Beyond Virtual Power Plants: Opportunities for Distributed Market Mechanisms in Coordinating PV and Battery Storage Systems in Electricity Networks

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Outline

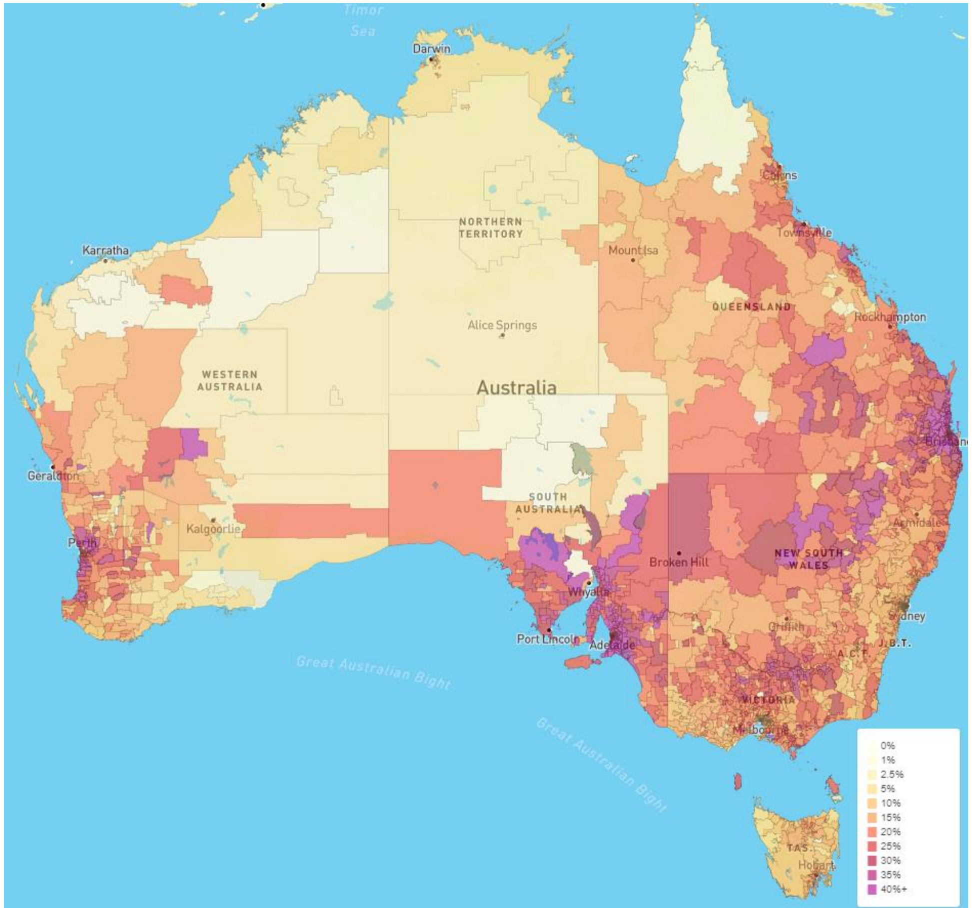
- **Context** – distributed energy resources in Australia & Singapore
- **The rise of distributed energy resources** – PV and batteries
- **Threats and opportunities** for distributed energy resources in power systems
- **Coordination of distributed energy resources**

  - An analysis of 6 proposed mechanisms for coordination or control
- **Network Aware Coordination** and the CONSORT Project approach to coordination
- **Concluding remarks**

Australian Context - Distributed Energy Resources

- **High penetration of rooftop PV**
  - Approx. 1 in 5 households with PV; 50% in some locations
- **Favourable tariffs for batteries**
  - Already seeing strong uptake
- **Electric Vehicles on horizon**
  - Transition will be rapid

% of dwellings with PV systems (source APVI / CER)



