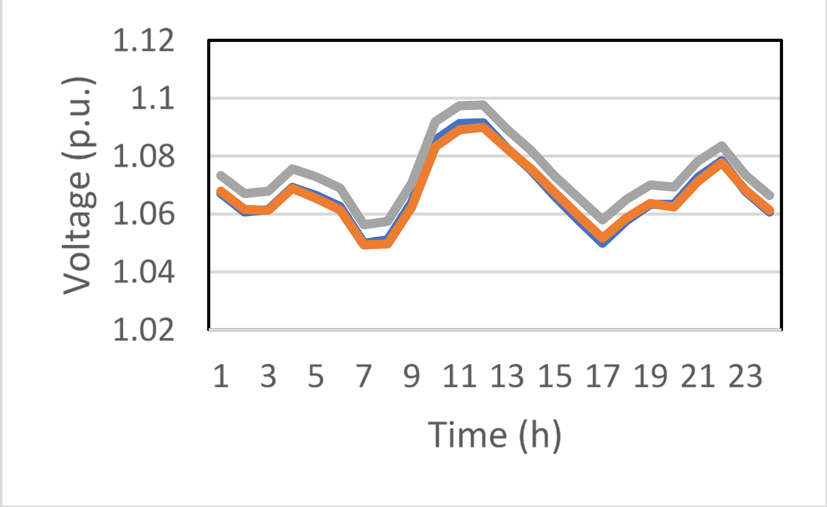
MV		
LV		

Load	1172 kW
PV	3216 kW
BB	0
Temp	15 deg

Donald Town Microgrid: Quasi-dynamic Simulations

MV





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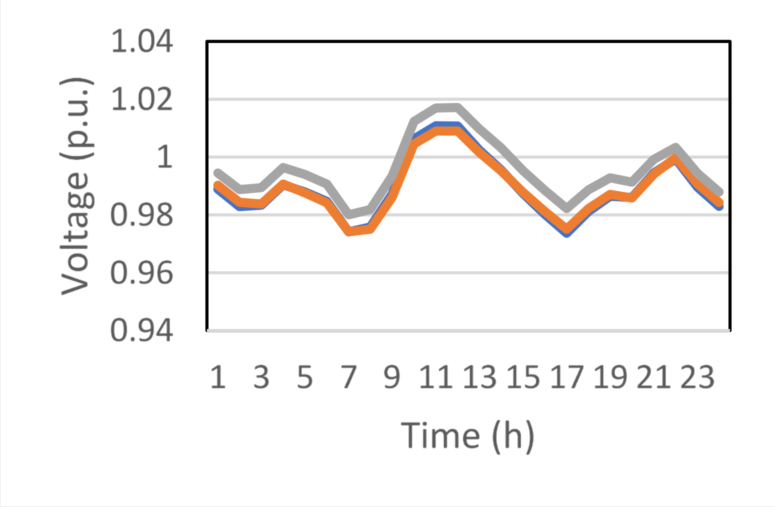
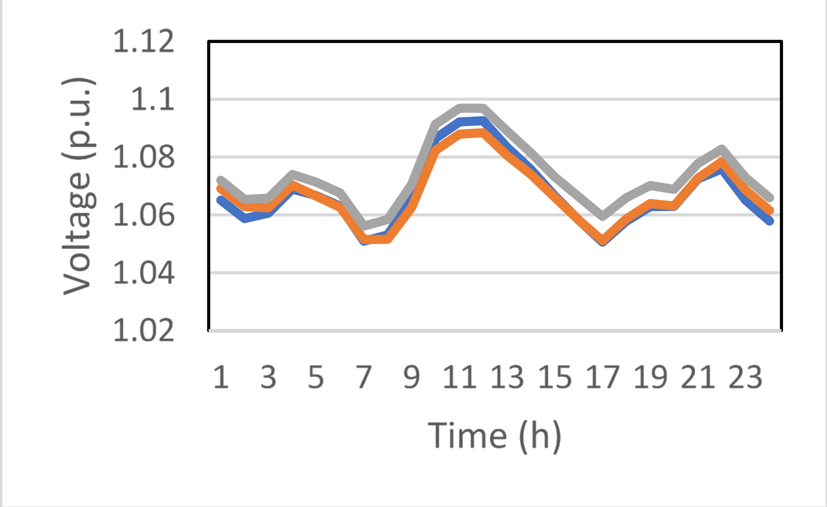
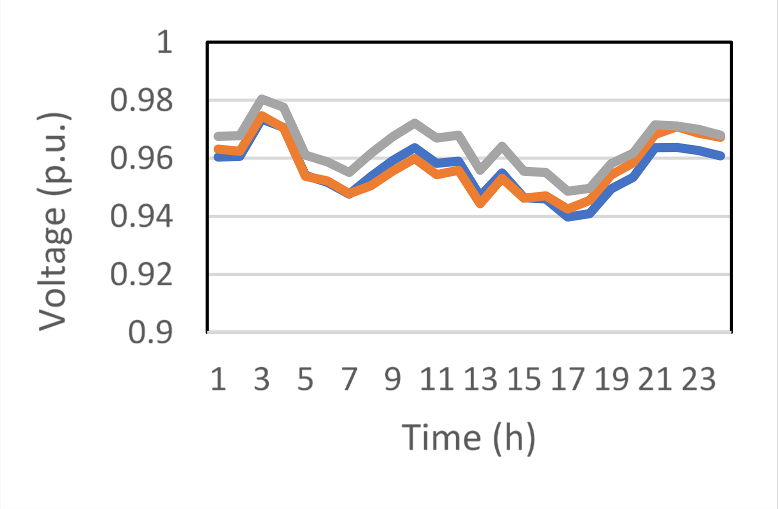


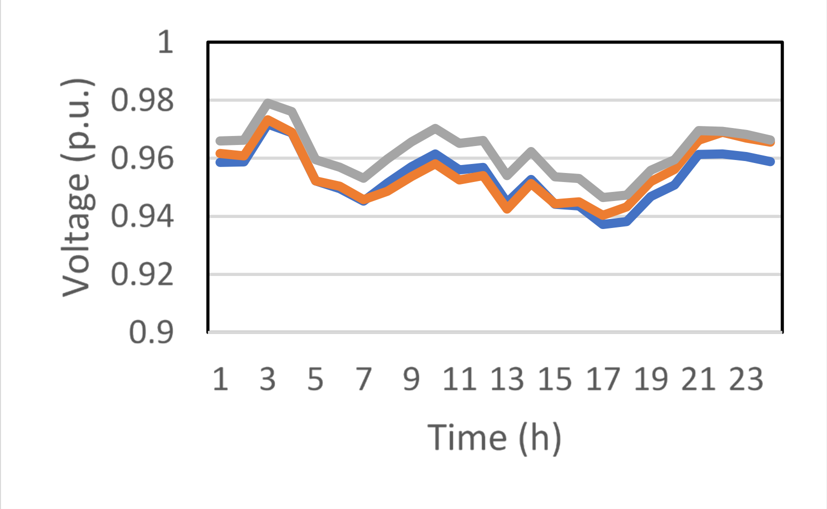


Load	1172 kW
PV	3216 kW
BB	1639 kW (c) & (d)
Temp	15 deg

Donald Town Microgrid: Quasi-dynamic Simulations

MV





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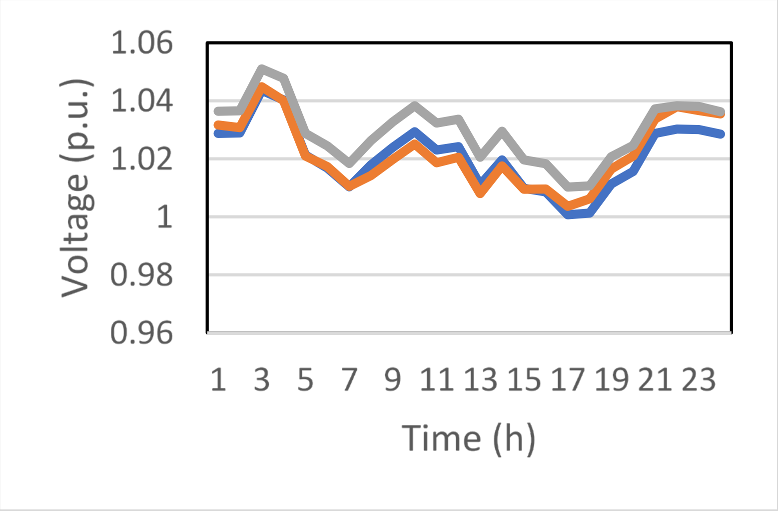
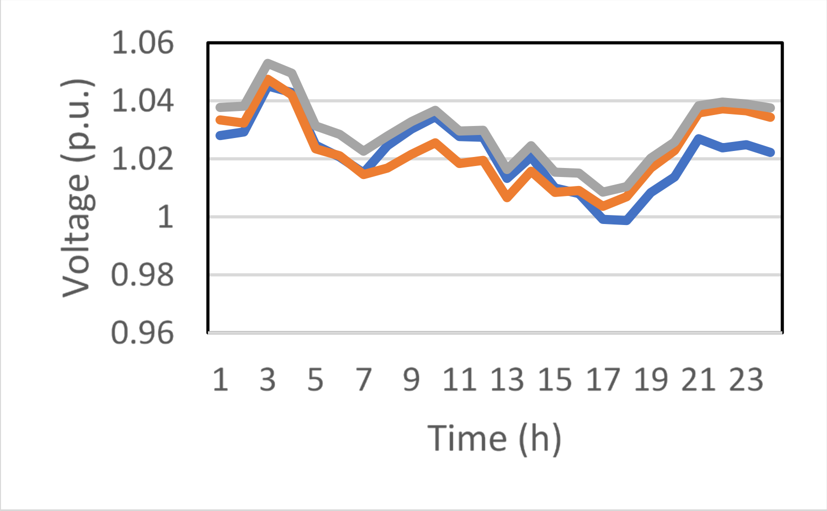
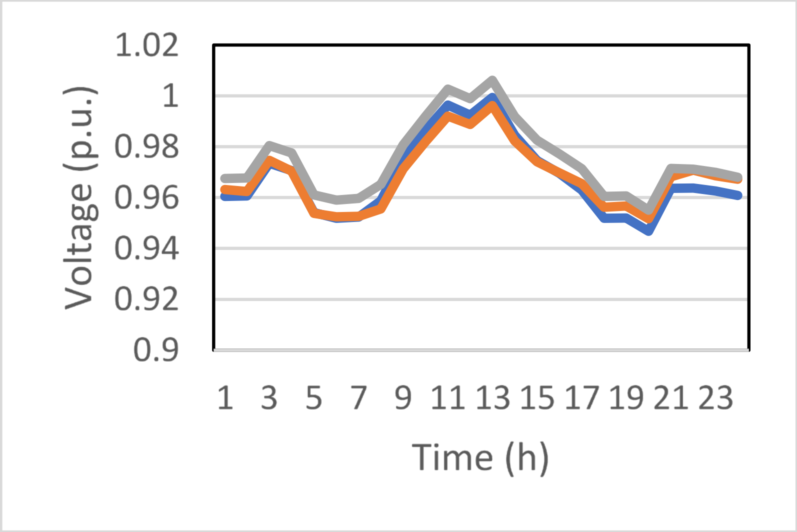


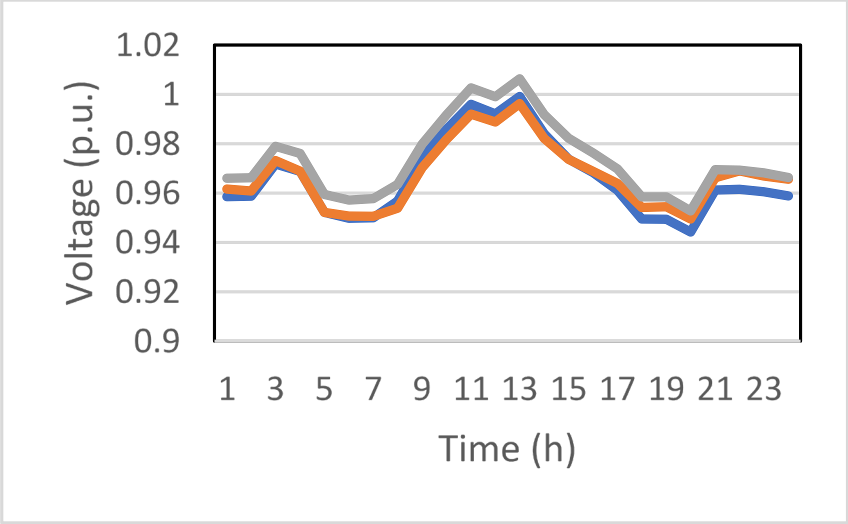


Load	2946 kW
PV	0
BB	0
Temp	40 deg

Donald Town Microgrid: Quasi-dynamic Simulations

MV





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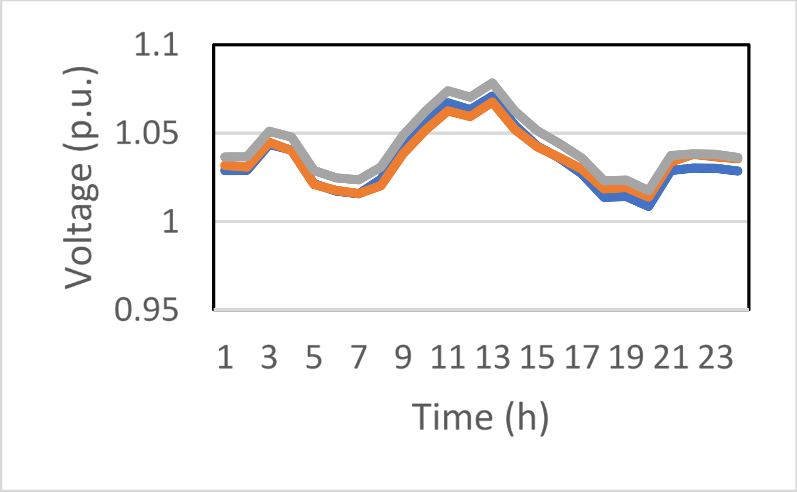
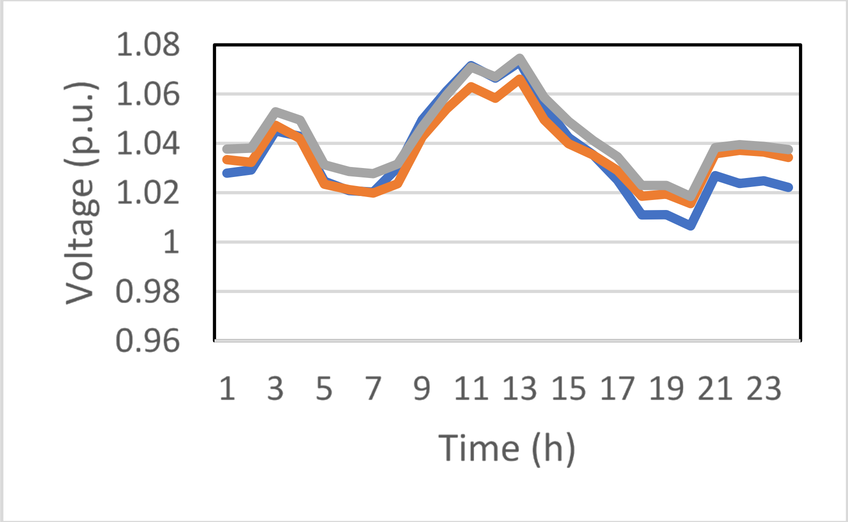
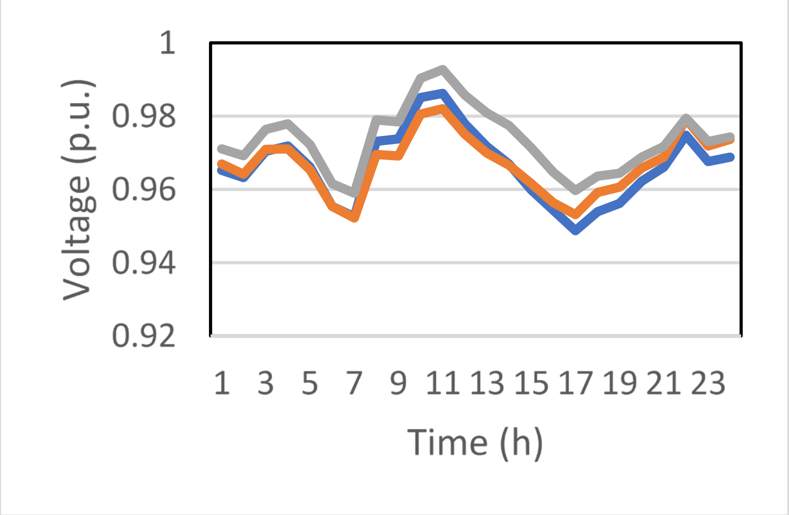


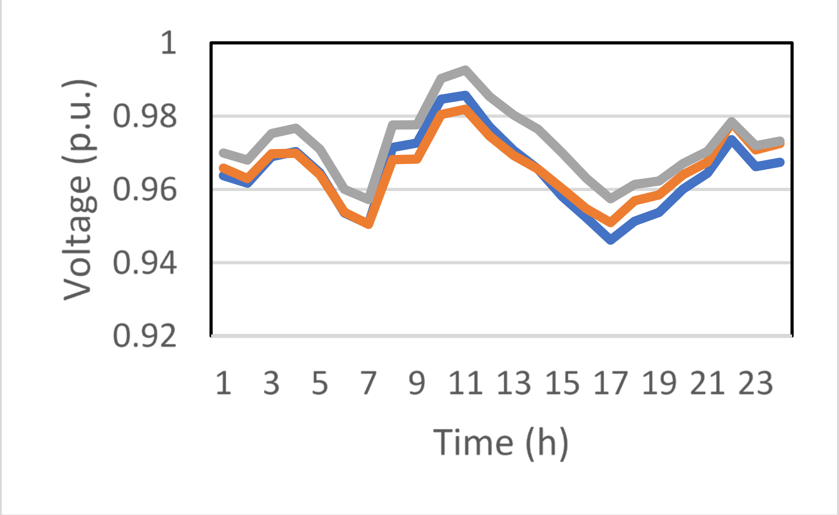


Load	2946 kW
PV	3216 kW
BB	0
Temp	40 deg

Donald Town Microgrid: Quasi-dynamic Simulations

MV





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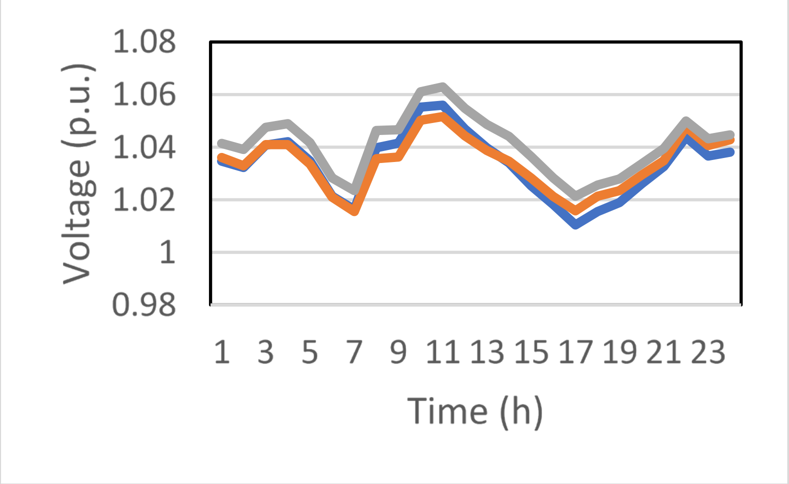

