Asia Pacific Solar Research Conference 2023

Investigating the impact of electric hot water load control on low-voltage distribution networks

What's next…

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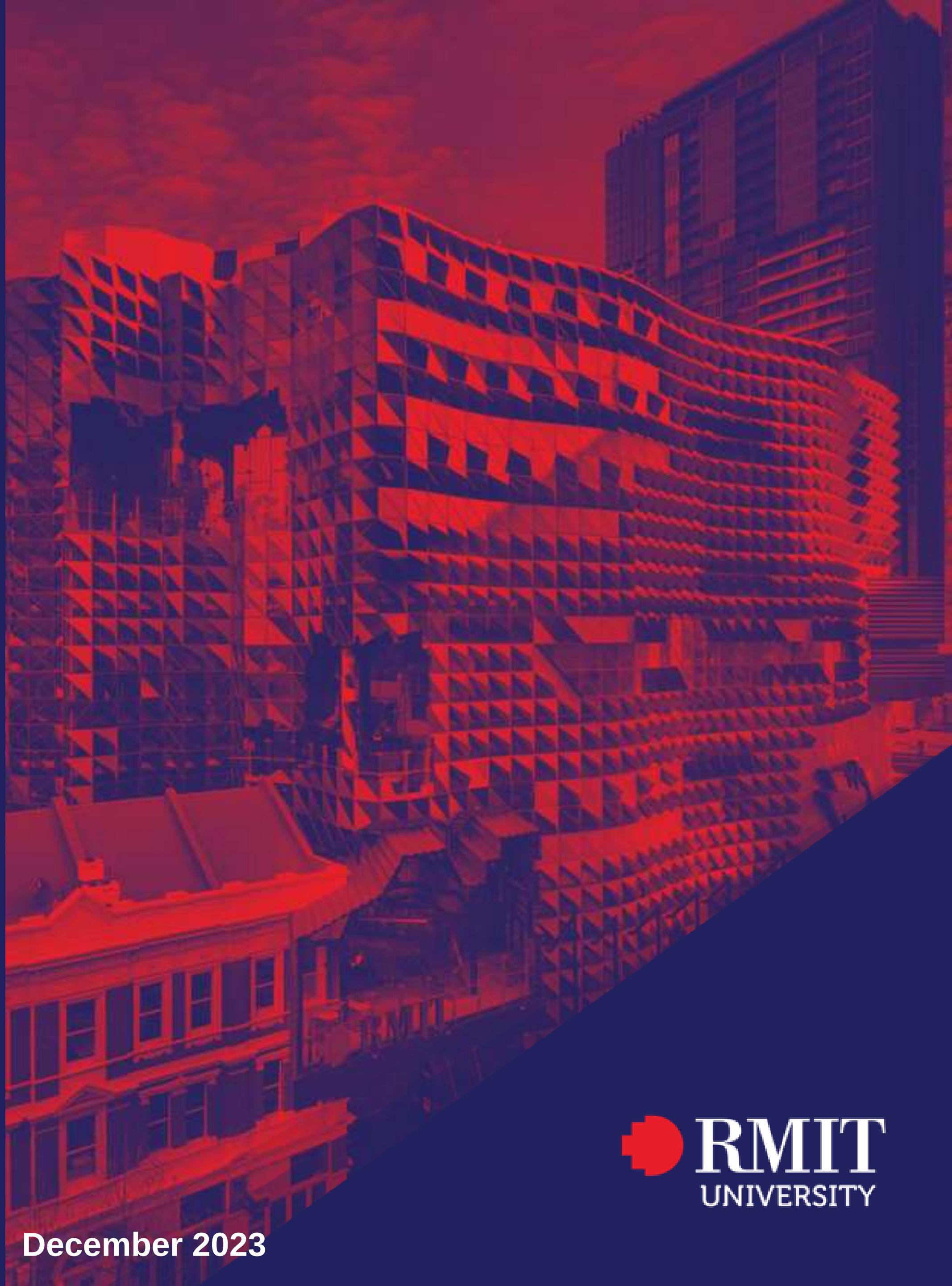