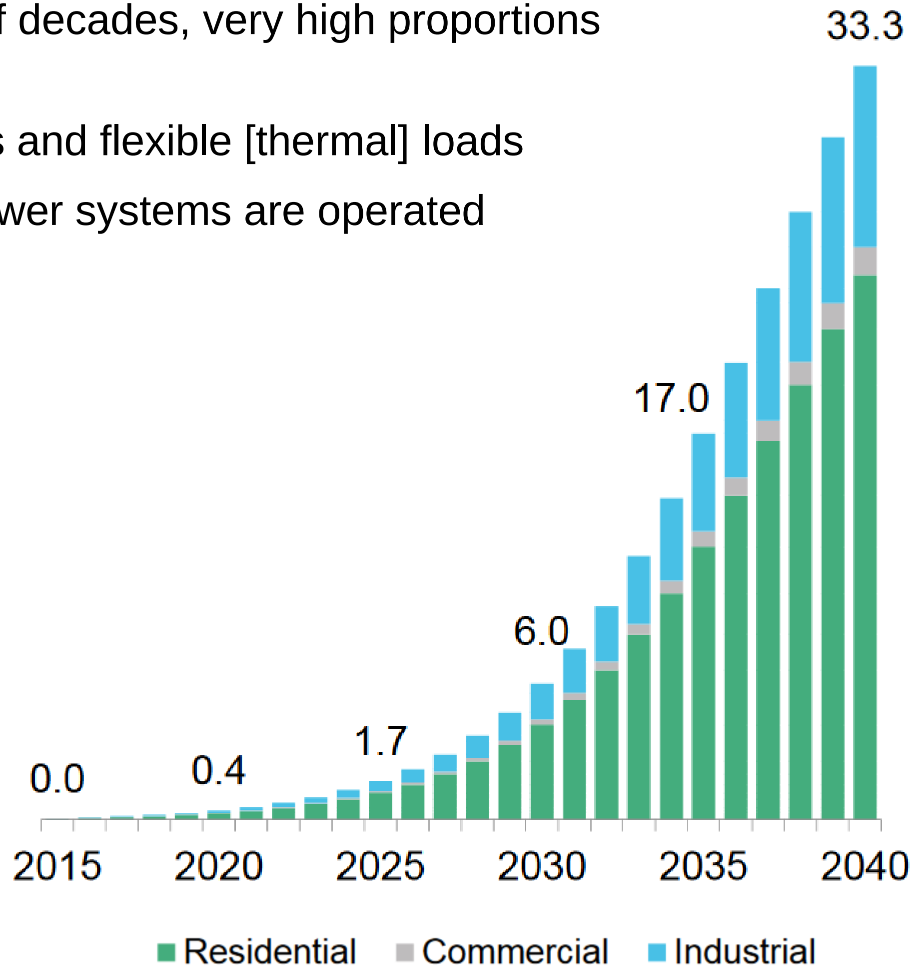
Singapore Context - Distributed Energy Resources

- **Target: 1 GW PV "beyond 2020"**
  - Will be 15% of peak capacity
- **Requirement for batteries**
  - Driven by solar intermittency and requirement for reserve (IPM)
- **Electric vehicles transition**
  - Transition will also be rapid

PV installations in Singapore (source: ema)

The Rise of Distributed Energy Resources (DER)

- **Trajectory a little uncertain, but destination is not in dispute!**
  - Networks will contain, within couple of decades, very high proportions of distributed energy resources
  - Mostly PV and batteries, but also EVs and flexible [thermal] loads
  - Will change the way networks and power systems are operated



Cumulative installed battery capacity (GWh) Australia – Source: BNEF New Energy Outlook 2015

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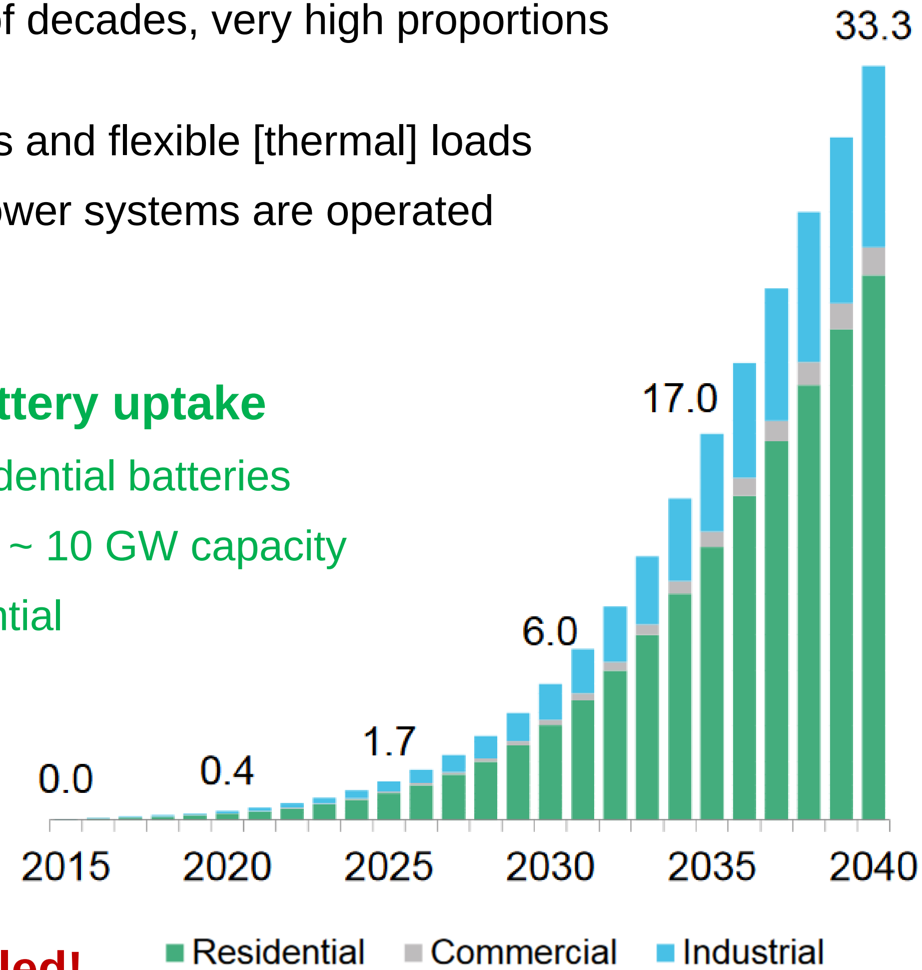
- **An example: Australian (NEM) battery uptake**
  - Various predictions: 2 – 4 million residential batteries
  - 2.5 million (1 in 5 houses) equates to ~ 10 GW capacity
  - 20 GW full cycle (charge/disch) potential
  - 35% of total NEM capacity