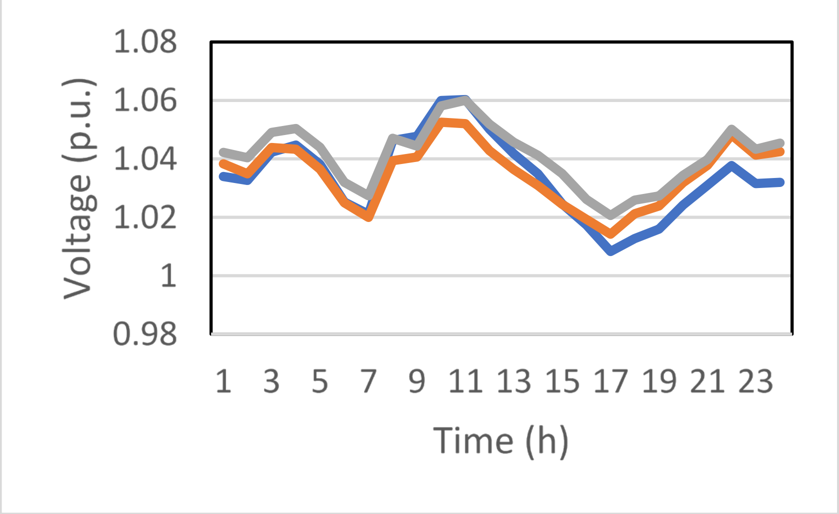

Load	2946 kW
PV	3216 kW
BB	1639 kW (c) & (d)
Temp	40 deg

Tarnagulla Time Sweep Scenarios

Integration Scenario	Total Load (KW)	Load Variation	Total PV (KW)	PV Variation	Total Battery Inveter (KW)	Battery Variation	Backup Generator
1	267.48	0-130%	0	0	0	0	
2	267.48		155	0-130%			
3	267.48		0		111 (c)	0-130%	
4	267.48		0		111 (d)	0-130%	
5	267.48		0		55.5 (c)	0-130%	
6	267.48		0		55.5 (d)	0-130%	
7	81.1		155	0-130%			
8	81.1		155	0-130%	111 (c)		
9	81.1		155	0-130%	111 (d)		
10	267.48		155	0-130%	111 (c)		
11	267.48		155	0-130%	111 (d)		
12	267.48	0-130%	0	0	0	0	320 kW
13	267.48		131	0-130%			320 kW
14	267.48		131	0-130%	101 (c)		320 kW
15	267.48		131	0-130%	101 (d)		320 kW

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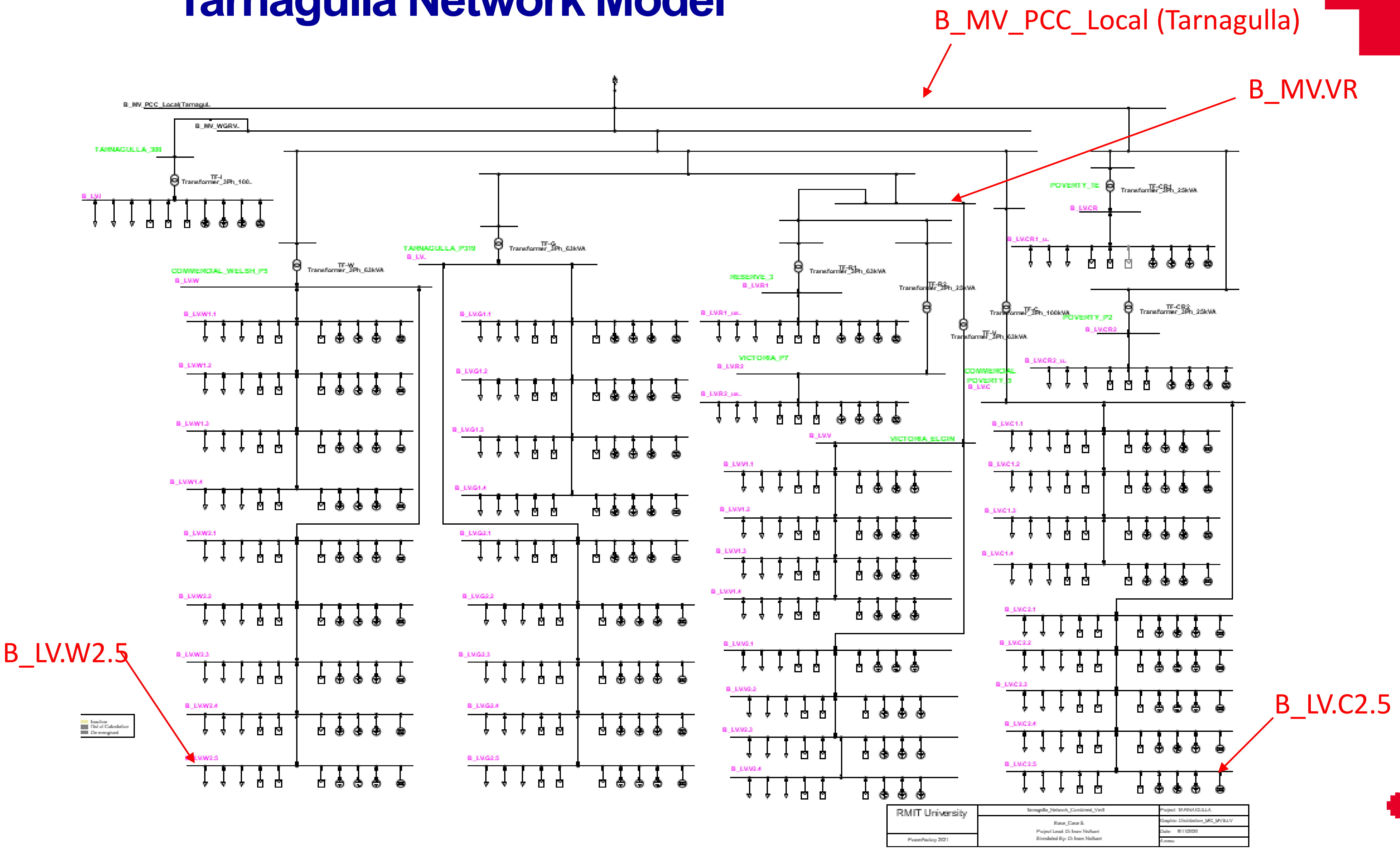
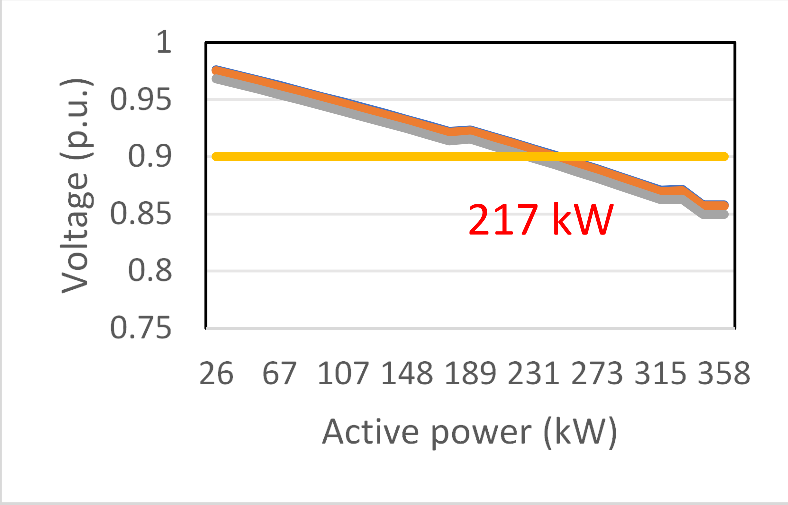
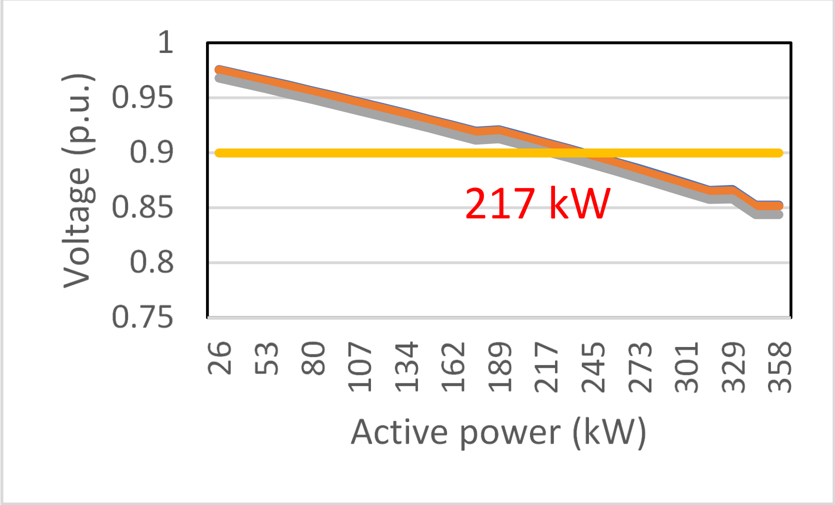
Tarnagulla Network Model



Tarnagulla Town Microgrid: Hosting Capacities

MV





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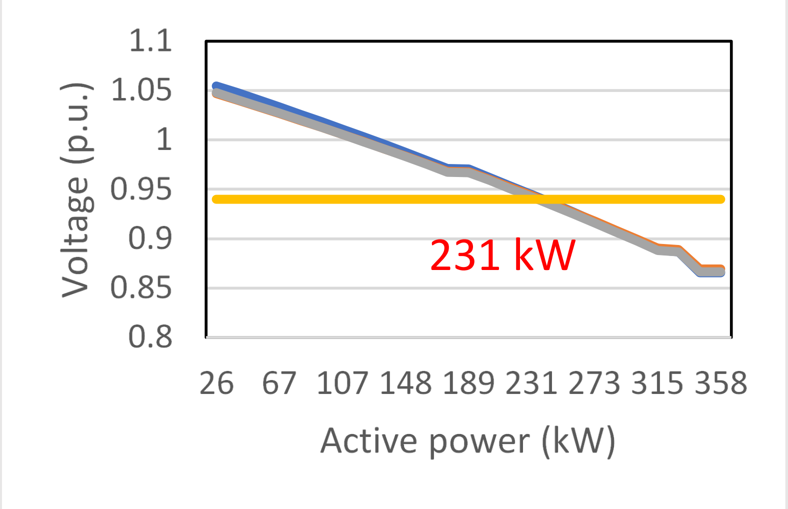
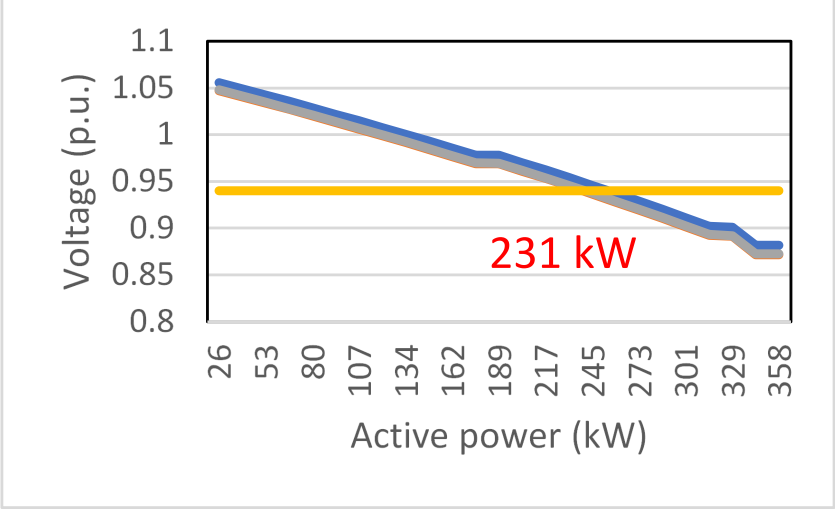
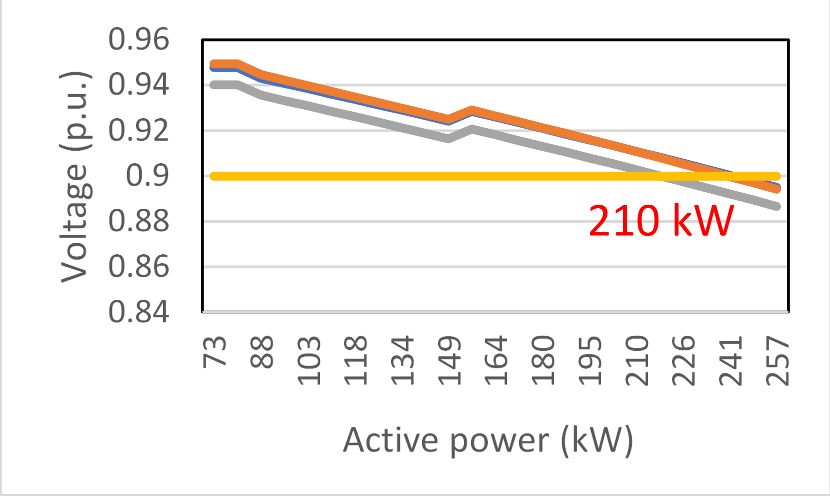


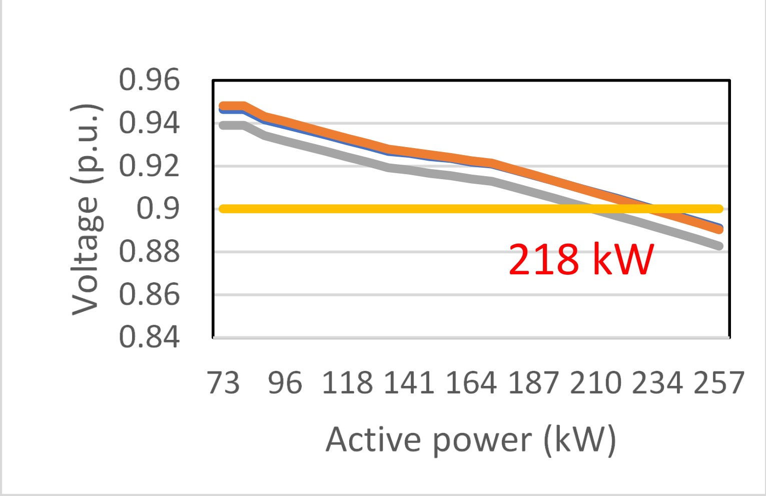


Metric	Magnitude	Variation
Load (kW) at 0.85 pf	**267.48**	**0-130%**
PV (kW)		
Battery (kW)		
Case		**1**

Tarnagulla Town Microgrid: Hosting Capacities

MV





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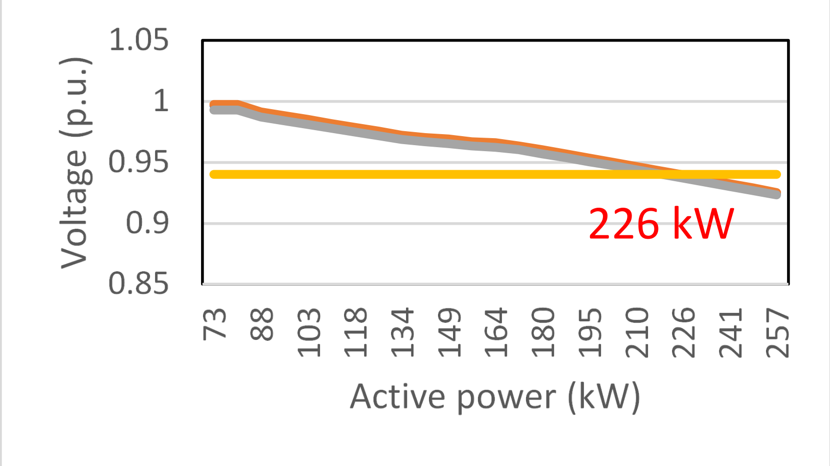
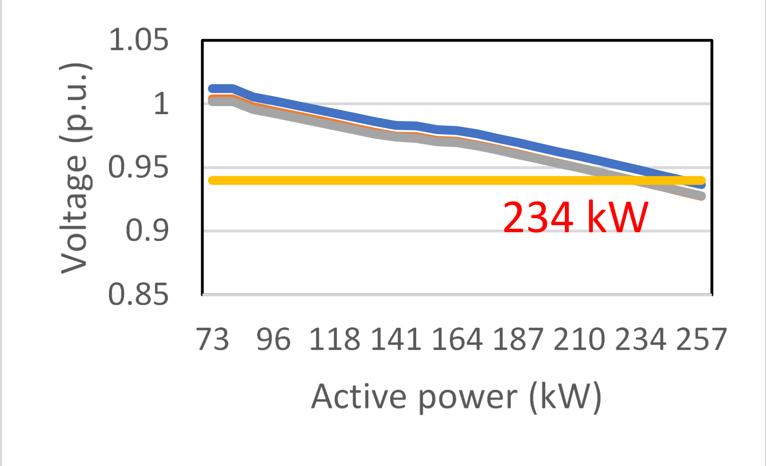
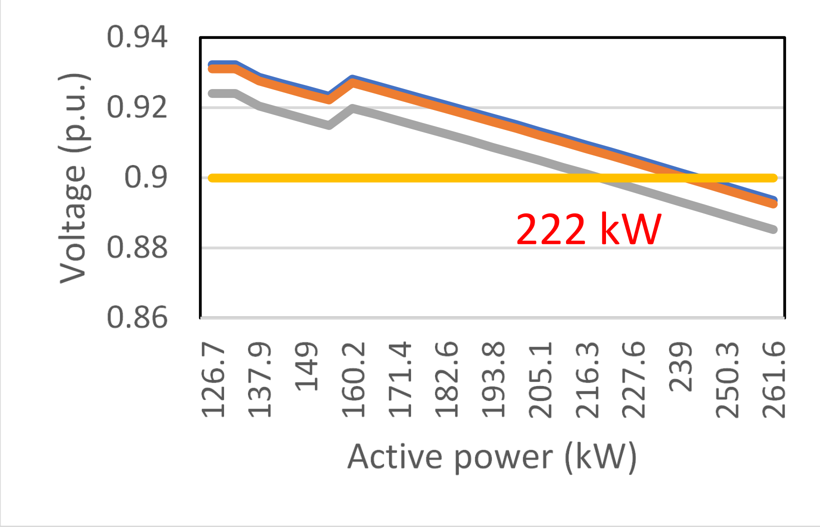


