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CSIRO UltraBattery & Renewable Energy Storage

Melbourne ATA meeting – 16 September 2009

Chris Phyland

CSIRO Energy Transformed Flagship

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Presentation Outline

CSIRO UltraBattery

UltraBattery in Wind Energy applications

Domestic Energy Storage (Vehicle to Grid – V2G)

The UltraBattery

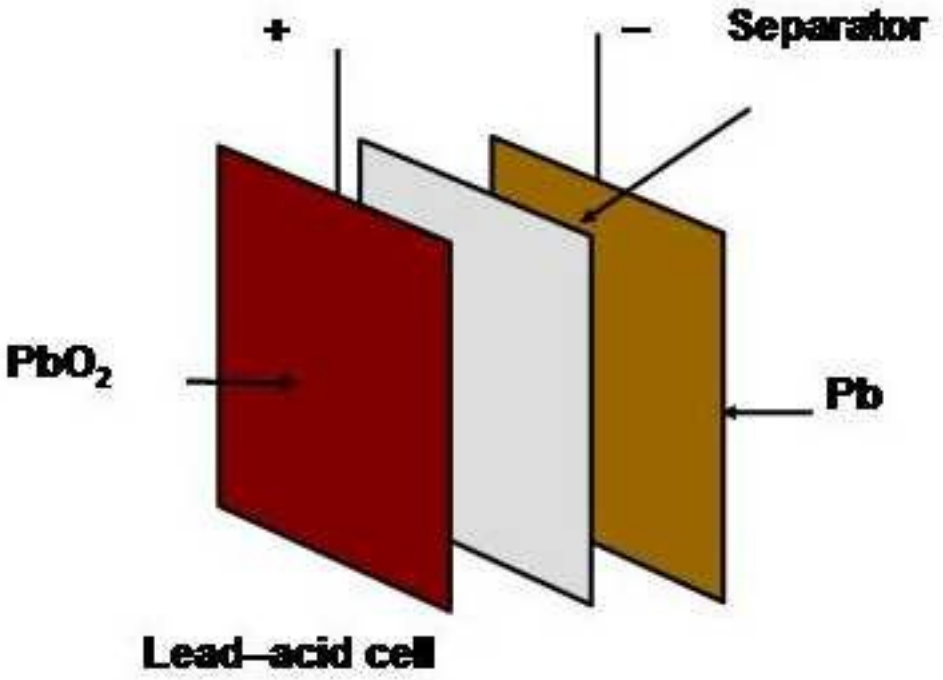
It combines a lead acid battery **and an** asymmetric supercapacitor **in one unit cell, without extra electronic control.**

It has longer life and low cost. It can be made in a conventional battery factory

Lead acid batteries

Discharging the positive lead oxide plate:

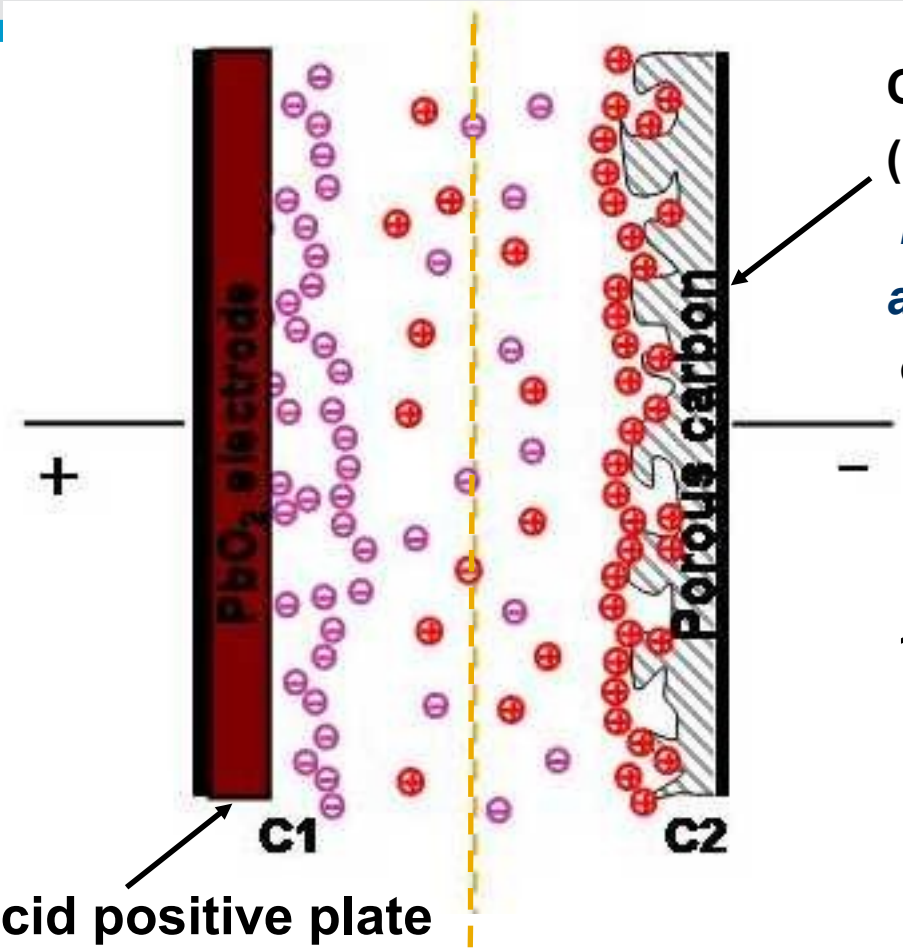
$$PbO + 3H + HSO + 2e \Rightarrow Pb + SO + 2H\,O$$



Discharging the negative sponge lead plate:

$$Pb + 3H + HSO - 2e \Rightarrow Pb + SO + 4H$$

Asymmetric supercapacitor



Carbon negative electrode (charged/discharged by *reversible adsorption/desorption* of ions)

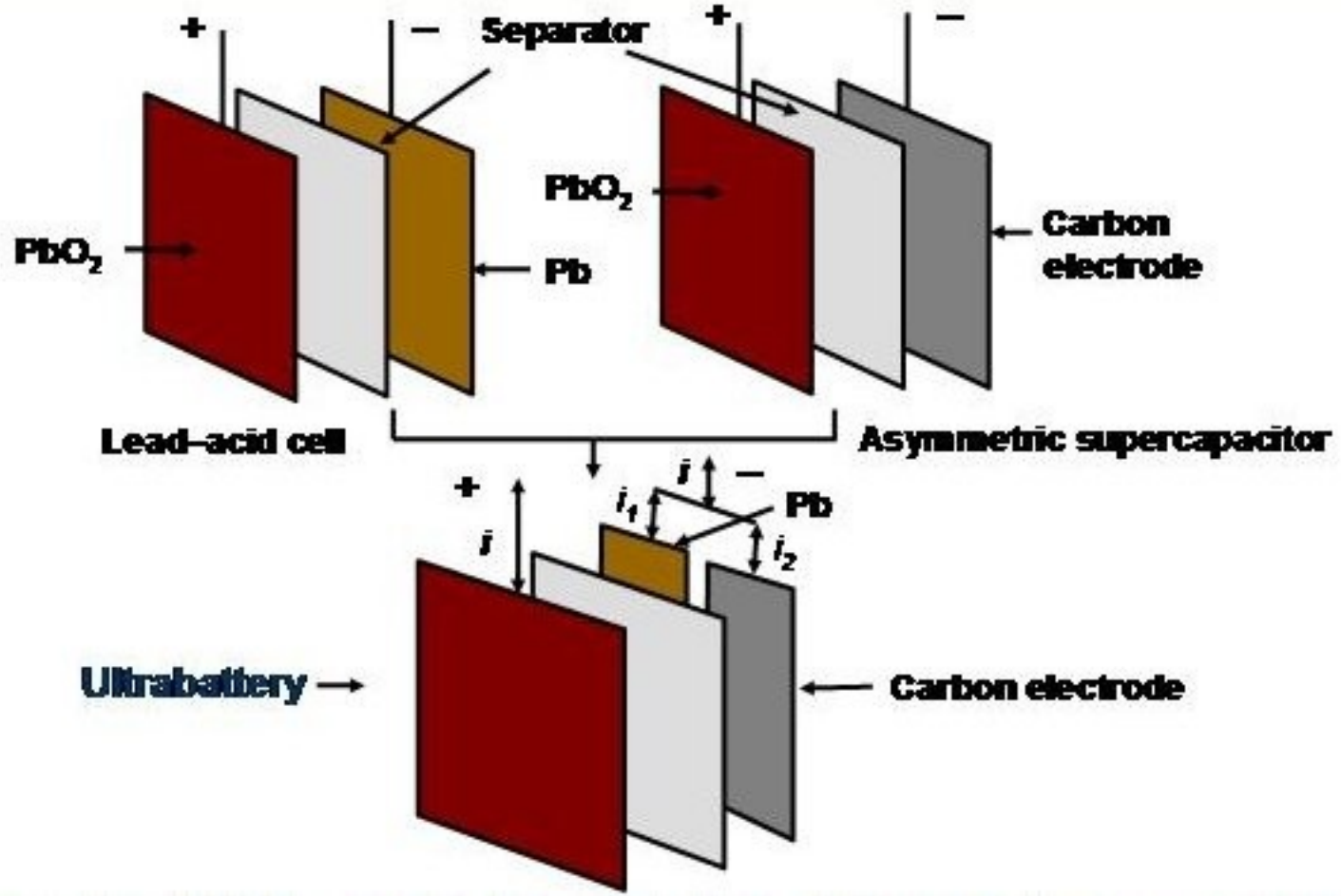
Lead-acid positive plate (charged/discharged by *reversible reduction/oxidation* processes)

$$1/C_T = 1/C_1 + 1/C_2$$

if $C_1 >> C_2$ then

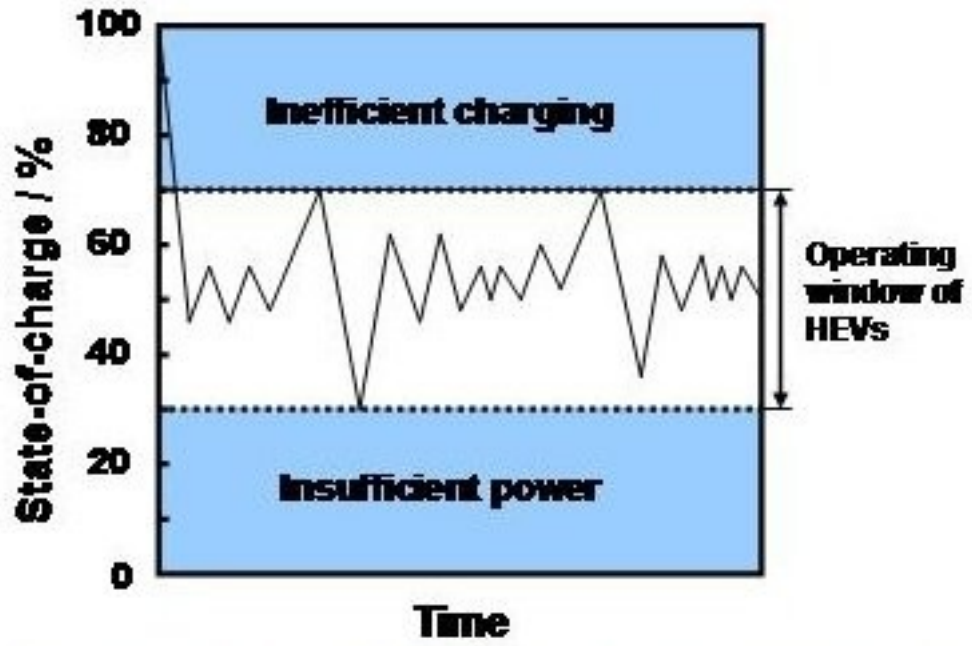
$$\mathbf{C_T = C_2}$$

Schematic of the Ultrabattery



- Ultrabattery is a hybrid energy-storage device, which combines an asymmetric capacitor and a lead-acid battery in one unit cell, without extra electronic control

Hybrid electric vehicle (HEV) duty



Operational state-of-charge of energy storage

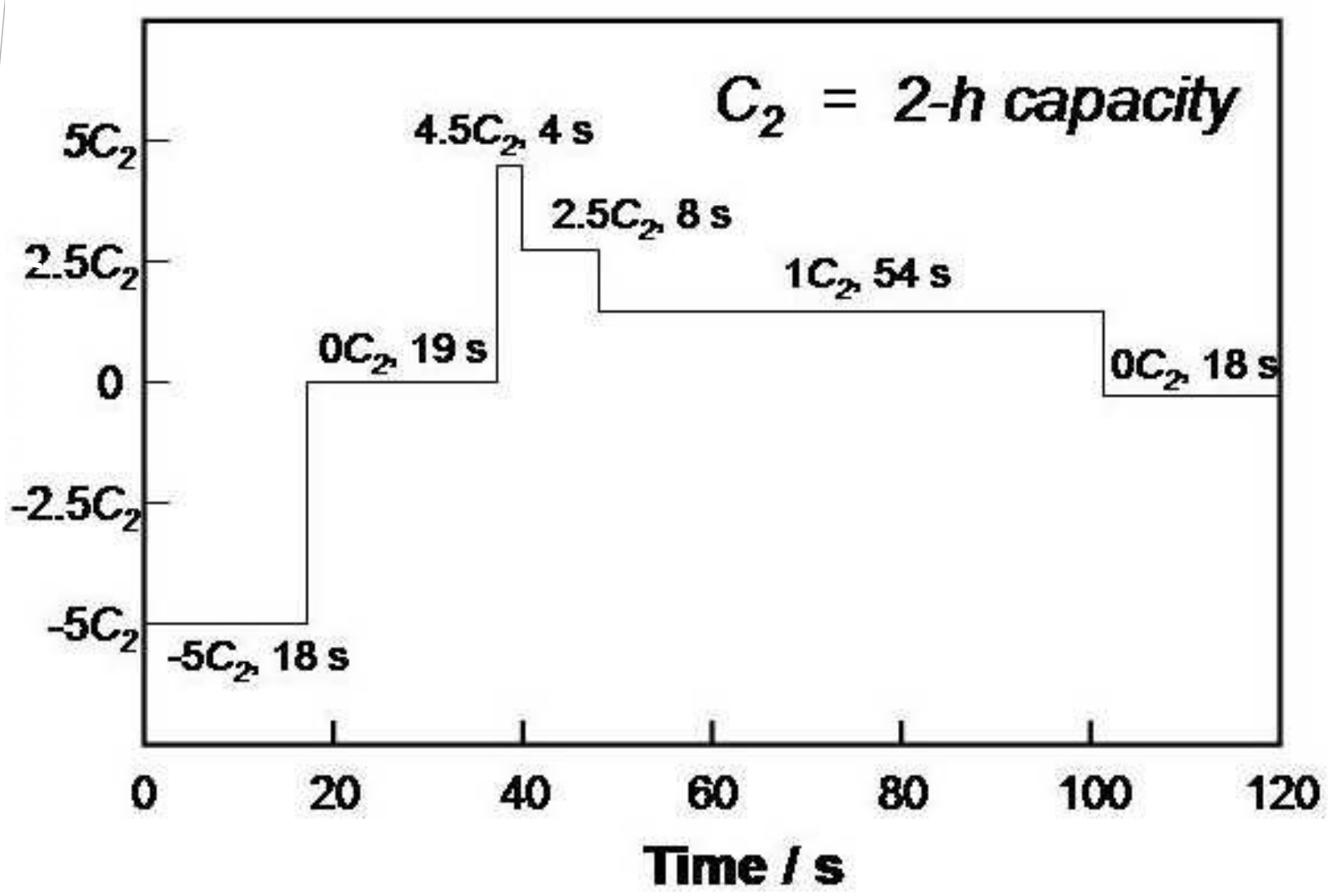
HEV duty is High-Rates Partial State-of-Charge operation