→ Cannot be left to act uncontrolled!

Cumulative installed battery capacity (GWh) Australia – Source: BNEF New Energy Outlook 2015

Threats and Opportunities

High penetration DER poses many threats to incumbents:

- **Energy retailers:**
  - Less energy sold / less revenue
  - Less predictable aggregate demand profiles
  - Exposure to greater wholesale price volatility
- **Network operators:**
  - Capacity constraints
  - Voltage management
  - Power quality
- **Power system operator:**
  - Dispatchability / forecastability
  - Dynamic stability (frequency, angular stability) / security
  - Reserve capabilities and reliability
- **Generators:**
  - Less energy generated / less revenue
  - Increased system security & stability burden
  - Peakier generation / more operational flexibility needed

Threats and Opportunities

But DER present many opportunities too:

- **DER technologies (esp. batteries) key features:**
  - Controlled by modern power electronics and communications
  - Unprecedented responsiveness & speed
  - Unprecedented flexibility
  - Can provide network visibility / in-built sensors and communications
  - Ability to act as generator or load (fast changeover)
  - Ability to supply reactive power for voltage support & stability

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- DER can provide **Retailers** with low-cost energy, new revenue, certainty in demand, enhanced consumer engagement

- DER can provide **Network operators** with better visibility, can help manage network voltage, satisfy capacity constraints and defer costly network augmentation

- DER can provide **Power system operators** with spinning reserve, renewable capacity firming, can provide fast frequency response for stability and security, reactive power for voltage support

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→ BUT, can only be realised if DER has in-built intelligence AND also only if DER is successfully coordinated!

DER Coordination and Control

- How should we control or coordinate the actions of millions of resources distributed throughout our electricity networks to fulfil their potential?

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- We briefly examine the main approaches being put forward:

1. Heavy regulation / strict operating limits
2. Centralised Optimisation Control
3. Virtual Power Plant models
4. Market approach 1: Peer to peer trading
5. Market approach 2: Open market approach
6. Hybrid Market – Distributed optimisation

* note: all require a level of DER functionality

1. Heavy Regulation / Strict operating limits

- Characterised by system operator and network operator imposing limitations on sizes of and outputs from DER. May include:
  - PV or battery installed capacity limits
  - PV or battery fixed output kW limits
  - System output dictated by strict settings: time-of-day, Volt-VAR, Volt-Watt, Freq-Watt control

Key Advantages	Main Disadvantages / Limitations
Simple to implement Low risk Designed to avoid network issues	Can stifle deployment Sub-optimal outcomes will result Can unfairly penalise some May result in under-utilised resources Locational value ignored

Examples: ➔ German KFW battery subsidy, imposed 70% output limit

➔ Horizon (WA utility) network feeder PV hosting capacity limits

2. Centralised Control

- Power System Operator (AEMO in Australia, EMA in Singapore) produces optimal dispatch for entire system
  - Optimisation includes all resources and constraints,
  - Dispatch instructions to all participants
  - Could be broken into two-layer system – central control, regional control

Key Advantages	Main Disadvantages / Limitations
Consistent with existing unit dispatch Will use resources optimally Network constraints observed	Massive communications overhead Computationally unfeasible at scale Requires data from every DER Requires 100% participation DER owner loses agency

Examples: ➔ No-one is or will take this approach!!

