Household Battery Network Impact Assessment

A/Prof. Brendan McGrath

School of Engineering

What's next...

Project Overview and Objectives

Background

- The Victorian government is providing a rebate on the Solar Homes Battery Program
    - 10,000 rebates over seven years ($40 million) to support installation of households solar battery systems
- Distribution Network Service Providers (DNSPs) have observed several issues:
    - Limited visibility over existing household batteries
    - Uncertainty around battery behaviour on the network
    - Uncertainty regarding technical requirements (e.g. inverter settings, pricing signals, etc.)

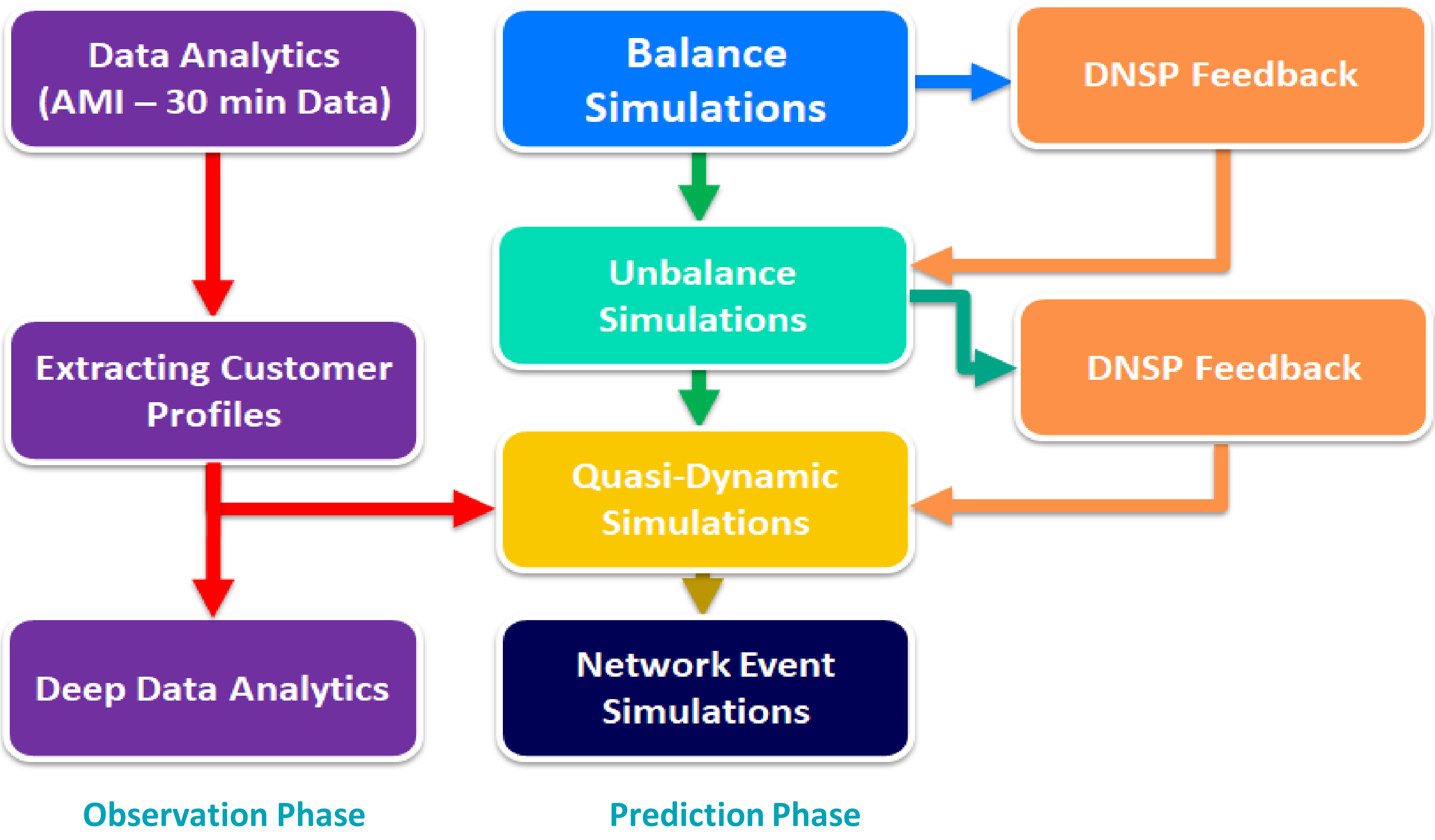
Objectives

- Identify distinct consumer behaviour profiles by applying data analytics to smart meter consumption patterns of households with installed batteries

- Understand the impact of household batteries on the distribution network under different scenarios (e.g. unbalance, daily fluctuation, seasonal factors, export constraints, etc.) by using simulations

- Provide evidence based policy guidance into household battery systems to maximise the potential benefits to both consumers and the distribution networks, and minimise potential adverse behavioural patterns

Methodology



Methodology – Data Analytics

- Consumption profiles provided by three DNSPs and two VPP operators
- Smart meter data (kWh - predominantly 30 mins resolution) from 2018 to 2020 (Pre-COVID19).

PV-Battery Customers

Distributor / VPP Operator	Number of customers	Period of time
Powercor	1130	01/05/2019 – 30/04/2020
Jemena	846	01/07/2018 – 30/06/2019
AusNet Services	321	01/07/2018 – 30/06/2020
Origin (VPP)	71	01/04/2020 – 31/08/2020
AGL (VPP)	10	01/09/2019 – 01/09/2020

- Pre-processing to detect battery installations
- Applied clustering algorithms (k-means) to identify representative behavioural patterns
- Clustering based on temperature zones and weekend/weekdays
- Comparative evaluation with base-line profiles for PV only and non-PV customers

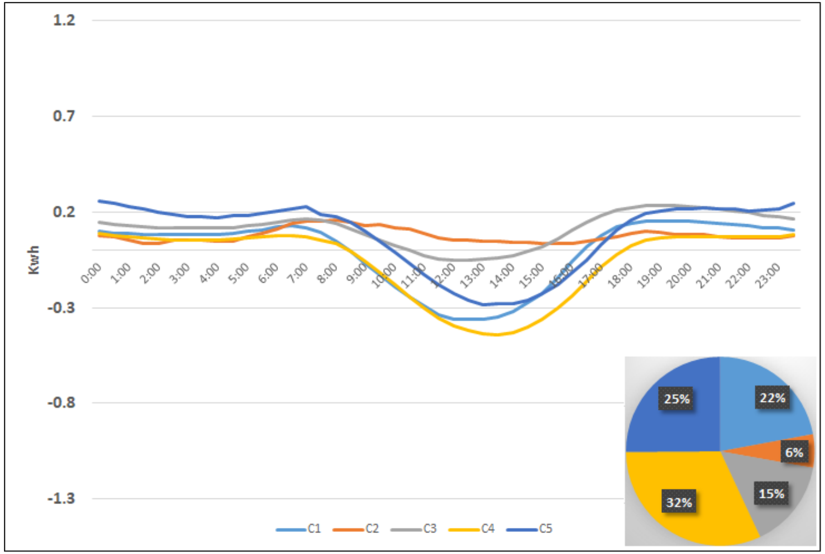
PV-only and Non-PV Customers

Distributor	Number of customers	Period of time
Powercor	1953 (with PV only)	01/01/2019 – 31/12/2019
Powercor	1044 (without PV)	01/01/2019 – 31/12/2019