- **High-rate discharge** is necessary for cranking and acceleration
- **High-rate charge** is associated with regenerative braking

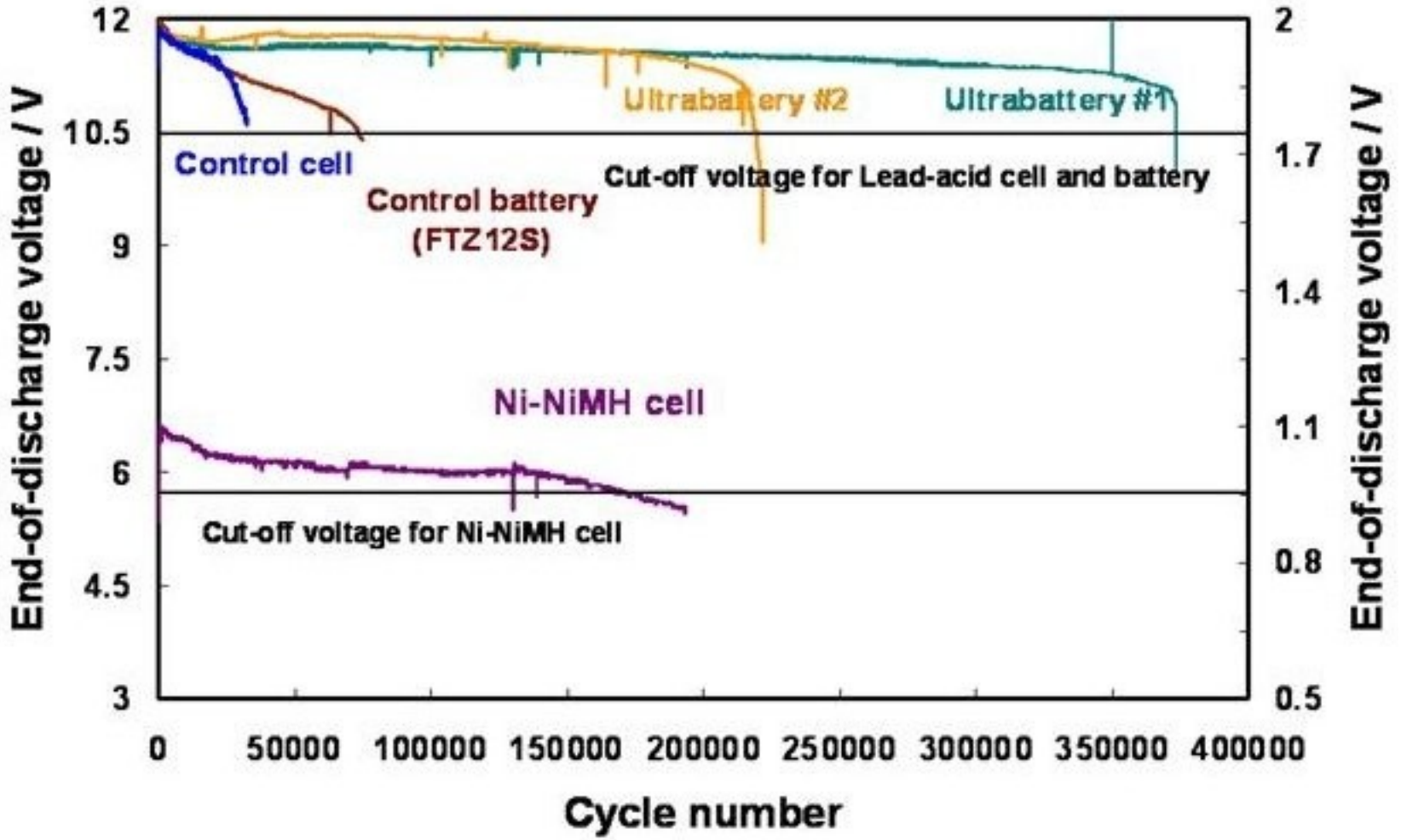
Key factors responsible for such failure

- **High-rate discharge**
- **High-rate charge**

Life Testing – EUCAR Test



Lab test results for the HEV Eucar testing



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Recent Press Release

“UltraBattery awarded $US32.5 million from US Government

The CSIRO-invented UltraBattery is set for accelerated development with the US Government awarding $US32.5 million to US manufacturer East Penn to produce the battery.”

The UltraBattery clocked up 100,000 miles in a hybrid vehicle under test conditions last year.

Photo by: Advanced Lead-Acid Battery Consortium

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CSIRO UltraBattery

UltraBattery in Wind Energy applications

Domestic Energy Storage (Vehicle to Grid – V2G)

Energy Storage for Wind

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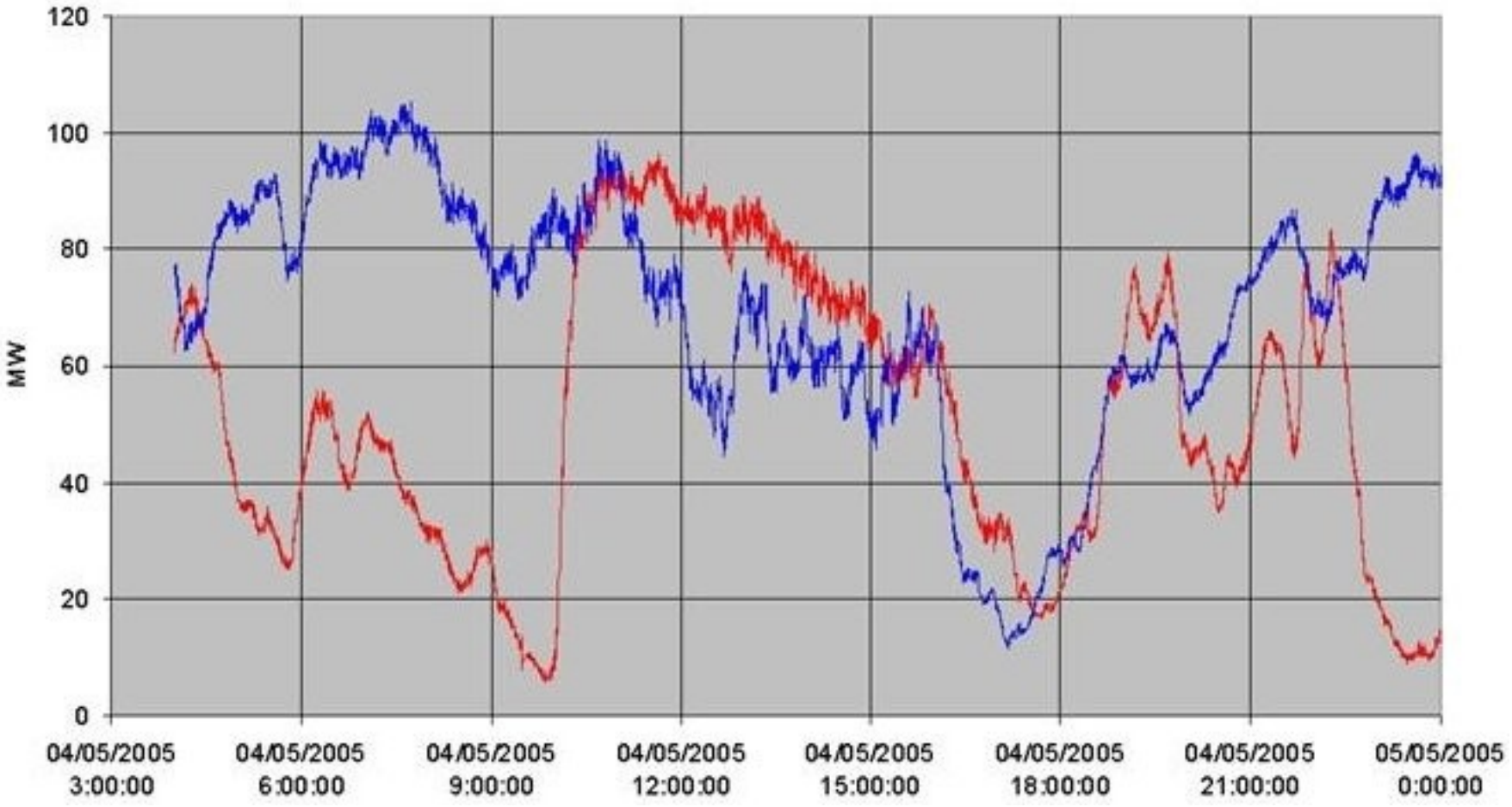
Issues of wind energy – high variation

Wind Energy is highly variable (10 second sample interval)



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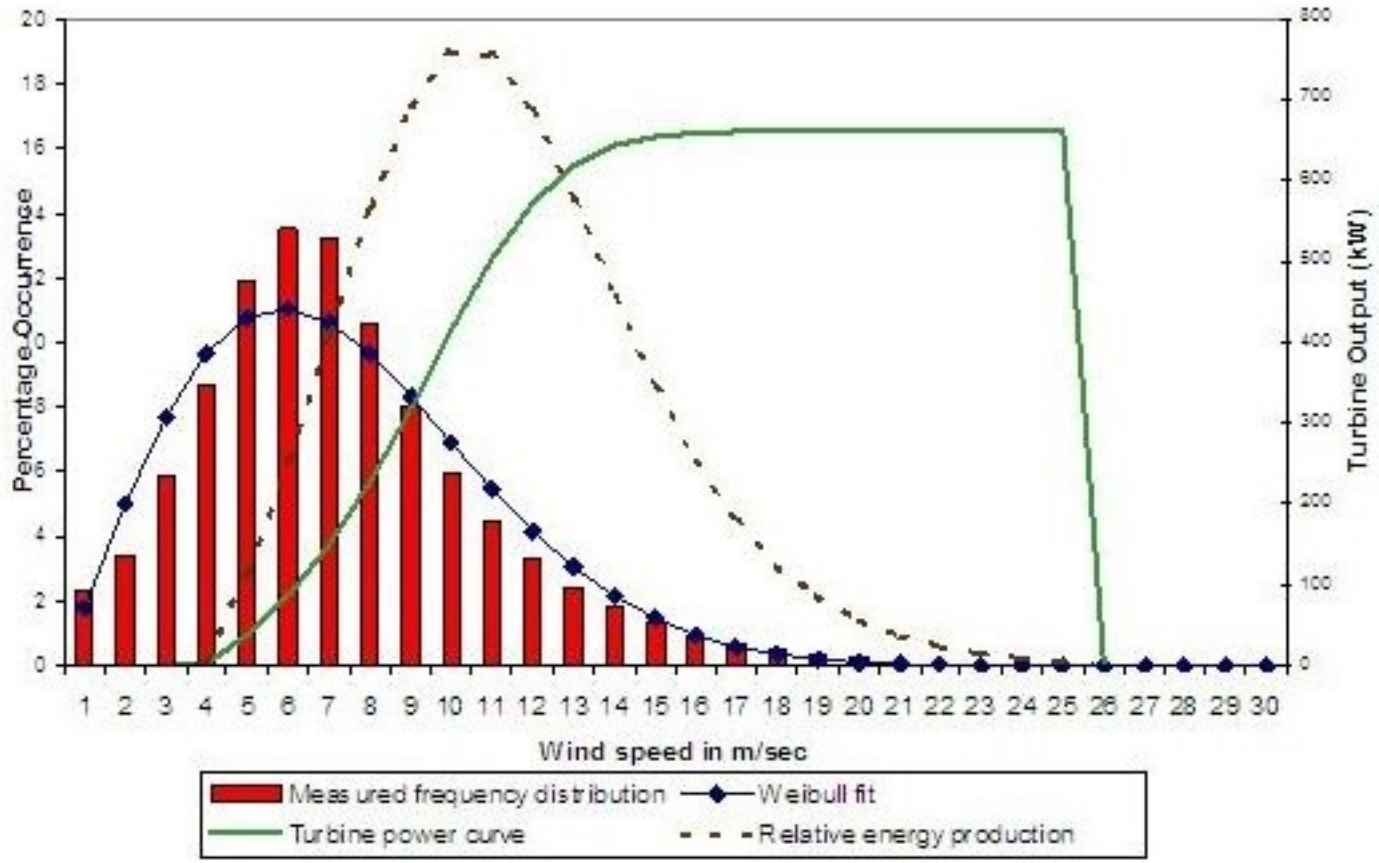
Output of wind turbine

Why Wind Energy is so variable – turbines mostly operate in the “cubic” region (power α V^3).