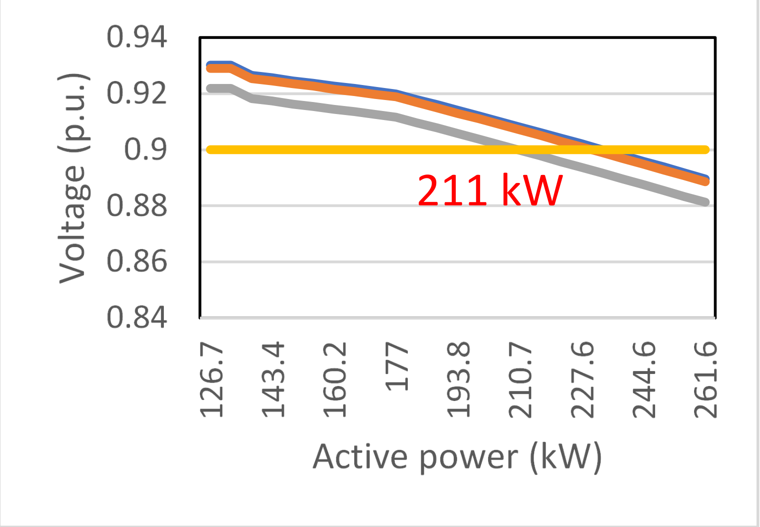


Metric	Magnitude	Variation
Load (kW) at 0.85 pf	**267.48**	
PV (kW)	**155**	**0-130%**
Battery (kW)		
Case		**2**

Tarnagulla Town Microgrid: Hosting Capacities

MV





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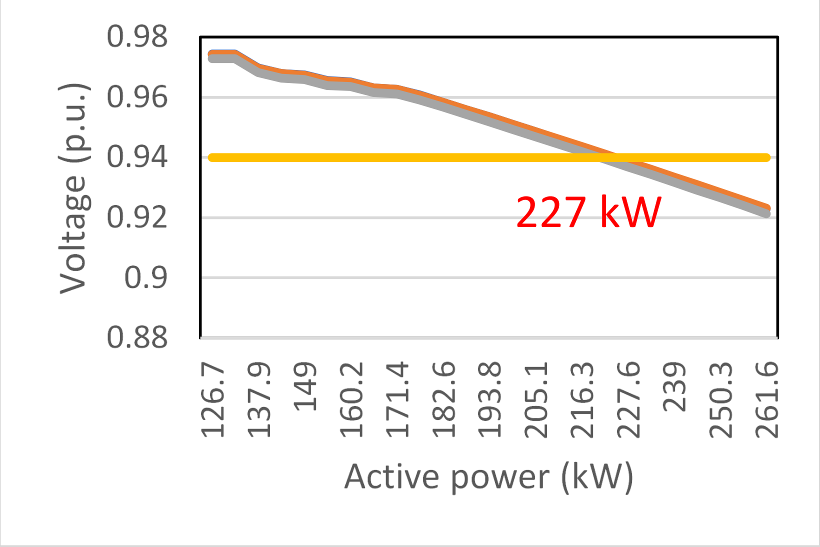
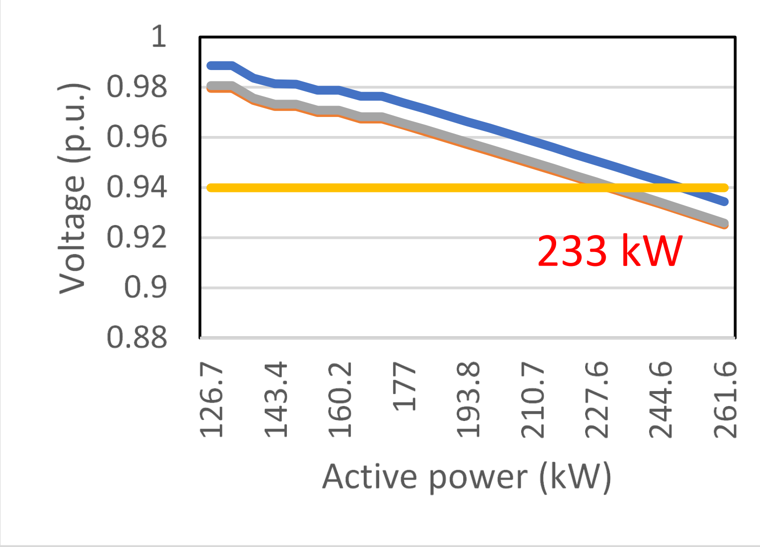
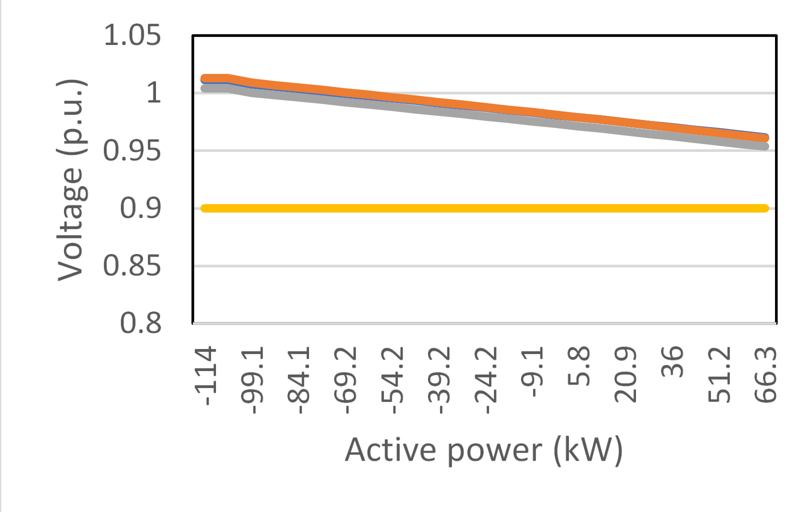


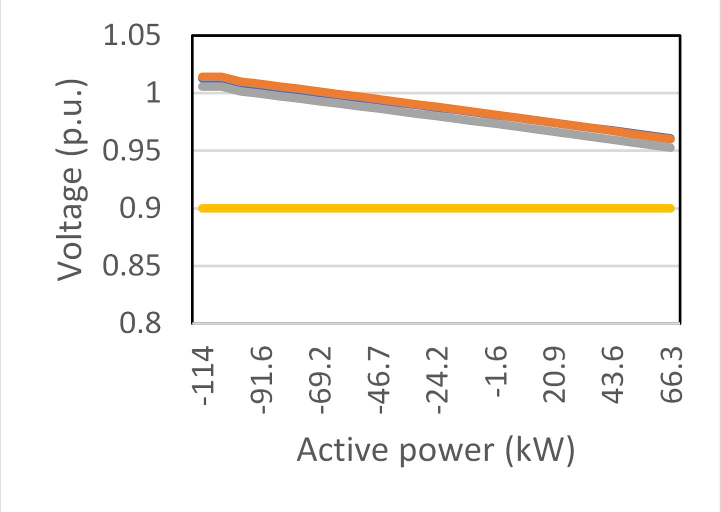


Metric	Magnitude	Variation
Load (kW) at 0.85 pf	**267.48**	
PV (kW)	**0**	
Battery (kW)	**111 (D)**	**0-130%**
Case		**4**

Tarnagulla Town Microgrid: Hosting Capacities

MV





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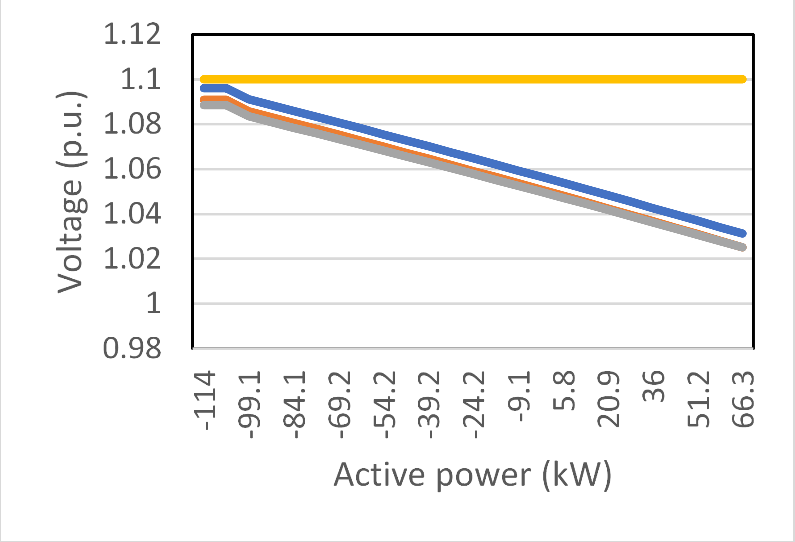
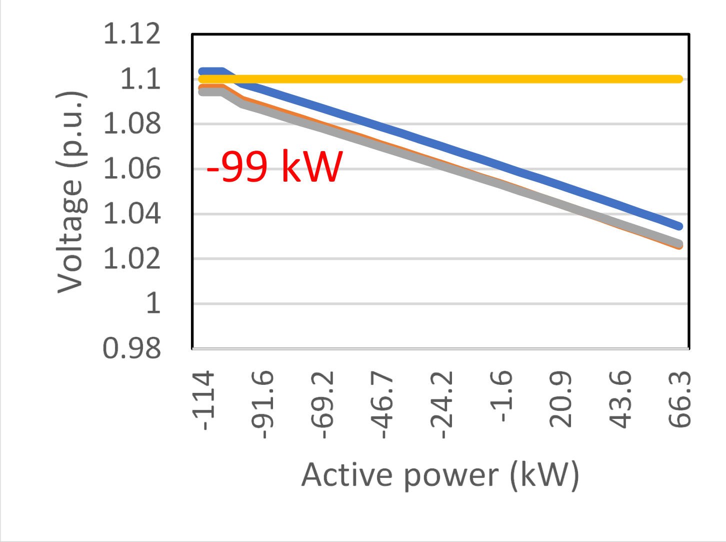
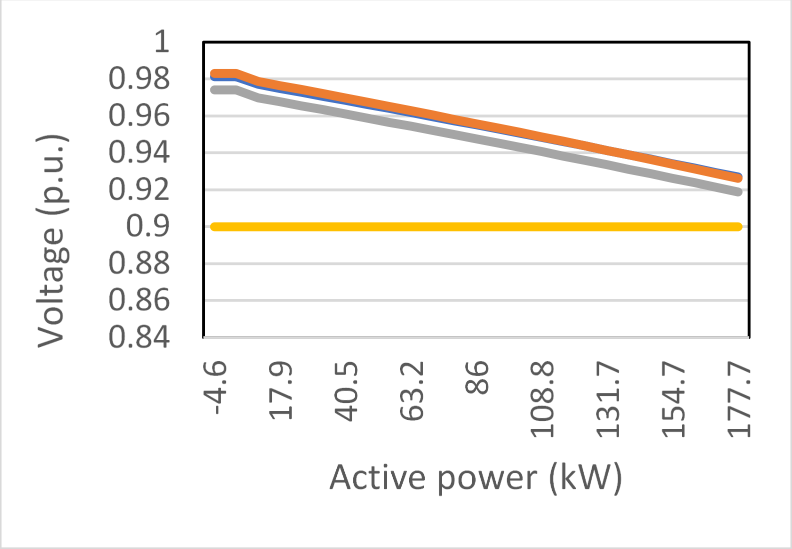


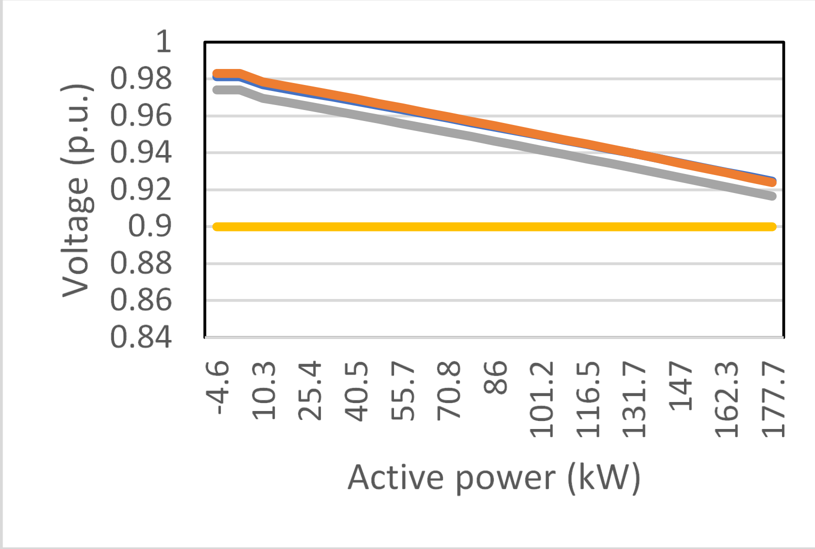


Metric	Magnitude	Variation
Load (kW) at 0.85 pf	81.1	
PV (kW)	155	0-130%
Battery (kW)		
Case		7

Tarnagulla Town Microgrid: Hosting Capacities

MV





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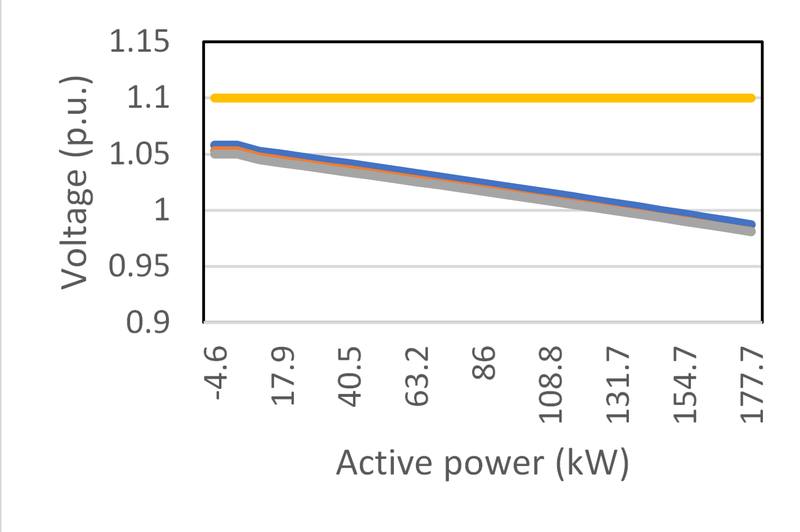

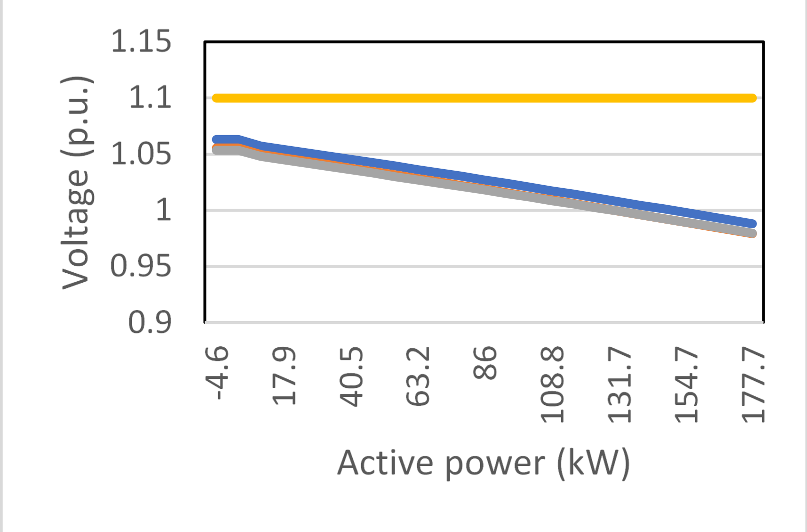

Metric	Magnitude	Variation
Load (kW) at 0.85 pf	81.1	
PV (kW)	155	0-130%
Battery (kW)	101 (c)	
Case		8