3. Virtual Power Plant approach

- Aggregators collectively manage fleets of DER as ‘virtual power stations’:
  - Entire fleet of DER typically operated in unison, eg. all increase simultaneously
  - Aggregator participates in wholesale market on DER owners behalf
  - Common VPP model assumes an unconstrained DER output is possible

Key Advantages	Main Disadvantages / Limitations
Virtual plant is part of unit dispatch DER access wholesale market Simple to implement	Networks not typically considered Yields non-optimal outcomes DER owner loses agency Locational value generally ignored

Examples: ➔ AGL VPP, and Tesla VPP - South Australia; Reposit VPP - ACT

➔ Kraftwerke operate VPP in Europe

4. Market approach 1: Peer-to-Peer Trading

- Individual DER trading energy with other consumers:
  - Uses independent offer / bid distributed ledger (eg. blockchain)
  - Currently can be considered an off-market trading for non-energy units
  - Only flourishes if time of generation, local transmission and distribution costs are reflected in energy retailer tariffs; or, is limited to embedded networks

Key Advantages	Main Disadvantages / Limitations
Uses ‘proven’ transaction ledger Non DER owners also participate	Doesn’t consider network constraints Doesn’t produce optimal outcomes Doesn’t try to meet objectives Generally ignores locational value

Examples: ➔ Power Ledger – Australia

➔ Brooklyn Microgrid, New York; GridX and Sonnen - Germany

5. Market approach 2: Open market approach

- Services offered to / from DER are traded on open digital market platform:
  - Products offered: energy, reserve capacity, fast-response power export or import
  - All stakeholders – DER, consumer, retailer, network operator, power system operator, generator – choose to participate in the market
  - Network operator, power system operator responsible for satisfying constraints
  - A digital distribution-level market operated to clear and settle transactions

Key Advantages	Main Disadvantages / Limitations
True market value discovered All stakeholders can participate	Difficult to ensure network constraints Requires sufficient market volume May result in market power imbalance Complex to implement Market may not meet all tech. needs

Examples: ➔ GreenSync's distributed energy exchange (deX) - Australia

6. Hybrid Market-Optimisation approach

- Distributed optimisation with market-based locational pricing incentives:
  - Similar market-optimisation approach as used at power system market level
  - Distributed optimisation breaks network into manageable optimisation problems
  - Iterative optimisation process ‘negotiates’ the locational prices that will result in DER actions which ensure all constraints are met – network constraints, power system needs – at lowest cost

Key Advantages	Main Disadvantages / Limitations
Delivers optimal outcomes Satisfies all necessary constraints Computationally feasible	Assumes all DER will respond “truthfully” Creates differential DER value

Examples: ➔ ANU’s Network Aware Coordination approach / CONSORT – being trialled in research collaboration with UTAS on Tasmania’s Bruny Island.

Network Aware Coordination / CONSORT Project

CONS**umer energy systems providing cost-effective grid supp**ORT

- A hybrid market-optimisation, distributed algorithm approach

- Project addresses three main research questions:

1. How to optimally coordinate a large number of battery systems?
2. How to fairly reward consumers for supporting the network?
3. How do consumers respond / adapt to the technology and to helping the network?

→ CONSORT is an ARENA 'R&D Rnd2' project: $2.9m funding, Apr 2016 – Apr 2019

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Network Aware Coordination / CONSORT Project

➢ The Bruny Island network:

- Small Island, 30 km SE of Hobart, Tasmania
- 300 permanent dwellings / 900 total (large ‘holiday’ population)
- 11 kV distribution network, connected via ~2 km undersea cable
- 1050 kVA practical cable limit / 1400 kW peak load (and growing)
- On-island diesel generation to avoid cable overload
- Low voltage at extents of network at peak load

➢ In the battery trial we are:

→ Installing 33 PV / Battery systems, ~ 130kW/300kWh

→ Developing and trialing novel coordination algorithms
  - for managing network demand and voltage

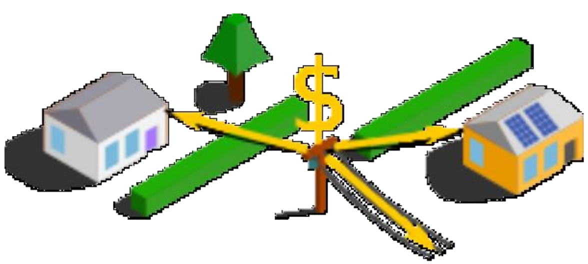
→ Developing appropriate incentive mechanisms