Network stability & “Ramp Rate”

The electricity grid needs to be balanced for stability

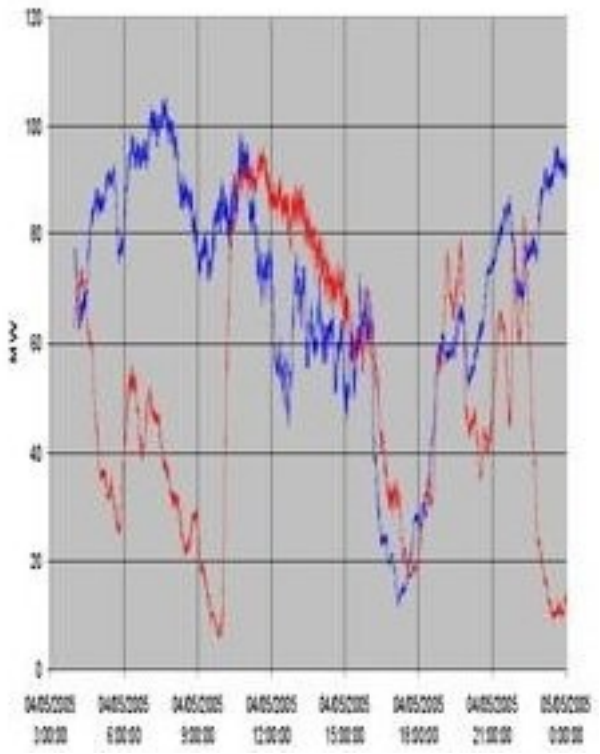
Energy In = Energy Out

Wind energy has variations in power generation

To maintain balance another generator has to be adjusted to “compensate” for the variations

Supply regulator doesn’t want generators to vary at a rate of more than 6MW per 5 minute interval – this is maximum allowable “Ramp Rate”

Wind farm often exceed Ramp Rate limits and cause network stability issues

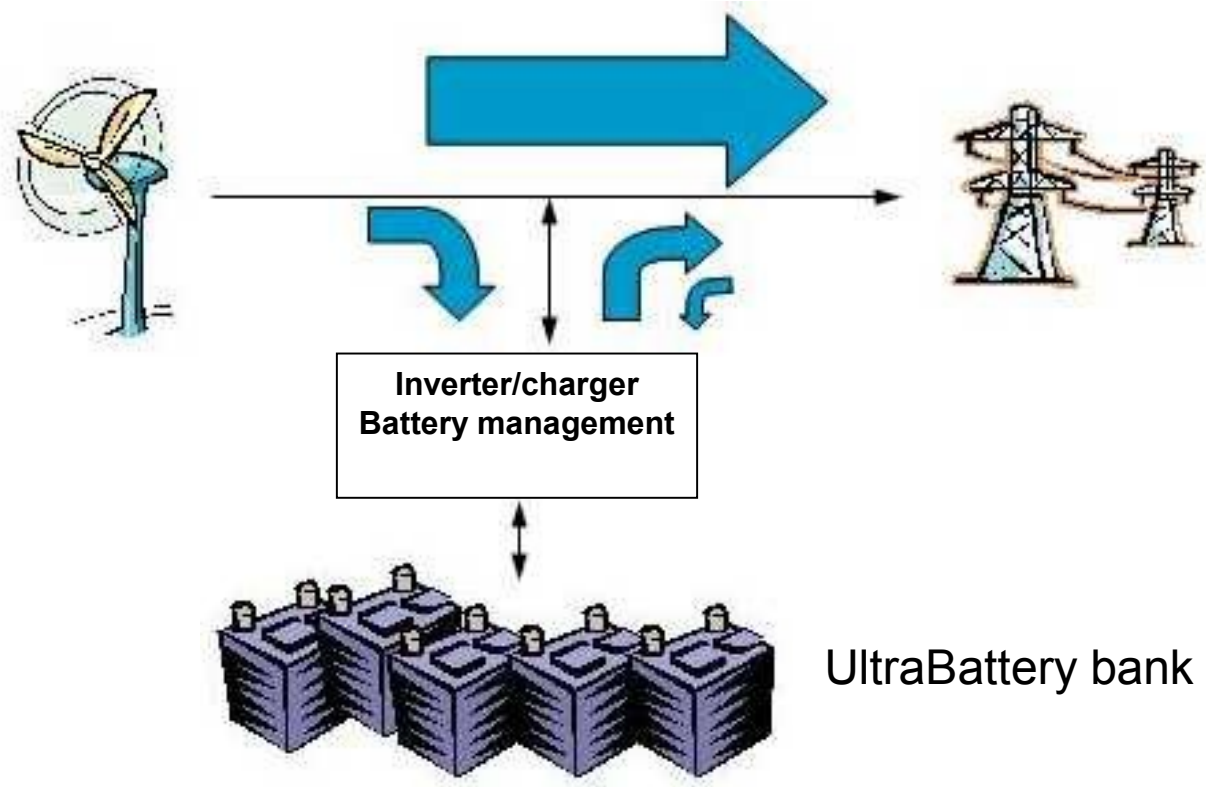


“**RAMP RATE**” = rate of change of power generation (MW/5min)

This is the issue limiting the uptake of wind energy

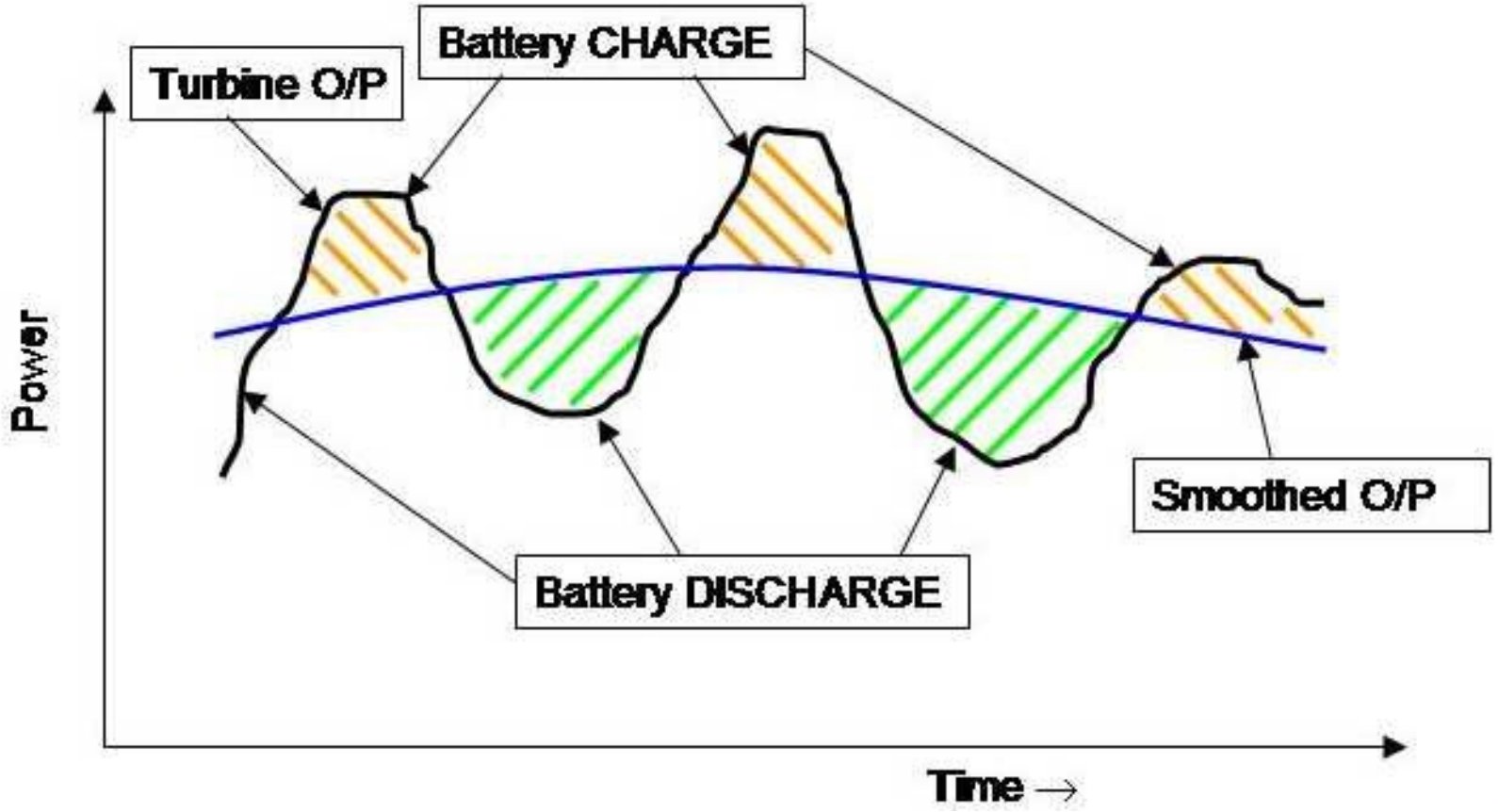
Energy storage for wind

- A solution is Energy Storage at the wind generator to smooth the power delivery