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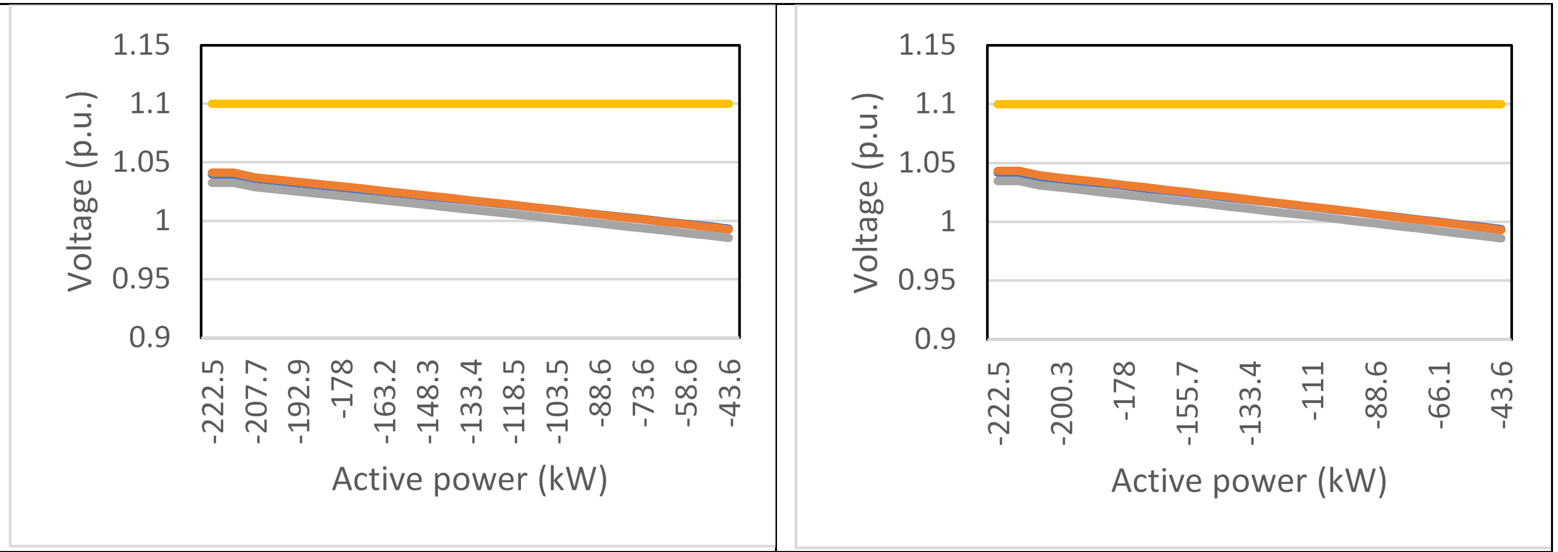
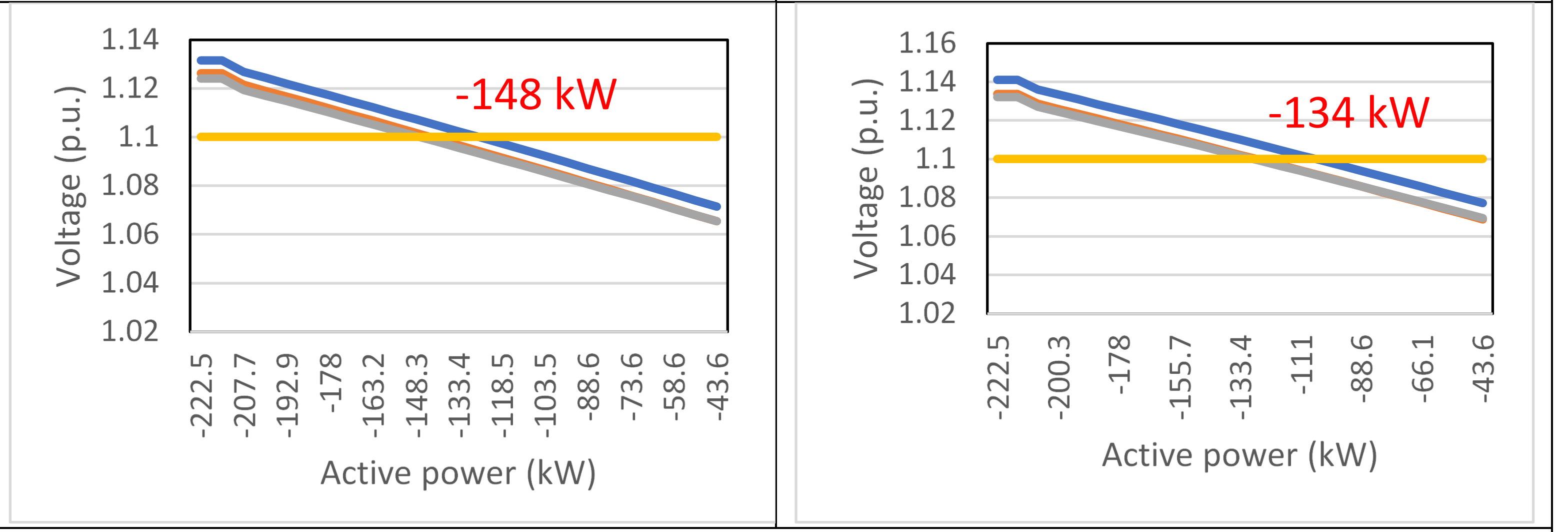
Tarnagulla Town Microgrid: Hosting Capacities

MV

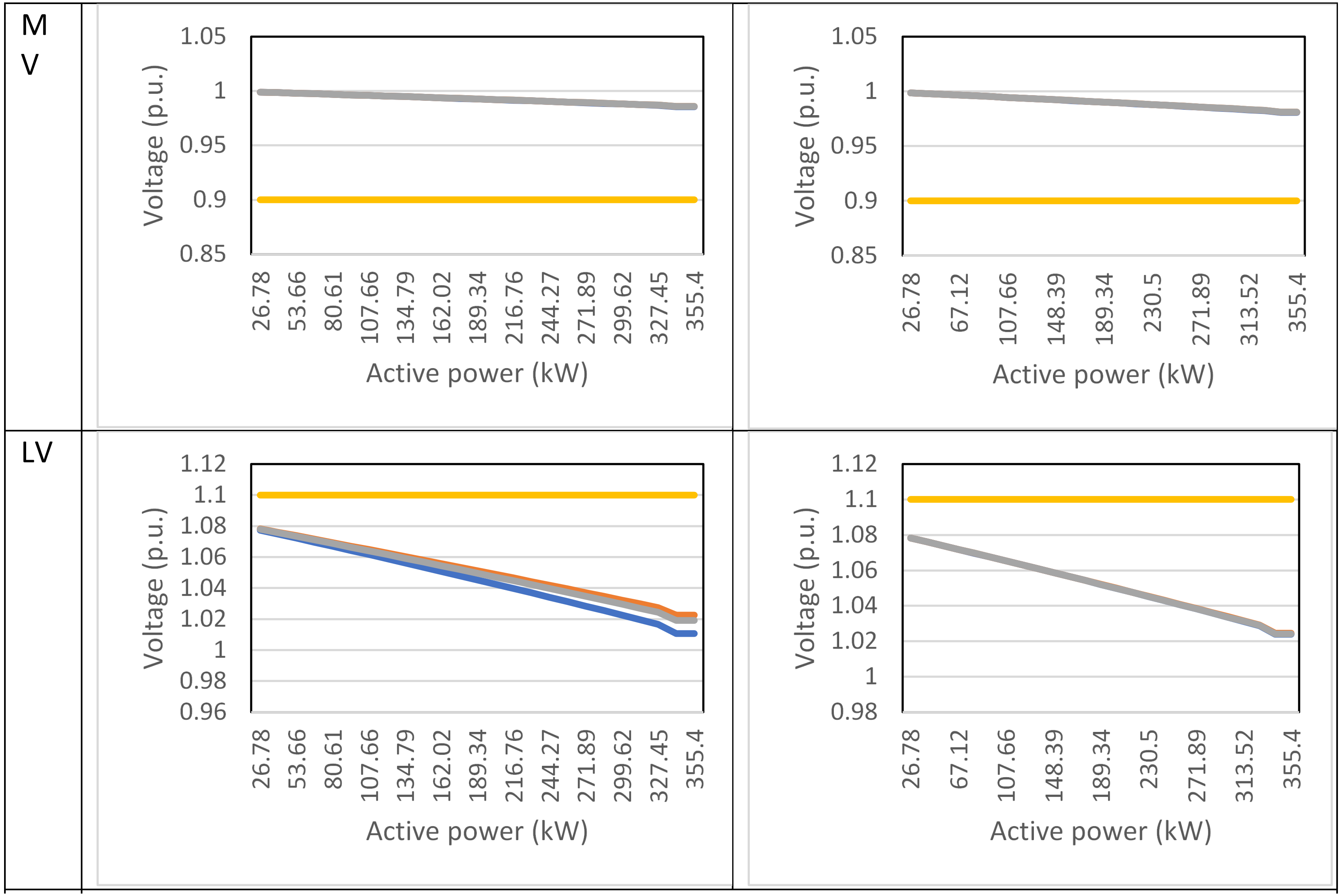


LV



Metric	Magnitude	Variation
Load (kW) at 0.85 pf	**81.1**	
PV (kW)	**155**	**0-130%**
Battery (kW)	**101 (d)**	
Case		**9**

Tarnagulla Town Microgrid: Hosting Capacities



Backup generator 320 kW

Metric	Magnitude	Variation
Load (kW) at 0.85 pf	**267.48**	**0-130%**
PV (kW)		
Battery (kW)		
Case		**12**

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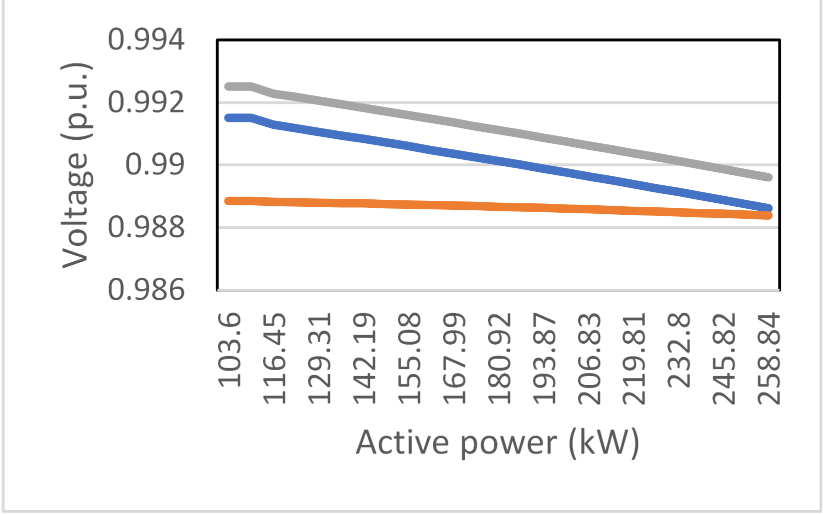
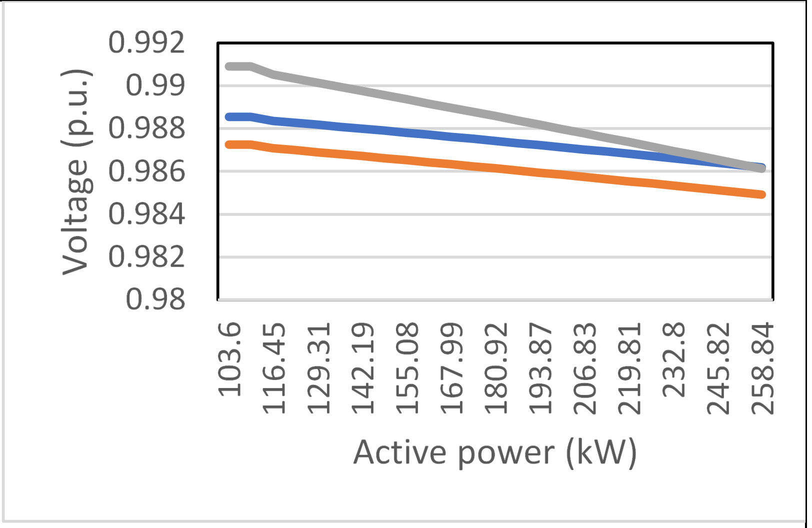
Tarnagulla Town Microgrid: Hosting Capacities

MV





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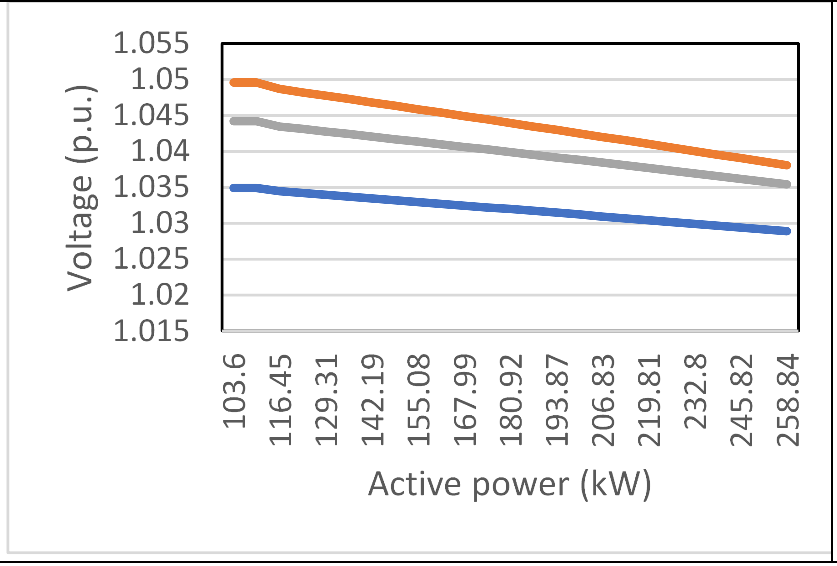
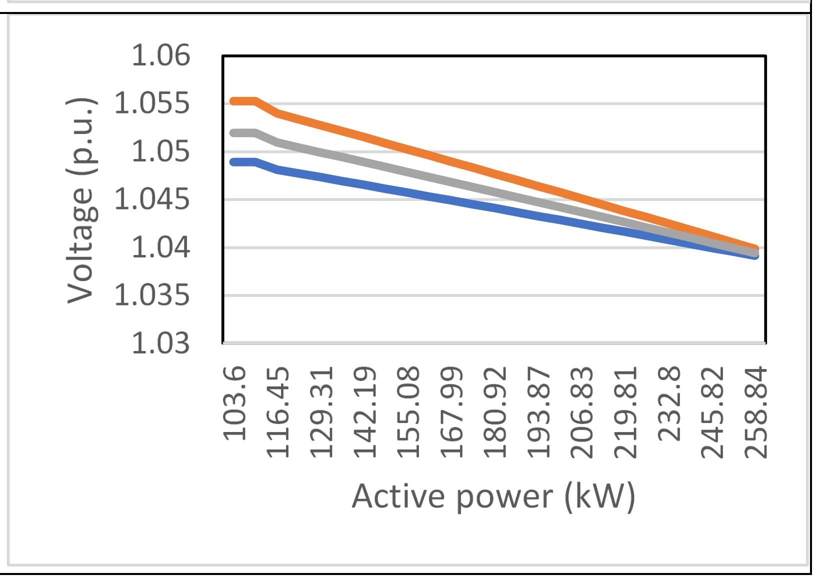


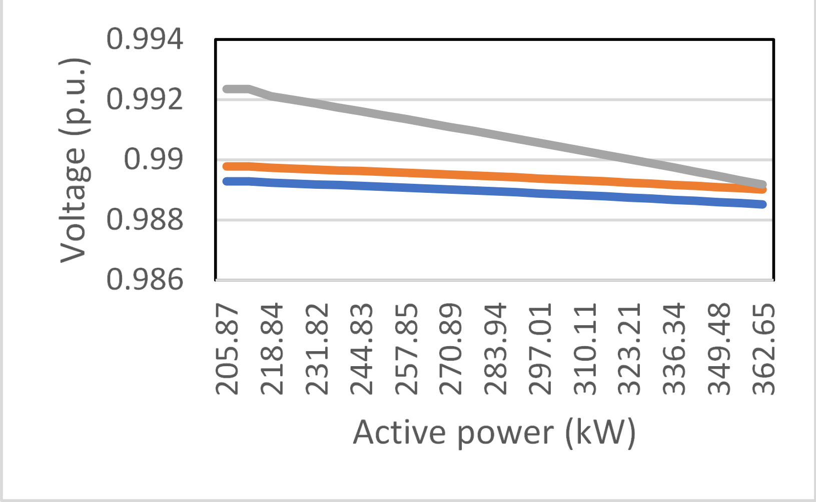


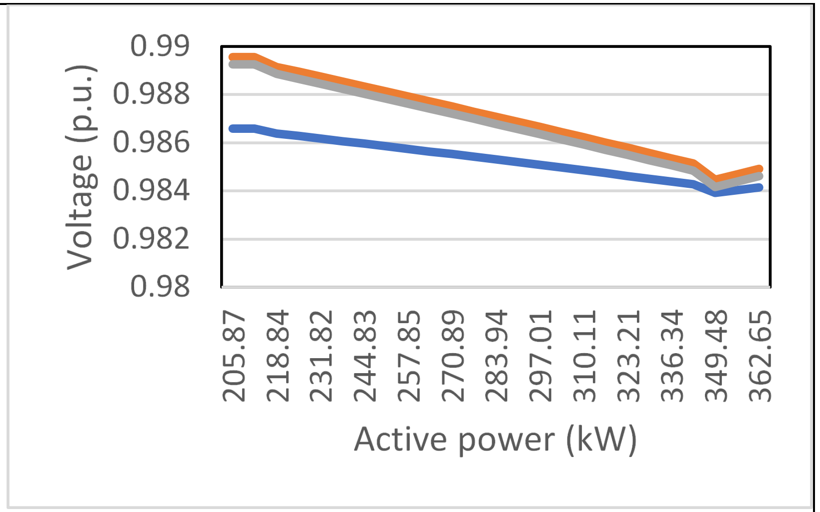
Backup generator 320 kW

Metric	Magnitude	Variation
Load (kW) at 0.85 pf	267.48	
PV (kW)	131	0-130%
Battery (kW)		
Case		13

Tarnagulla Town Microgrid: Hosting Capacities

MV





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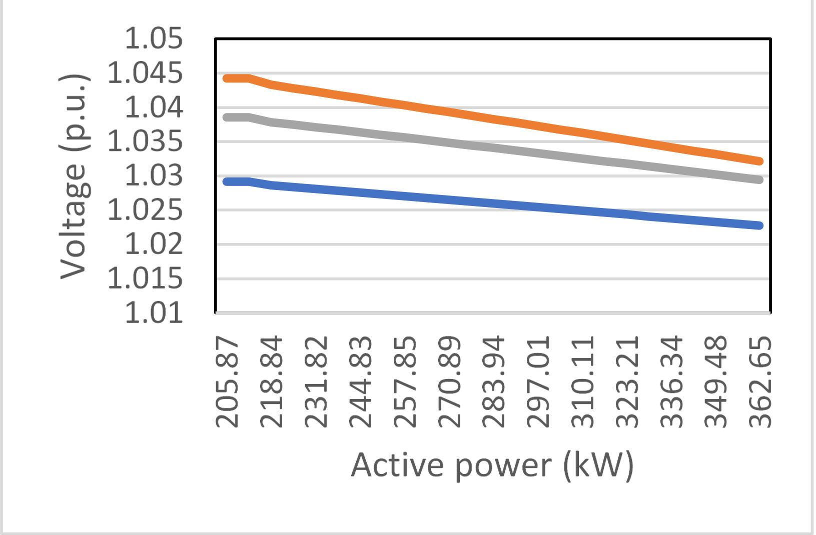