RMIT UNIVERSITY

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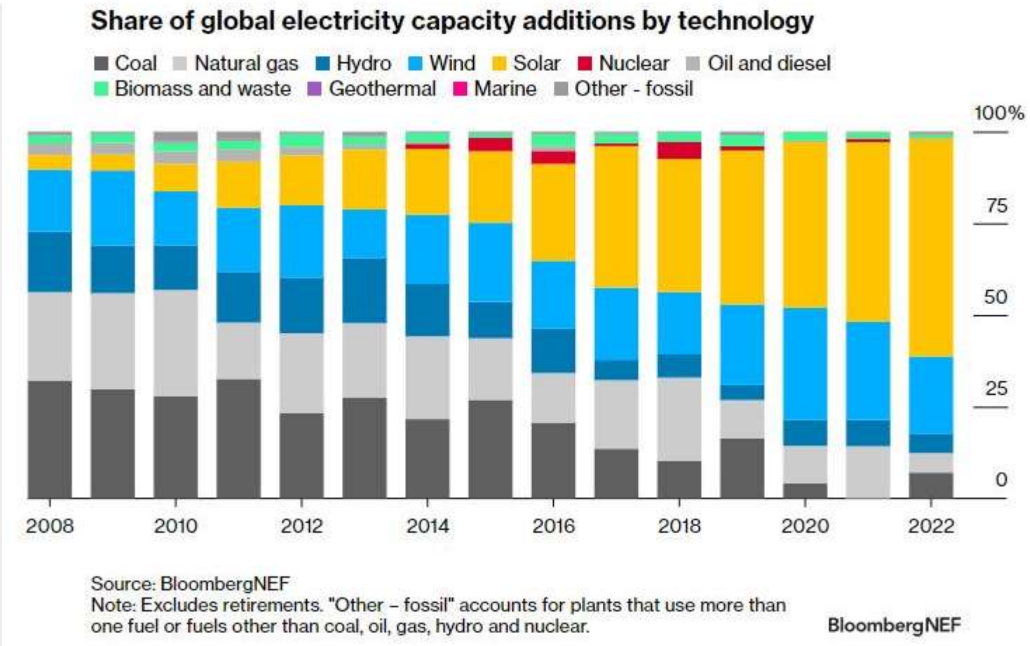
Introduction



- Climate change awareness and impacts → diversification of power generation sources
- Increase in RE, Transport electrification and electrification of other services intensify the loads on electrical networks
- NSPs invest in added grid reinforcement due to voltage/frequency impacts associated with increased loads and RE gen.

Introduction

No.	Strategy	Benefits	Limitations	Ref.
1.	Batt. Energy Storage System (BESS)	Reliability	High upfront capital	[1]
2.	Spinning Reserve Capacity	Reliability	High upfront capital; Ramp rates; Fuel costs	[2]
3.	Active Power Curtailment	Reliability	High upfront capital	[2]

Table 1. Conventional Strategies

No.	Strategy	Benefits	Limitations	Ref.
1.	Electric Vehicles/V2G	Peak load shaving	Further studies on eval. Methods needed	[3-4]
2.	Heat Pumps/Water Heating	Elect. Storage; low. consumer costs	Thermo-electrical sims; Real-time comms	[5-7]

Table 2. Demand Response Strategies

[1] R. Sinha, B. B. Jensen and J. Radhakrishnan Pillai, "Impact Assessment of Electric Boilers in Low Voltage Distribution Network," *2018 IEEE Power & Energy Society General Meeting (PESGM)*, Portland, OR, USA, 2018, pp. 1-5, doi: 10.1109/PESGM.2018.8586236
[2] T. Chen, Y. Zheng, B. Chaudhuri and S. Y. R. Hui, "Distributed Electric Spring Based Smart Thermal Loads for Overvoltage Prevention in LV Distributed Network Using Dynamic Consensus Approach", IEEE Transactions on sustainable energy, 2020, Vol. 11, Issue 4, pp.2098-2108, DOI: 10.1109/TSTE.2019.2950421
[3] Swinson, V., J. Hamer, and S. Humphries, "Taking demand management into the future: Managing flexible loads on the electricity network using smart appliances and controlled loads",. *Economic Analysis and Policy*, 2015, Vol. 48, pp. 192-203.
[4] Clift, D.H., et al., "Assessment of advanced demand response value streams for water heaters in renewable-rich electricity markets", *Energy*, 2023. Vol. 267, pp. 126577
5] Navarro-Espinosa, A. and P. Mancarella, "Probabilistic modeling and assessment of the impact of electric heat pumps on low voltage distribution networks", Applied Energy, 2014, Vol.127, pp. 249-266
[6] Angelim, J.H. and C. de M. Affonso, "Probabilistic Impact Assessment of Electric Vehicles Charging on Low Voltage Distribution Systems", *IEEE*, pp.1-6
[7] Clift, D.H. and H. Suehrcke, "Control optimization of PV powered electric storage and heat pump water heaters", *Solar Energy*, 2021, Vol. 226, pp. 489-500