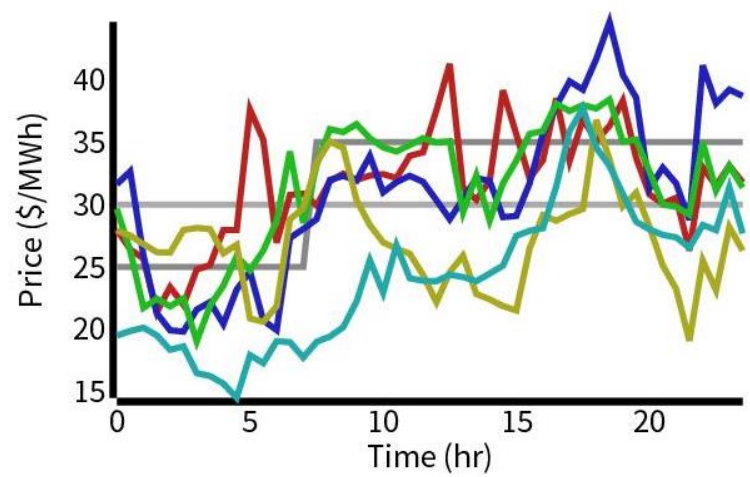
→ Investigating customer’s response to technology

Network Aware Coordination / CONSORT Project

- Battery Coordination Mechanism
  - **optimal**ly schedules batteries
  - **network-aware**: models the network and its constraints
  - **consumer-aware**: respects privacy, preferences
  - online, **distributed**, scalable, fully automated

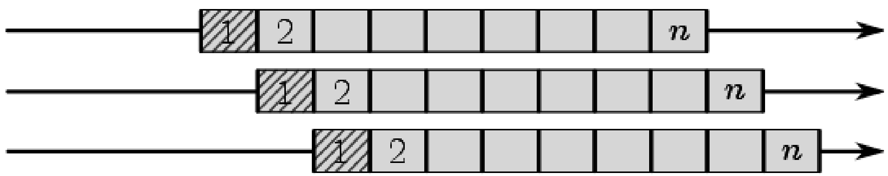
- Mechanism creates a local network-support market
  - produces **real-time nodal** price signals
  - incentivises controllers to prevent constraint violations

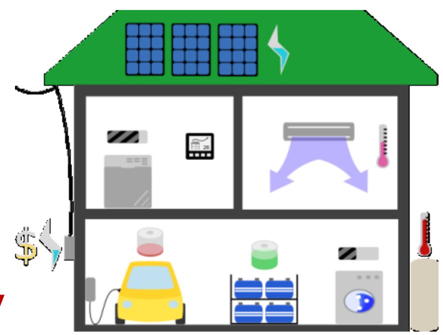




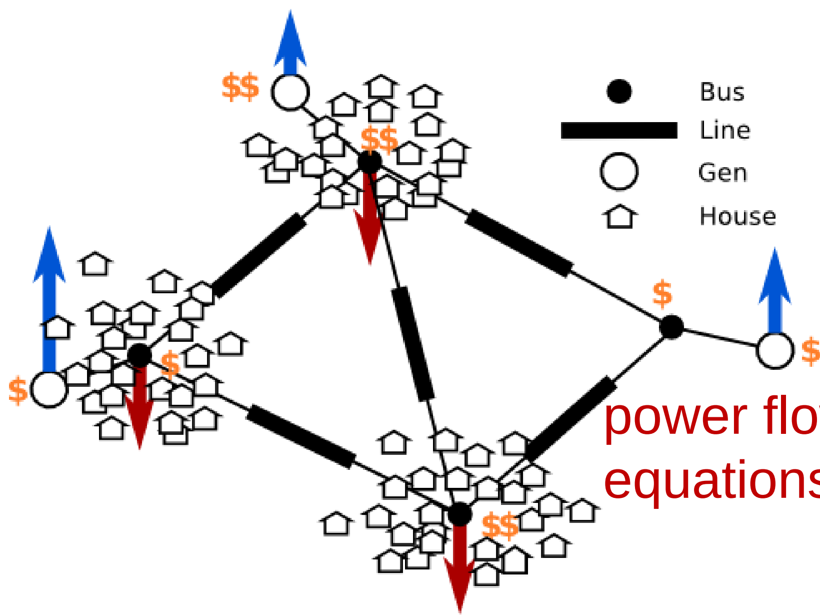
Network Aware Coordination / CONSORT Project

- Solve multi-period unbal. 3-Φ **optimal power flow** problem
  - in a distributed (iterative) manner, finds solution for every 5 min over horizon
  - every participant (selfishly) solve their own sub-problem
  - ADMM (multipliers = nodal price of constraint violation)