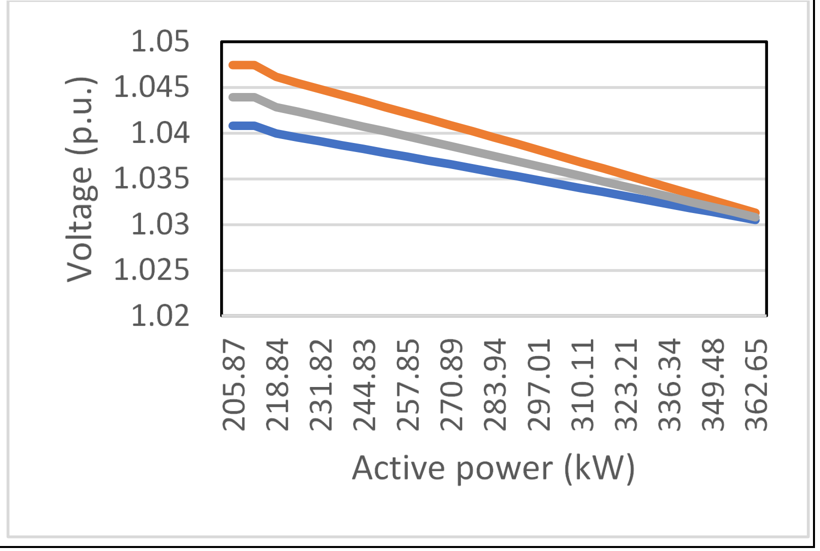

Backup generator 320 kW

Metric	Magnitude	Variation
Load (kW) at 0.85 pf	**267.48**	
PV (kW)	**131**	**0-130%**
Battery (kW)	**101(c)**	
Case		**14**

Tarnagulla Quasi–Dynamic Scenarios

Operational Scenario	Maximum Load (KW)	Maximum PV (KW)	Maximum Battery Inveter (KW)	Temperature Zone
1	81	0	0	15 degrees
2	81	155	0	15 degrees
3	81	155	101 (c & d)	15 degrees
4	267	0	0	15 degrees
5	267	155	0	15 degrees
6	267	155	101 (c & d)	15 degrees
7	81	0	0	40 degrees
8	81	155	0	40 degrees
9	81	155	101 (c & d)	40 degrees
10	267	0	0	40 degrees
11	267	155	0	40 degrees
12	267	155	101 (c & d)	40 degrees

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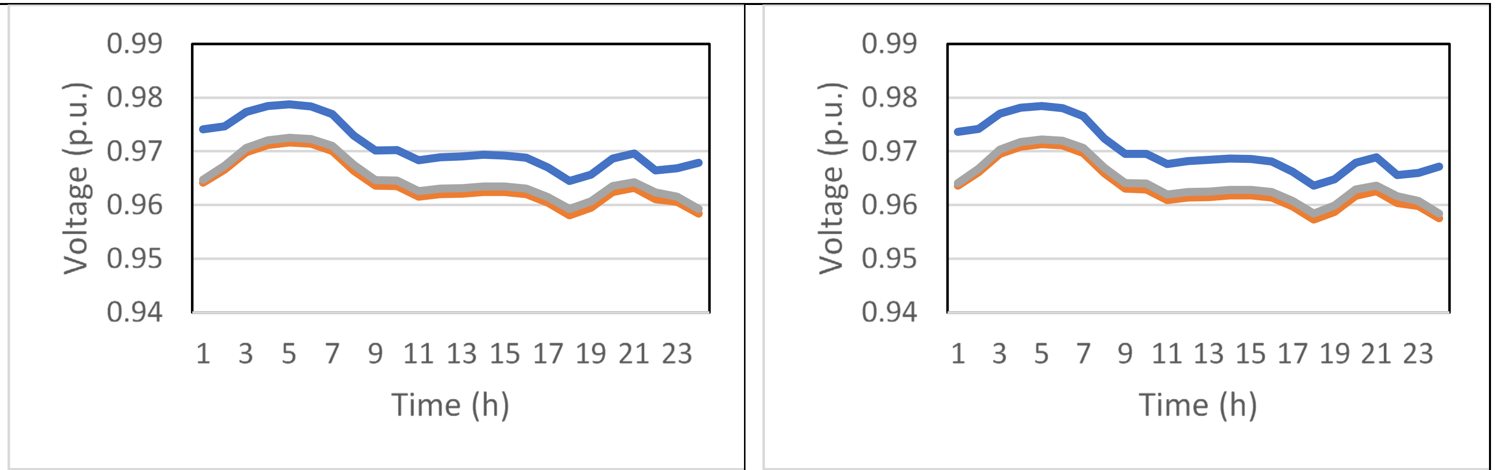
Tarnagulla Town Microgrid: Quasi-Dynamic Simulation

MV



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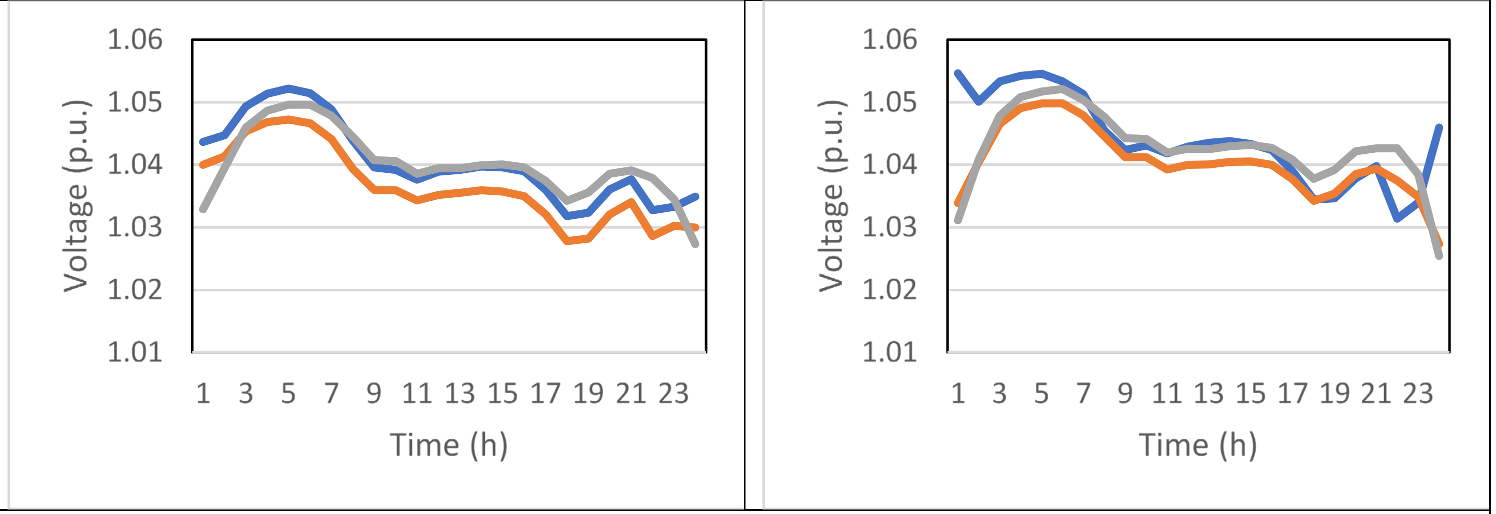
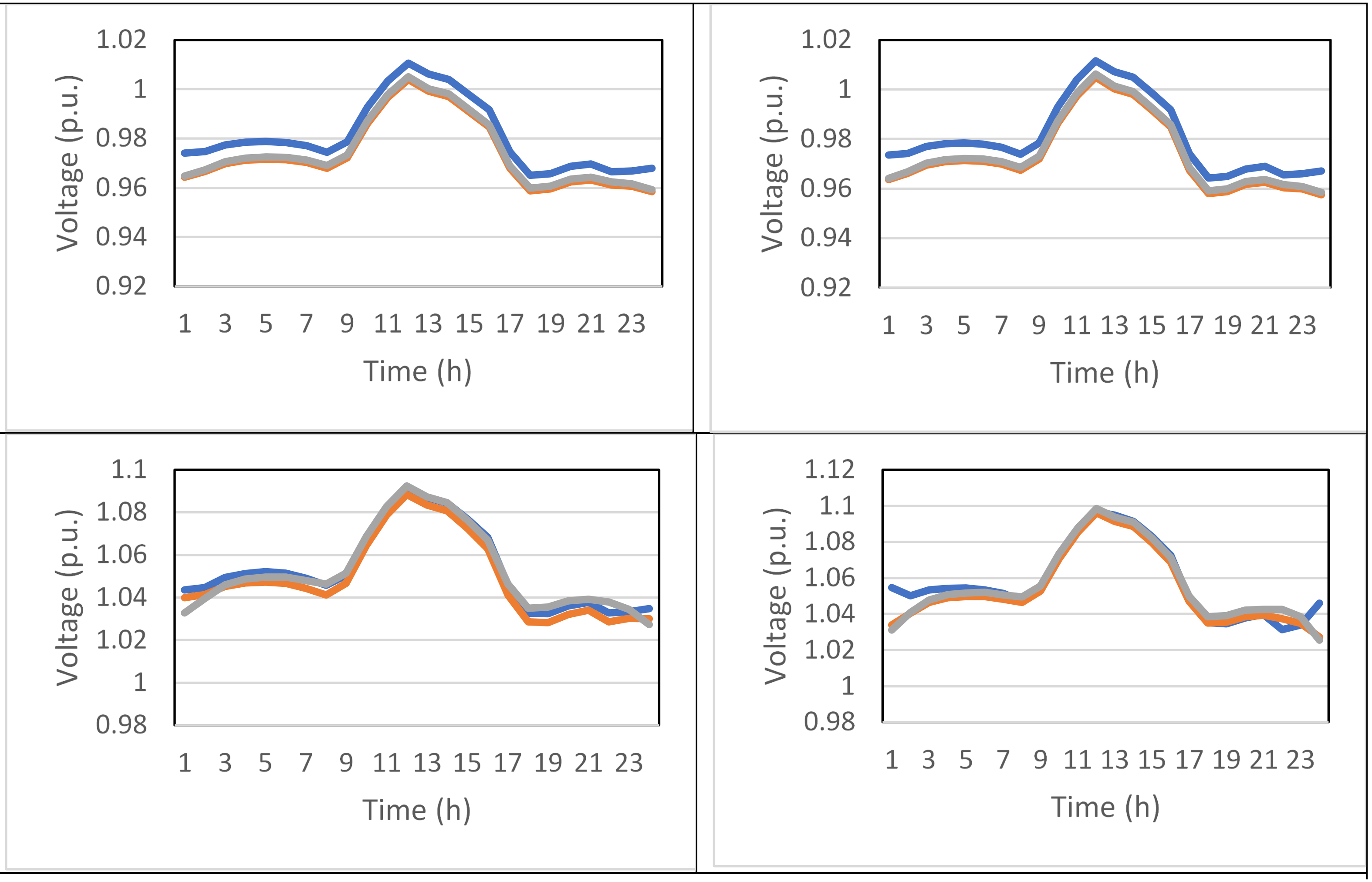


Load	81 kW
PV	0
BB	0
Temp	15 deg

Tarnagulla Town Microgrid: Quasi-Dynamic Simulation

MV

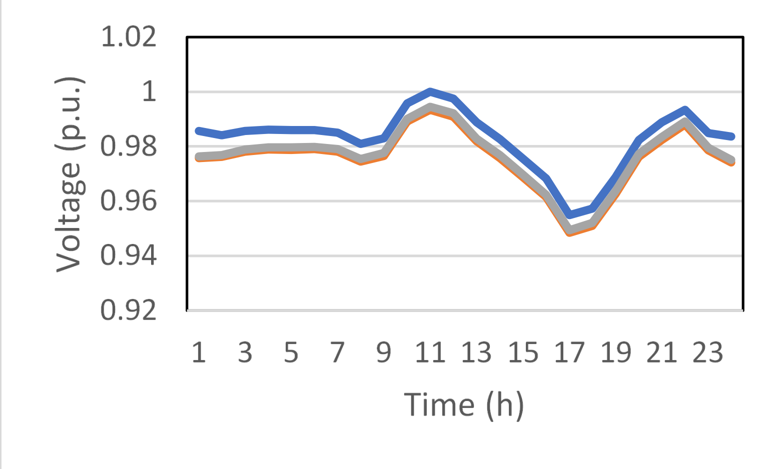
LV

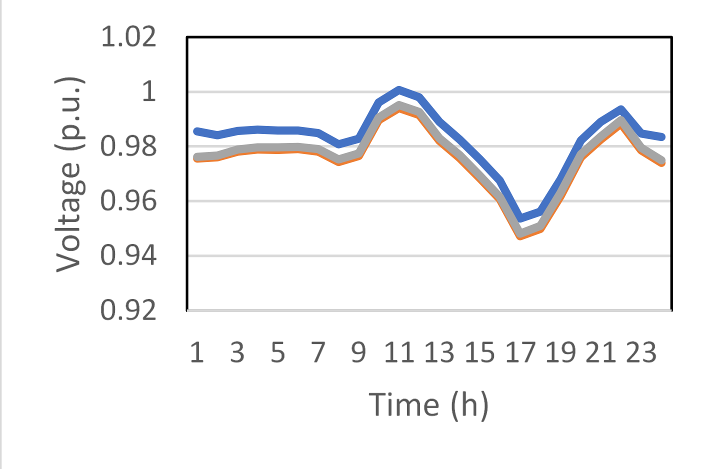


Load	81 kW
PV	155 kW
BB	0
Temp	15 deg

Tarnagulla Town Microgrid: Quasi-Dynamic Simulation

MV





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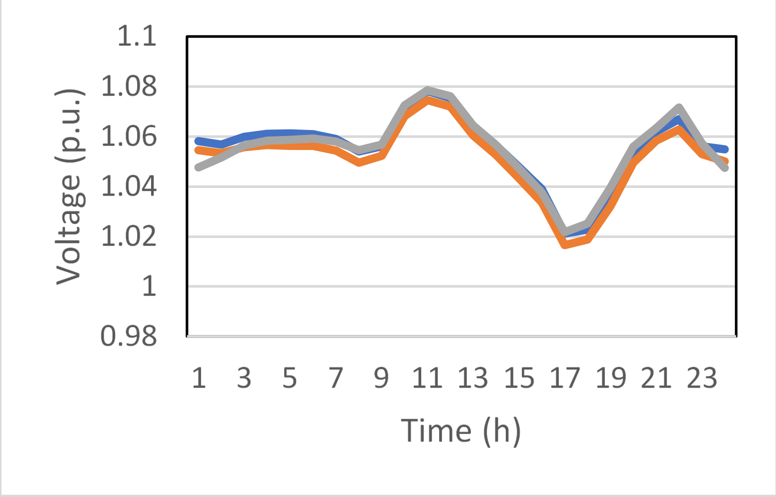
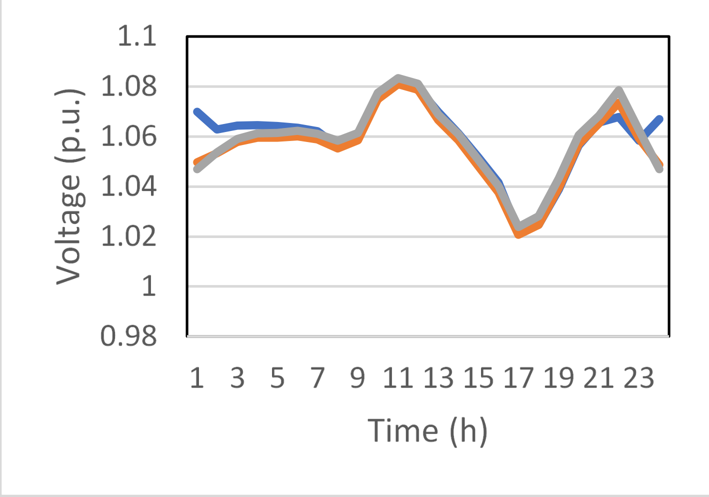
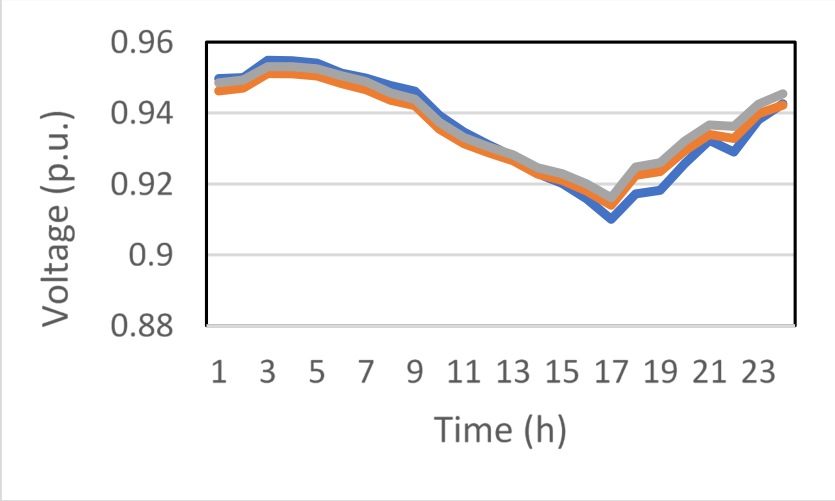