Motivation

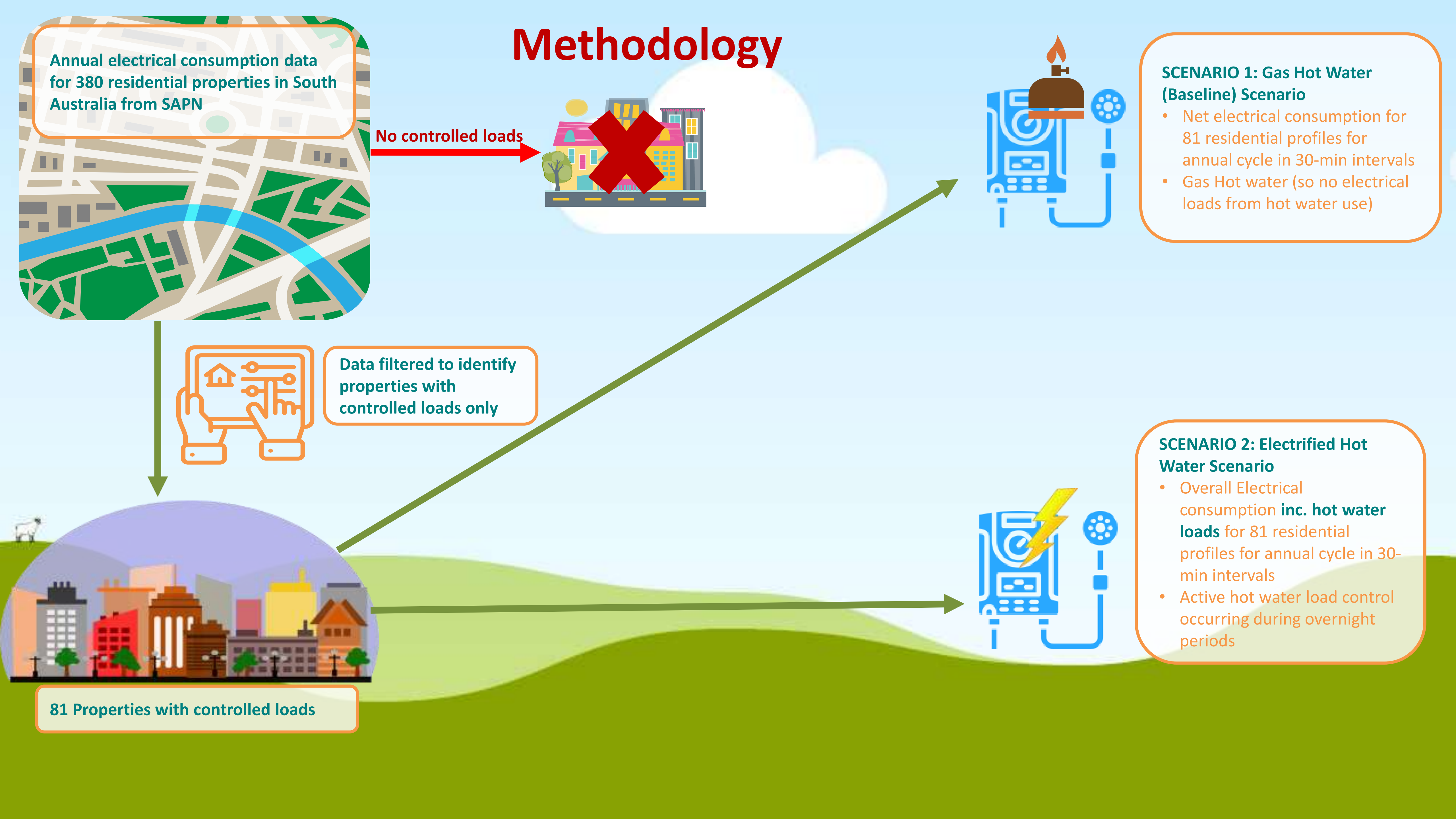
- Most studies focus on EV impacts to network and heat pumps.
- Despite approx. 25% of domestic loads owed to hot water, limited studies on impact of EWH on low-voltage networks.
- Current EWH is limited to applying conventional demand-response strategies and do not consider load control operating sympathetically with network