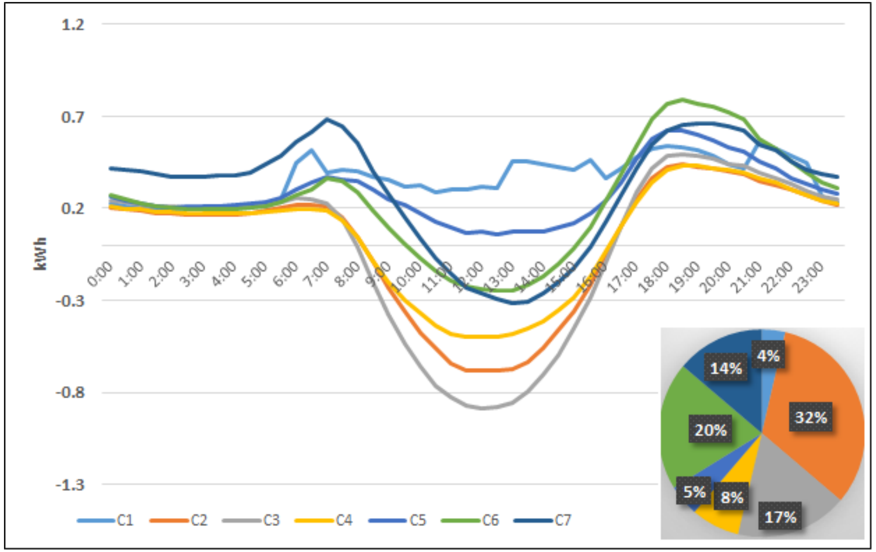
Data Analytics Results

Impact of battery on consumption profiles in cold days (weekdays)

- Informed by optimal clustering of net consumption profiles.
- At least a 20% reduction in power exports during the peak sun hours on cool and pleasant days
- Power imports during the evening peak (i.e. 18:00-22:00) are significantly reduced by at least 60%.
- There are less behavioural variations (less clusters) for Battery customers than those with PV only.



PV-Battery Customers

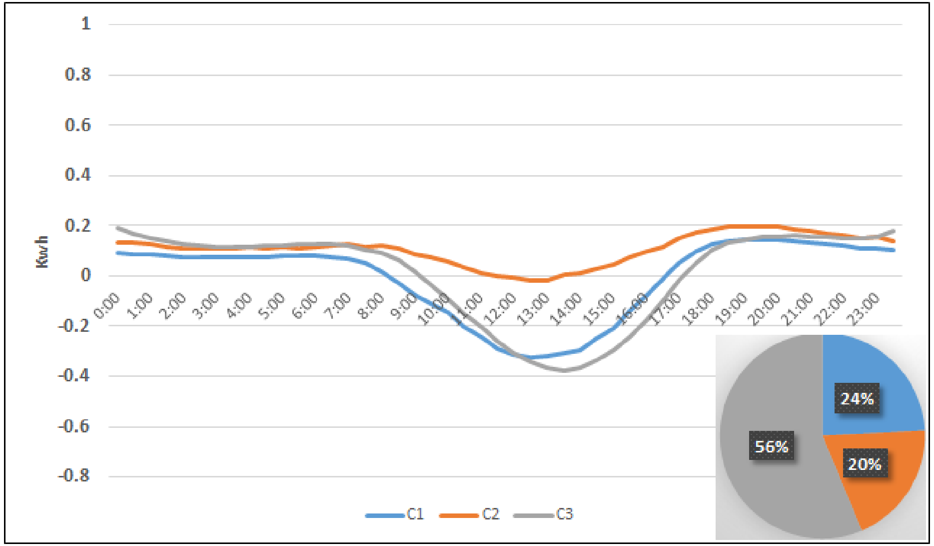


PV-only Customers

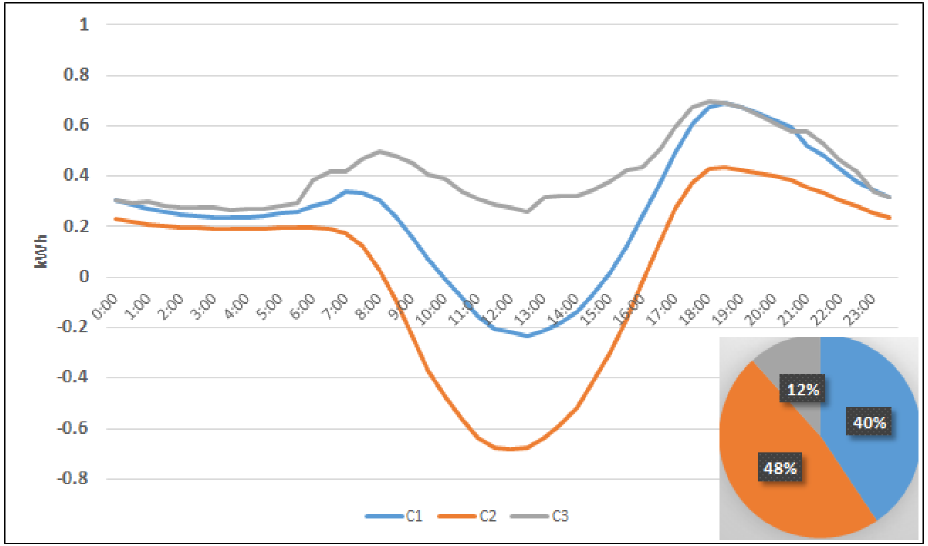
Data Analytics Results

Impact of battery on consumption profiles in cold days (weekends)

- Less variability compared to weekdays.
- Significant reduction in power exports during the peak sun hours
- Almost flat evening peak in battery customers.