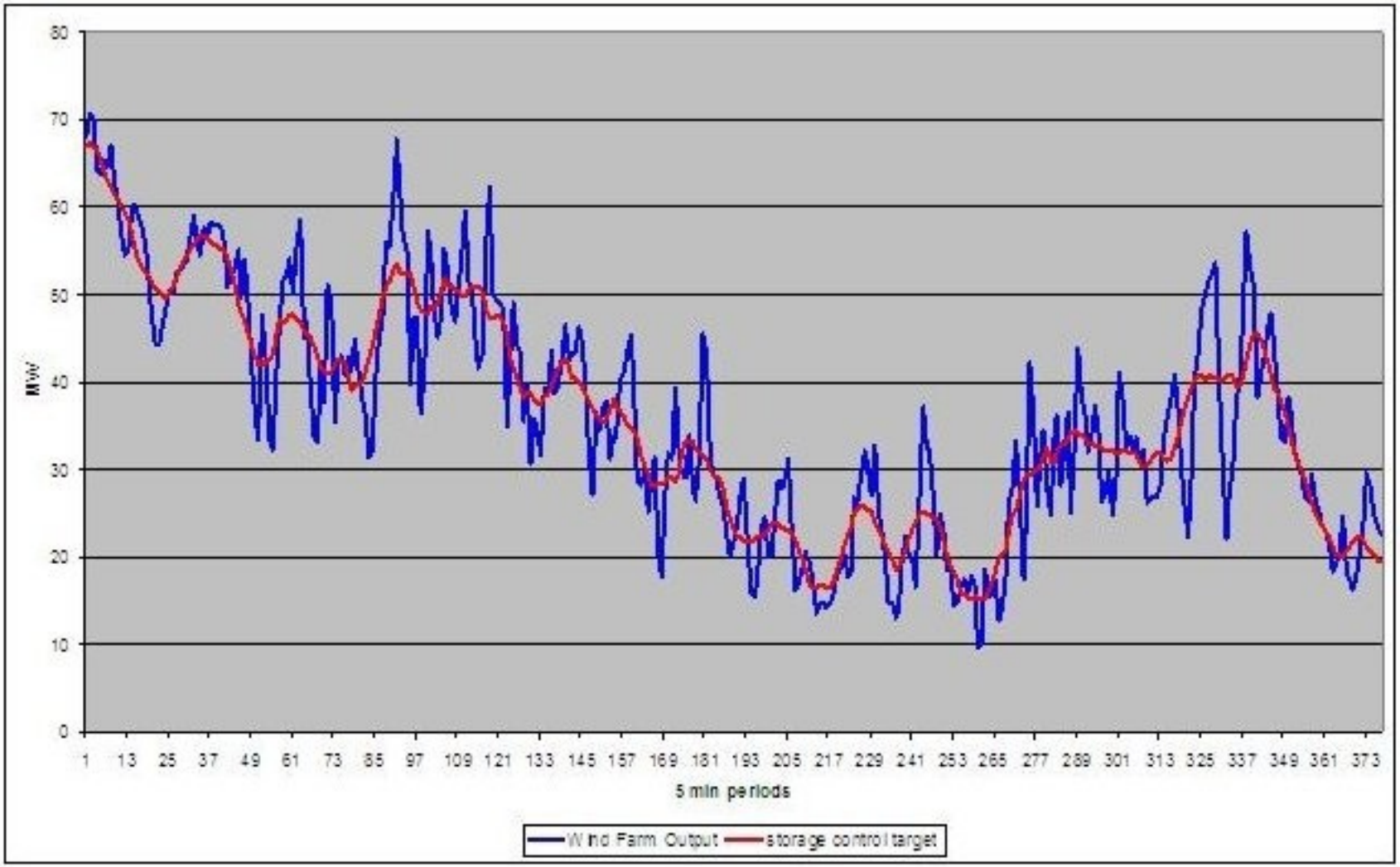
Energy Storage for Renewables

- Smoothing of Power Delivery

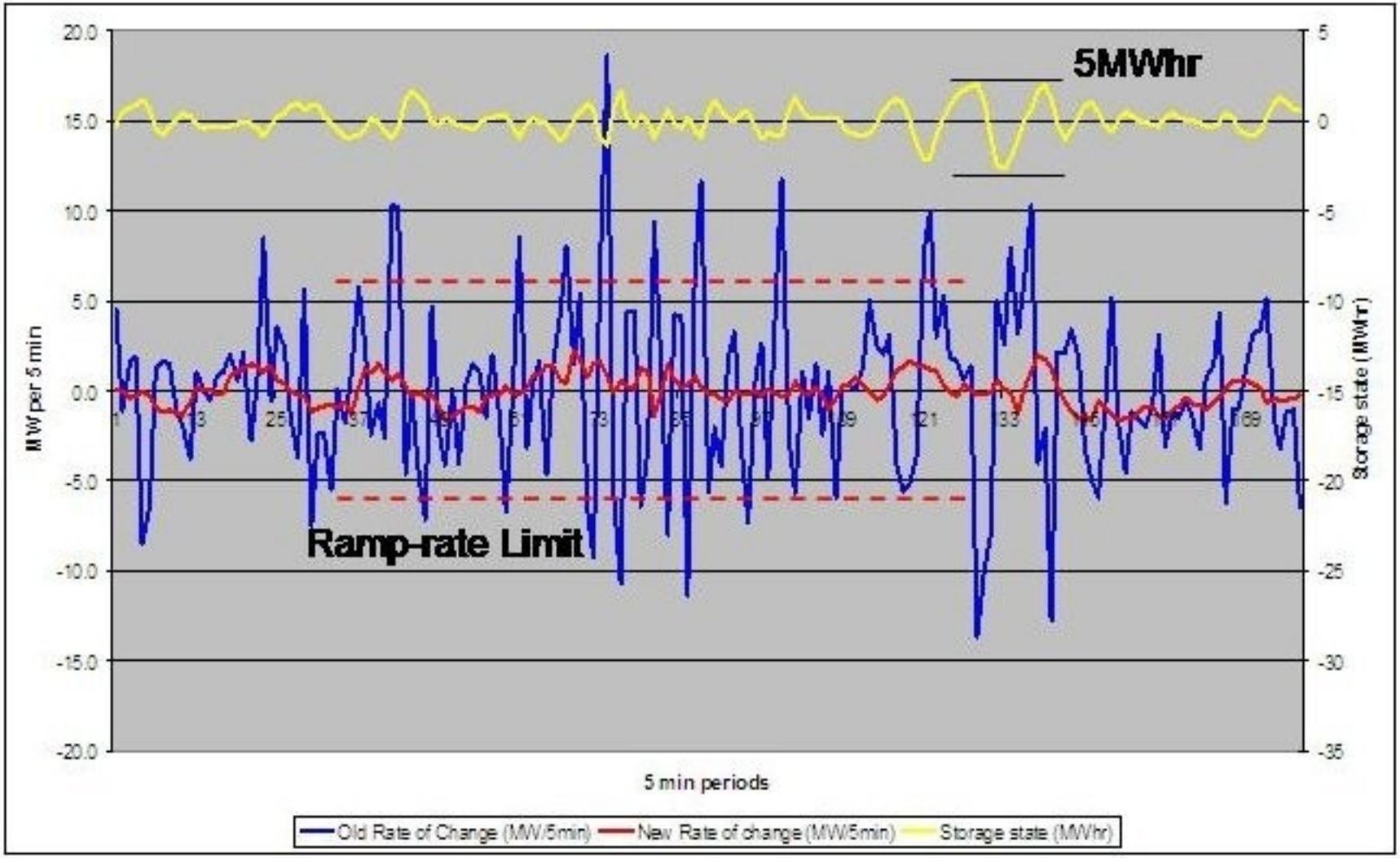


Filtered wind farm output simulation

30min centered running mean

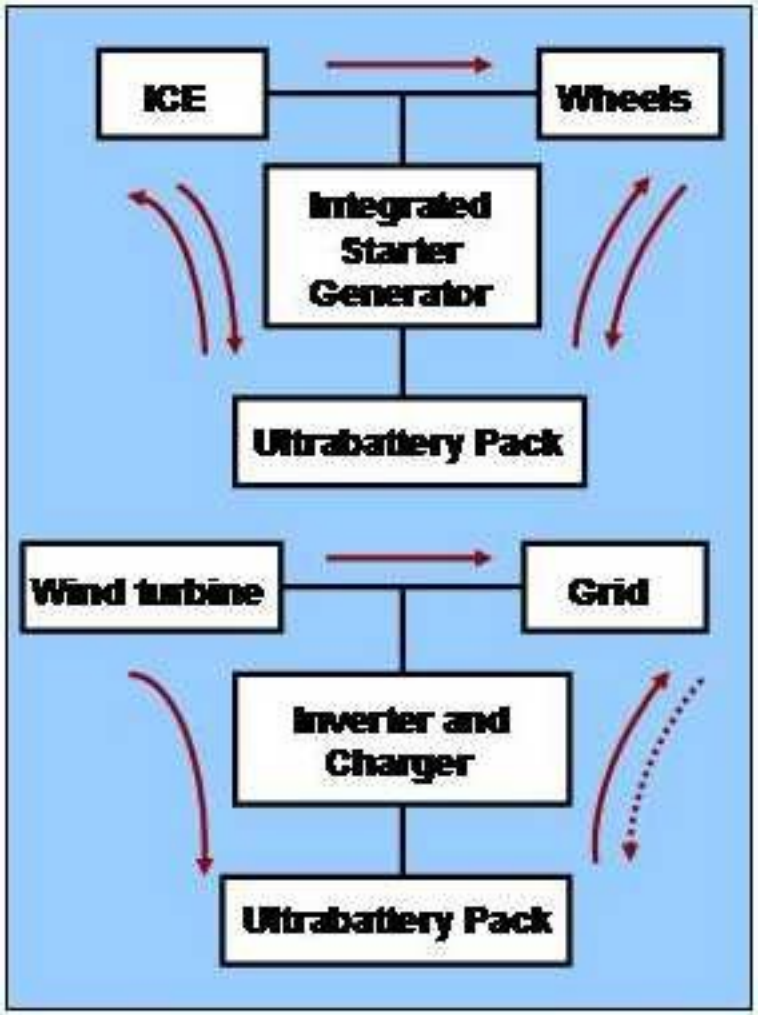


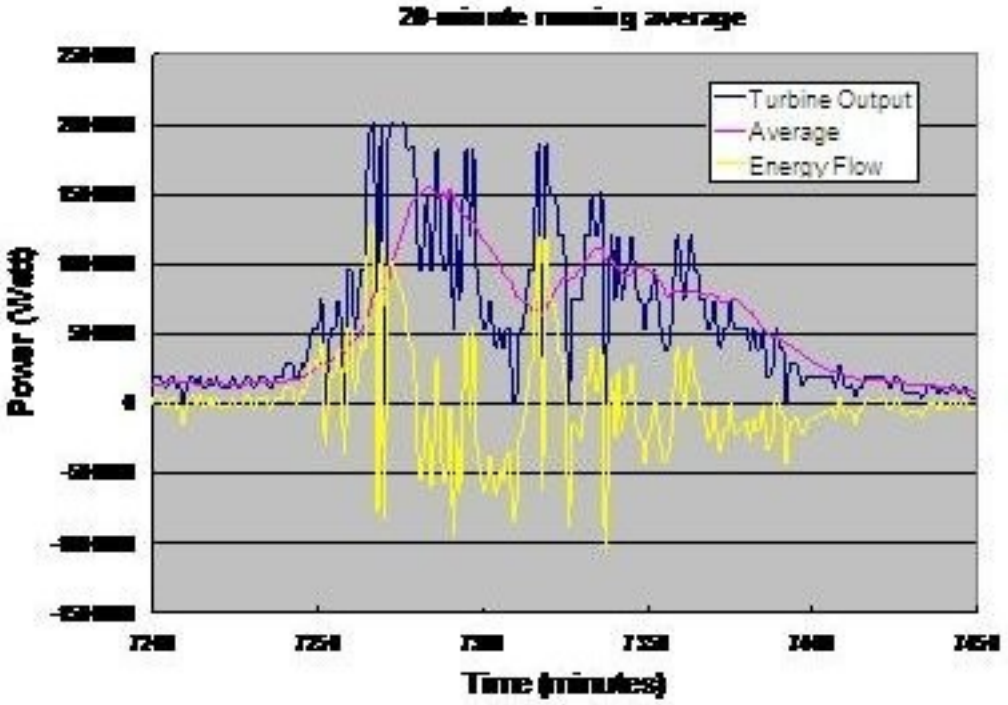
Battery effect on ramp rate and capacity required



Battery Development HEV to renewable energy

Similarity between HEV and wind turbine systems





Our research in HEV batteries provides a good starting point for development of the Wind UltraBattery.

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CSIRO Energy Centre Newcastle

Newcastle Energy Centre Demonstration

Westwind 20kW
3 on site

UltraBattery and conventional VRLA Modules installed at Newcastle Energy Centre

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UltraBattery Modules installed at Newcastle Energy Centre

UltraBattery Storage Module

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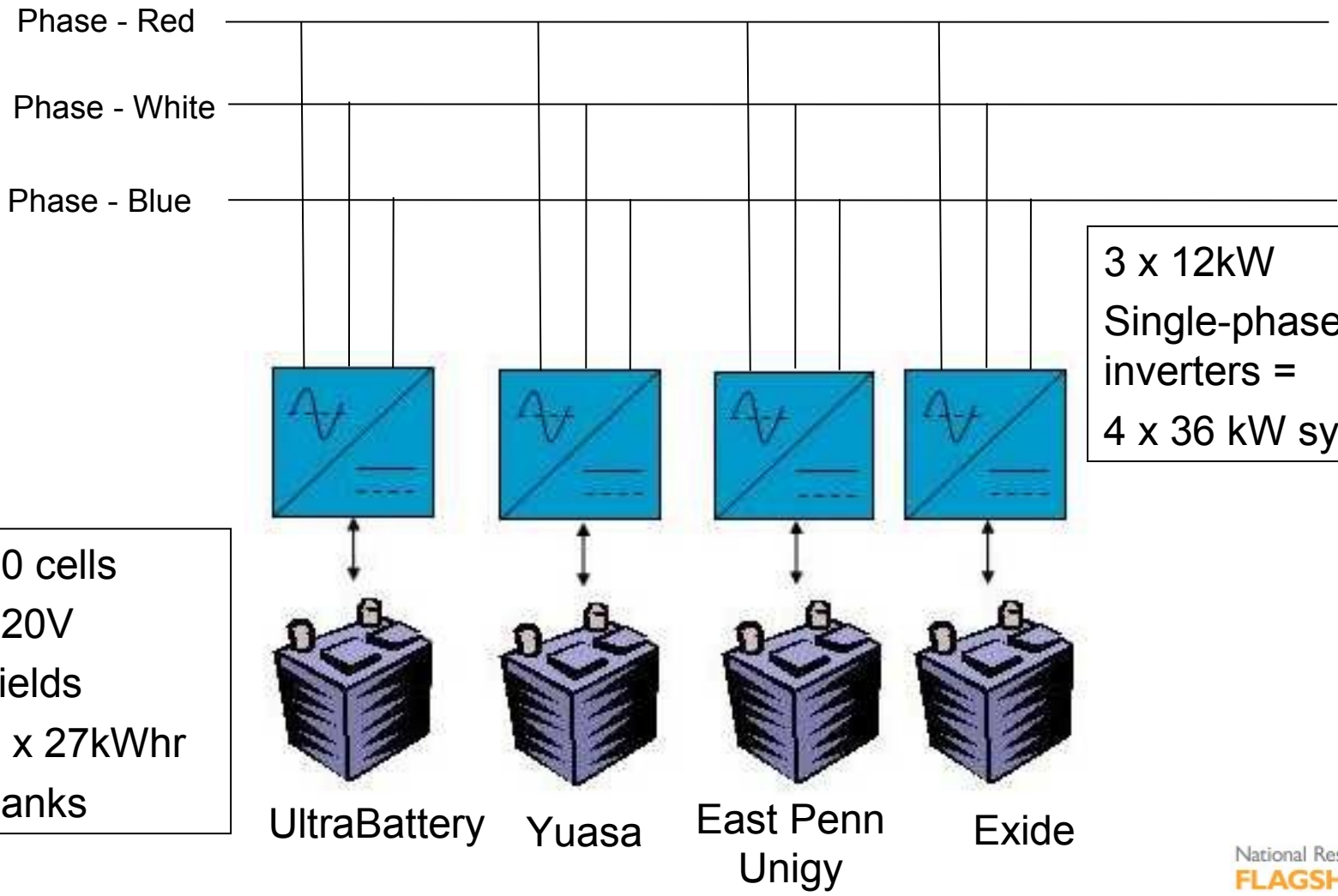
AEST - Grid Connected Trial

Hampton Wind Park
2 Vestas V47-660kW

Configuration – Module I

Vestas V47 660kW turbine
690V – 3 phase

To 11kV step-up transformer



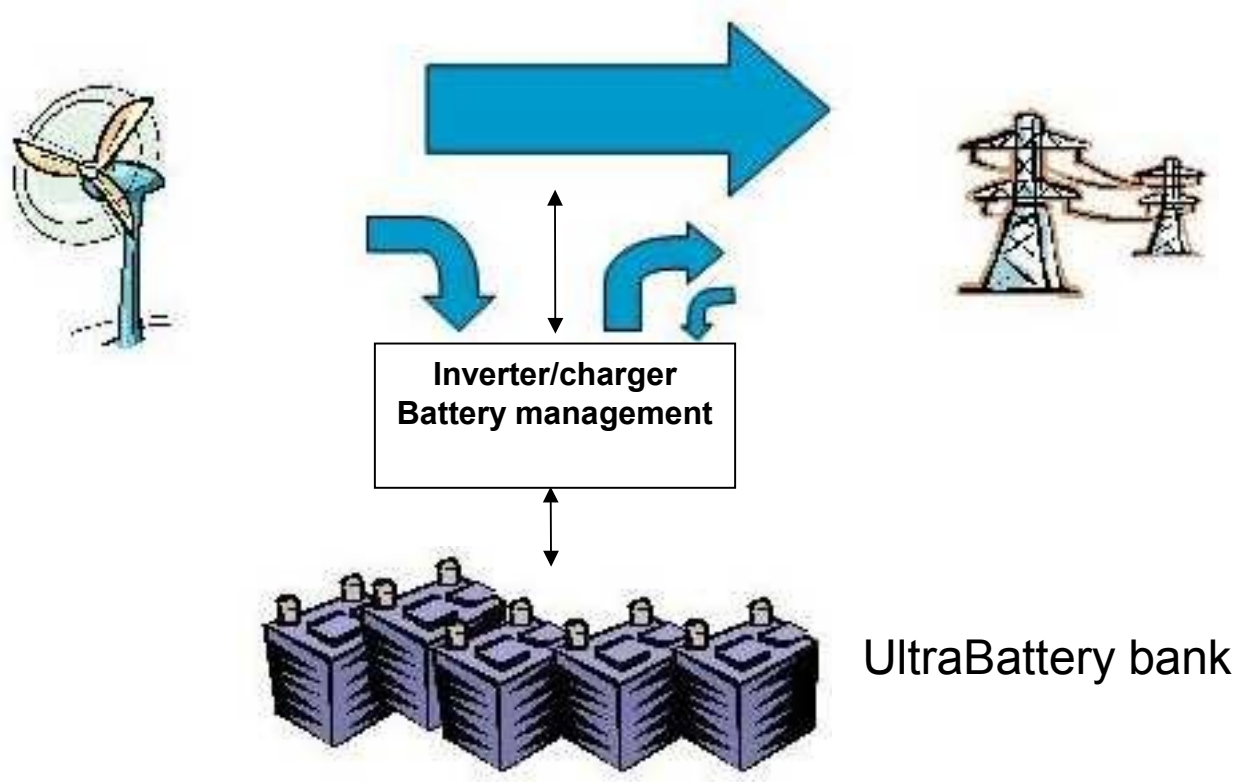
3 x 12kW
Single-phase inverters =
4 x 36 kW systems

