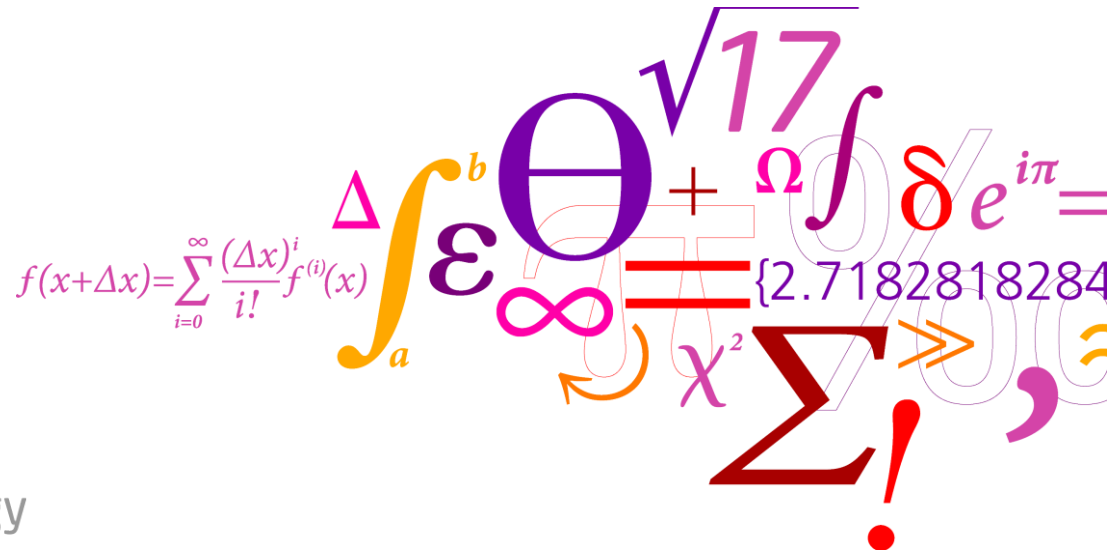
Vanadium Battery – Initial Test Results

Henrik Bindner, Claus Krogh Ekman
Risø DTU

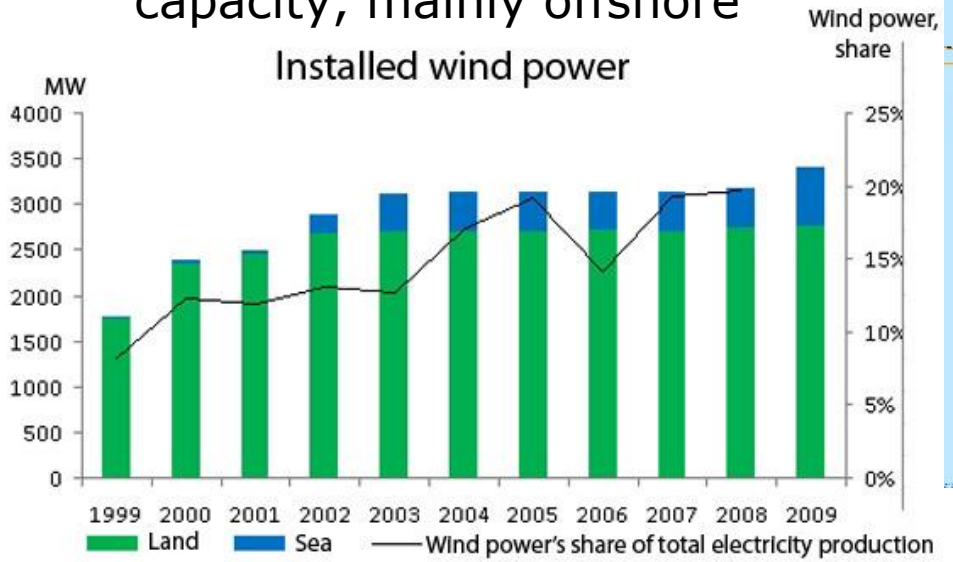
Energy Storage Workshop, Santa Clara
29-30 April 2010