PV-Battery Customers

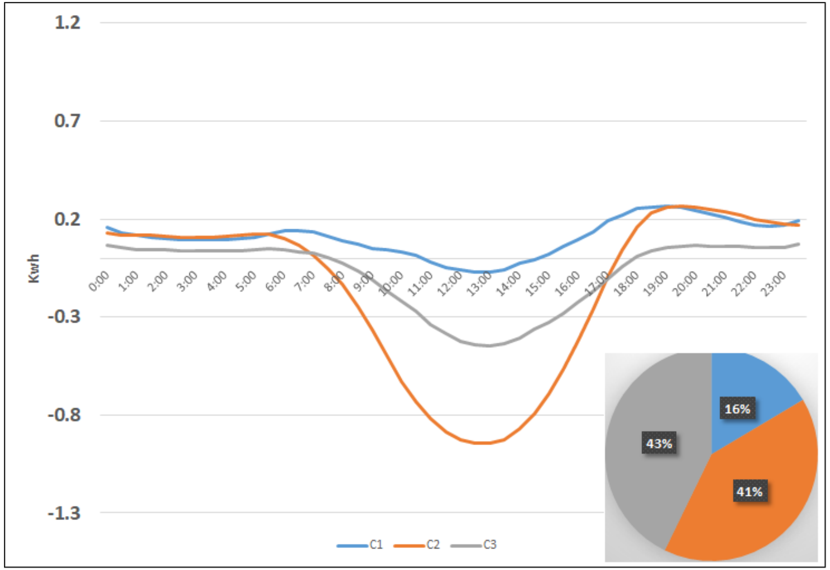


PV-only Customers

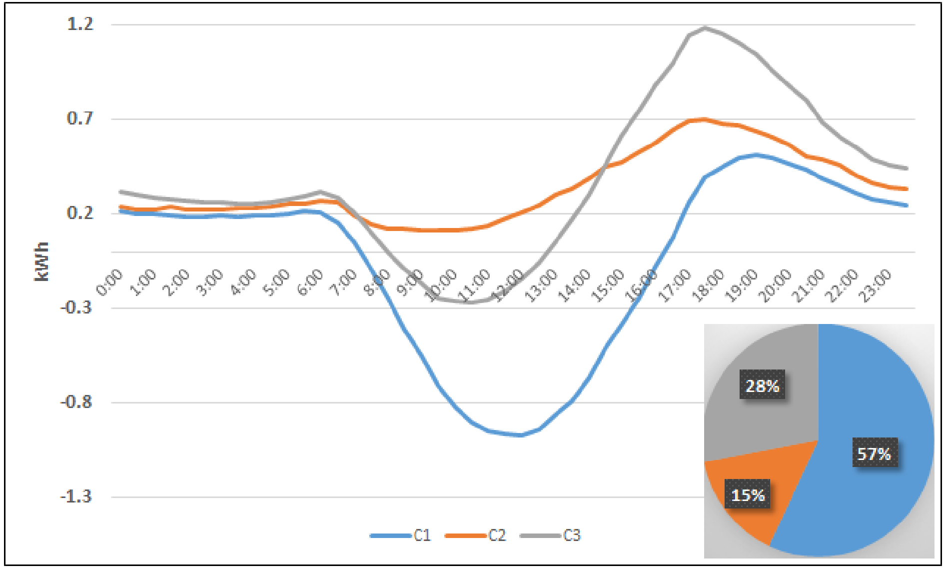
Data Analytics Results

Impact of battery on consumption profiles in hot days (weekdays)

- Less cluster size compared to cold days (i.e. households behave more similarly in hot days).
- 79% of battery customers showed considerably more power export in the peak sun hours compared to PV customers (likely due to larger PV sizes and fast charging).
- Still, the evening peak consumption is significantly reduced.



PV-Battery Customers

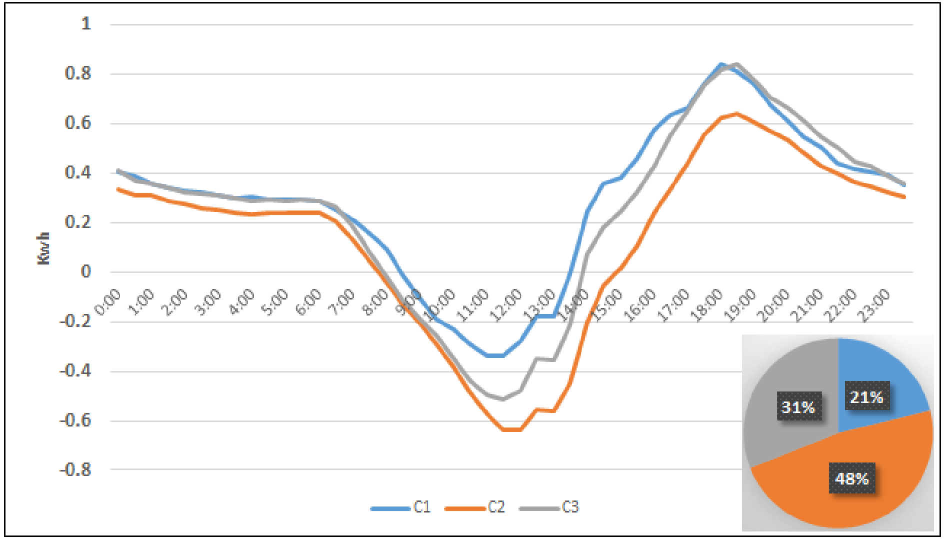


PV-only Customers

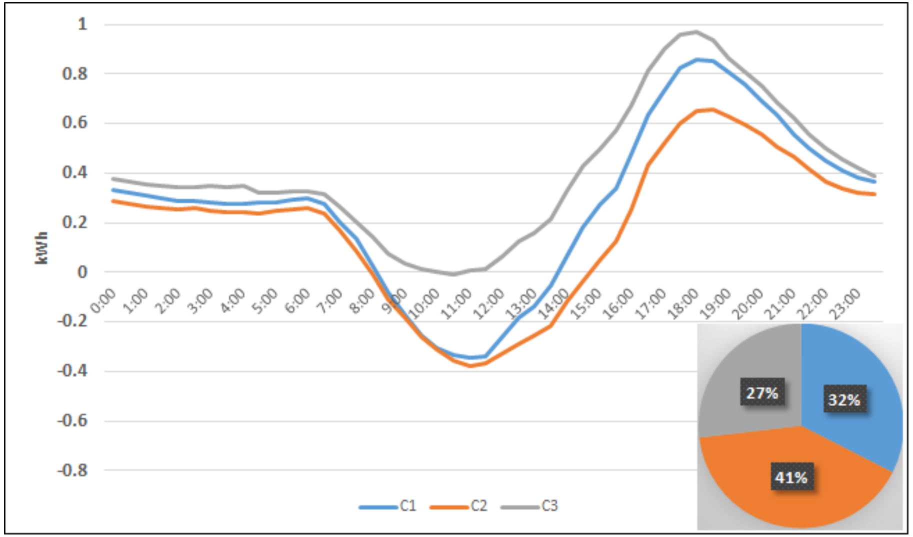
Data Analytics Results

Impact of battery on consumption profiles in hot days (weekends)

- Similar to weekdays, battery customers export more than PV ones during peak sun hours.
- The average peak export is less than weekdays (more household consumption).
- Evening peak consumption is only slightly less in battery customers than those with only PV.