60 cells
120V
yields
4 x 27kWhr
banks

Storage containers under construction

UltraBatteries, Inverters

Energy storage for wind



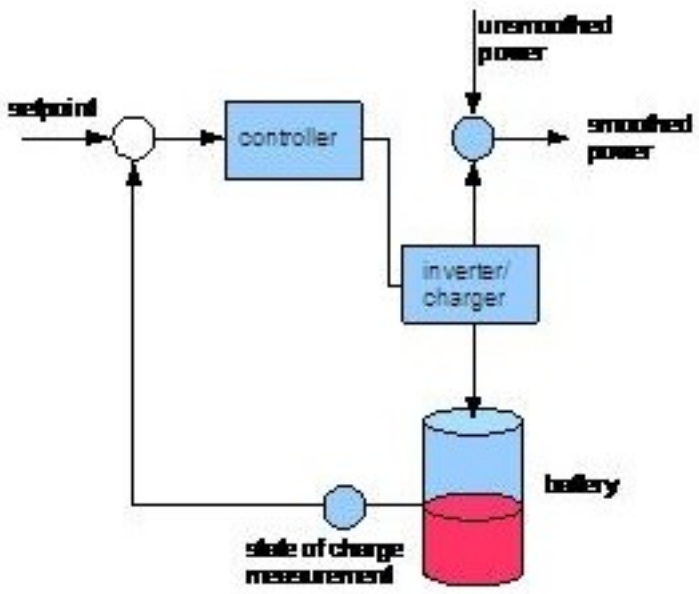
UltraBattery bank

Algorithm deployment

Proportional Integral Controller

From level control algorithm for surge tanks

- smooth the flow rate while simultaneously manipulating the tank level
- tank level is controlled towards 50%.

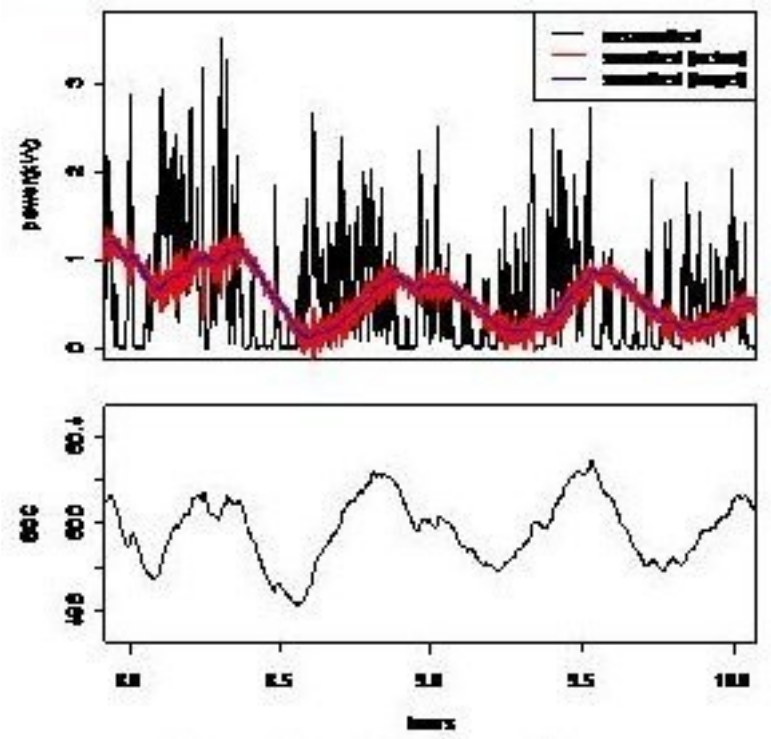


Algorithm deployment

Low Battery Algorithm Controller

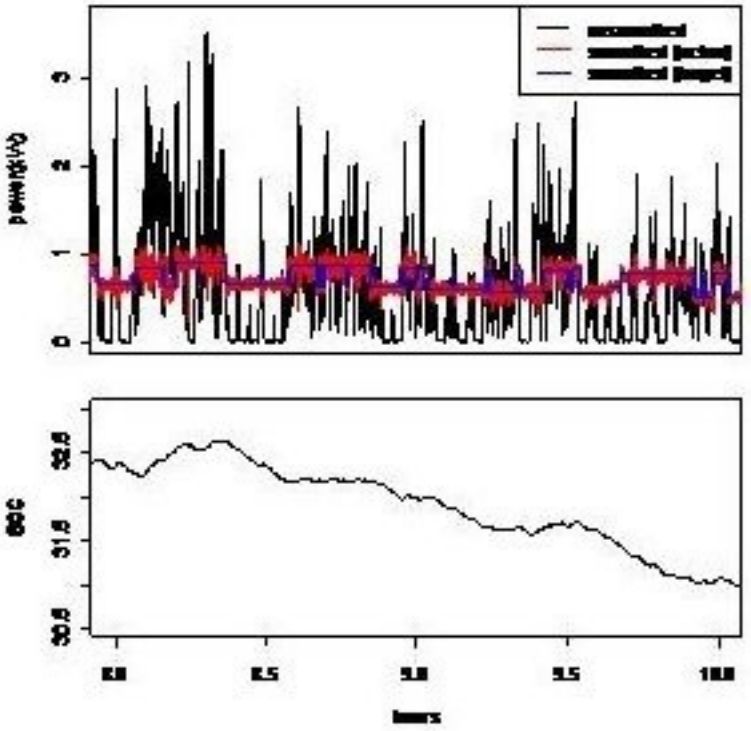
- Keep the battery at a level appropriate to state of input
    - relatively low while wind is low – with capacity ready to absorb peaks as required
    - relatively high while wind is high – with capacity ready discharge to fill lulls as required
    - maintain output rate-of-change below set ramp rate limit.