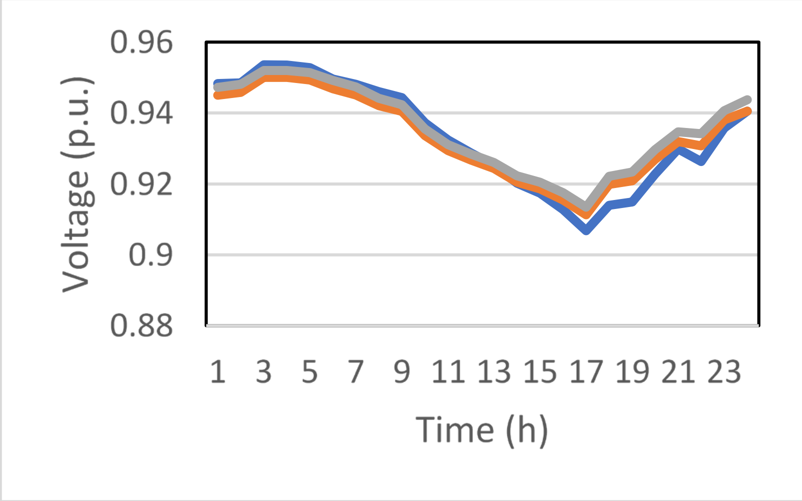


Load	81 kW
PV	155 kW
BB	101 kW (c) & (d)
Temp	15 deg

Tarnagulla Town Microgrid: Quasi-Dynamic Simulation

MV





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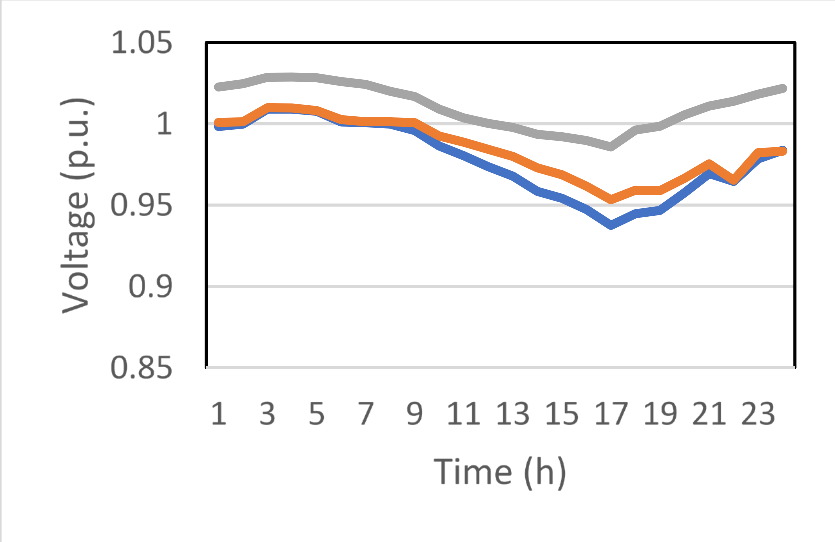
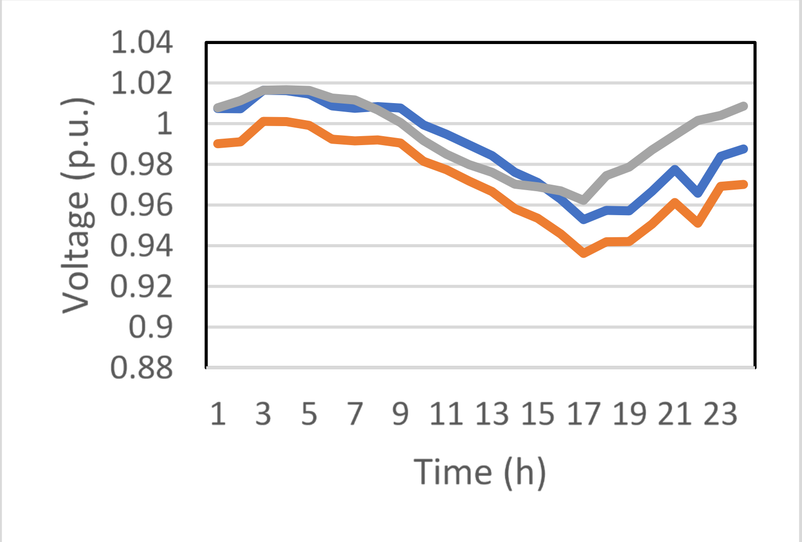
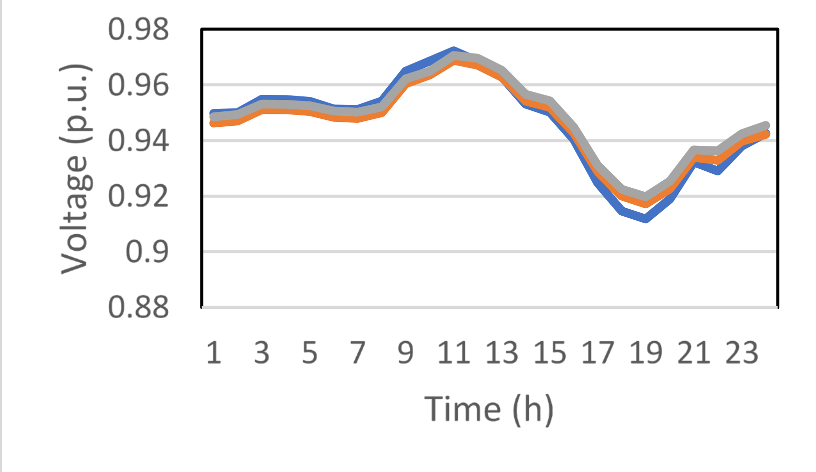


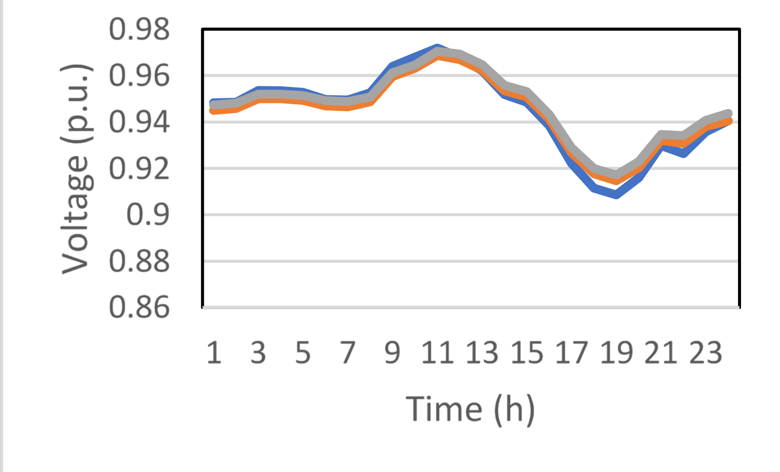


Load	267 kW
PV	0
BB	0
Temp	40 deg

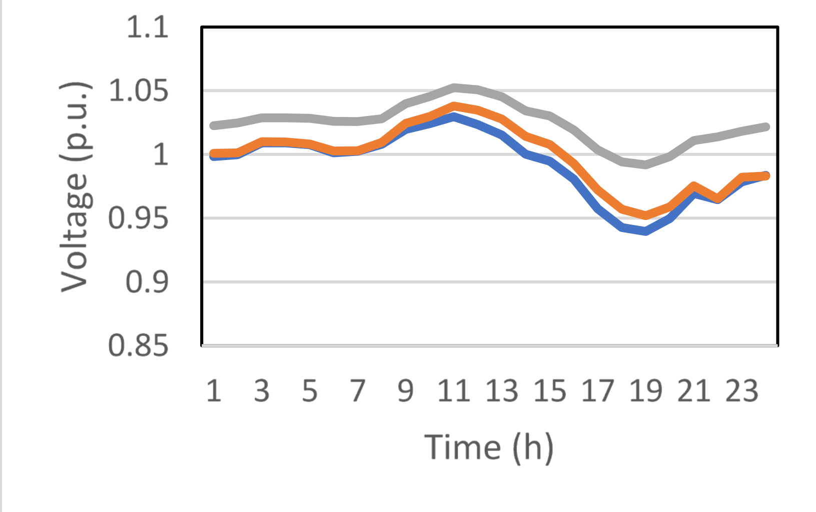
Tarnagulla Town Microgrid: Quasi-Dynamic Simulation

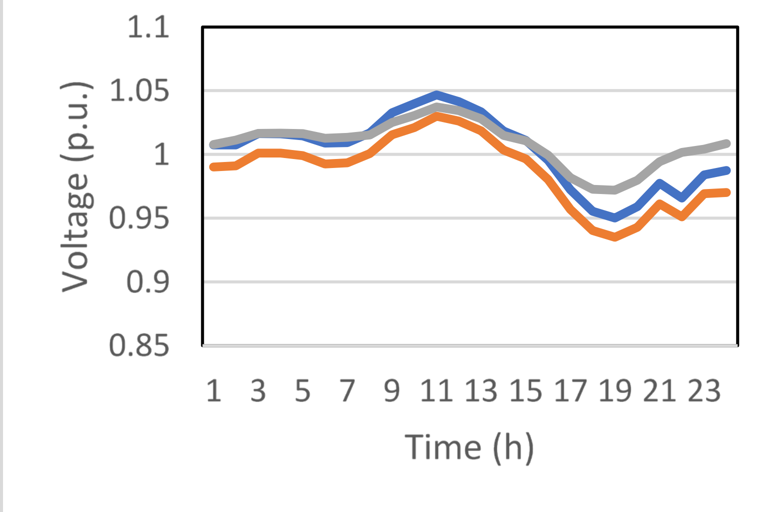
MV





LV

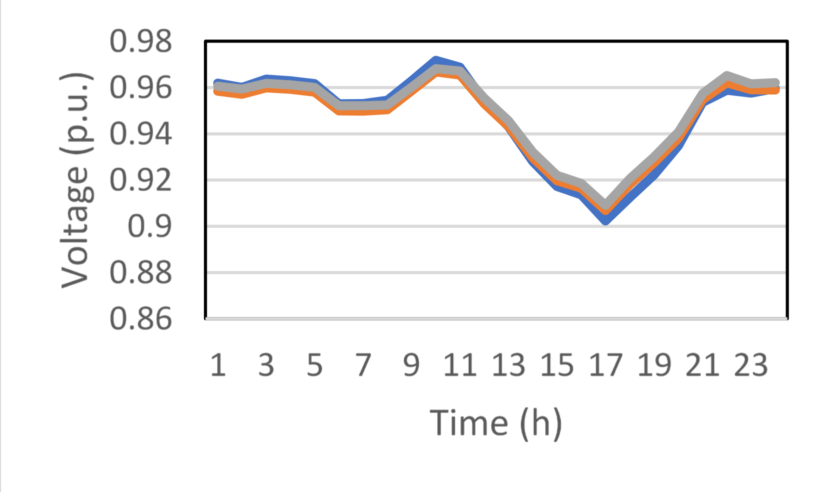


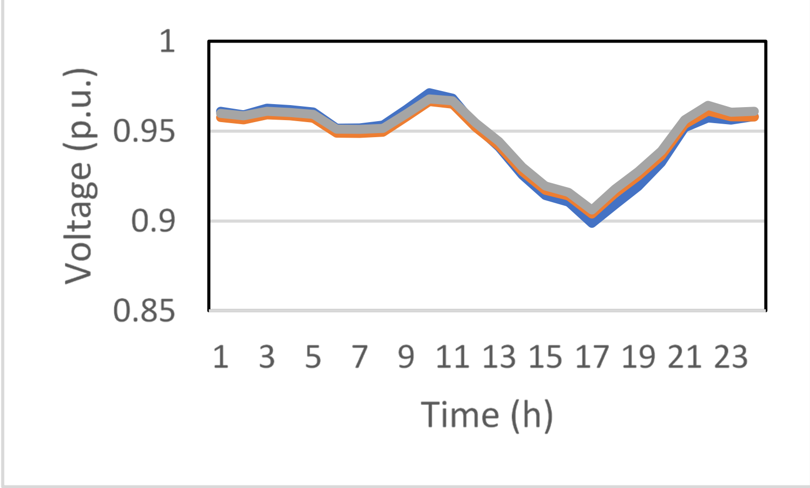


Load	267 kW
PV	155 kW
BB	0
Temp	40 deg

Tarnagulla Town Microgrid: Quasi-Dynamic Simulation

MV





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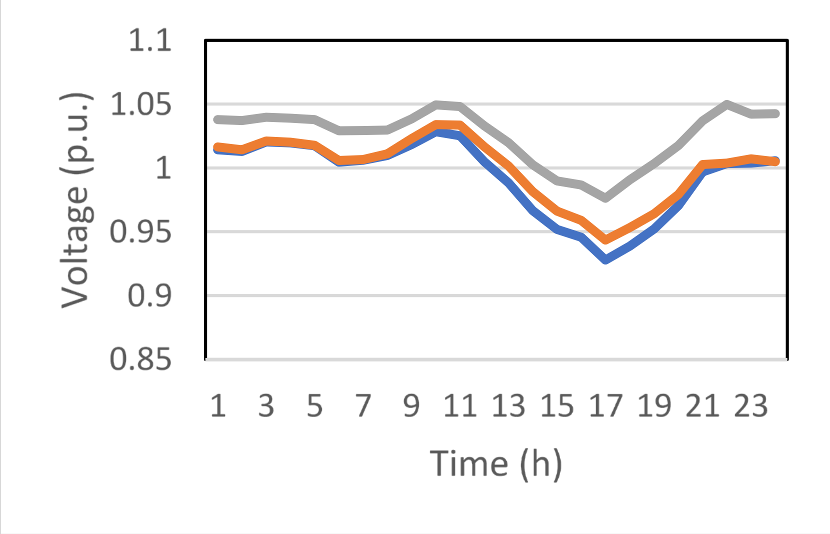
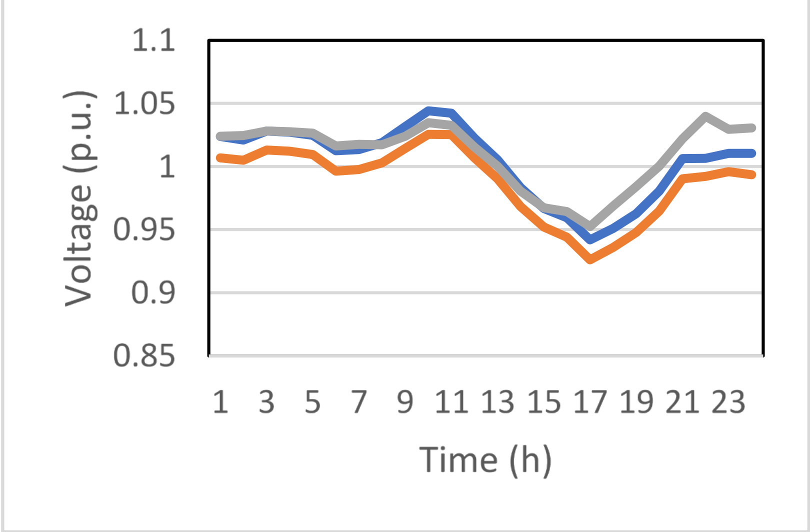




Load	267 kW
PV	155 kW
BB	101 kW (c) & (d)
Temp	40 deg

Conclusions

- The MV and LV systems of Donald are capable of supplying the load well above the peak load of the network can also host the PV and battery as identified in hosting capacity assessment studies.
- The Tarnagulla network has been more sensitive to load and generation changes
- Supply feeder is the main limiting factor in the hosting capacity of load and local generation of both Donald and Tarnagulla
- The voltages across the network in stand-alone operation modes were more consistent due to the voltage support of the back-up generator
- The quasi-dynamic simulations support the findings through time-sweep analysis as the networks did not experienced major over or under voltages in many realistic operational scenarios
- Minor overvoltage were observed in the LV network during low load and high PV generation conditions with no batteries which were improved by considering the batteries in the system

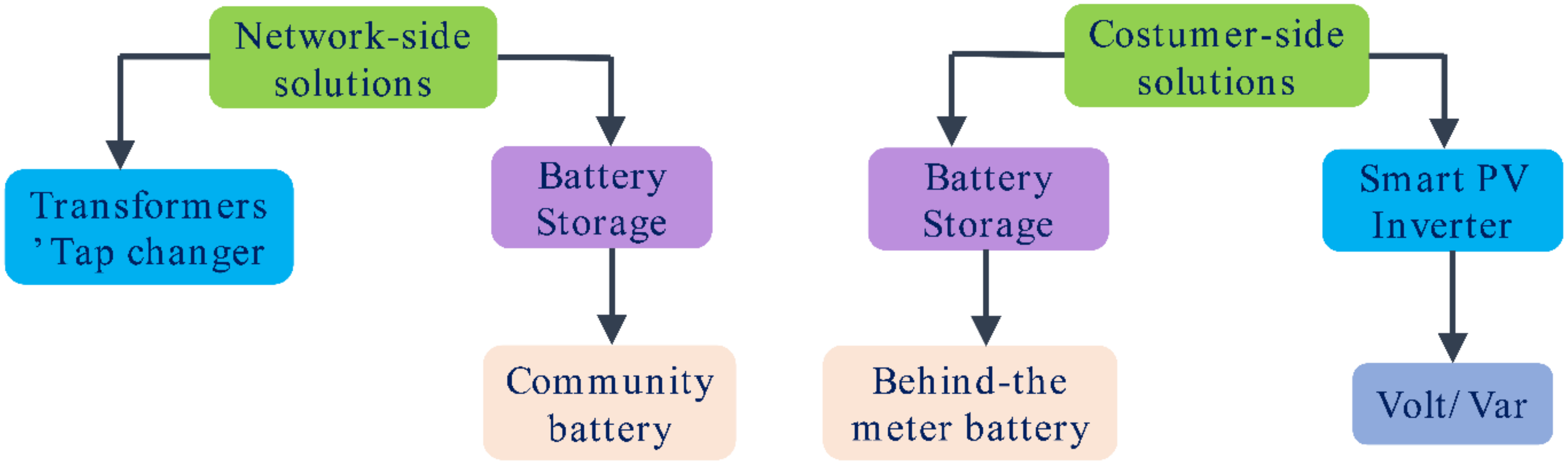
MONASH University

Improving the PV Hosting Capacity of the Tarnagulla and the Donald Microgrid

Dr. Reza Razzaghi

Yasin Zabihinia Gerdroodbari

Methodology

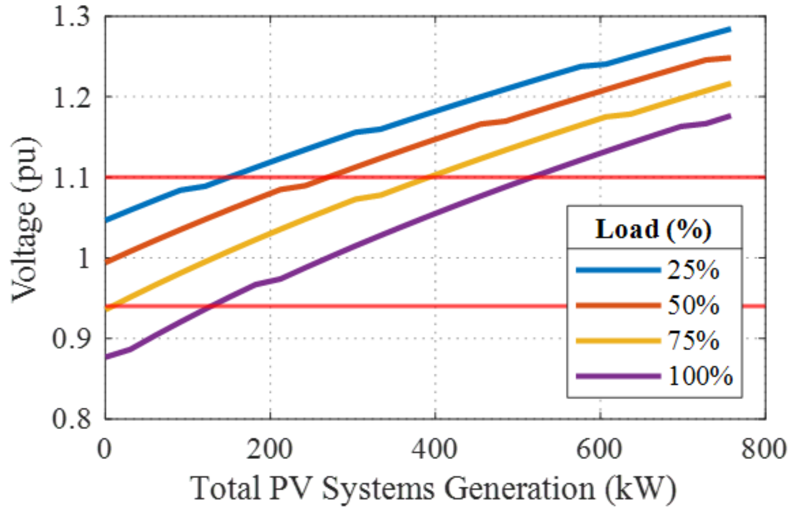


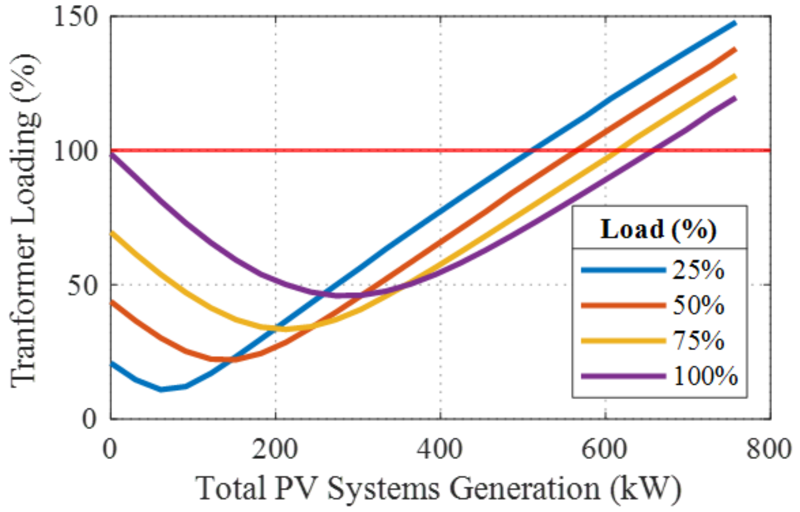
- **Network-Side:**
  - Changing MV/LV transformers’ tap changer to control LV side voltage;
  - Installing a community battery in LV feeders to absorb surplus generated power by PV systems.
- **Customer-Side:**
  - Utilising *volt/var* control in smart inverters;
  - Installing residential batteries to absorb the surplus generated active power by the PV inverter.