PV-Battery Customers

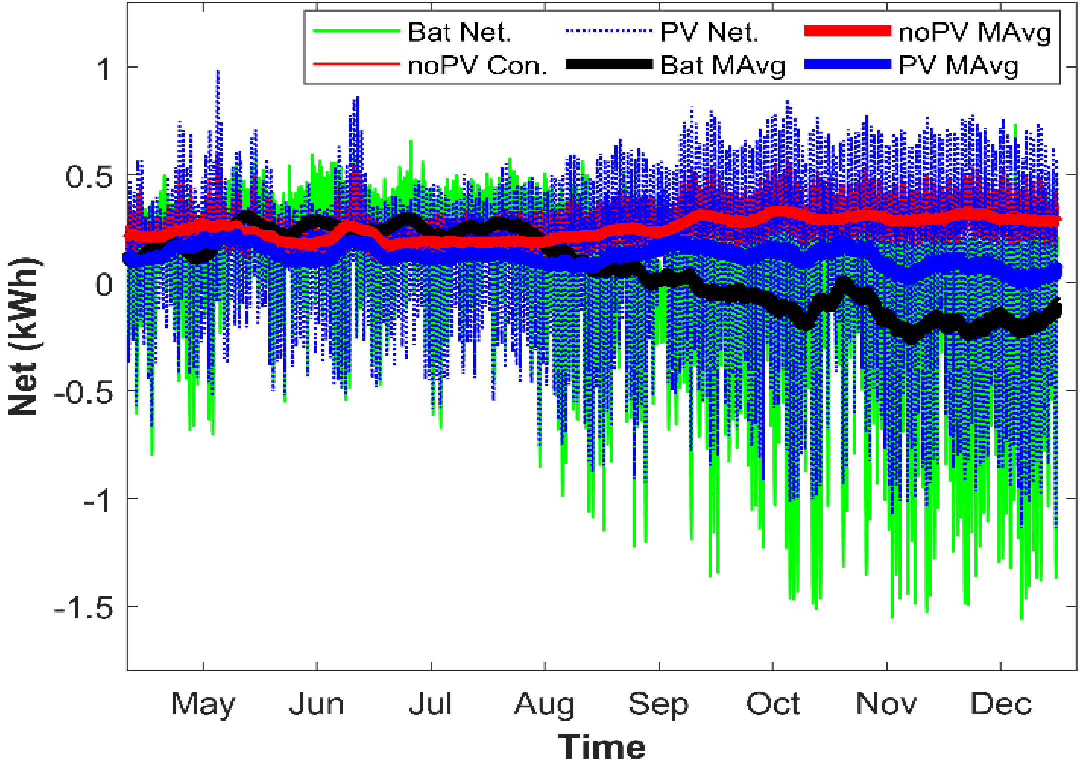


PV-only Customers

Data Analytics Results

Average (daily) consumption/export profiles

- Battery customers export significantly more on hot days (likely due to larger PV sizes).
- Solution: limiting the PV size, introducing incentives for slow charging and/or considering community battery in feeder level to mitigate voltage rise issues.

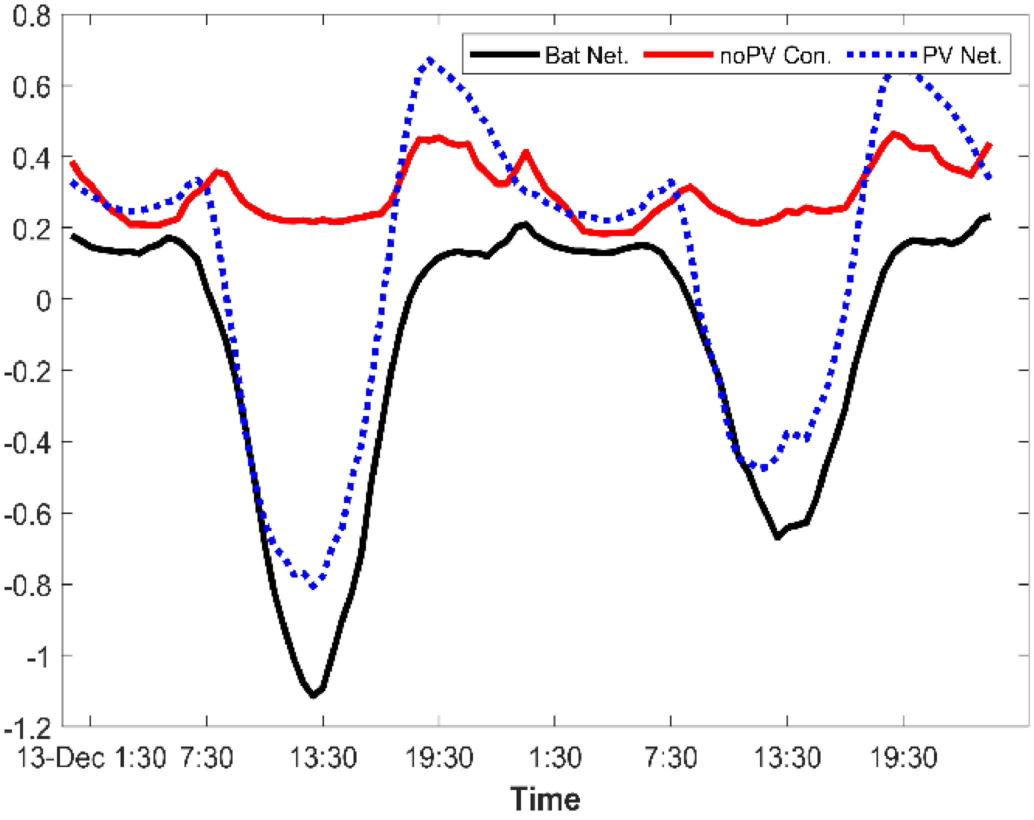


Net energy consumption of Battery, PV and Non-PV consumers

Data Analytics Results

Average net consumption in typical hot days

- Average profile of customers (13th and 14th Dec 2019)
- Flattened morning and afternoon peak in households with battery
- More export in peak sun hours in battery customers (possibly due to larger PV sizes)
- More consumption in PV customers than non-PV in after sun hours (mechanism is not clear)



Data Analytics: Key findings

Beneficial Battery Behaviour

- Household batteries reduce PV export by at least a 20% in cool weather, mitigating the side-effects of rooftop PV generation, and potentially enhances hosting capacity.
- Peak evening power imports for households with batteries (i.e. 18:00-22:00) are significantly reduced (60%) due on mild temperature days.