Comparison of smoothing algorithms

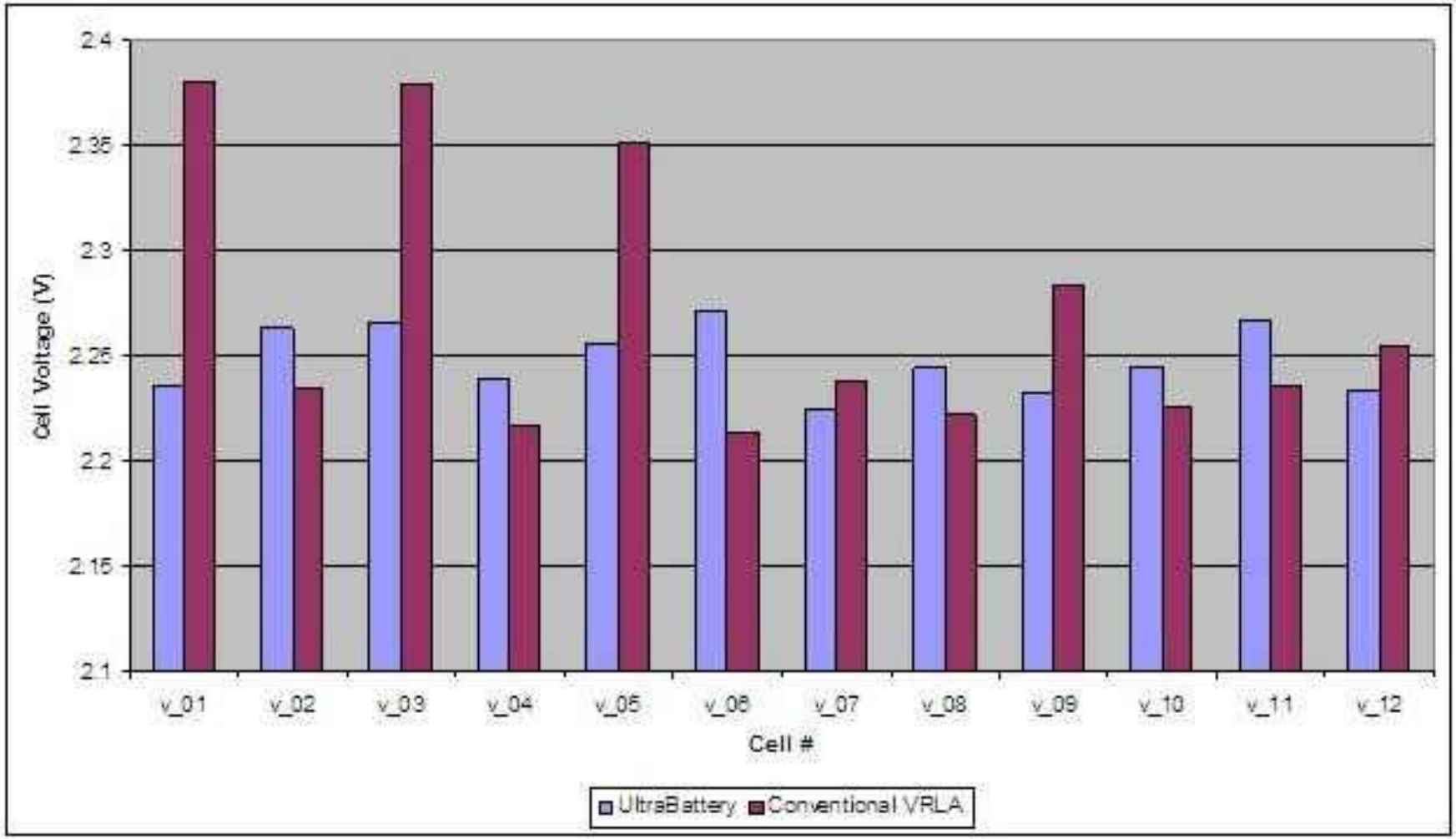


Baseline PI algorithm

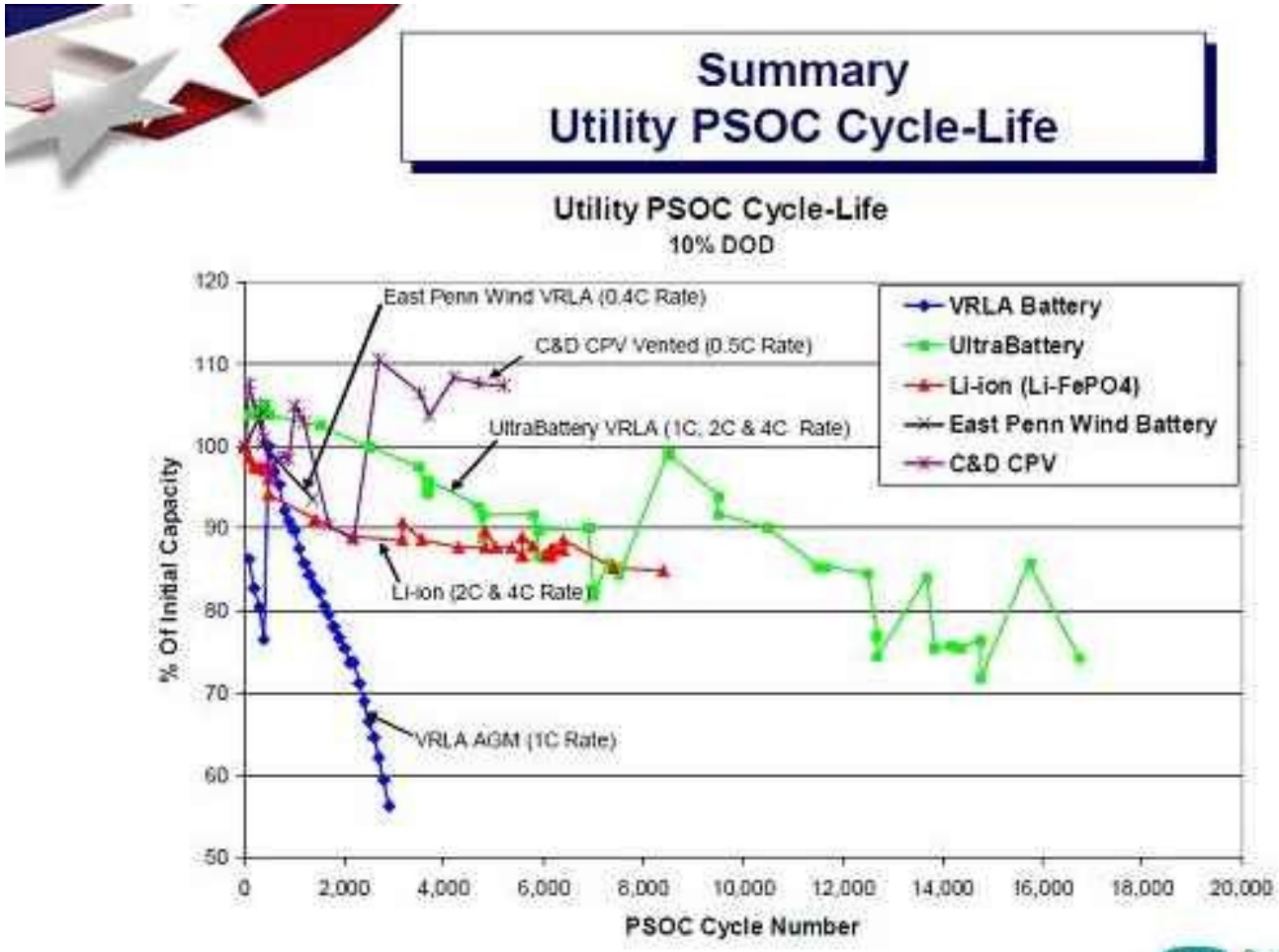
“Low battery” algorithm



String Cell Voltages after 5 months of intermittent trials

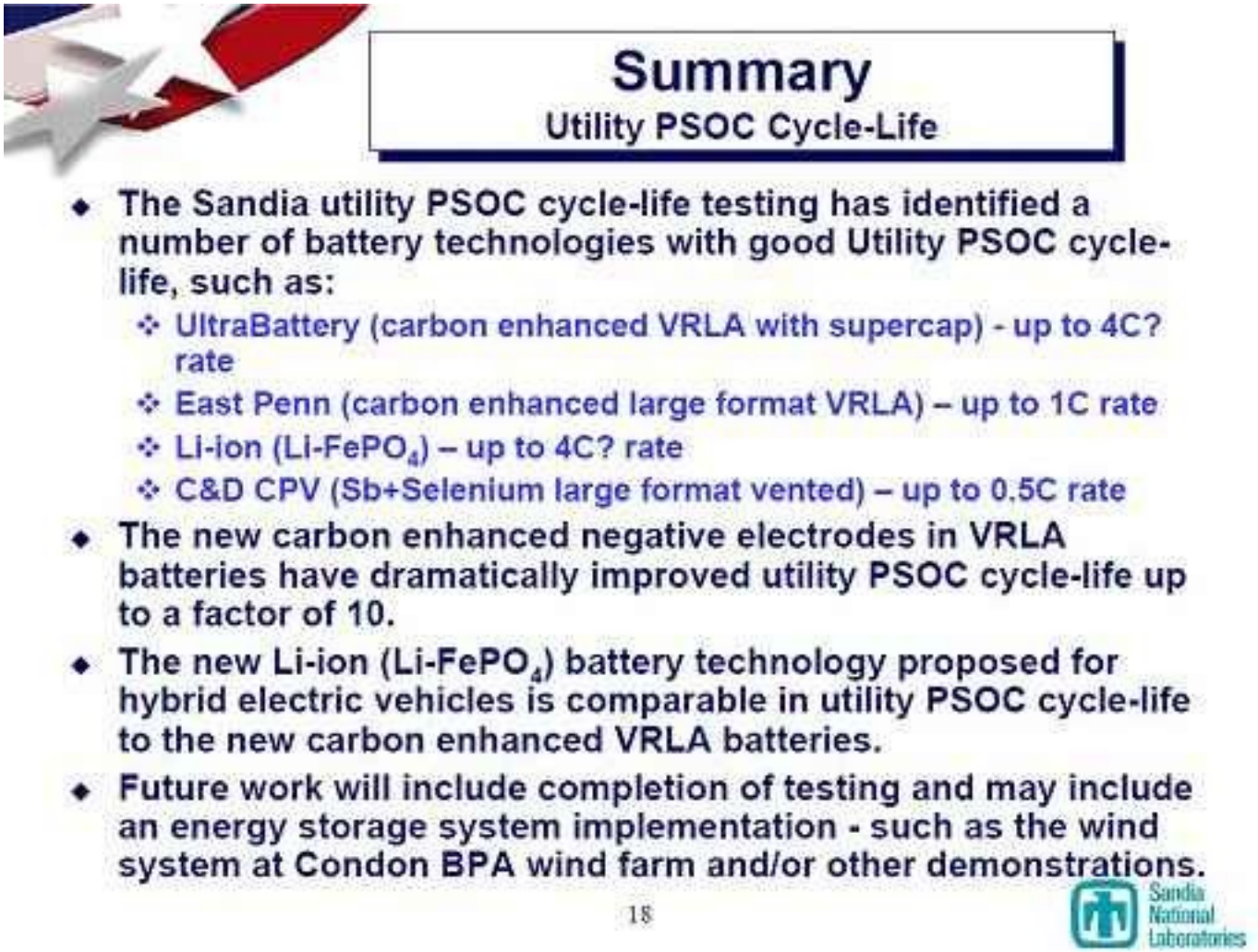


Sandia results



Source: Hund, et al. “Testing and Evaluation of Energy Storage Devices”, DoE Energy Storage Systems Program review, Washington, Sept. 2008

Sandia results



Summary
Utility PSOC Cycle-Life

- The Sandia utility PSOC cycle-life testing has identified a number of battery technologies with good Utility PSOC cycle-life, such as:
  - UltraBattery (carbon enhanced VRLA with supercap) - up to 4C? rate
  - East Penn (carbon enhanced large format VRLA) – up to 1C rate
  - Li-ion (Li-$FePO_4$) – up to 4C? rate
  - C&D CPV (Sb+Selenium large format vented) – up to 0.5C rate
- The new carbon enhanced negative electrodes in VRLA batteries have dramatically improved utility PSOC cycle-life up to a factor of 10.
- The new Li-ion (Li-$FePO_4$) battery technology proposed for hybrid electric vehicles is comparable in utility PSOC cycle-life to the new carbon enhanced VRLA batteries.
- Future work will include completion of testing and may include an energy storage system implementation - such as the wind system at Condon BPA wind farm and/or other demonstrations.

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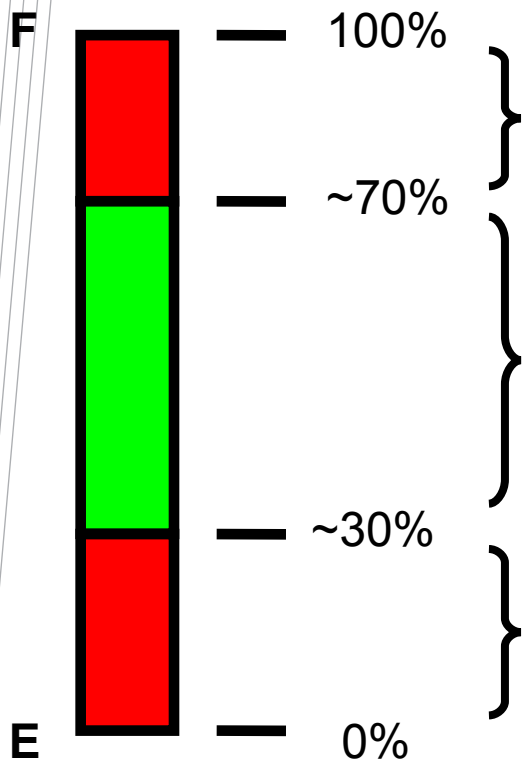
Sandia National Laboratories

Source: Hund, et al. “Testing and Evaluation of Energy Storage Devices”, DoE Energy Storage Systems Program review, Washington, Sept. 2008

Energy Storage for Renewable Energy

Partial State-of-Charge (PSoC)

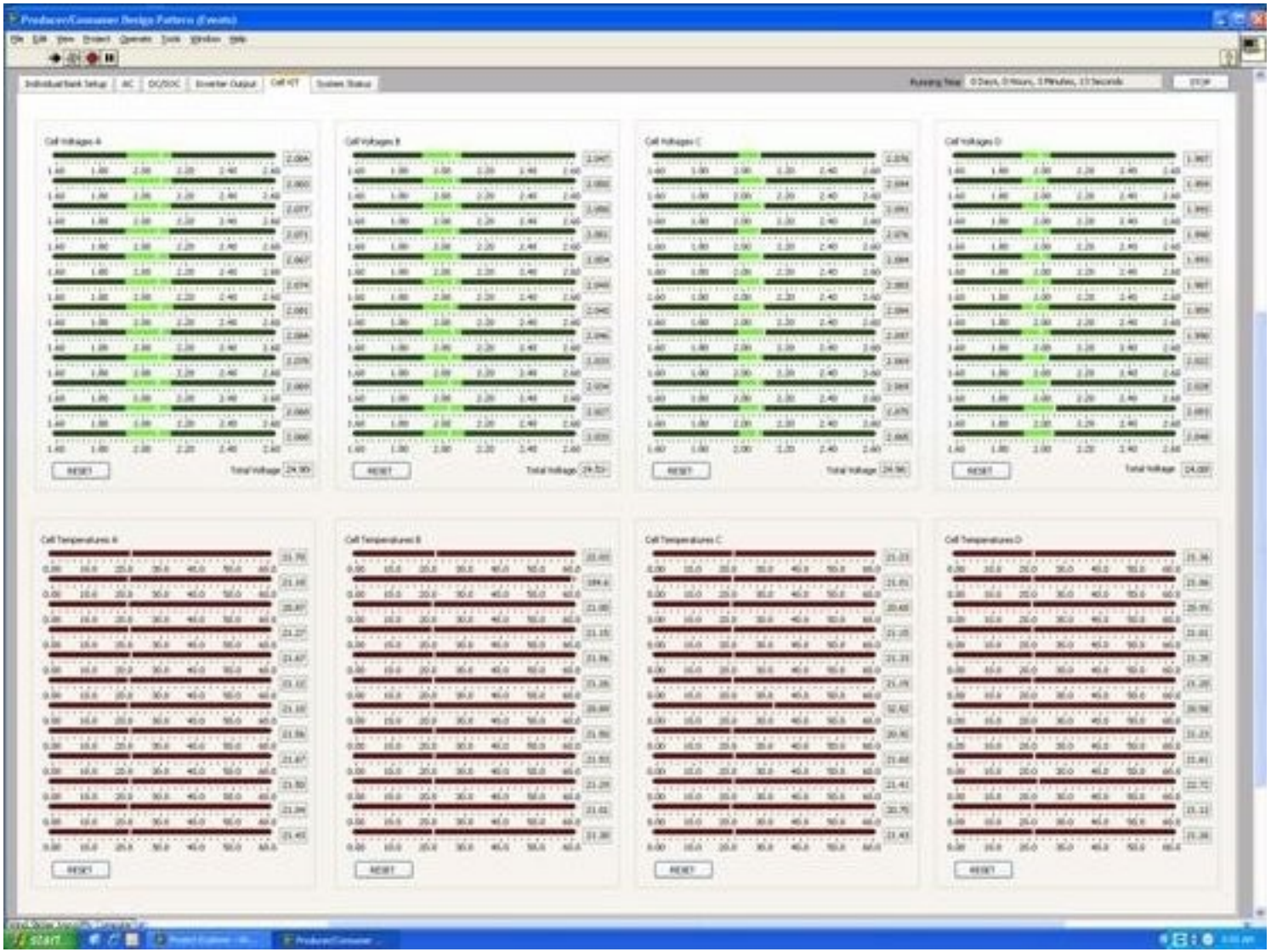


Poor charge acceptance (inefficient, slow), gassing, corrosion

Best Operating region ("Operating Window")
Good power delivery & acceptance
Long life, efficient

Poor charge delivery, sulphation, high internal impedance – poor charging!

Battery Pack Monitoring



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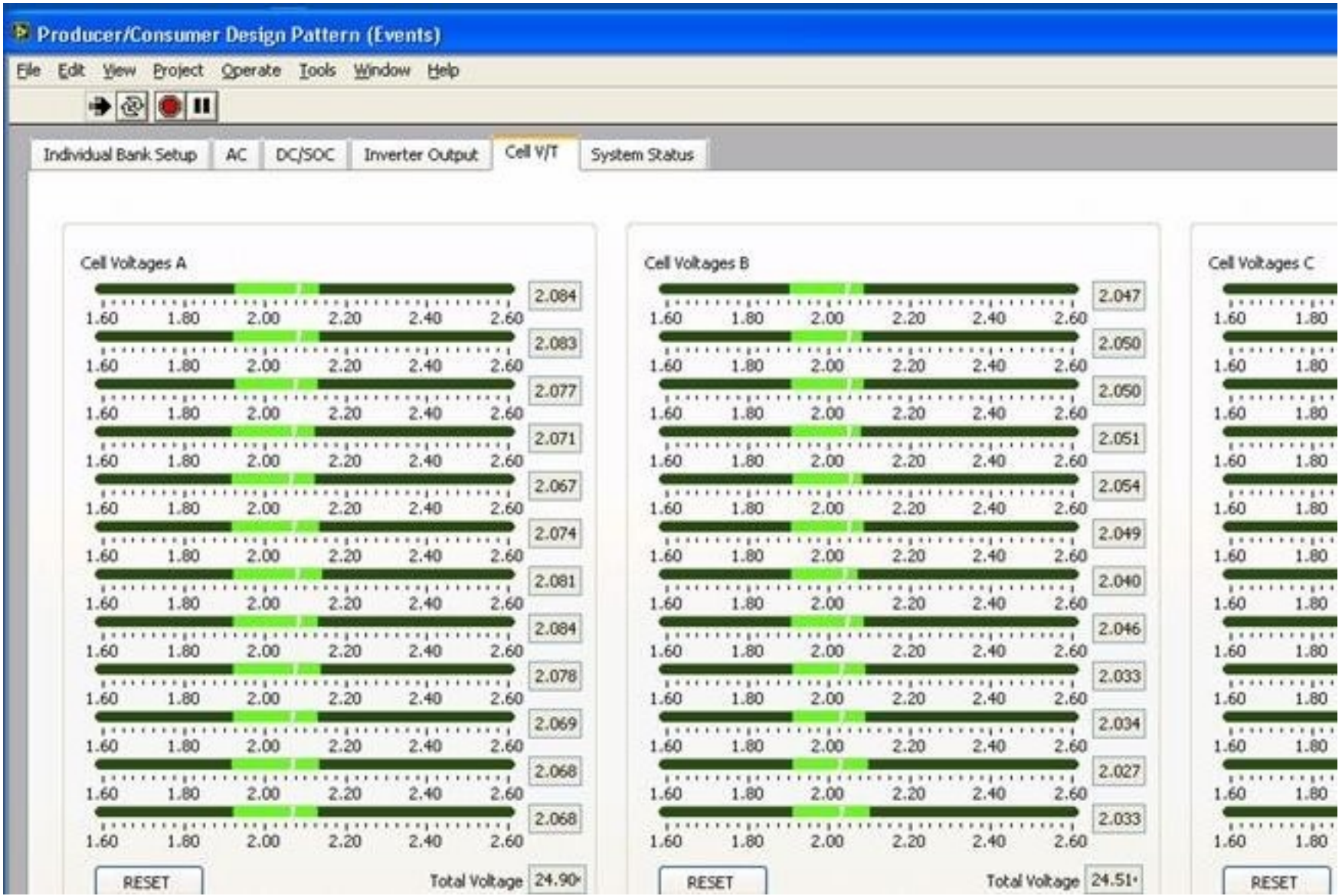
Battery Pack Monitoring