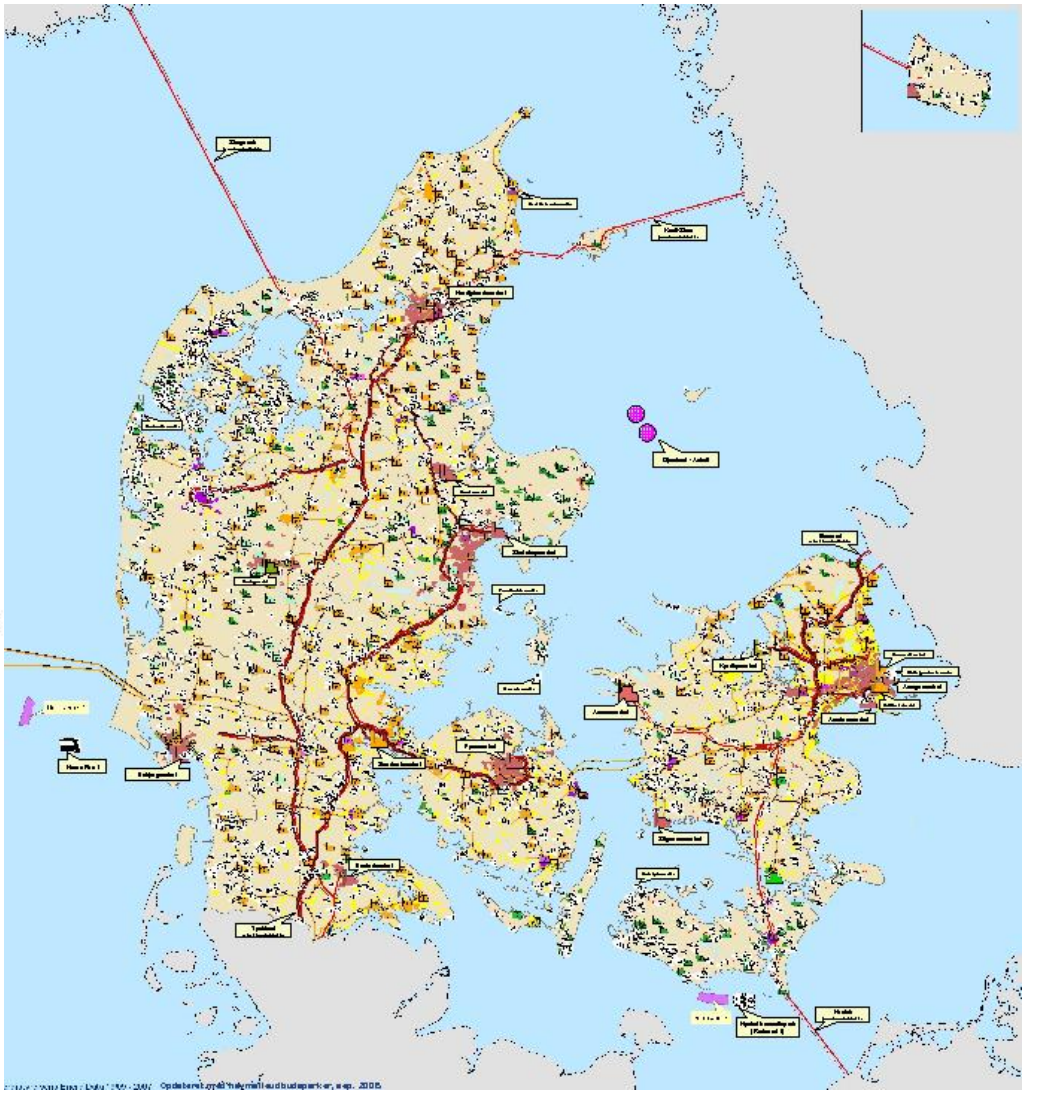


Risø DTU
National Laboratory for Sustainable Energy

Targets for wind energy in Denmark

- Current situation
  - 3400MW installed capacity
  - 20% of annual electricity consumption
- Target for 2025
  - 50% of annual electricity consumption
  - Ca. 3000MW Additional capacity, mainly offshore