Objectives

Aim: To investigate and compare the impacts of gas hot water vs electrified hot water systems on low voltage distribution networks

- Continuation of previous studies that investigated the consumer benefits of using smart load control strategies on thermally stratified electric water heaters

- Focus on next stage to assess impact of EWH load control on voltage profiles of low voltage distribution networks


Methodology
Annual electrical consumption data for 380 residential properties in South Australia from SAPN
No controlled loads
Data filtered to identify properties with controlled loads only
81 Properties with controlled loads
SCENARIO 1: Gas Hot Water (Baseline) Scenario
• Net electrical consumption for 81 residential profiles for annual cycle in 30-min intervals
• Gas Hot water (so no electrical loads from hot water use)
SCENARIO 2: Electrified Hot Water Scenario
• Overall Electrical consumption inc. hot water loads for 81 residential profiles for annual cycle in 30-min intervals
• Active hot water load control occurring during overnight periods

Methodology Cont'd

SCENARIO 1: Gas Hot Water (Baseline) Scenario

- 81 residential (with net electrical consumption) profiles allocated to 307 buses for load flow simulation

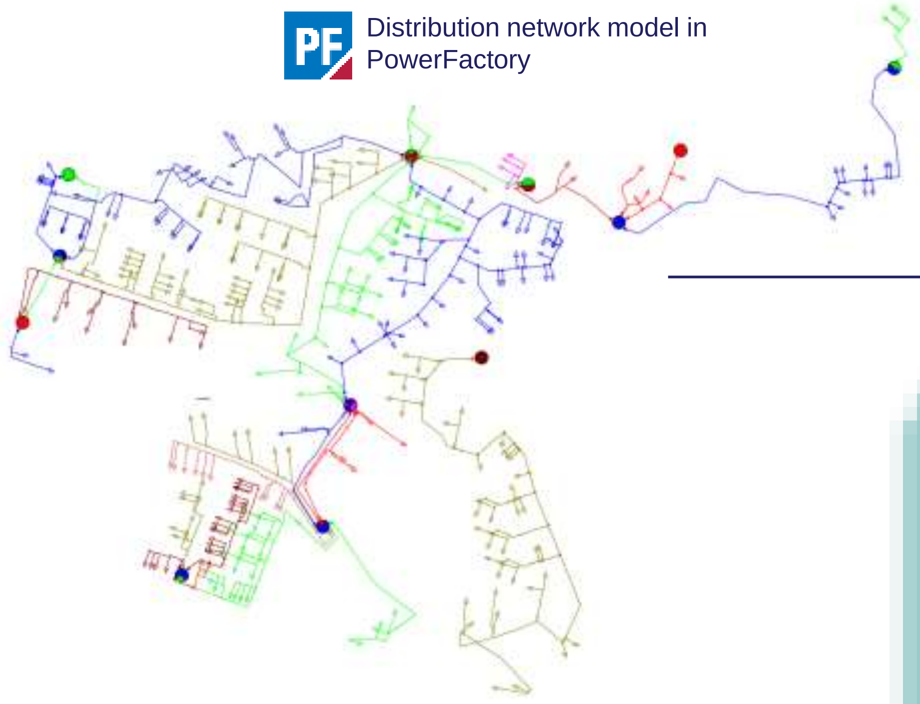
SCENARIO 2: Electrified Hot Water Scenario

- **Active hot water load control occurring during overnight periods**
- 81 profiles (with total/overall elect. consumption) allocated to 307 buses **in same configuration as baseline scenario** for load flow simulation

Low-Voltage Network Characteristics

- 0.4kV Network derived from larger-model power network in PF, adjusted to smaller size – 546 buses.
- Load-flow simulation performed producing voltage profiles for each bus for annual cycle for each scenario.