Presentation Outline

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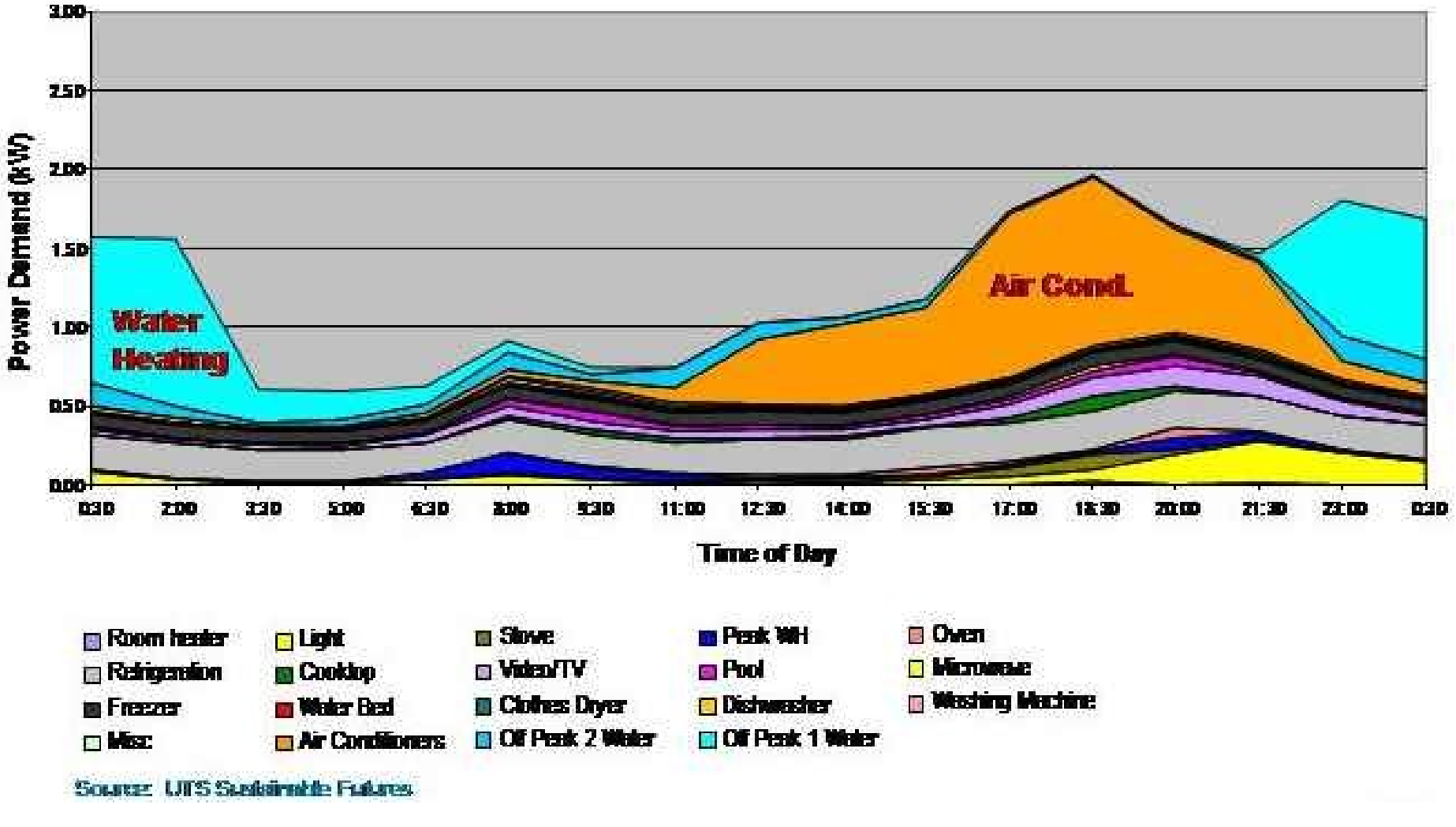
UltraBattery in Wind Energy applications

Domestic Energy Storage (Vehicle to Grid – V2G)

PHEVs as domestic energy stores

Example Residential Power Demand (Summer Peak- NSW)



Source: UTS Sustainable Futures

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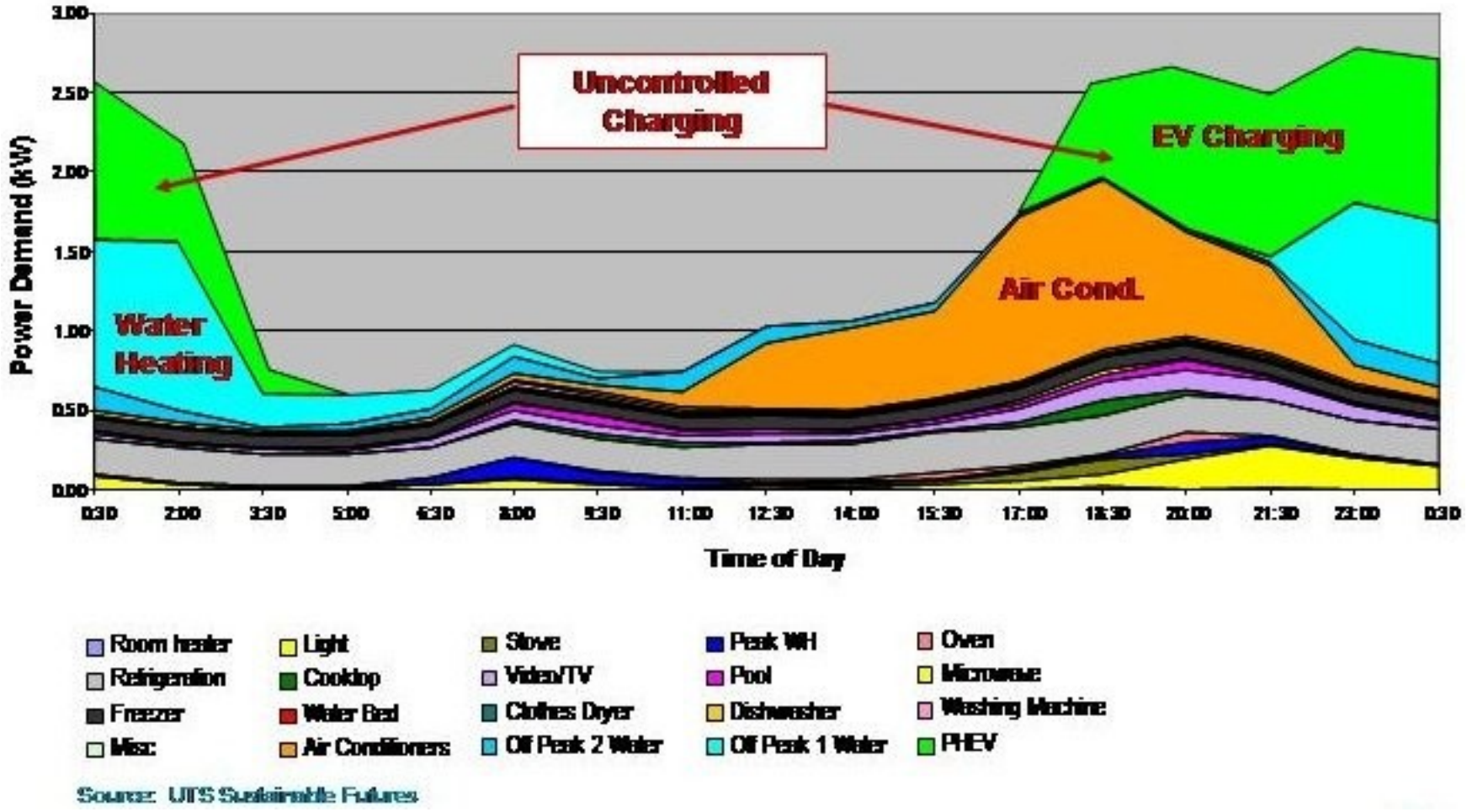
Example Uncontrolled Charging (Summer Peak- NSW)



Source: UTS Sustainable Futures

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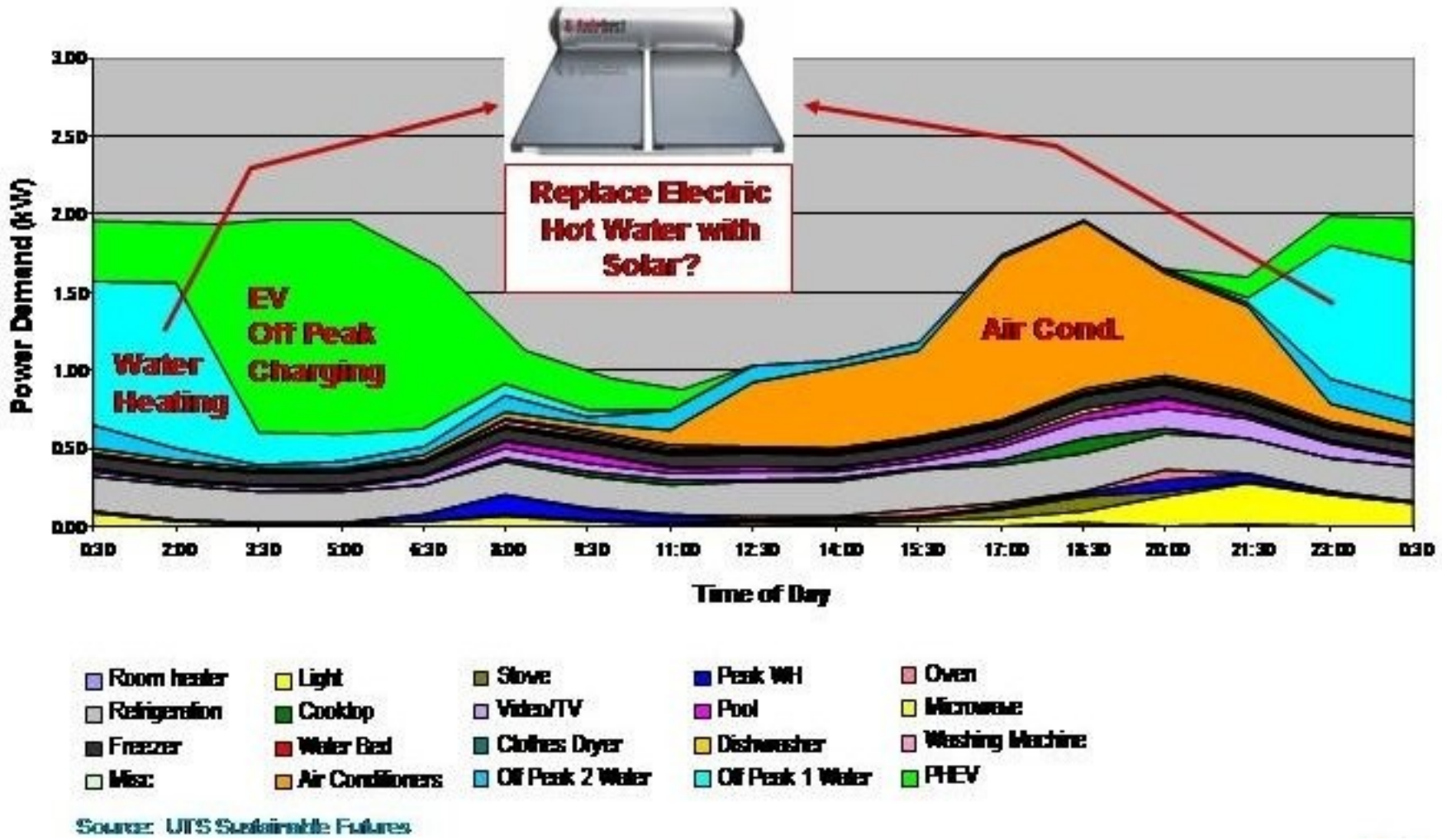
Example Off-Peak Charging (Summer Peak- NSW)



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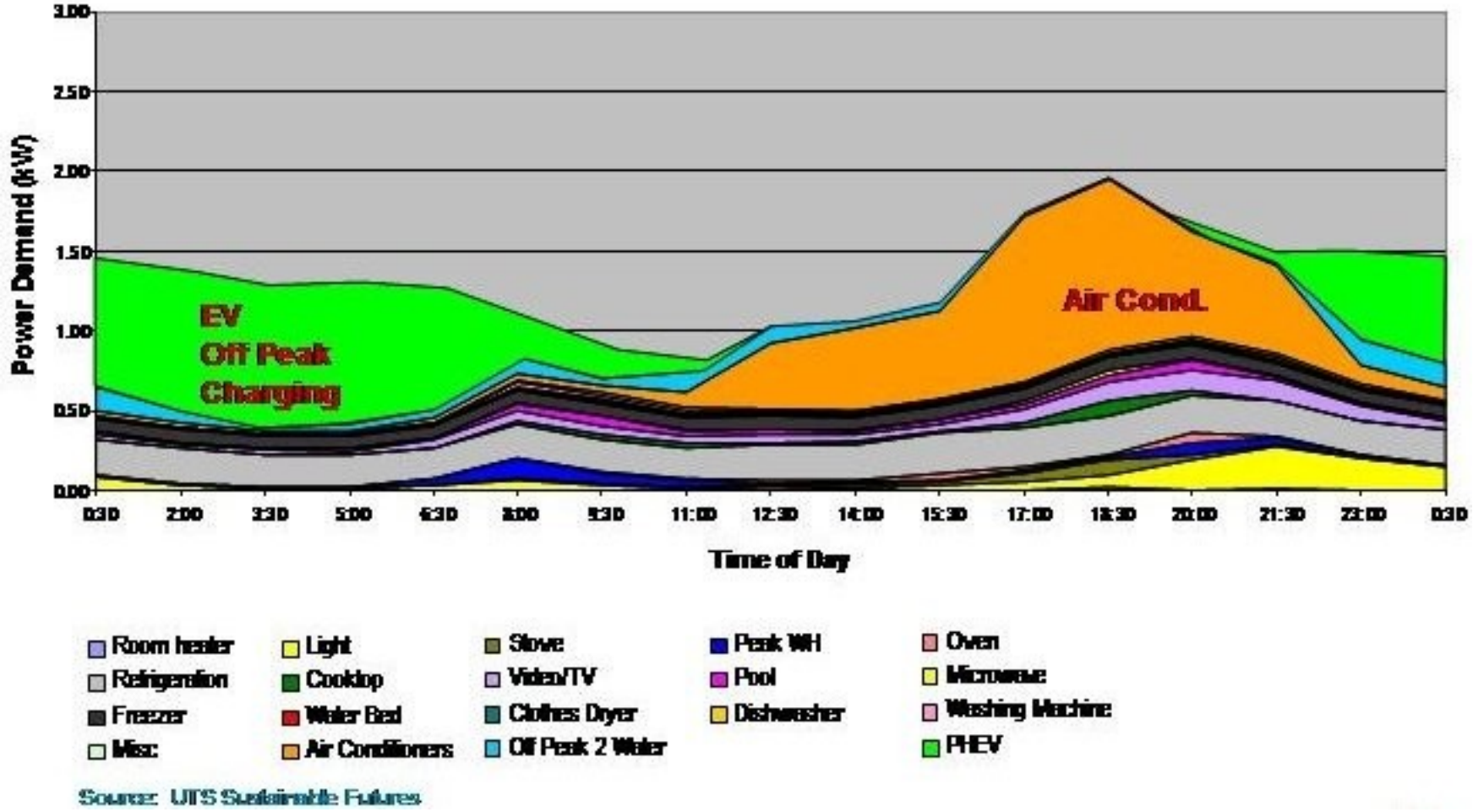
Controlled Charging + Solar Water (Summer Peak- NSW)