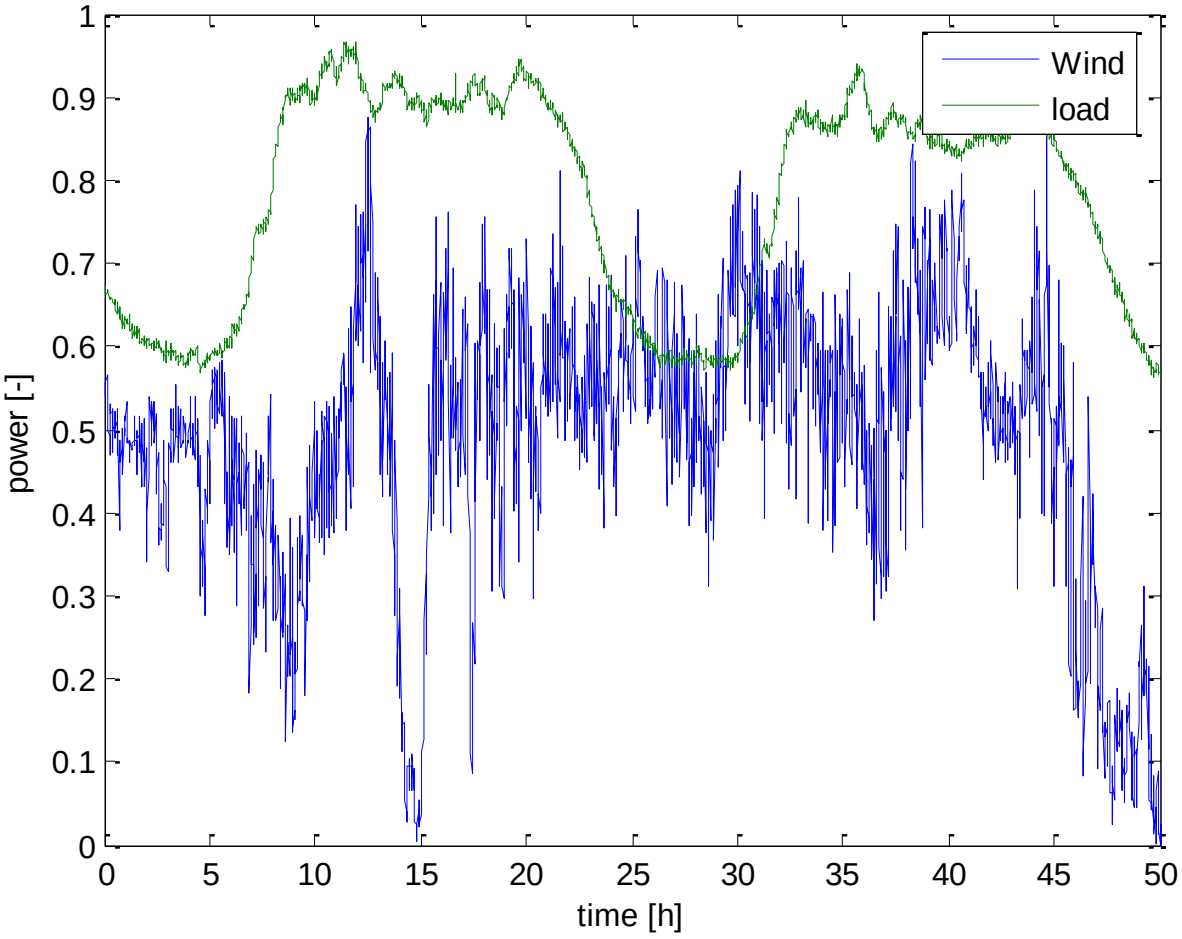




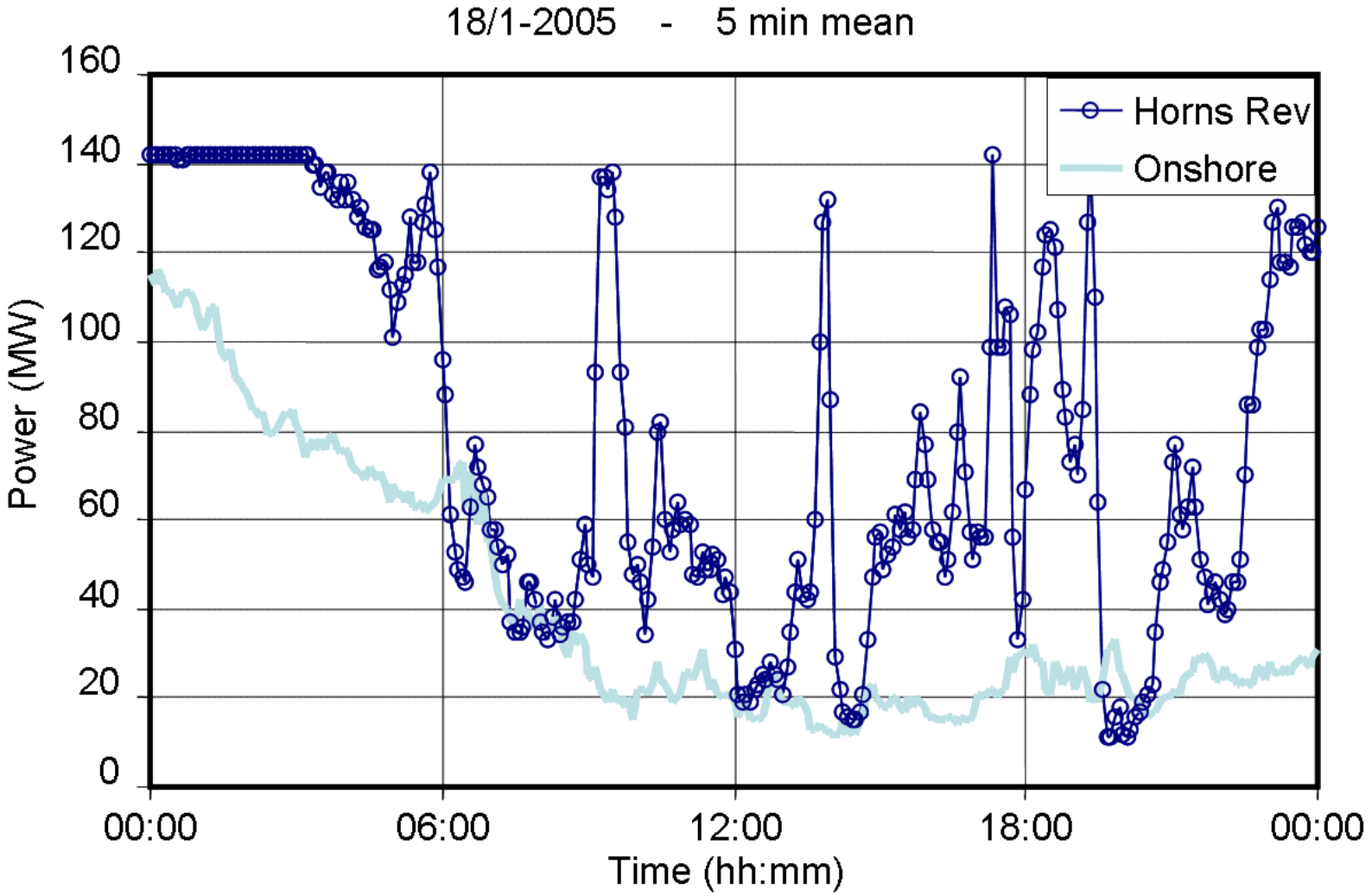
Source: Danish Energy Agency

Power Systems with high penetration of wind

- Issues with wind power
  - Fluctuations and Variations
  - Predictability
- The rest of the system has to provide flexibility
- Flexibility can be provided by several means
  - Production
  - Flexible/intelligent consumption
  - Energy storage



Fluctuations from wind farms



Power System Control

- Power system control is build to make sue that this is fulfilled also when faults occur.
- Set of system control services are defined to simplify control
- Power control (global but limited by bottlenecks)
  - primary control (frequency, automatic)
  - secondary (re-establish primary)
  - spotmarket
  - long term markets
- Voltage control (local)

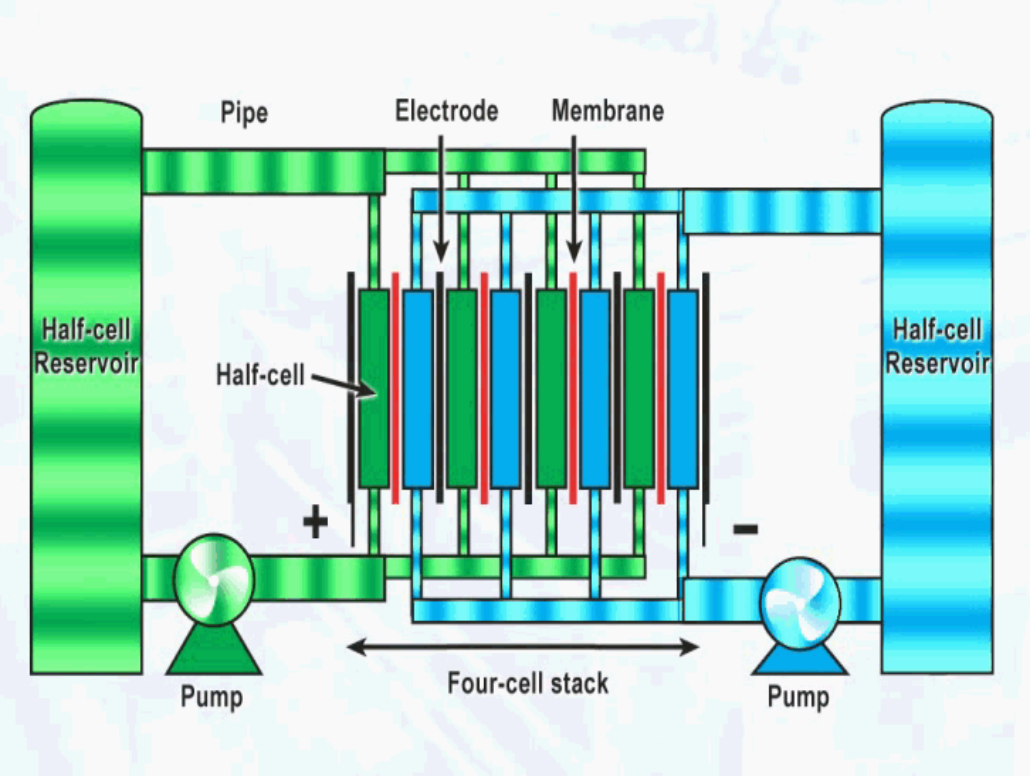
- Central power plants are used to deliver control services

- Can a combination of energy storage and small distributed energy resources be used to deliver control services thus substituting large power plants and improve efficiency?