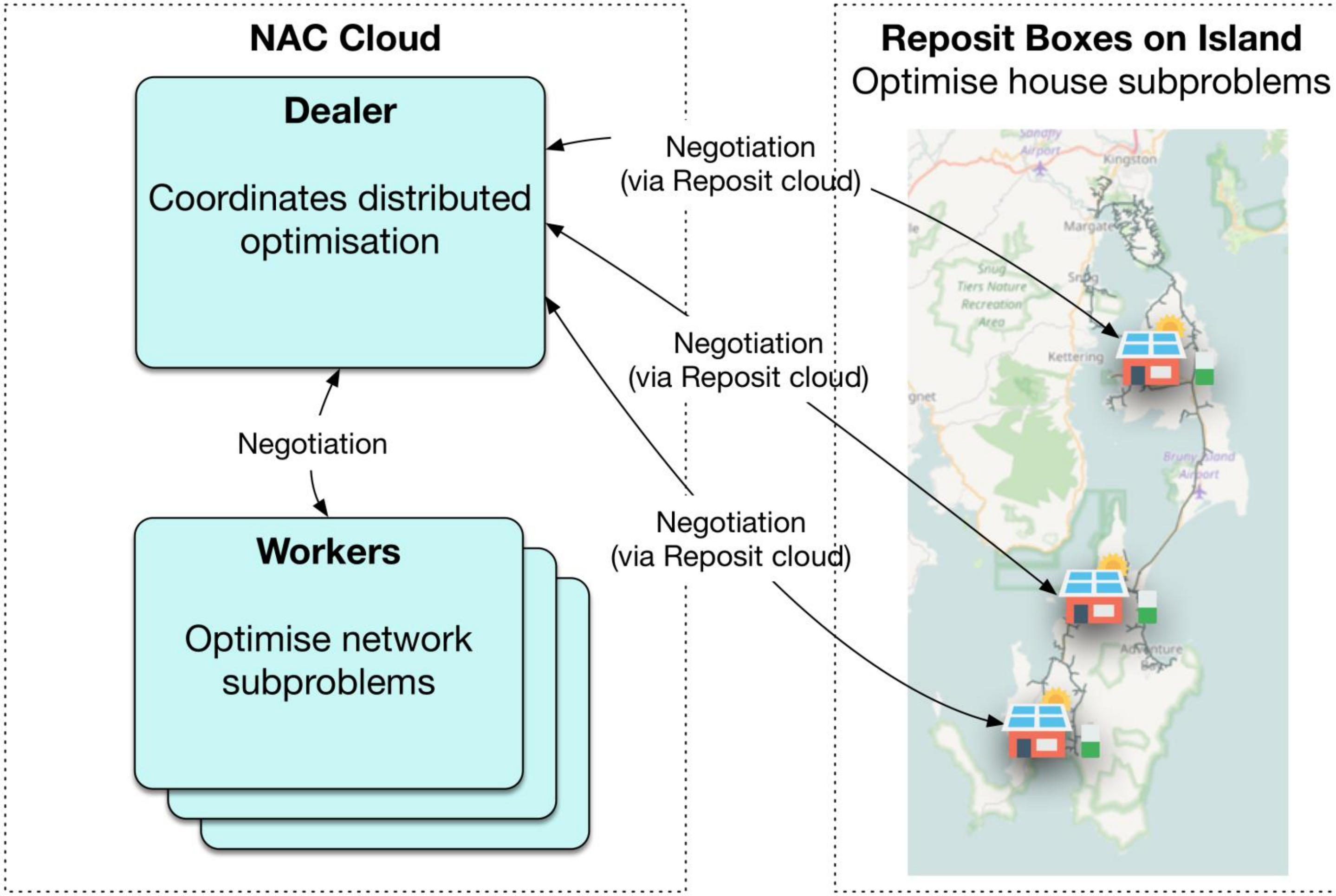
battery
controller



power flow
equations

Network Aware Coordination / CONSORT Project

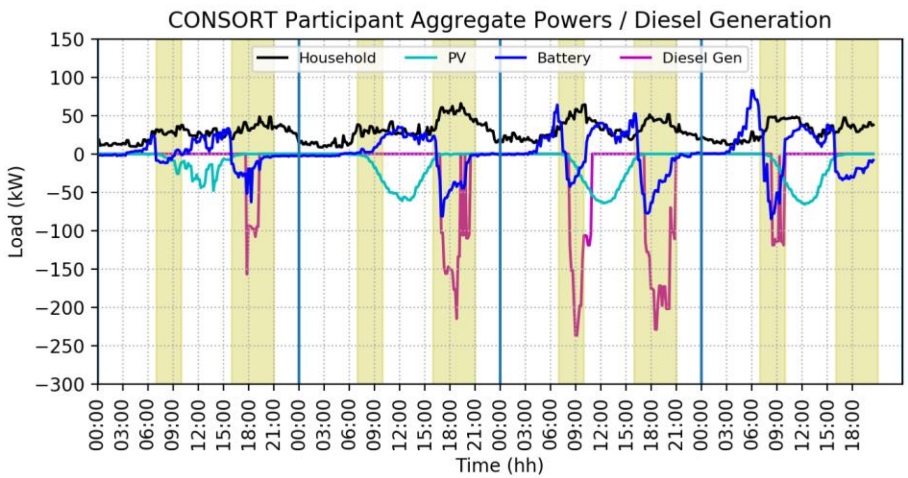
- Distributed optimisation architecture

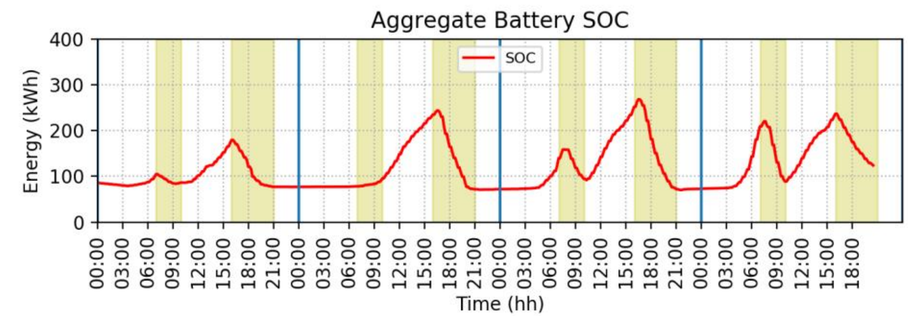


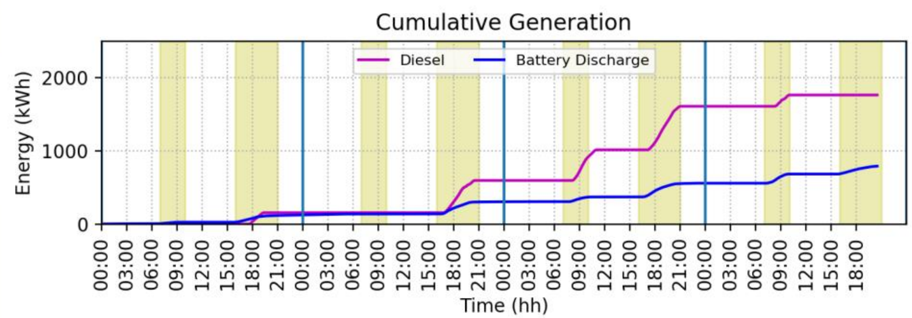