Adverse Battery Behaviour

- The peak export from most customers with household batteries (approx. 79%) during hot weather increases compared to PV only (approx. doubled). Possibly due to over-sizing PV systems in battery installations, and rapid battery charging in the morning.

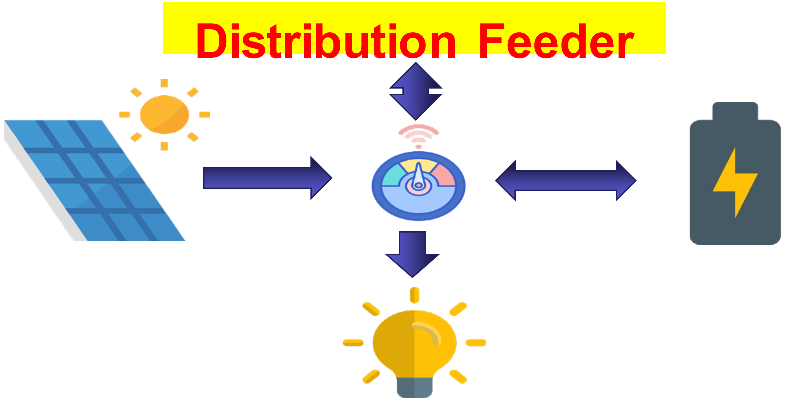
Network Simulation Studies - Overview

- **Balanced Network Simulations –** Network simulations are conducted using a balanced network LV feeder (the customer load on each phase is the same) to understand the voltage performance and loading profile of the LV feeder for the entire feasible operating range for consumers/prosumers and to set the base line cases for the simulation investigations to follow
- **Unbalanced Network Simulations –** In this case, networks with a different number of consumers on each phase (phase connection unbalance) are simulated to characterize the impact on voltage unbalance with battery system installations
- **Quasi Dynamic Simulations** – 24-hour dynamic simulations are conducted with the customer net load profiles extracted from the data analytics phase of the project and the unbalanced network models, to understand the network impact at different times of the day with batteries in customer premises

Balanced Network Simulations

- The following configuration was assumed for a customer having a solar-PV and a battery system

Solar-PV Inverter: 5 kW Active Power and 5.5 kVA rating

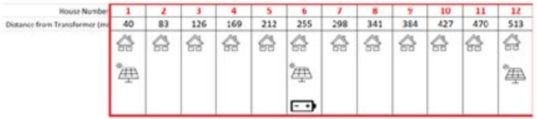


Battery inverter: 5 kW Active Power and 5.5 kVA rating

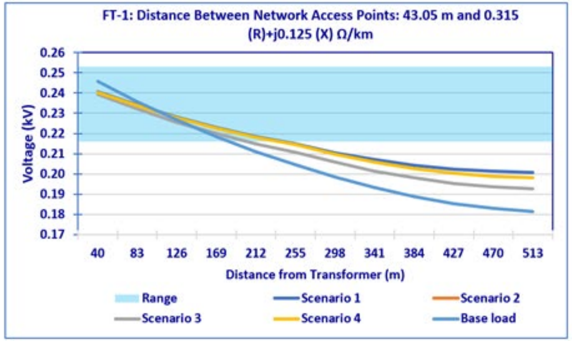
Active power	Power factor (pf)	Reactive power
Low load: 1.8 kW	0.95 lagging	0.59 kVAr
Medium load: 3.4 kW	0.95 lagging	1.12 kVAr
Heavy load: 8.4 kW	0.95 lagging	2.76 kVAr

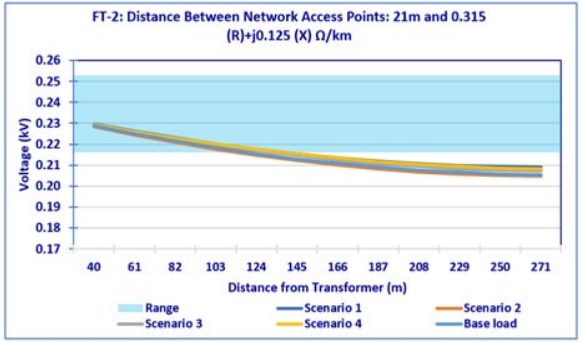
Network Simulation Results

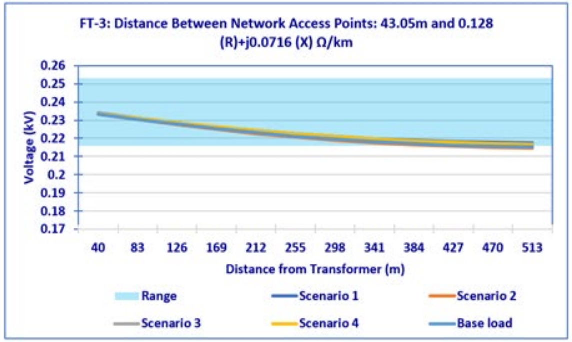
The voltage profiles for low load scenarios (customer load 8.4 kW)



Load: 8.4 kW	Scenario Description			
	Battery Charging		Battery Discharging	
Scenario Number	PV (kW)	Battery (kW)	PV (kW)	Battery (kW)
Scenario 1	5	-5		
Scenario 2	1	-5		
Scenario 3			0	5
Scenario 4			1	5



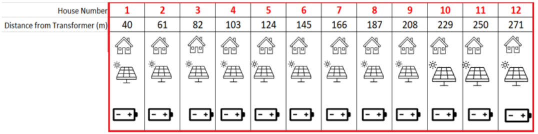




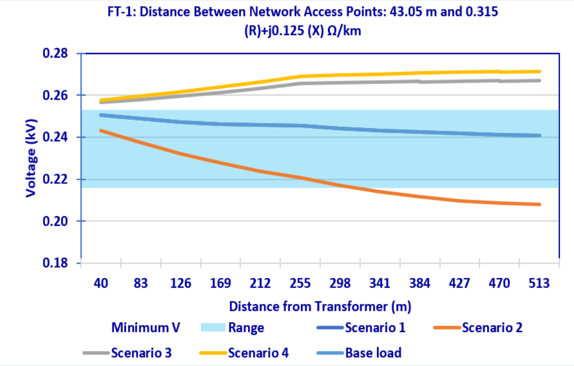
- Battery discharge has a positive effect on the distribution feeder voltage profile under peak load events.
- E.g. - On hot summer days (with high residential load peaks) household batteries can reduce the feeder voltage variation by 2% to 8.5%.
- Ameliorates outside limit voltage excursions (the limits are set to +10% and -6%).
- Voltage violations can also be mitigated by charging the batteries during high PV generation periods