- Several energy storage exist
- Vanadium batteries is a good candidate in the min-hours range

VRB Flow Battery Technology

A liquid electrolyte that is separate from the electrode.

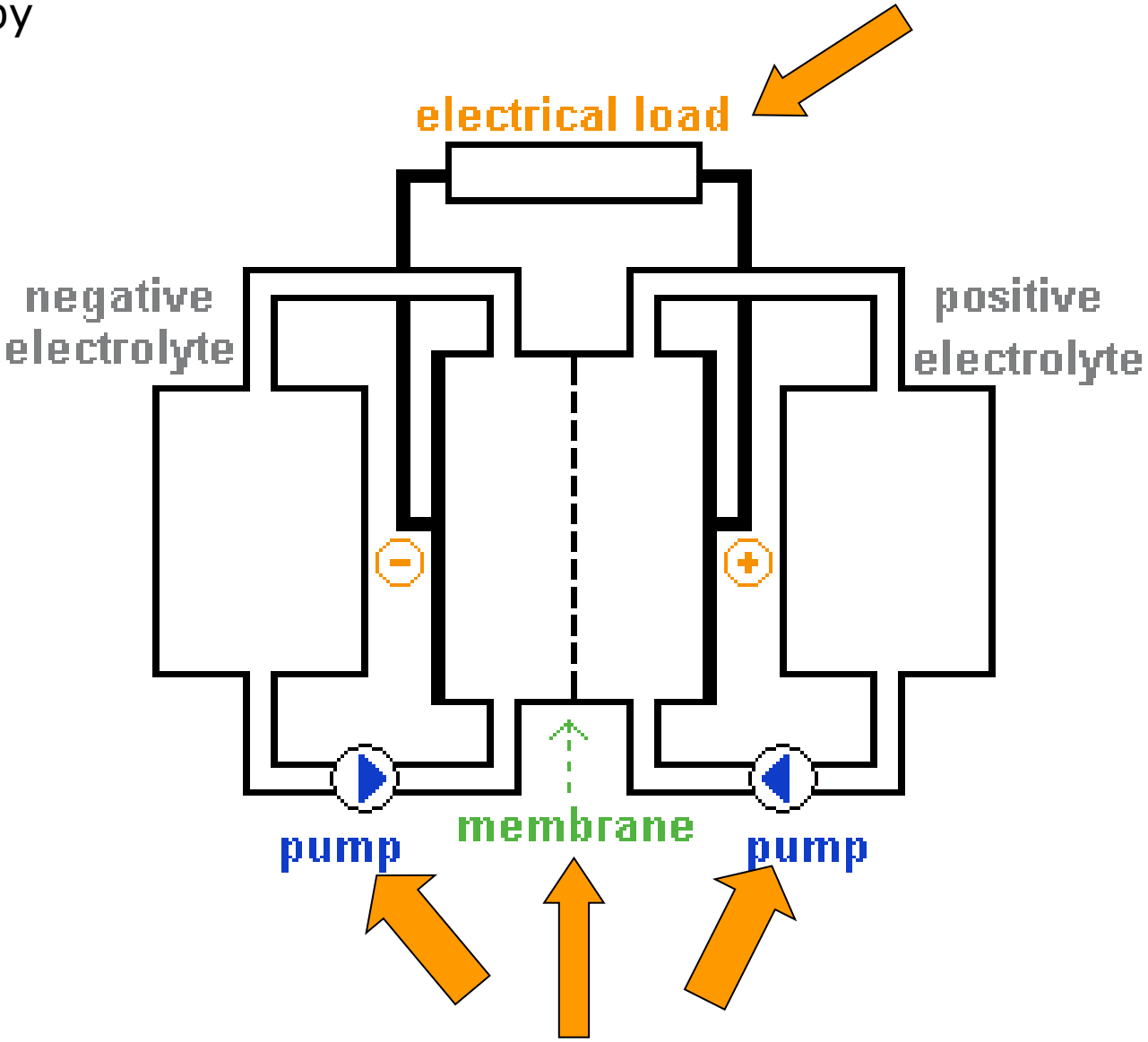


- An electrochemical energy storage system operating at ambient temperatures
- Reversible fuel cell – reduction and oxidation of single unique element: Vanadium
- No cross contamination as with other storage systems. Electrolyte never wears out – high residual value
- Very low maintenance
- Deep cycles (20 to 80%) >10,000
- Low self discharge – indefinite energy storage
- Energy can be recovered instantaneously
- Battery can recharge as fast as it discharges (1:1)
- Power and Energy separately scalable

Oxidation process		Reduction process
$V^{4+} \Rightarrow V^{5+} + e^-$	Charge ⇐	$V^{3+} + e^- \Rightarrow V^{2+}$
$V^{5+} + e^- \Rightarrow V^{4+}$	Discharge ⇒	$V^{2+} \Rightarrow V^{3+} + e^-$

Characterisation of vanadium batteries

- PSO-project – supported by Energinet.dk
- Hands-on experience
- Efficiency @ different operating conditions
- Response time etc.
- Limits for operating range
- Cycling ability
- Grid interface



SYSLAB – Intelligent Energy System Laboratory

- SYSLAB is a **platform** for Decentralised Energy Resources research and testing
- It is a flexible experimental setup up
- It includes several production and consumption units
- It has embedded computing power and flexible communication
- It has very flexible control possibilities
- It can be extended
- It is being used for proof-of-concept implementations