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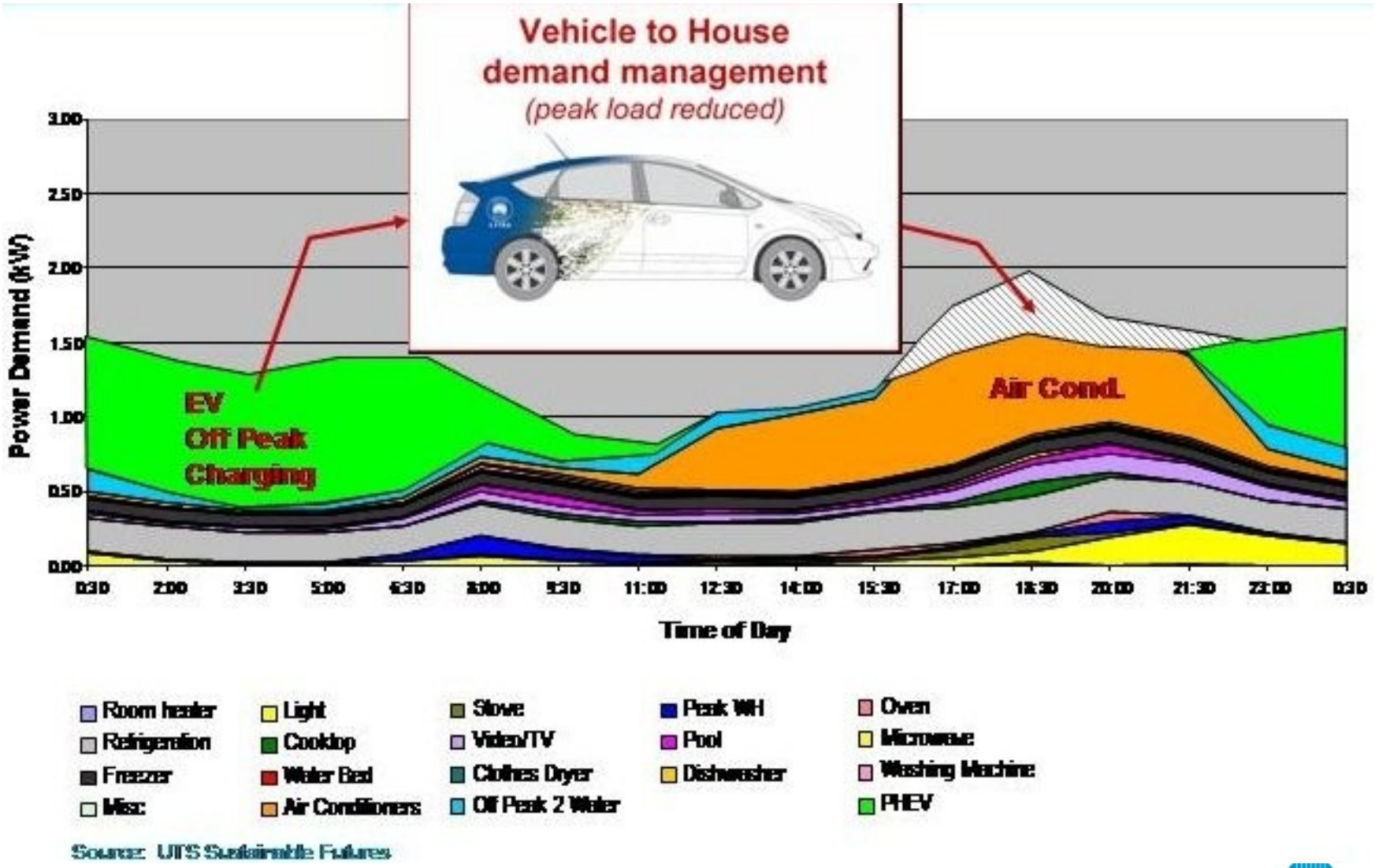
Vehicle to House Load Management (Summer Peak- NSW)



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Current Status

- **Conversion of three Toyota Prius**
  - **Plug-in charge & discharge**
  - **Extra battery capacity**
  - **Advanced monitoring & control of energy flow**

Acknowledgements:

- Dr Lan Lam UltraBattery material
- Dr Peter Coppin Wind Energy Storage material
- Dr Phillip Paevere PHEV to Grid material

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Thank You

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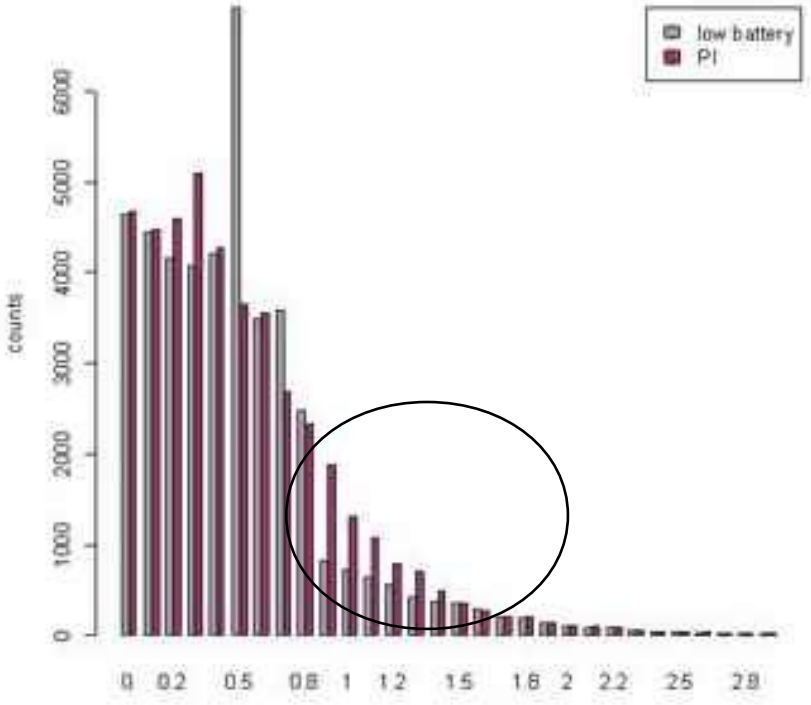
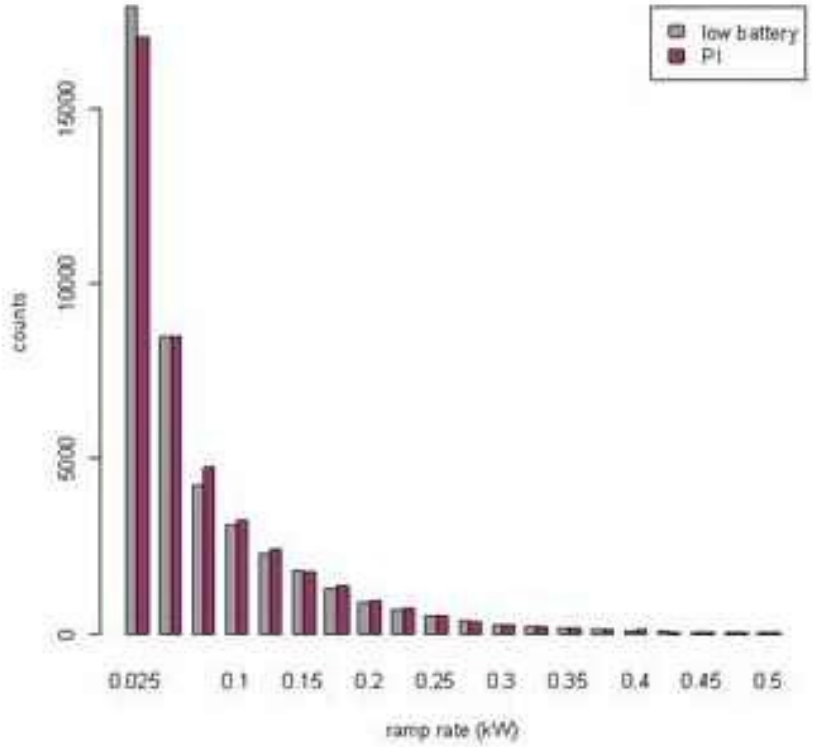
UltraBattery pack

Testing Stationary version

Power flow stats

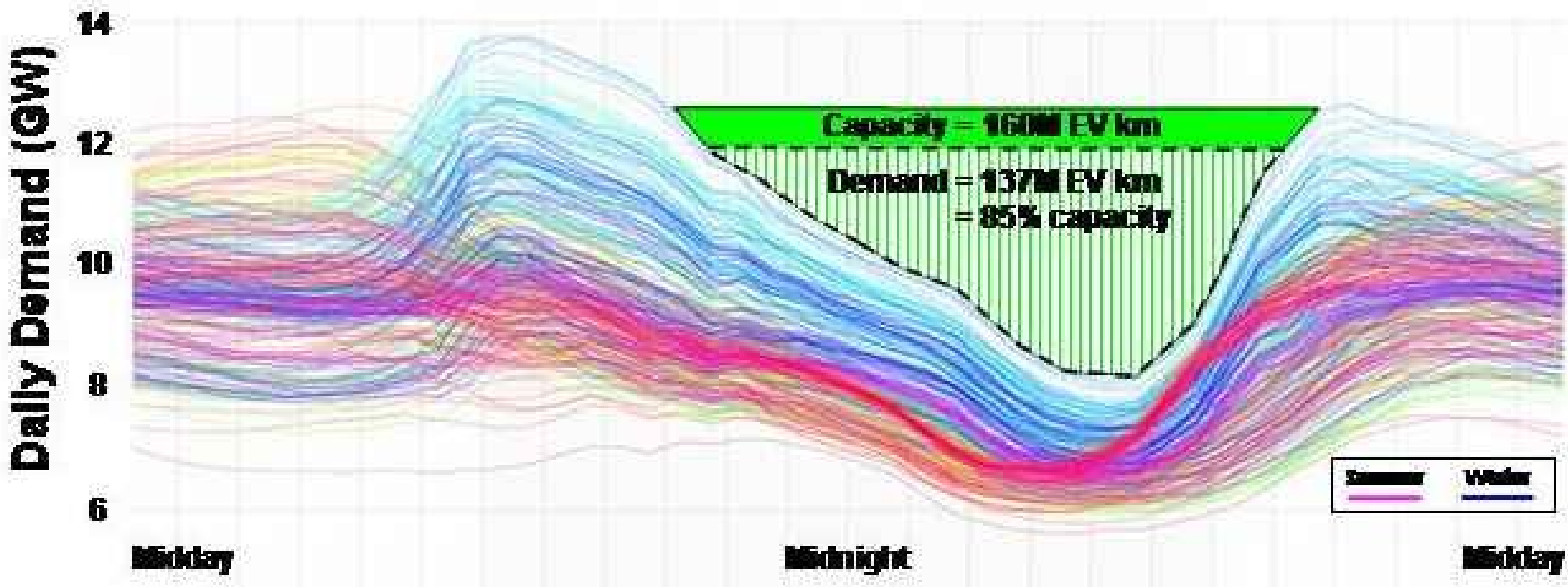


Inverter power



Output signal ramp rate
(rate of change)

Daily Electricity Demand - NSW



Source: NEMMCO 2007; ABS 2007

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Energy Storage for Renewable Energy

How Battery Packs Fail

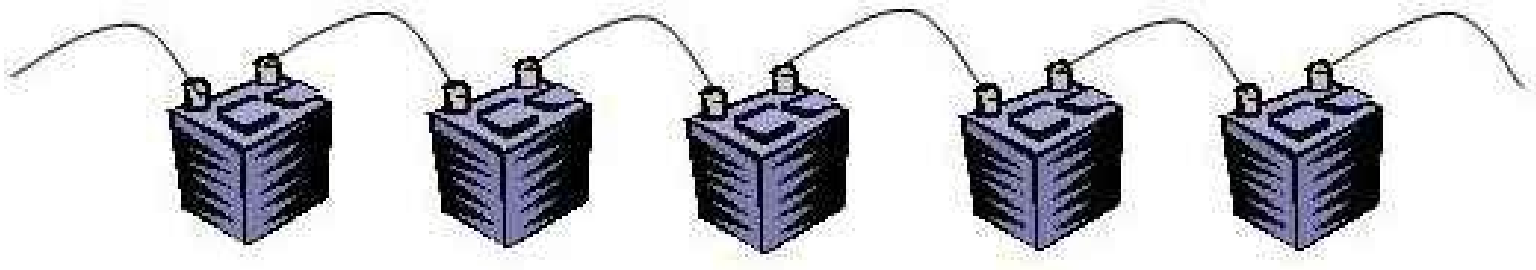
100 Ah 99 Ah 100 Ah 101 Ah 100 Ah

This battery will cycle deeper
⇒ Less life
⇒ Deteriorate faster

This battery will cycle shallower
⇒ More life
⇒ Deteriorate slower

Energy Storage for Renewable Energy

Battery Packs Become Unbalanced



50% SoC 47% SoC 50% SoC Ah 54% SoC 50% SoC

To restore battery pack balance, the pack needs an “equalisation charge”