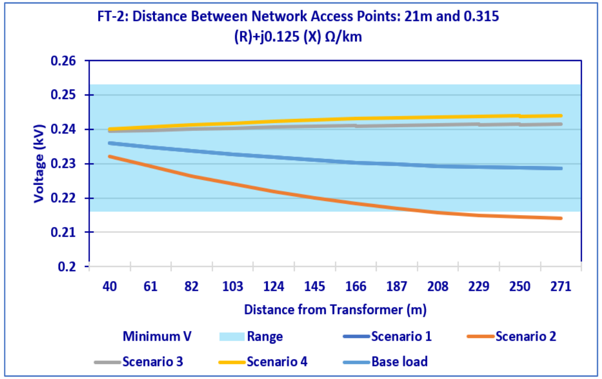
Network Simulation Results

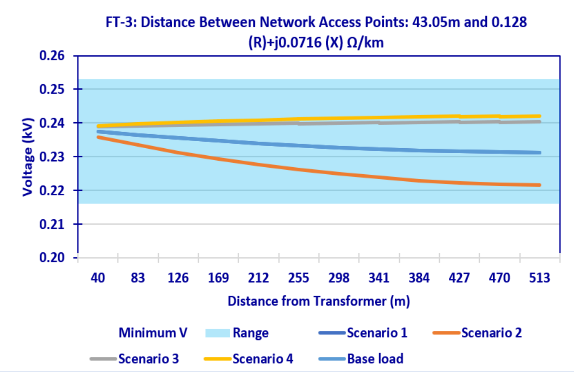
Voltage profiles for low load scenarios (customer load 3.4 kW)



Load: 3.4 kW	Scenario Description			
	Battery Charging		Battery Discharging	
Scenario Number	PV (kW)	Battery (kW)	PV (kW)	Battery (kW)
Scenario 1	5	-5		
Scenario 2	1	-5		
Scenario 3			0	5
Scenario 4			1	5

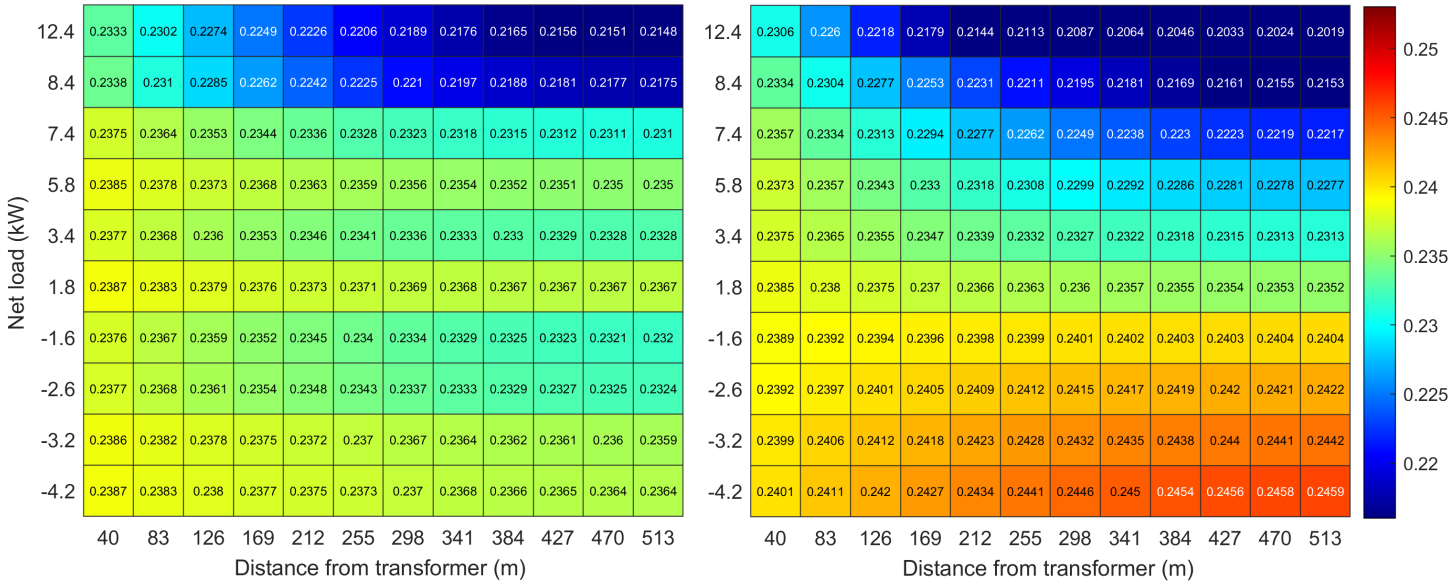






- The magnitude of the voltage variation in feeders due to solar and battery installations is strongly coupled to the feeder cable impedance properties.
- A large penetration of household batteries can enable a flatter voltage profile to be achieved in the low voltage distribution feeder under high rooftop solar generation, provided that the battery charging regime is coordinated with the solar production.