Vanadium Battery at SYSLAB I

- AC power: ±15 kW
- Storage: 120 kWh

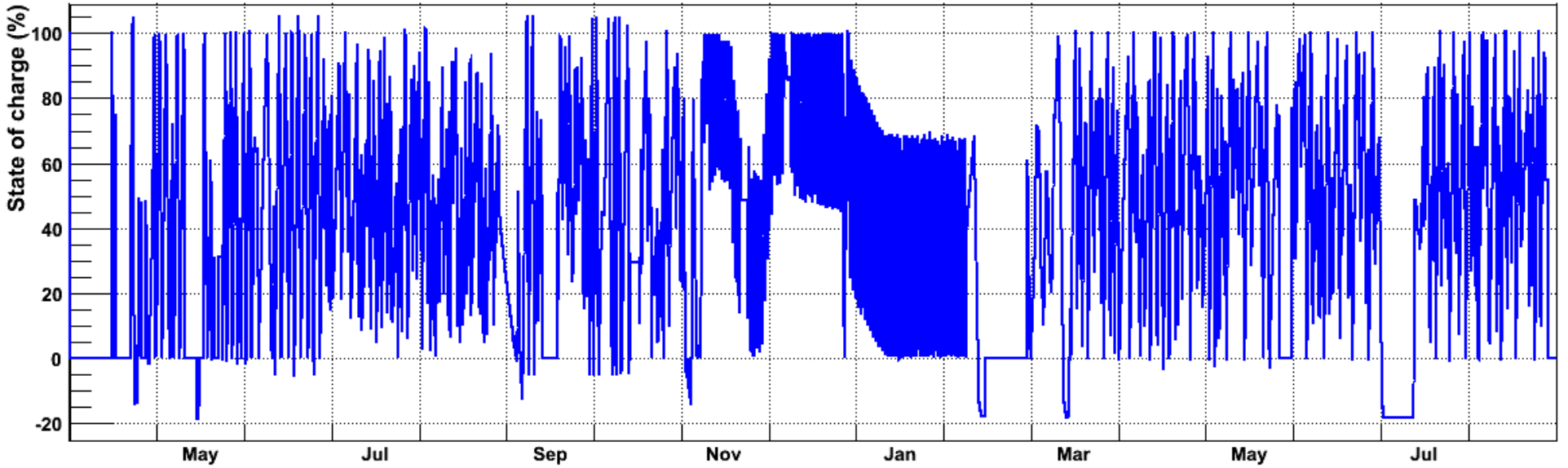
- <u>Battery system includes:</u>
- Cell stacks (3×40 cells in total)
- Electrolyte and storage (2×6500liter)
- Balance of plant (pump, pipes, etc.)
- Control and communication unit
- Four quadrant AC/DC power converter

- Total price: 750000 DKK ~ 140000 USD

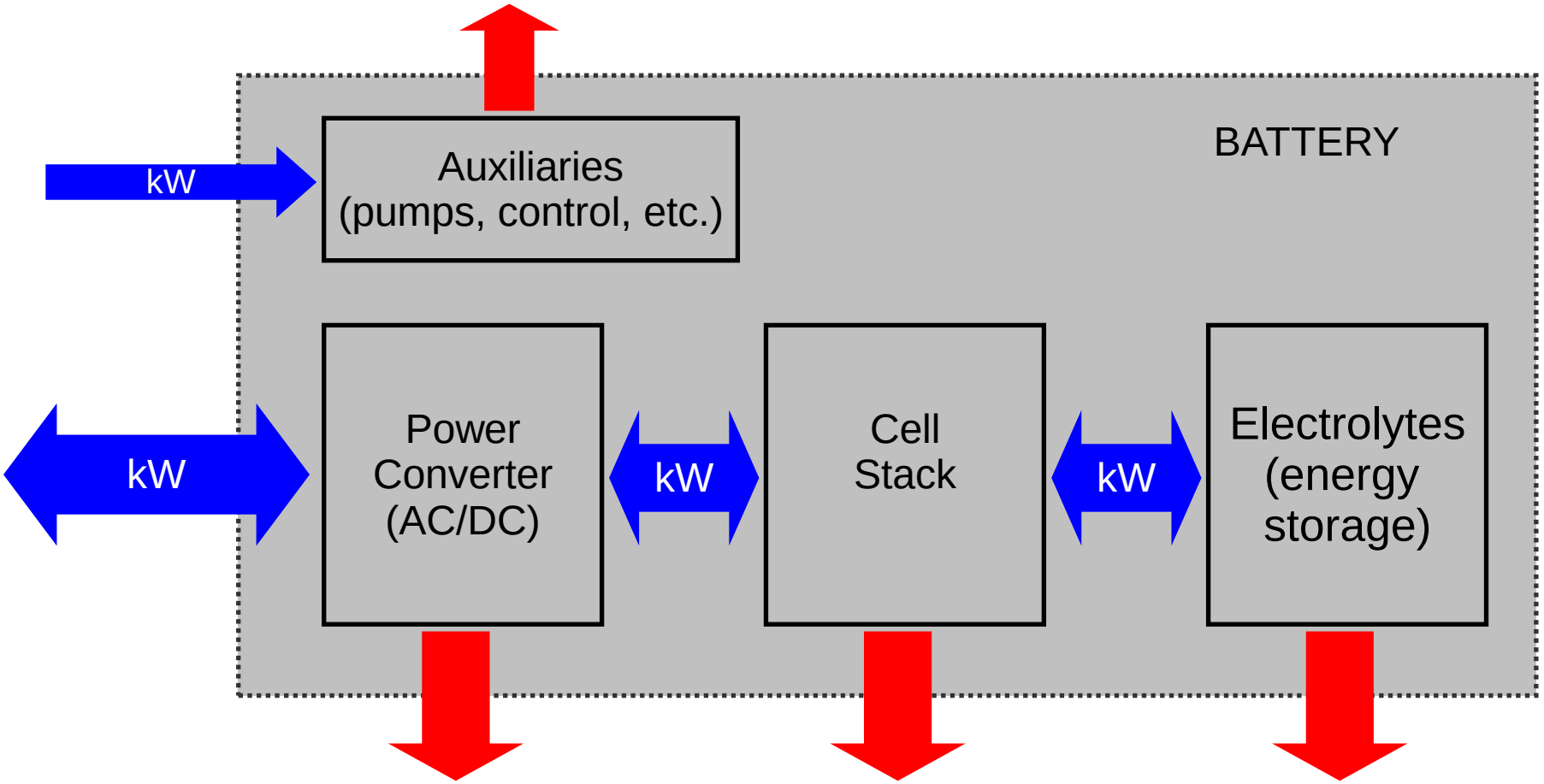
Vanadium Battery at SYSLAB II

- Battery has been in operation since January 2008
- Stacks have been changed twice
  - Shortly after commissioning due to short circuit
  - Nov 2009 due to leakage
- It has been cycled at various SOC and powers