Network Aware Coordination / CONSORT Project

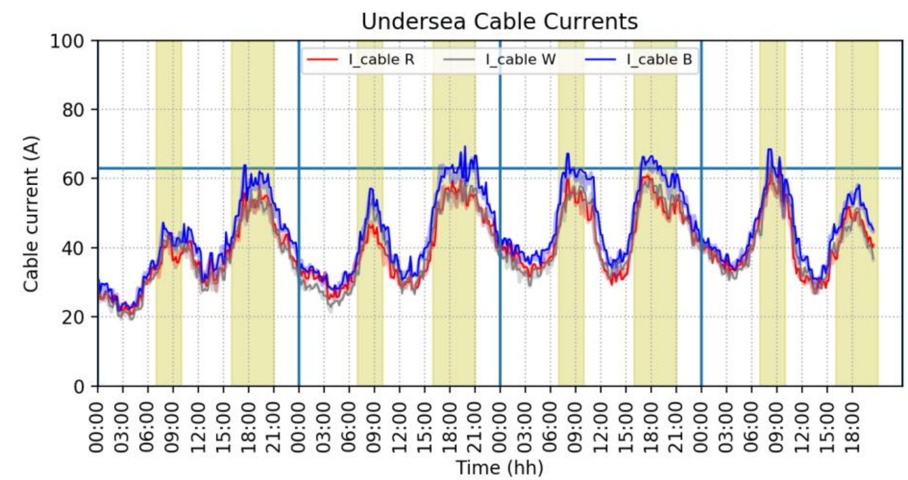
➢ Our first full on-network trial: June 2018 long weekend

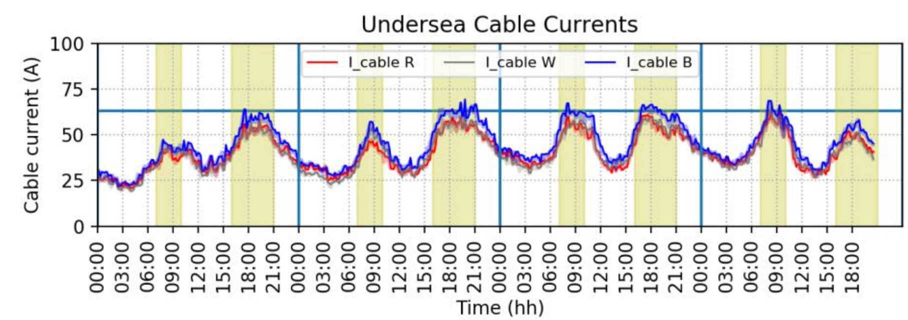
- NAC automatically scheduled batteries over long weekend peaks
- Forecast accuracy and phase unbalance needs improvement