Distribution network model in PowerFactory



Bus voltage profiles from PowerFactory processed in MATLAB

MATLAB Results Processing

- Voltage profiles showed voltage magnitudes in per unit (p.u.)
- Critical bus identified in each scenario and corresponding voltage
- Monthly and hourly critical bus voltage profiles processed in box plots.

Results & Discussion

What's next...

Results & Discussion

Monthly Critical Bus Voltage Comparison for Two Scenarios

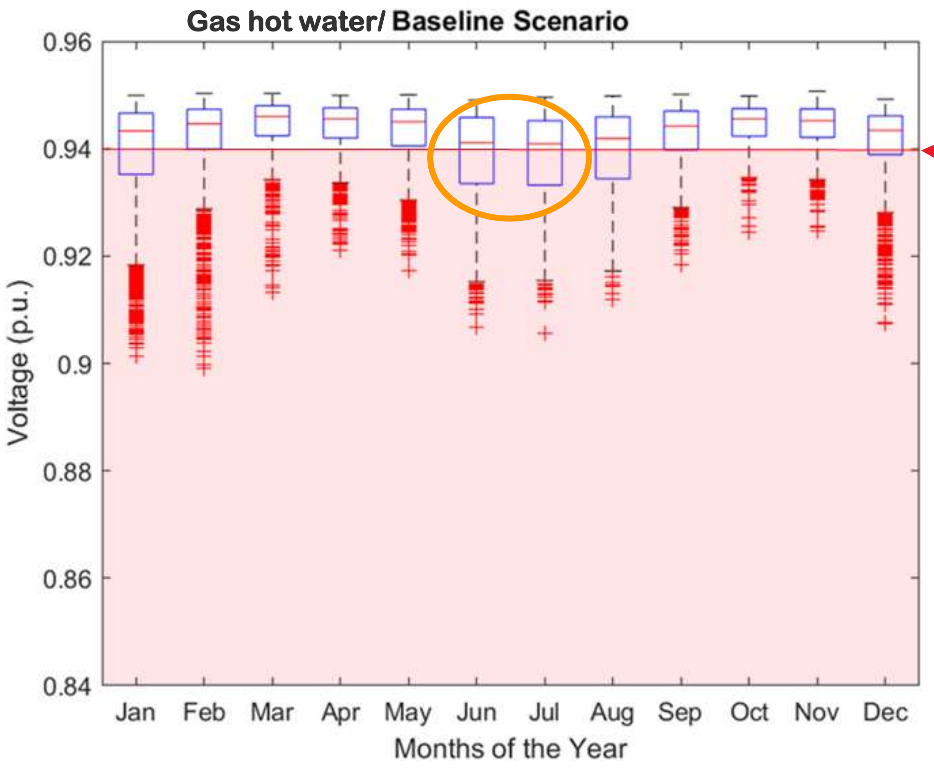


Fig. 1 Monthly critical bus voltage profile for Baseline (Gas Hot Water) Scenario