VRB at SYSlab

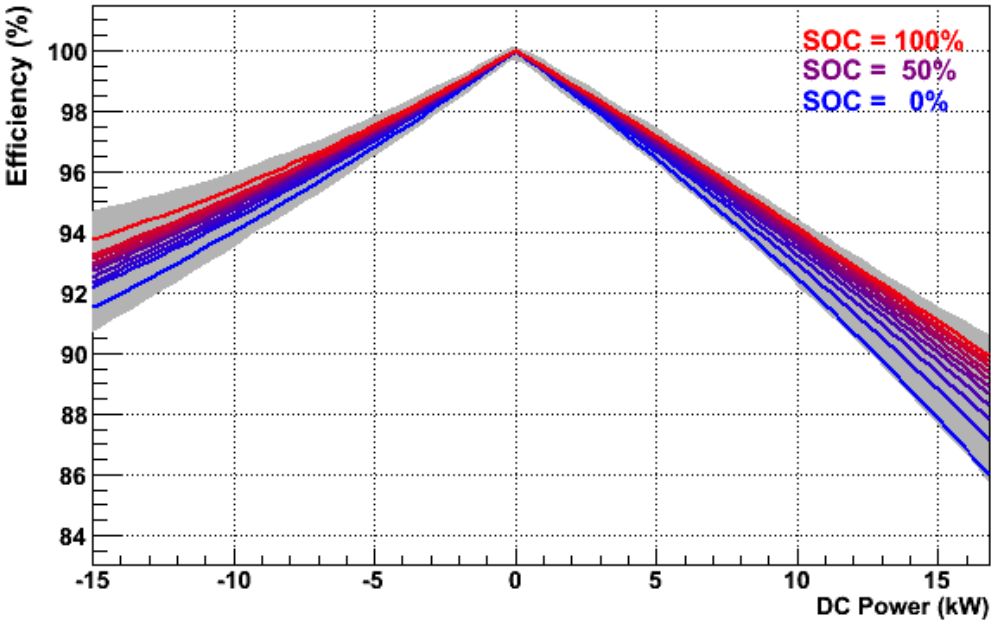


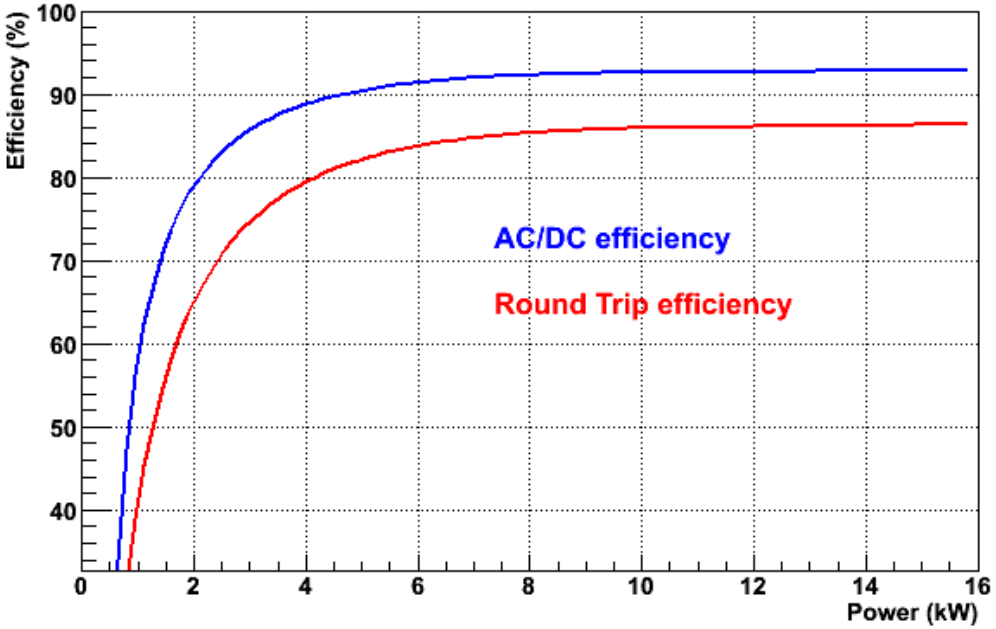
Schematic drawing – loss sources

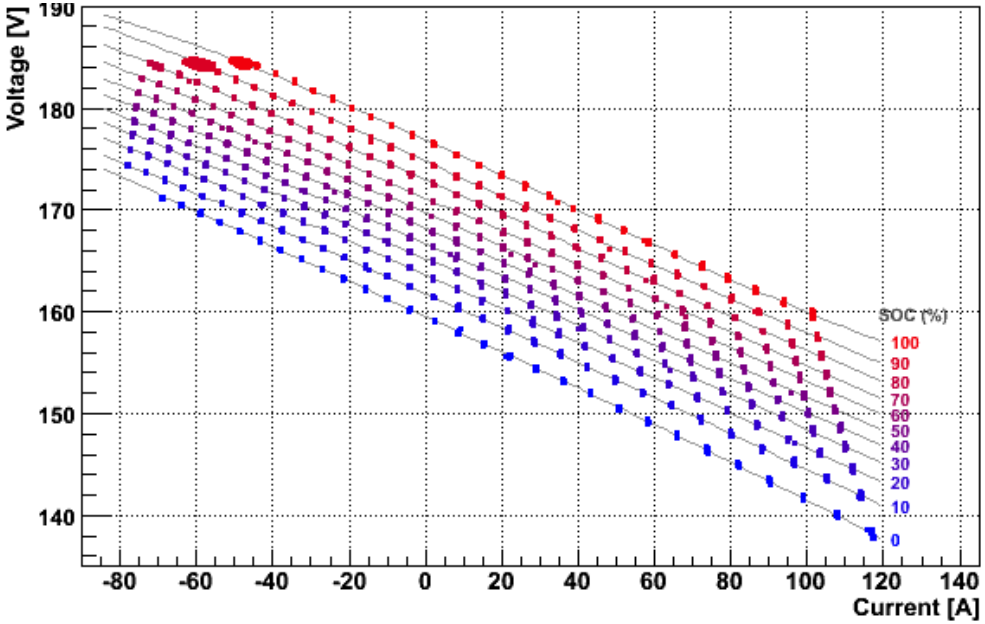


Cell stack and Converter Efficiency

- The stack losses are mainly ohmic
- Stack efficiency is good
- Converter efficiency is about 86% round trip, but with a flat curve