Base Case

❖ **Tarnagulla Network:**

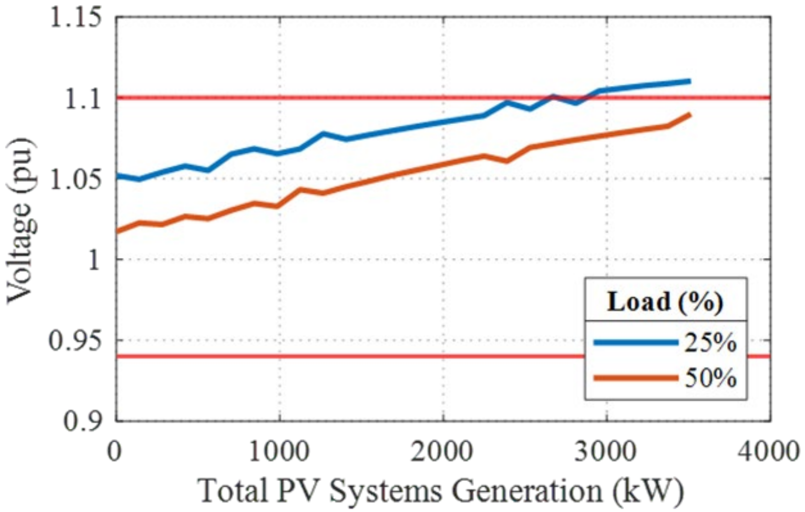
Load (%)		P_{Gen} (kW)
	25	150
	50	270
	75	392
	100	517

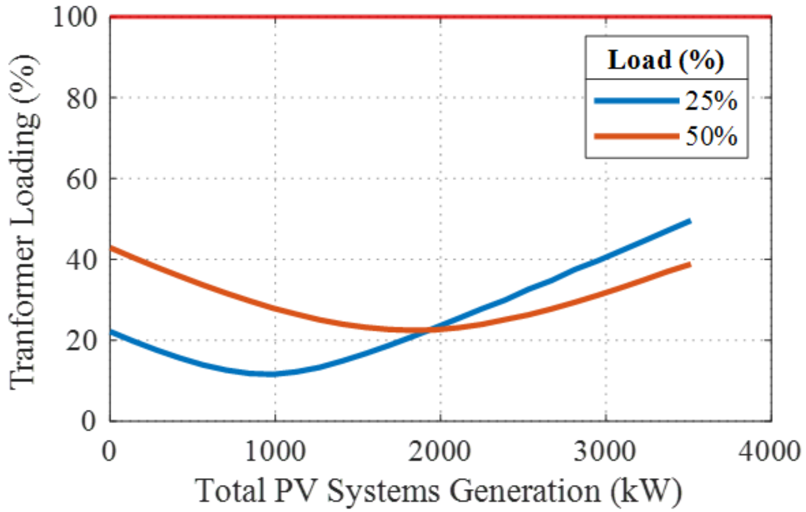




❖ **Donald Network:**

Load (%)		P_{Gen} (kW)
	25	2657
	50	3514

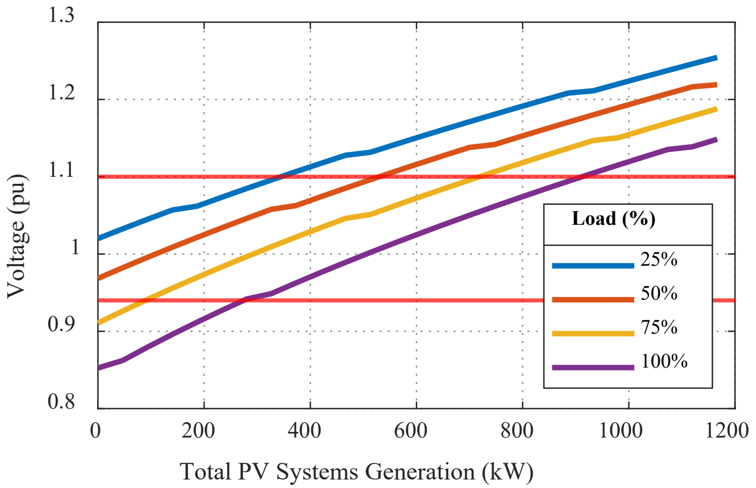




Transformers' tap changer (Tarnagulla)

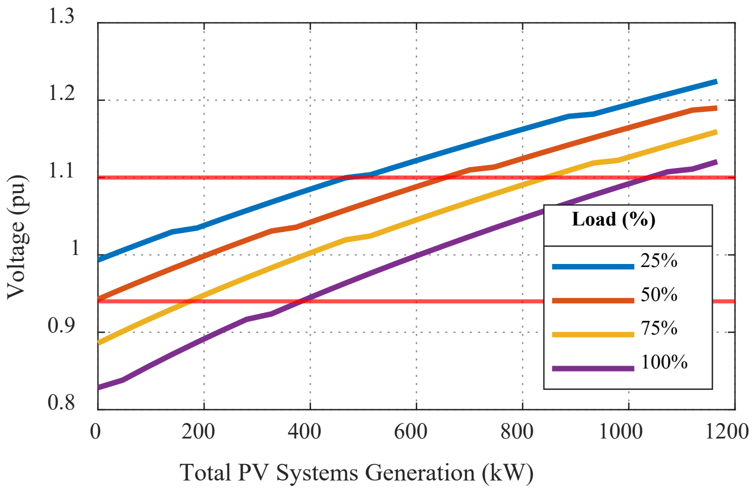
❖ **Tap Position=-1**

		P_{Gen} (kW)
Load (%)	25	170 (13% ↑)
	50	345 (28% ↑)
	75	467 (19% ↑)
	100	593 (15% ↑)



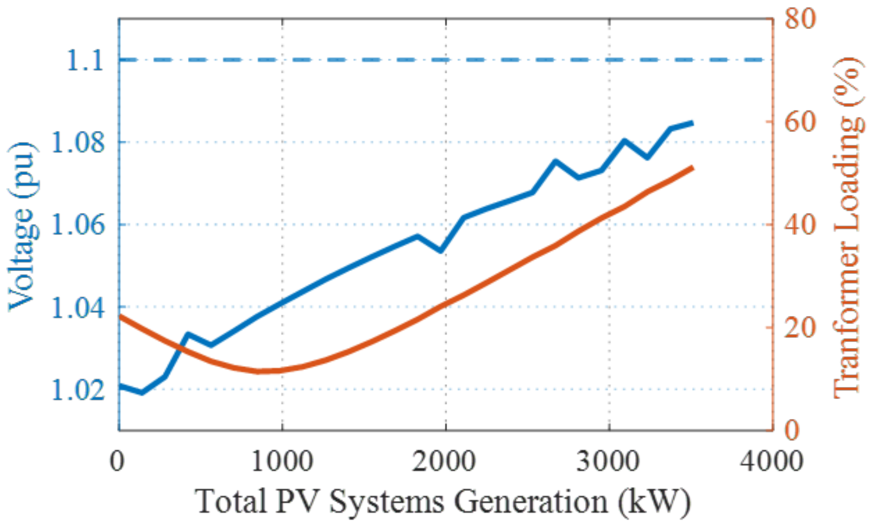
❖ **Tap Position=-2**

		P_{Gen} (kW)
Load (%)	25	306 (103% ↑)
	50	426 (58% ↑)
	75	549 (40% ↑)
	100	632 (22% ↑)

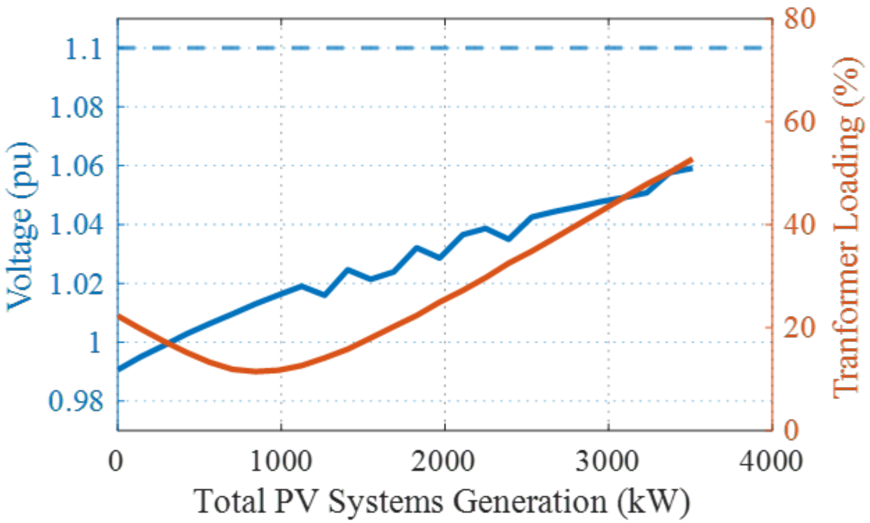


Transformers' tap changer (Donald)

❖ **Tap Position=-1**



❖ **Tap Position=-2**

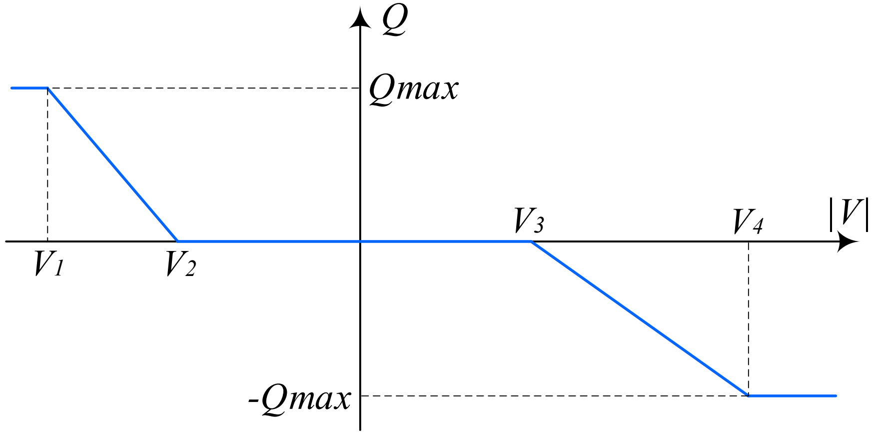


	P_{Gen} (kW)
Tap Position= -1	3514 (32% ↑)
Tap Position= -2	3514 (32% ↑)

Volt/Var

- **Case 1:** All PV inverters have Volt/Var Control
- **Case 2:** Half of PV inverters have Volt/Var Control

- **Used Volt/Var Curve:**



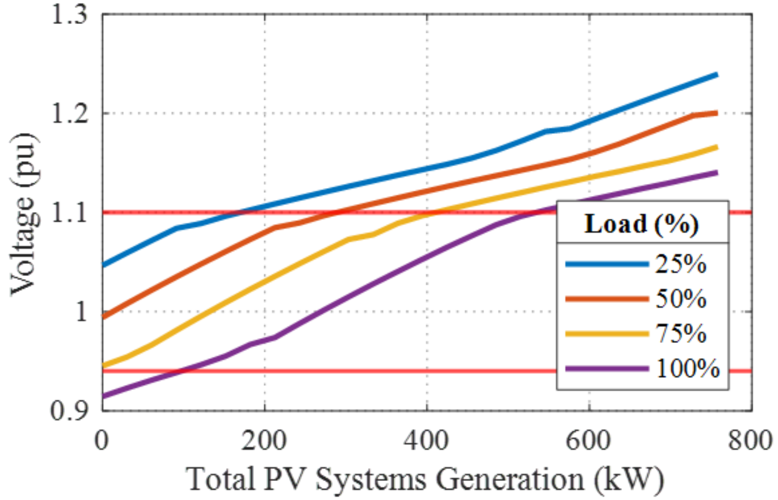
Adopted from AS4777.2

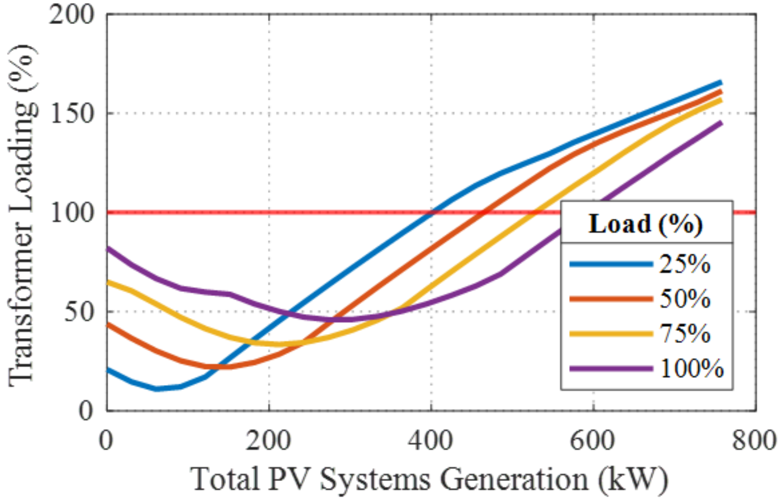
	Voltage (pu)	Var % rated VA
V_1	0.9	30%
V_2	0.96	0%
V_3	1.08	0%
V_4	1.15	-30%

Volt/Var (Tarnagulla)

❖ **All PV inverters are smart**

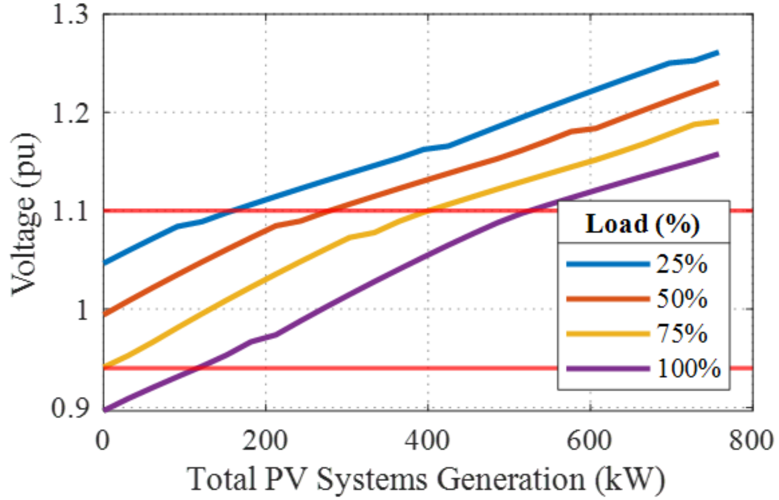
		P_{Gen} (kW)
Load (%)	25	170 (13% ↑)
	50	289 (7% ↑)
	75	411 (5% ↑)
	100	534 (3% ↑)

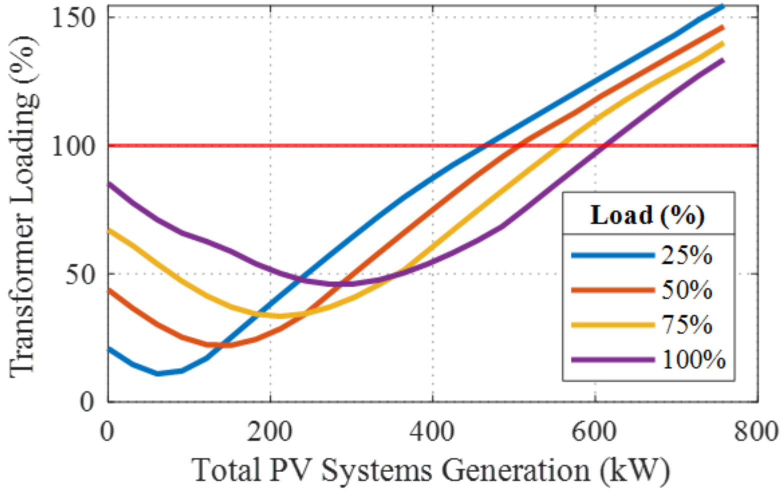




❖ **Half of PV inverters are smart**

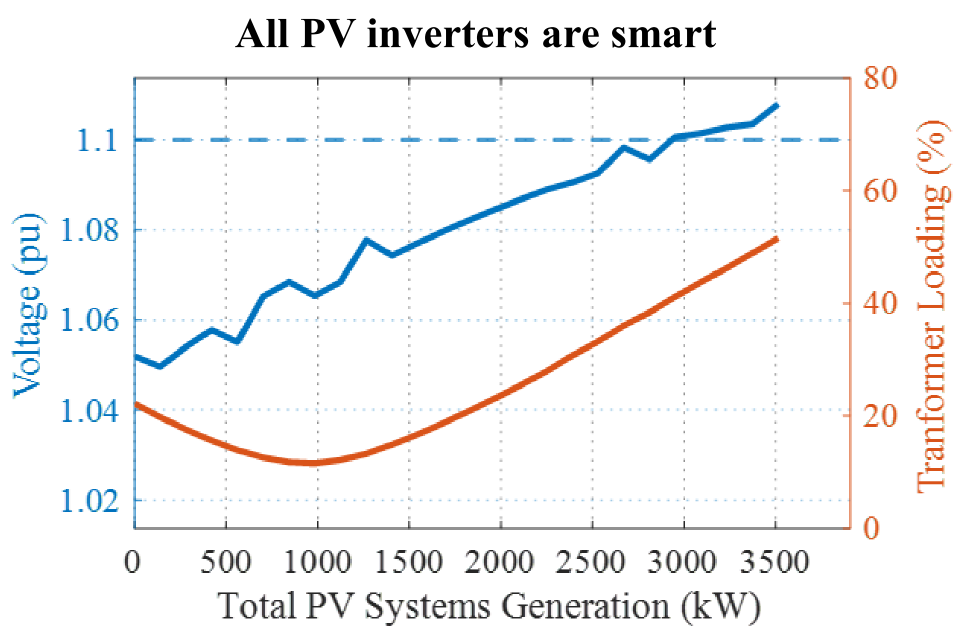
		P_{Gen} (kW)
Load (%)	25	159 (6% ↑)
	50	278 (3% ↑)
	75	400 (2% ↑)
	100	525 (2% ↑)