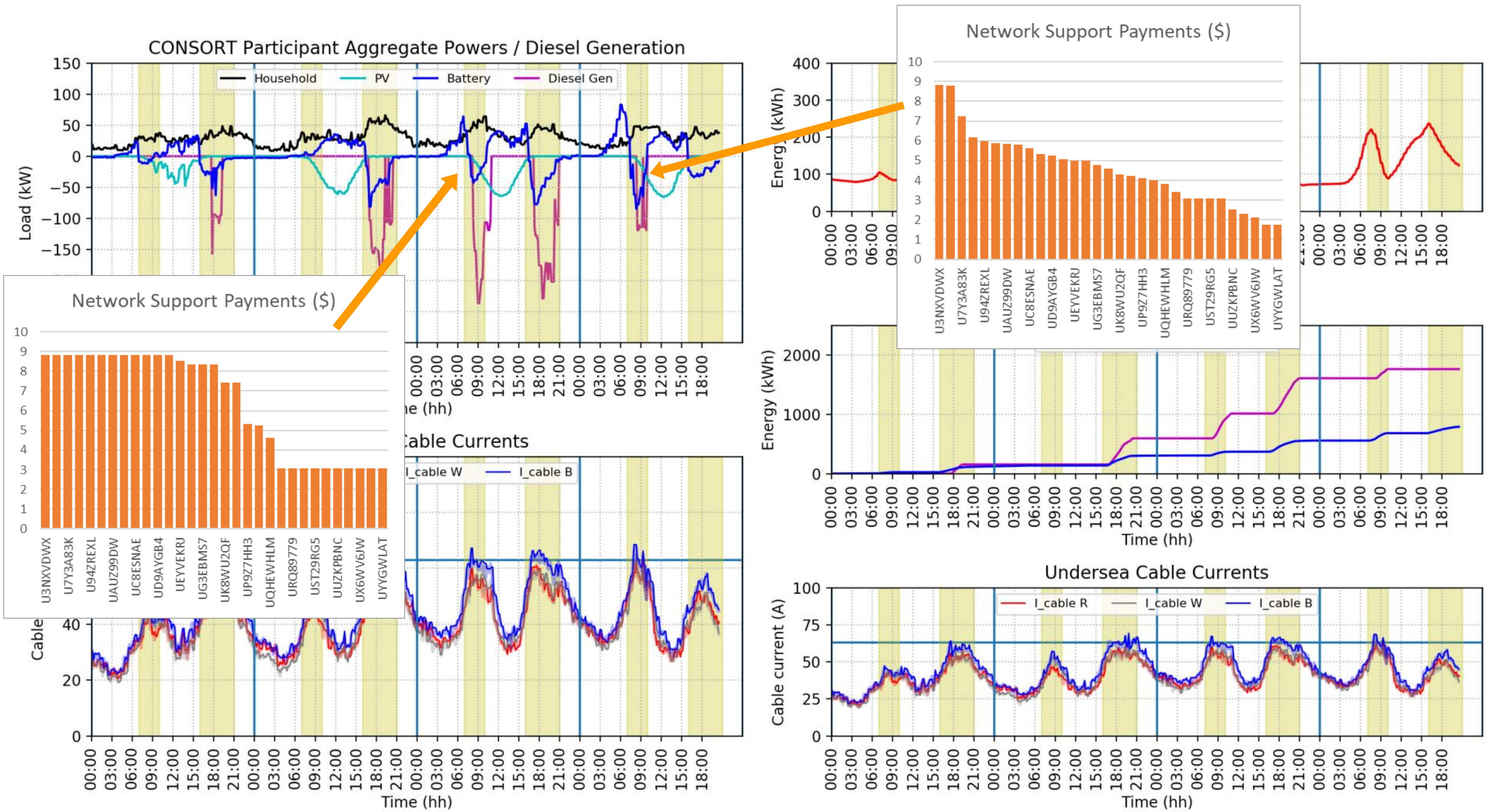






Network Aware Coordination / CONSORT Project

- Our first full on-network trial: June 2018 long weekend
  - Locational / temporal market value of batteries reflected in Network Support Payments that we made to battery owners



Concluding remarks

- Future electricity grids will include **vast amounts of distributed energy resources** (DER) - Solar PV, battery storage and electric vehicles will dominate

- Transition will only be successful if distributed resources are operated in a highly **coordinated approach**

- All DER will need to have **in-built intelligence**

- **Market-based approaches** may offer solutions – observing technical / network constraints is a challenge

- **Hybrid market-optimisation network-aware coordination** (NAC) technology currently being developed and tested in Australia

Thank you for your kind attention

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