Balanced Network Results

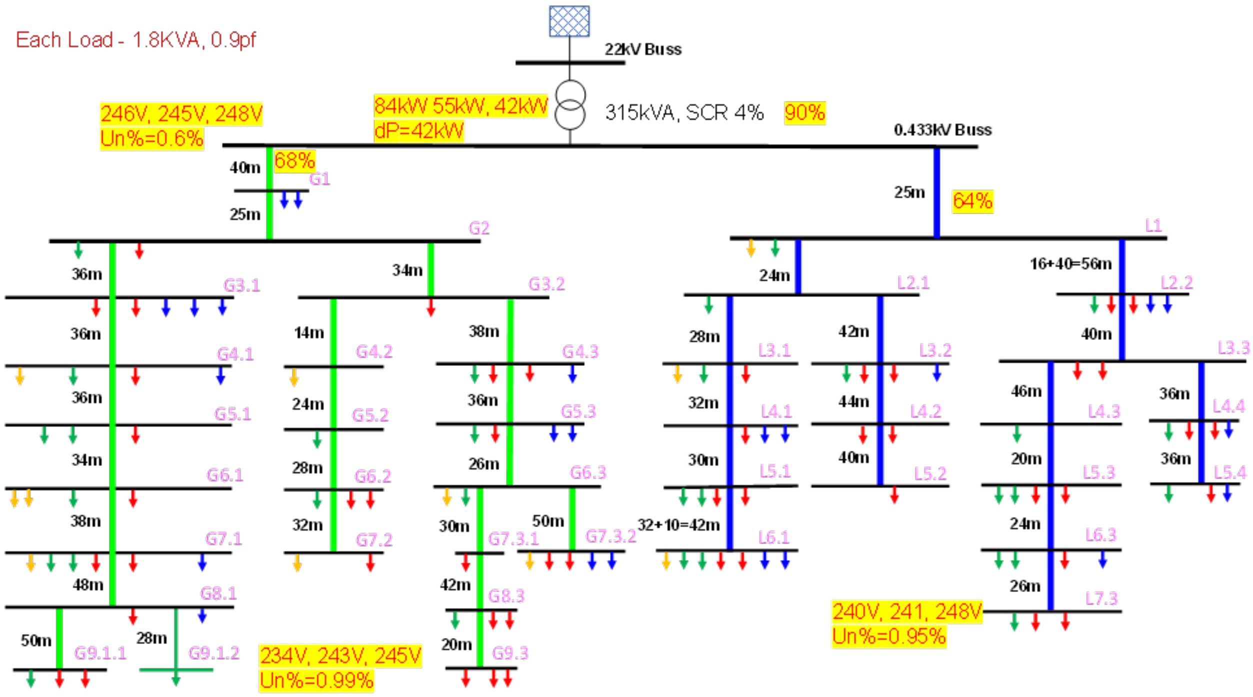


Low battery penetration **High battery penetration**

- Customers **at the end of LV distribution feeders may experience large voltage excursions** resulting from PV import from other households and/or charging and discharging patterns of the other household batteries. These customers may be prioritised in offering battery incentives.

Unbalanced Network Simulations

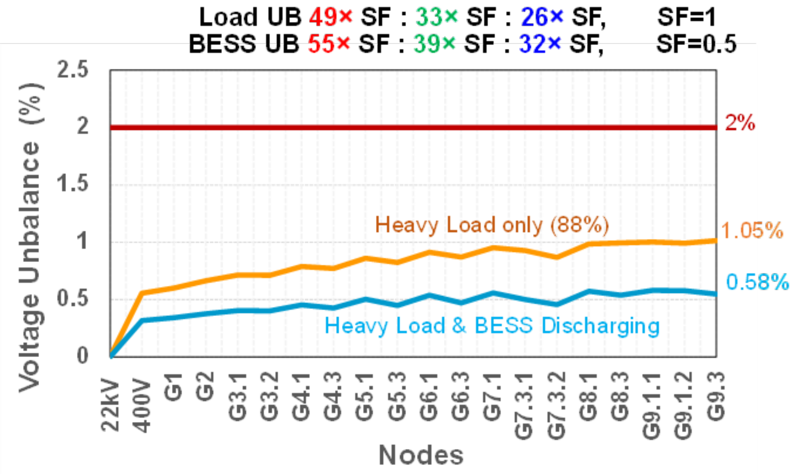
Practical Distribution Network



- This network comprises 42 nodes, 109 customers and 307m of feeder length. The customers' connection on the phases are highly unbalanced, where the number of single-phase customers on Phase A, B, and C are 46, 30, and 23, respectively.

Unbalanced Simulation Results

Unbalanced Simulation Results for IS: battery UB 55:39:32 and OS: battery discharging.



Ph-A : Ph-B : Ph-C
TF Load: 84 : 56 : 42 kW
TF ΔP: 42 : 28 : 14 kW
TF ΔP: 17 : 11 : 6 %
BESS Penetration: 0% of TF

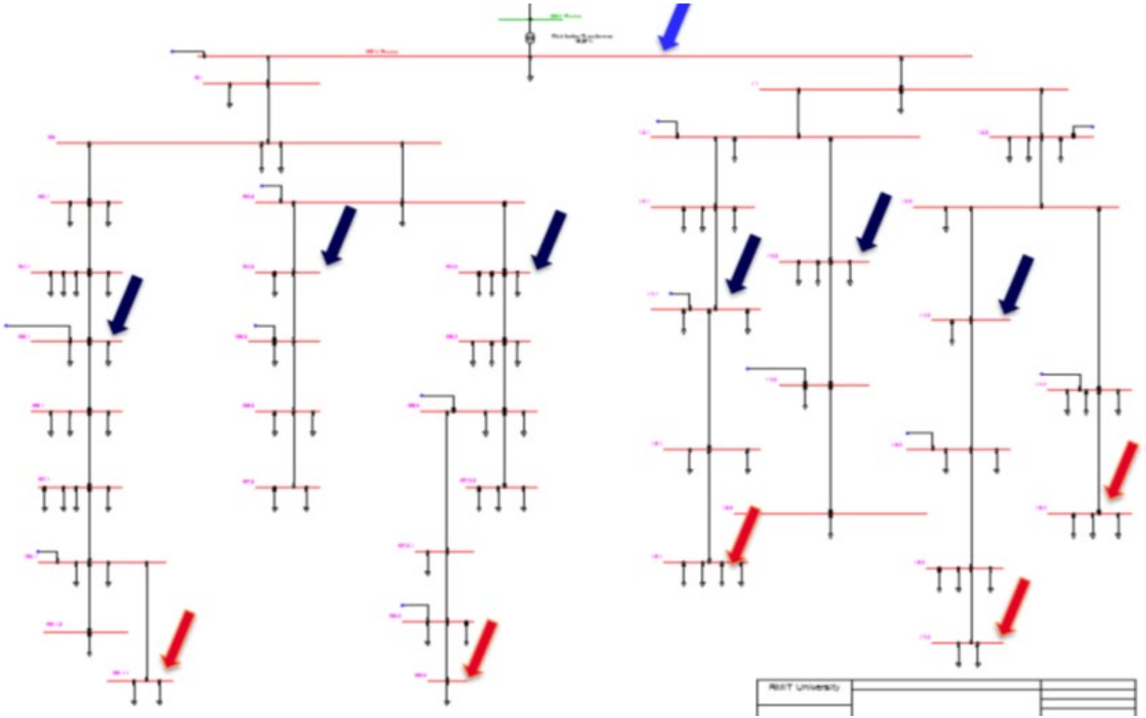
Ph-A: Ph-B : Ph-C
BESS P : -137 : -97 : -80 kW
BESS ΔP : 57 : 40 : 17 kW
TF Load: -47 : -42 : -24 kW
TF ΔP: 15 : 10 : 5 kW
TF ΔP: 6 : 4 : 2 %
BESS Penetration: -125% of TF

- Unbalanced simulation models showed the ability of household batteries to improve the voltage unbalance factor in distribution networks that contain significant imbalance of customer connections across the phases can be constrained by the thermal ratings of the upstream transformers.