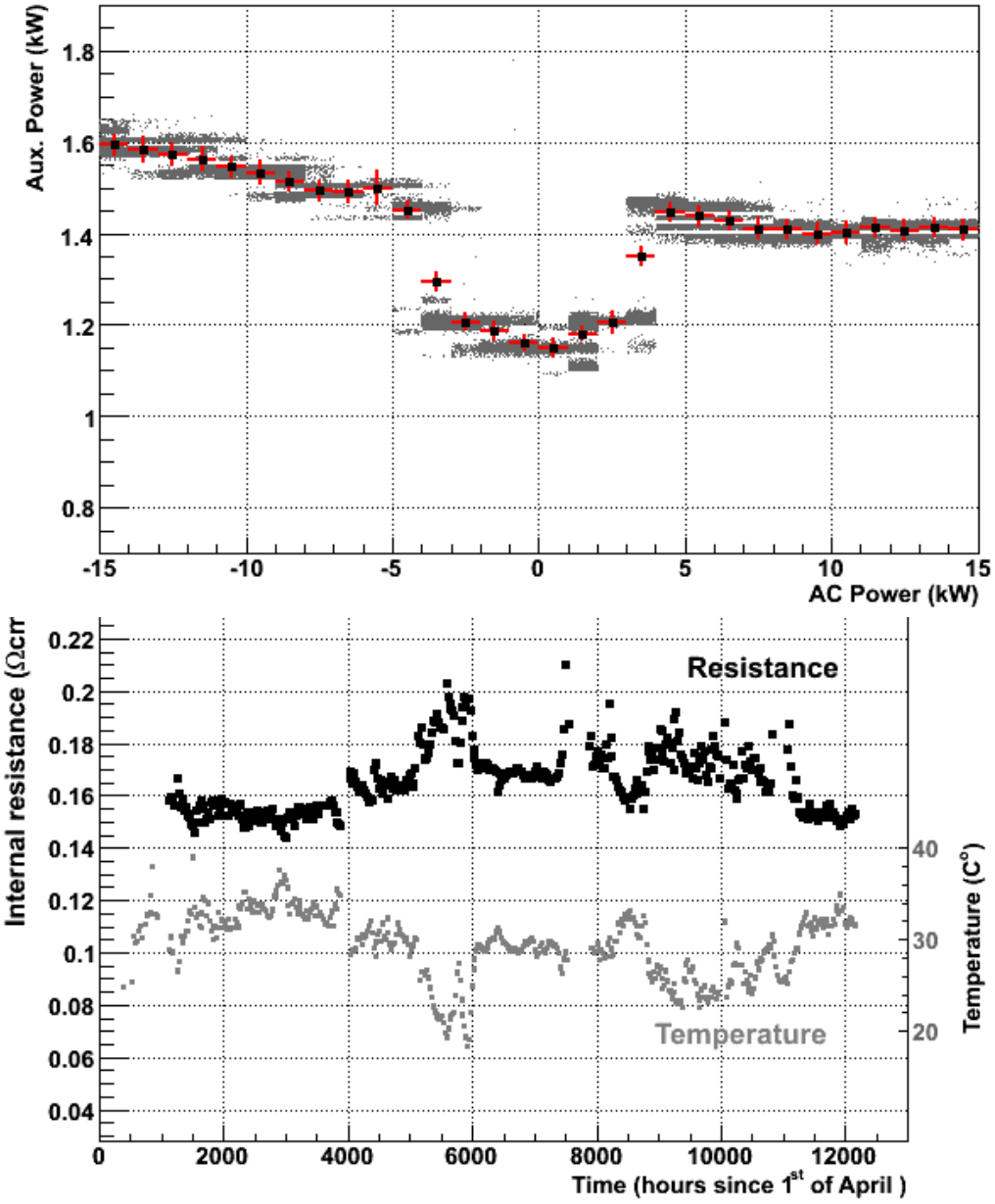




Auxillary Power Consumption and Degradation

- Auxillary power consumption, mainly pumps, contribute significantly to the losses
- These losses are almost independent on the power level

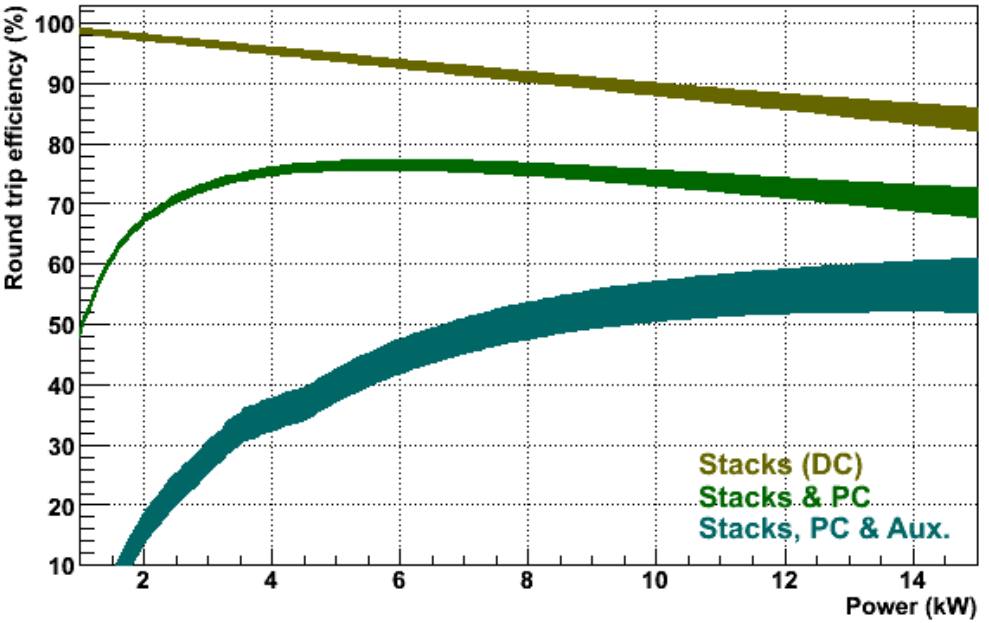
- During the test period no significant degradation was measured