0.94 p.u. Min. acceptable operating voltage in Australian distrib. networks

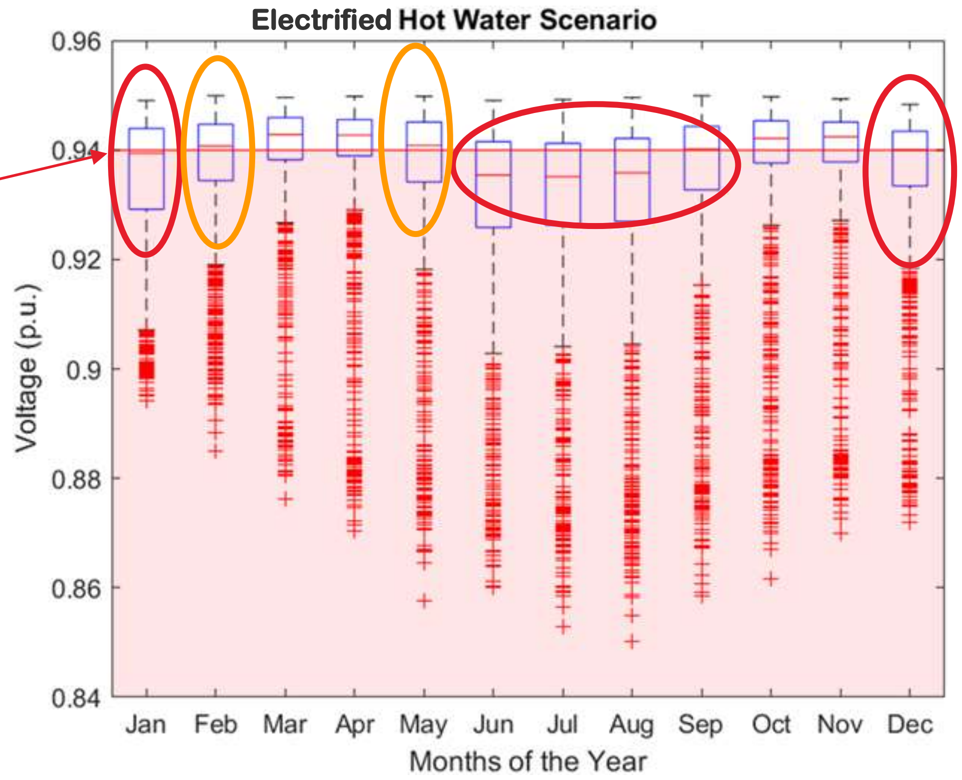


Fig. 2 Monthly critical bus voltage profile for Electrified Hot Water Scenario

- No voltage violation limit but **June and July most at risk**.
- Wide interquartile ranges **esp. during winter/summer**.
- Neg. skewed voltage distribution showing **dangerously low voltage levels overall even before hot water electrification**

- Even **lower critical bus voltage profiles** than Base case with wider interquartile ranges.
- **Jun – Sept., and Dec. – Jan.** show median values that violate voltage limit. **Feb & May** show medians just above 0.94 p.u. limit.