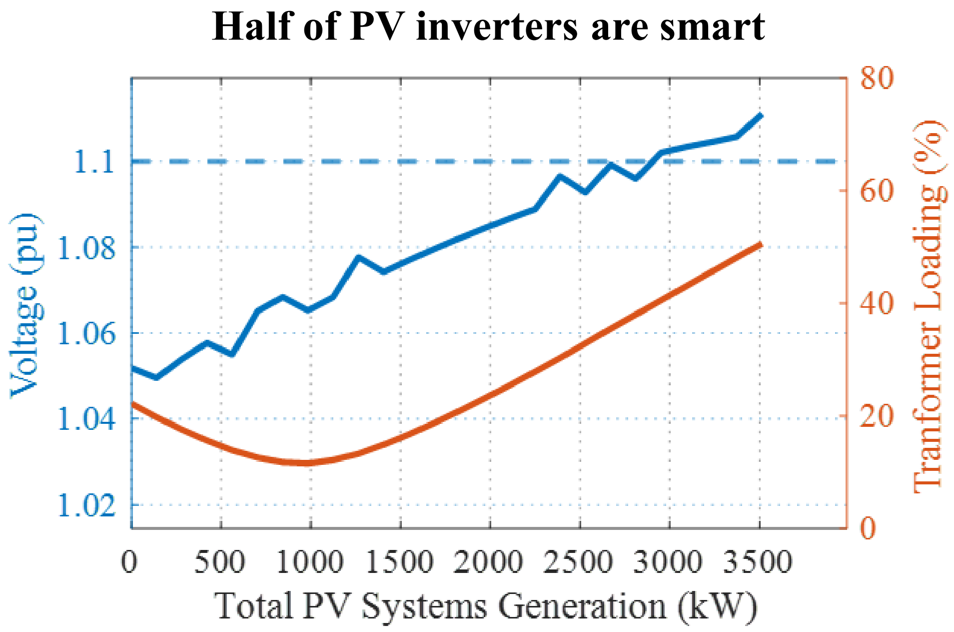




Volt/Var (Donald)

	P_{Gen} (kW)
All PV inverters are smart	2934 (10% ↑)
Half of PV inverters are smart	2905 (9% ↑)

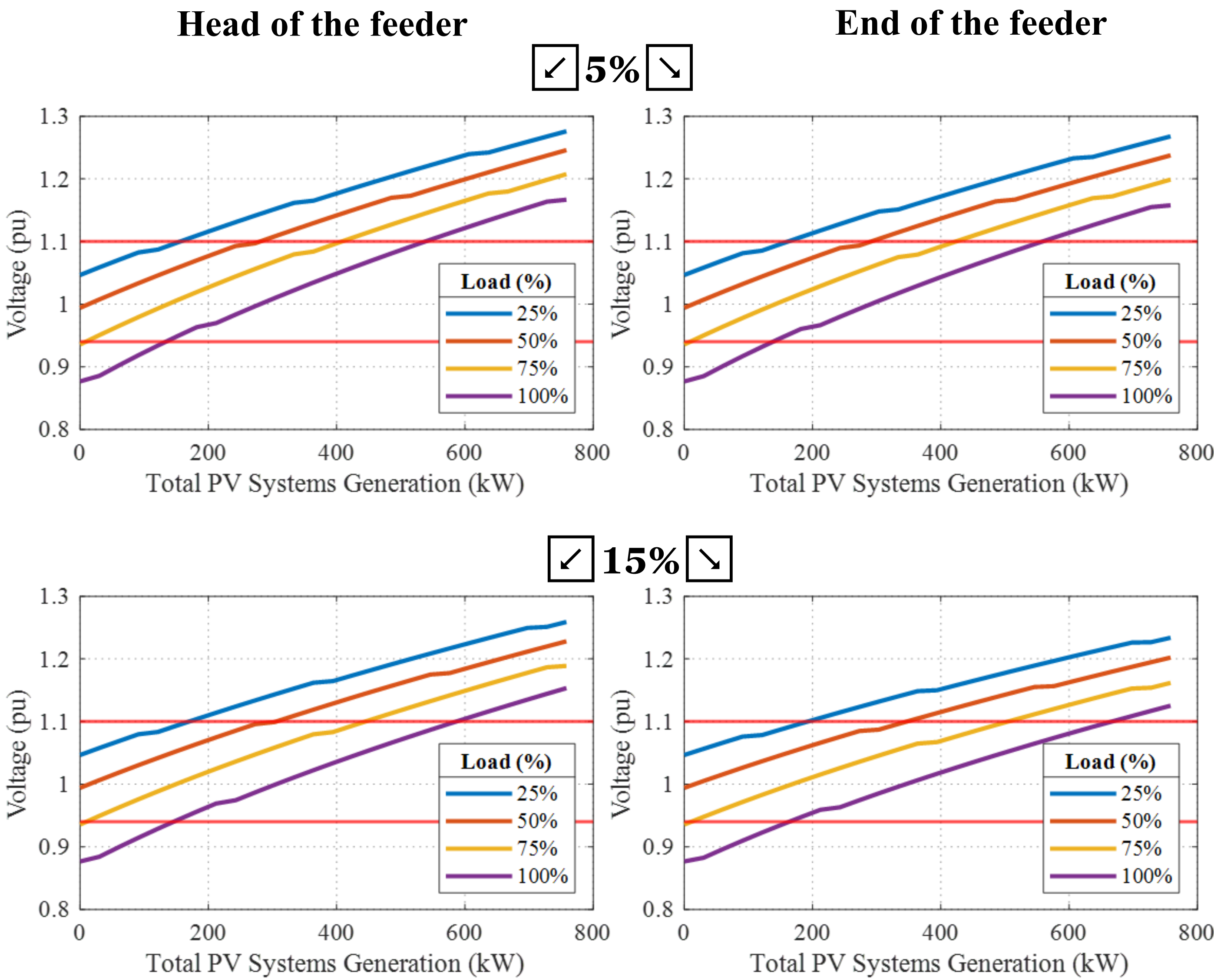




Community Battery (Tarnagulla)

Head of the feeder				
		P_{Gen} (kW)		
		Battery storage absorption ratio		
		5%	10%	15%
Load (%)	25	156 (4% ↑)	163 (8% ↑)	170 (13% ↑)
	50	281 (4% ↑)	293 (8% ↑)	306 (13% ↑)
	75	408 (4% ↑)	426 (9% ↑)	445 (13% ↑)
	100	538 (4% ↑)	562 (9% ↑)	586 (13% ↑)

End of the feeder				
		P_{Gen} (kW)		
		Battery storage absorption ratio		
		5%	10%	15%
Load (%)	25	162 (8% ↑)	176 (17% ↑)	192 (28% ↑)
	50	291 (8% ↑)	317 (17% ↑)	347 (29% ↑)
	75	423 (8% ↑)	460 (17% ↑)	505 (29% ↑)
	100	558 (8% ↑)	608 (18% ↑)	667 (29% ↑)

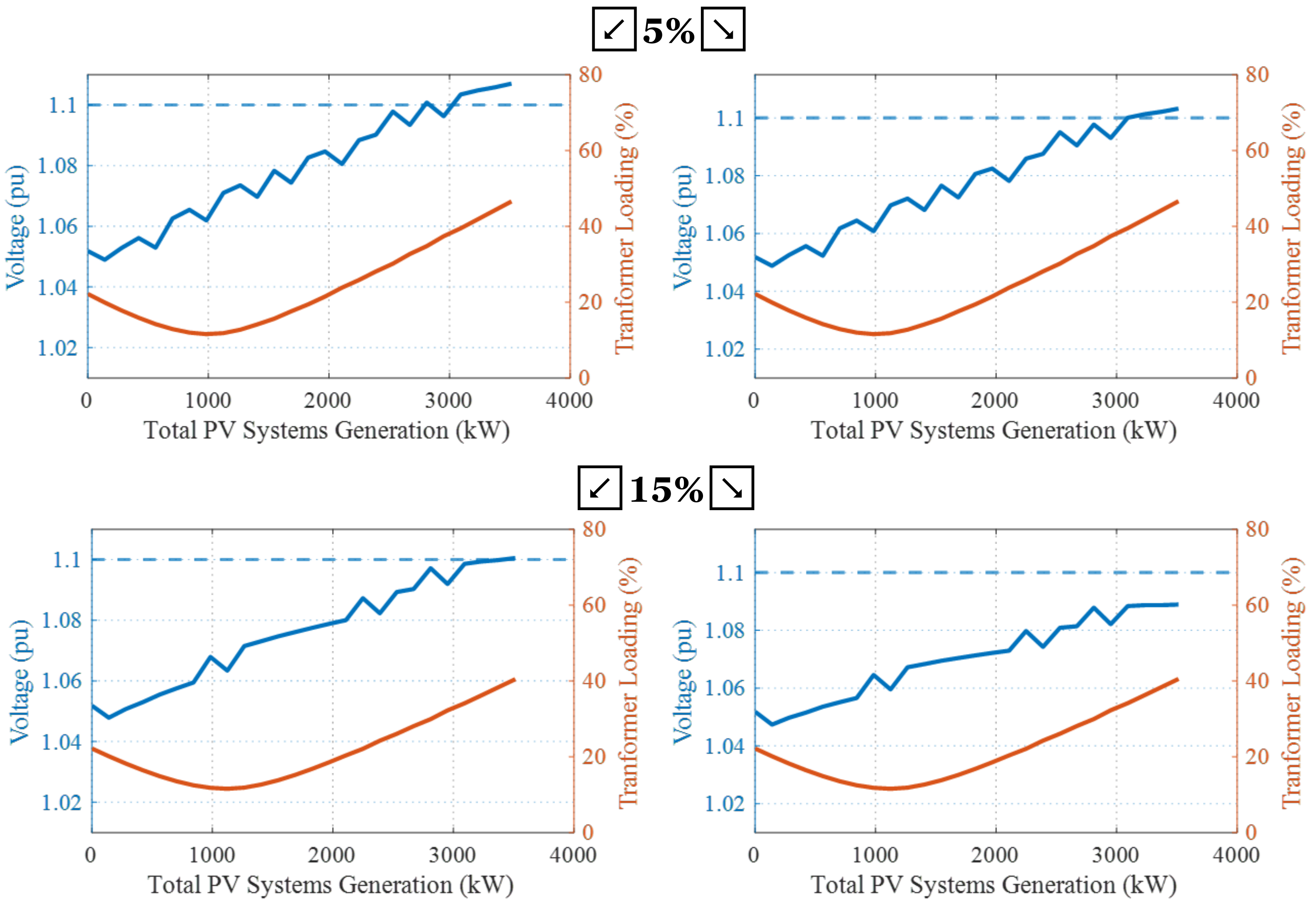


Community Battery (Donald)

Head of the feeder		
P_{Gen} (kW)		
Battery storage absorption ratio		
5%	10%	15%
2796 (5% ↑)	2950 (11% ↑)	3410 (28% ↑)

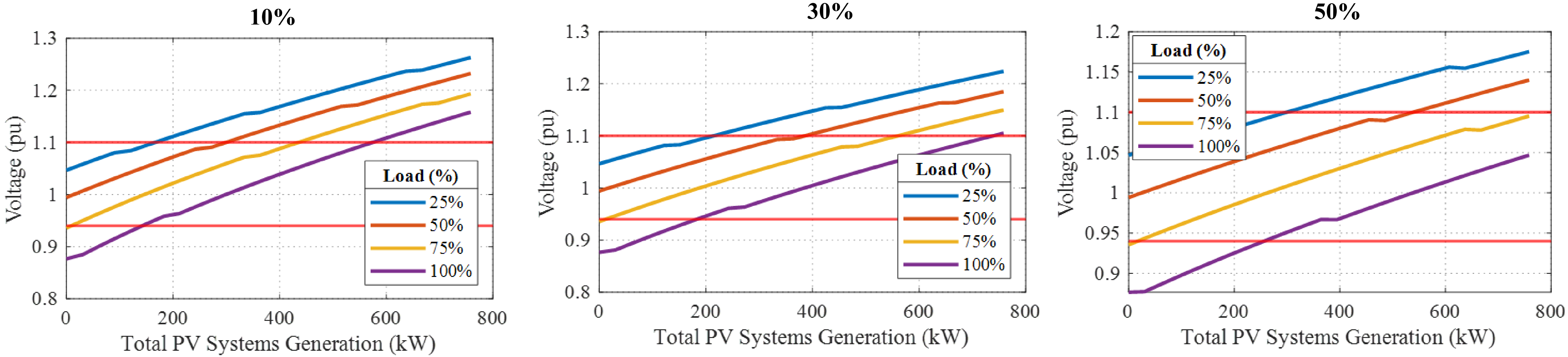
End of the feeder		
P_{Gen} (kW)		
Battery storage absorption ratio		
5%	10%	15%
3090 (16% ↑)	3469 (31% ↑)	3514 (32% ↑)

Head of the feeder **End of the feeder**



Residential Battery (Tarnagulla)

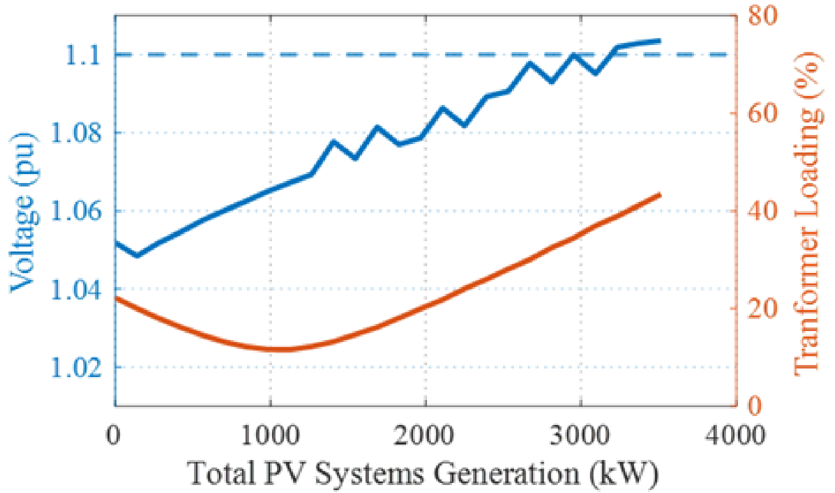
		P_{Gen} (kW)				
		Battery storage absorption ratio				
		10%	20%	30%	40%	50%
Load (%)	25	166 (11% ↑)	187 (25% ↑)	214 (42% ↑)	250 (66% ↑)	300 (100% ↑)
	50	300 (11% ↑)	337 (25% ↑)	385 (43% ↑)	449 (67% ↑)	540 (100% ↑)
	75	436 (11% ↑)	490 (25% ↑)	560 (43% ↑)	653 (67% ↑)	758* (93% ↑)
	100	574 (11% ↑)	646 (25% ↑)	738 (43% ↑)	758* (47% ↑)	758* (47% ↑)



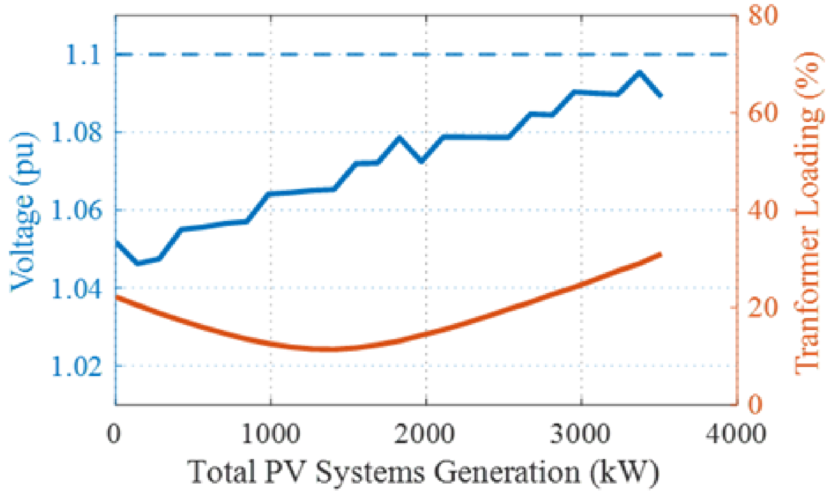
Residential Battery (Donald)

	P_{Gen} (kW)				
	Battery storage absorption ratio				
Storage Converter	10%	20%	30%	40%	50%
PV Generation	3194 (20% ↑)	3322 (25% ↑)	3514 (32% ↑)	3514 (32% ↑)	3514 (32% ↑)

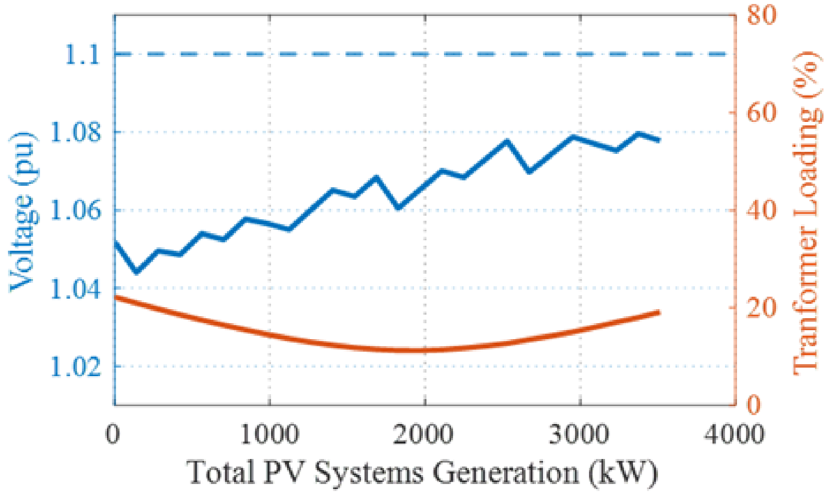
10%



30%



50%



Conclusion

- Changing MV/LV transformers' tap position can be effective, however it may negatively impact the capability of the grids for hosting loads.

- Equipping PV inverter with *volt/var* improves P_{Gen}. However, due to reactive power control, network losses and the occupied capacity of lines and transformers need to be taken into account. For example, for the Tarnagulla network, with the 25% load level, having *volt/var* control for half of PV systems, can improve P_{Gen} by 6%.

- Installing community batteries has been shown to more effective if they are installed at the end of the feeder. As an example, in the Donald network, having batteries at the end of each feeder with 10% absorption ratio can improve P_{Gen} by 31% in 25% load condition.

- Utilising residential batteries can be effective since the surplus generation can be absorbed locally. As an example, in the Tarnagulla network, having residential batteries with 30% absorption ratio can improve P_{Gen} by 42% in 25% load condition.

Thank You

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