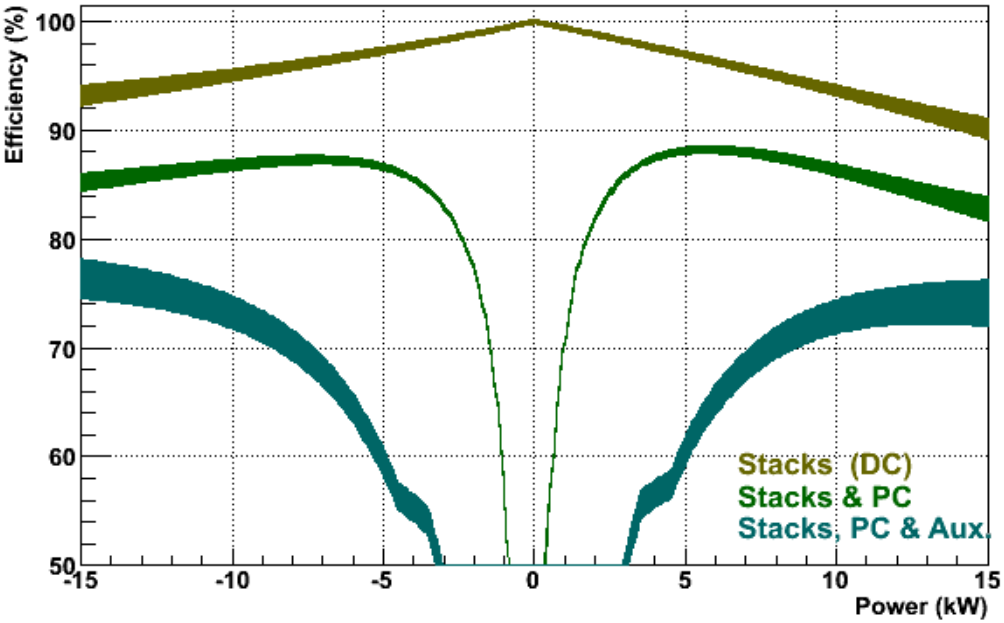


Overall efficiency

- Overall round trip efficiency is just below 60%

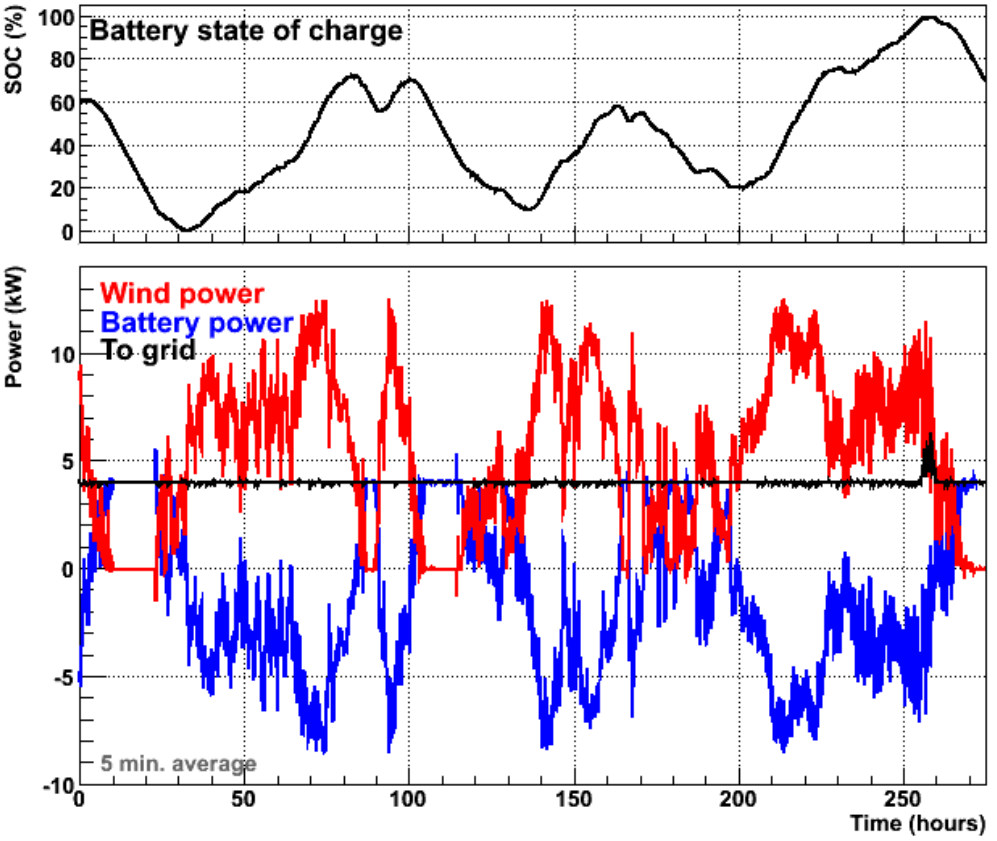
- Power Converter efficiency
  - ~85%
- Auxilliary Power Consumption
  - ~1.4kW (almost constant)
- Cell stack efficiency high
- Converter losses are high
- Auxilliary power consumption is relatively high





Combination with Renewable Energy

- Firming the output from wind turbine/farm
  - Will make the wind power act more as a conventional power plant
- Smoothing of output to eliminate or reduce fluctuations from wind turbine/farm
  - Will reduce the requirements for fast acting units



Summary

- Advantages
  - Efficiency (?)
  - Power performance
  - Power and Energy scalability
  - Control flexibility
- Good operational experience (after some initial problems)
- Battery has good performance characteristics
- It can be developed to have useful functionality

- Disadvantages
  - Cost
  - Hazardous/toxic electrolyte
  - Energy density
- Still a lot development work on the technology
- Various applications will be tested using SYSLAB
  - How can it be used to smooth wind power
  - How can it be aggregated with other DER units

Thank you