Results & Discussion

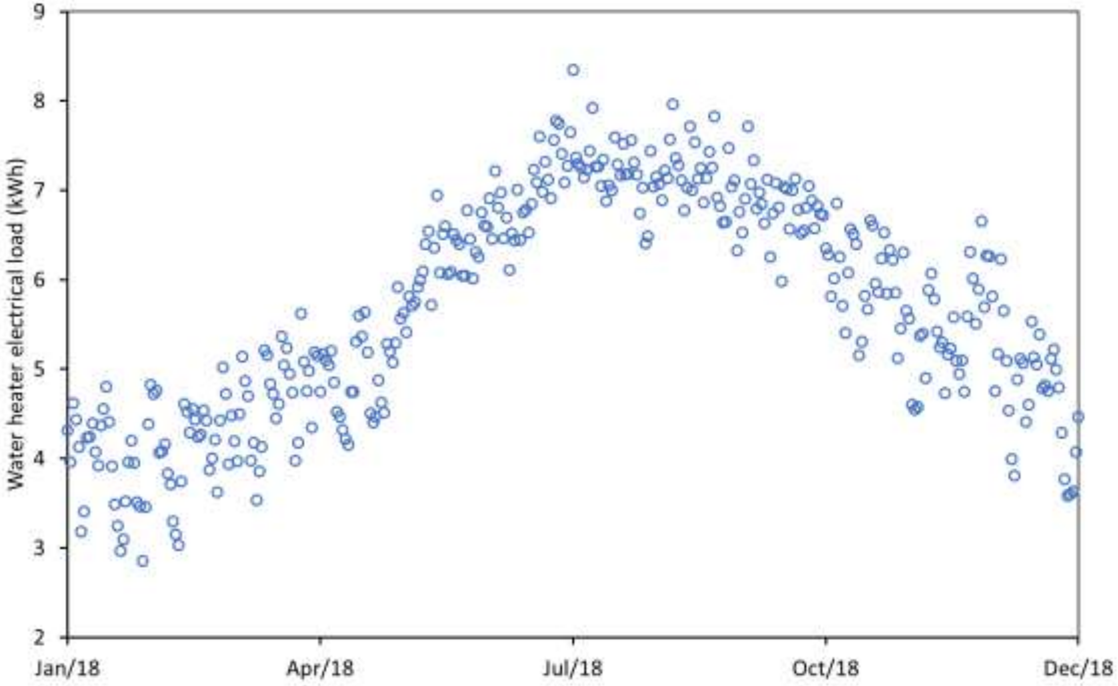


Fig. 3 Average electric hot water consumption from 81 SAPN households

- Average hot water electrical consumption extracted from SAPN residential data for the 81 households. Fig. 3 shows significant increases in elect. Hot water consumption as winter approaches.

- Critical bus voltage profile comparison between the 2 scenarios demonstrate seasonal impact on water heating loads, mainly driven by lower temp. of cold water during cooler seasons.

- Expected that larger thermal load in winter will exacerbate the seasonal voltage excursions on the critical bus → demonstrated in the electrified hot water scenario.