- This inhibits the coordination of battery charging regimes under **heavier loading scenarios to mitigate the unbalanced feeder loading**. The simplest strategy to address this problem is for the DNSPs to balance customer connection points, or alternatively to establish special time-of-use pricing strategies for household batteries.

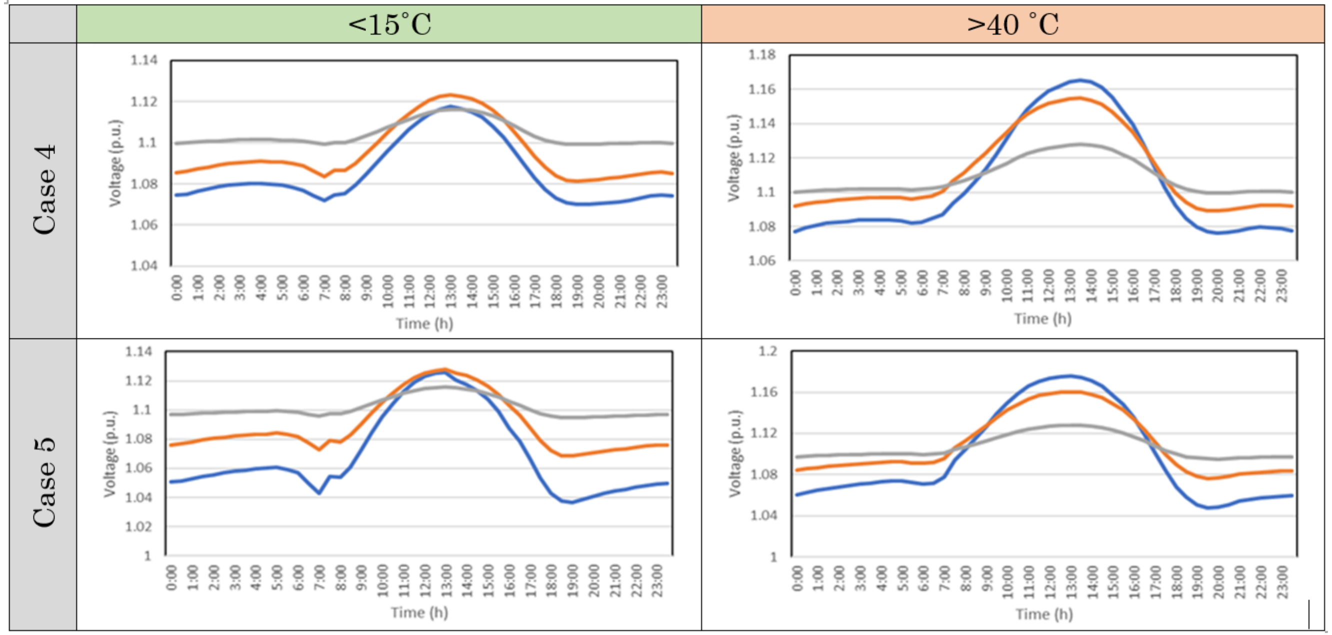
Quasi Dynamic Simulations

Practical Distribution Network and the analysed buses.



- The practical network considered in the unbalanced simulations is adopted.
- Loads modified according to the load profiles derived through the data analytic studies
- Leads to customer peak loading conditions of around (3 – 3.5 kW)
- Bias effect of controlled water heating loads in the non-PV and PV only load data was eliminated by removing offset step in the load profiles

Quasi Dynamic Simulation Results



Voltage profile at the middle point

❑Case 4: 66% PV & Battery , 33% PV Only

❑Case 5: 33% PV & Battery , 66% PV Only

- Quasi-dynamic simulation models showed that batteries could reduce overvoltage limit excursion at the solar illumination peak (midday) by lowering the worst-case feeder voltage by 3% on average. This enables the voltage gradient across the feeder to be minimised which increases the hosting capacity for distributed energy resources.

Network simulation: Key findings

Beneficial Network Impact from Batteries

- Battery discharge behaviour during peak load events can reduce the feeder voltage profile variation by as much as 2% to 8.5% (voltage limits are +10%/-6%). This is a potential control mechanism for DNSPs.
- High battery penetration enables a flatter voltage profile to be achieved with high PV generation if the battery charging regime is coordinated. Similarly the effect of unbalanced customer connections is also mitigated with household batteries.

Adverse Network Considerations

- End-point feeder customers are very sensitive to voltage excursions from PV generation and/or battery charging/discharging from other households. Similarly the type of network (urban/rural) has a significant impact on the sensitivity.
- With unbalanced customers the thermal ratings of the feeder can constrain the ability of batteries to mitigate voltage unbalance during high load and charging scenarios.

Recommendations

- Mechanisms may be required to encourage battery charging/discharging behaviours that support the LV network (e.g. charging during high solar illumination periods & discharging during the evening peak).
- Slow charging of batteries during hot weather may be needed to suppress the high peak export of PV/battery customers. Further study regarding the size of PV systems with battery installations would also be beneficial to understand the high export effect.
- Distribution feeder end points need careful management to avoid large voltage variations. Larger batteries at these locations may provide support.
- Aggregate battery control may provide a mechanism to alleviate high PV export. This could take the form of virtual power plants or community batteries.
- PV and battery penetration levels are evolving. Planned monitoring, analytics assessments and matching simulation investigations to quantify customer behaviour. Additional parameters such as State of Charge would indicate battery utilisation levels.

Acknowledgments

We highly appreciate C4NET, DELWP, Solar Victoria, AusNet Services, Jemena, UE/Citipower/Powercor, AGL and Origin energy for their contributions during the project.

Research Team

- A/Prof. Brendan McGrath, Dr. Ali Moradi, Dr Mahdi Jalili, Dr Lasantha Meegahapola, Dr Arash Vahidnia, Dr Inam Nutkani, Dr Manoj Datta, Dr Anima Ganeshan, Mr Nameer Al Khafaf, Mr Ahmad Asgharian Rezaei, Mr Moudud Ahmed, Dr Kazi Hasan and Dr Reza Razzaghi