Results & Discussion

Hourly Critical Bus Voltage Comparison for Two Scenarios

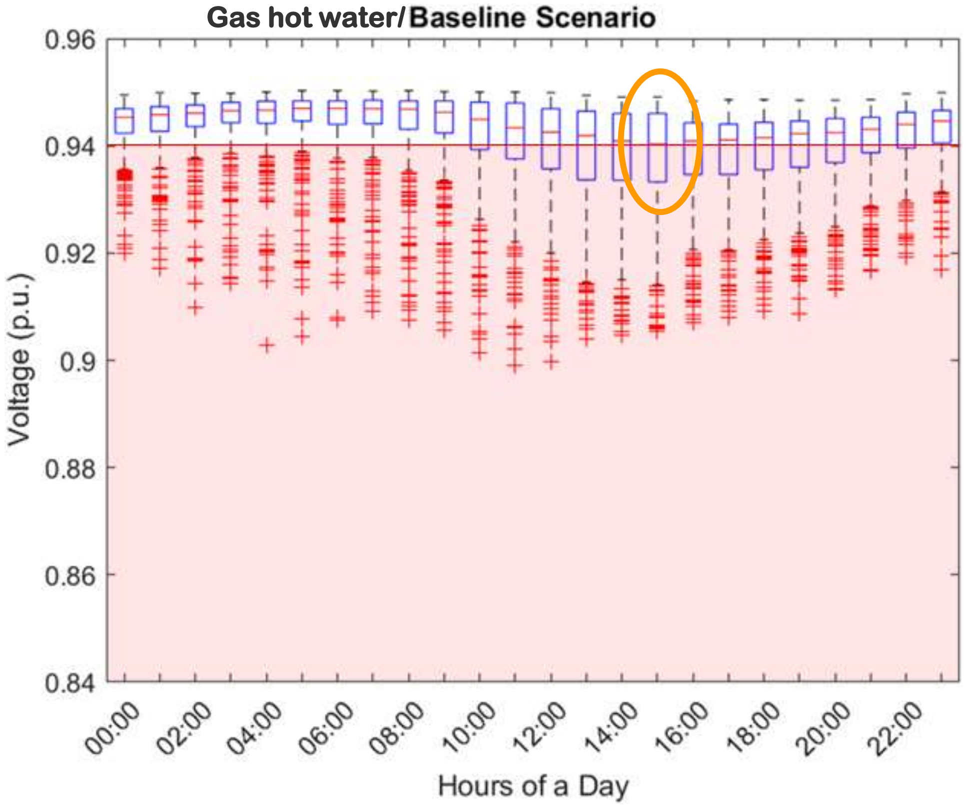


Fig. 4 Hourly critical bus voltage profile for Baseline (Gas Hot Water) Scenario

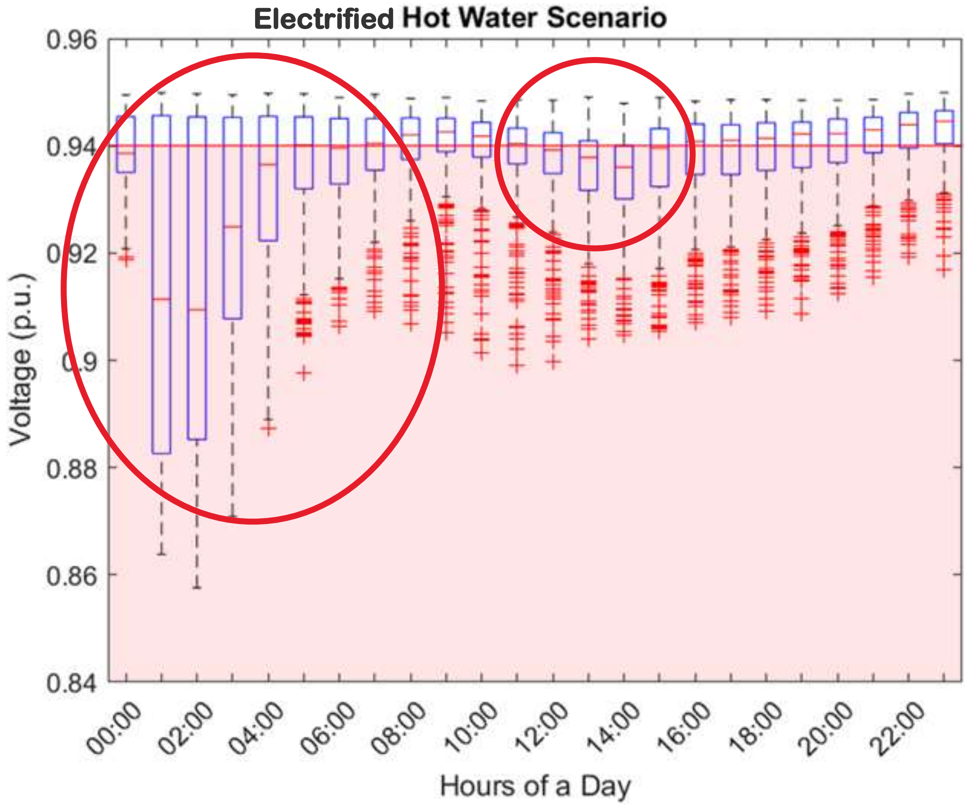


Fig. 5 Hourly critical bus voltage profile for Electrified Hot Water Scenario

- Baseline shows decreases in voltage from **late afternoon to early evening** → peak network loads and lack of RE gen. during this period.
- Voltages below operating voltage limit **1 time** daily.
- Neg. skewed voltage distributions.

- Elect.hot water scenario shows decreases in voltage from **midnight**.
- Voltages below operating voltage limit **13 times** daily.
- Neg. skewed voltage distributions,
- **Wider dispersal of values at midnight** for several hours → active control measures at this time.

Results & Discussion Cont'd

- **17% of year** on the verge of violating acceptable voltage limits in baseline scenario vs **50% of year** voltage is at or below acceptable limits for elect. hot water scenario.
- Peak reductions in voltage shown in EHW case as water heaters operate concurrently for all houses, despite active hot water load control strategy.

Conclusion

Difference between results of 2 scenarios shows:

- →potential for negative impacts of **excessive or uncontrolled electrification**
- →limitations of conventional control strategies
- →need for better/more efficient load control strategies such as intelligent or smart controls, especially as efforts to shift to hot water electrification

Exploring most effective water heating load control strategies could:

- Exploit inherent thermal energy storage within water heaters to separate time of electrical energy consumption and times of thermal delivery
- Optimise thermal energy storage benefits to minimise voltage excursions

Next Steps

Explore using the same network:

- Impact of distributed solar PV
- Use of different control strategies and their effect on voltage and grid performance
- Intelligent schedule of water heaters that consider the urgency to heat, network conditions and rooftop PV generation for enhanced low-voltage network stability

THANK YOU!

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What's next…

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