

# Battery activities at Department of Energy Technology, Aalborg University

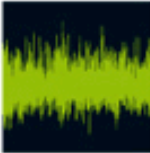
Applied battery modelling, research and engineering

Søren Juhl Andreassen  
Associate Professor  
Department of Energy Technology  
Aalborg University

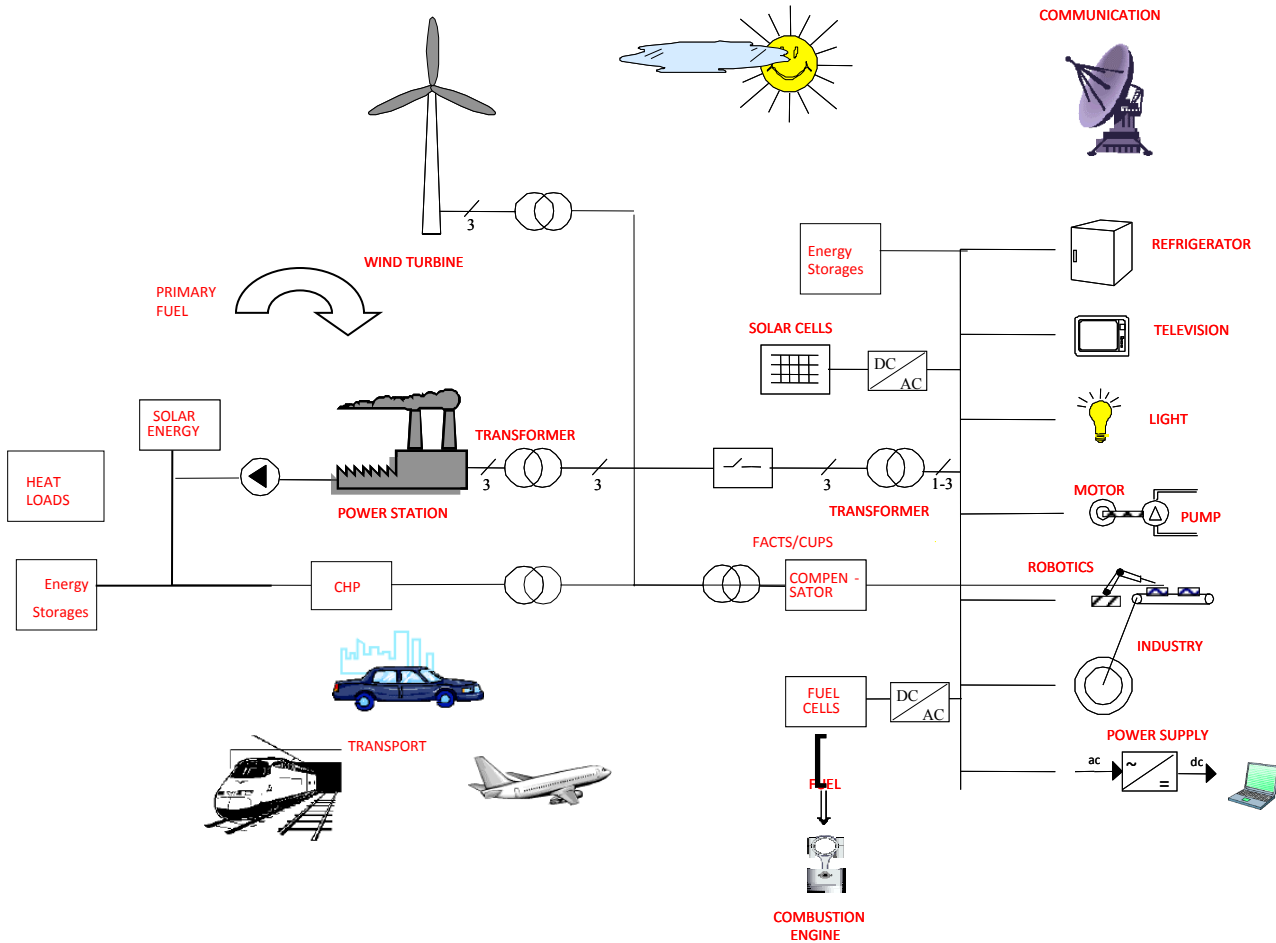


# Agenda

- **Introduction to the Department of Energy Technology at AAU**
- **Battery related research areas**
  - Cell modelling
  - Battery pack design
  - Battery and hybrid electric vehicles
- **Battery specific laboratory facilities**
- **Project examples**
  - Future High Efficiency Electric Car (Vækstforum)
  - Advanced Lifetime Prediction in Battery Energy Systems (DSF)
  - Intelligent Energy Management System for a Virtual Power Plant (HTF)
  - Coherent Energy and Environmental System Analysis (DSF)
  - Batteries2020 (FP7)



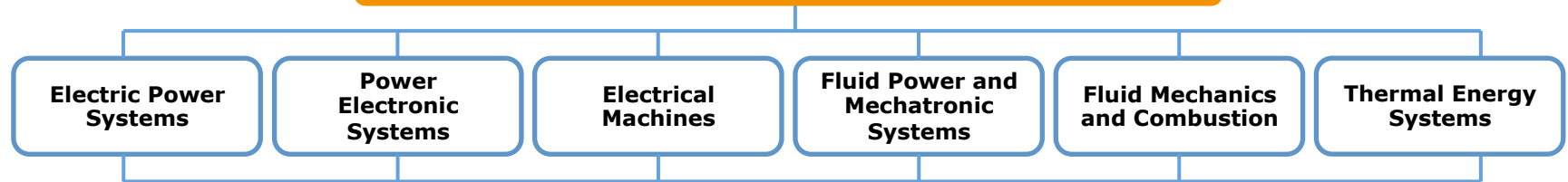
# Energy Technology



**Keywords: Energy production – Energy distribution – Energy consumption – Energy control**

# Organisation

## Department of Energy Technology



### Strategic Networks:

- EMSD
- CEES
- ECPE
- VE-NET
- DUWET
- WEST
- VPP
- REN-DK
- HUB NORTH
- Energy Sponsor Programme

- 70 VIP
- 74 PhD
- 10 Guest Researchers
- 10 Research Assistants
- 31 TAP

### Multi-disciplinary Research Programmes

Wind Turbine Systems

Fluid Power in Wind and Wave Energy

Biomass

Photovoltaic Systems and Microgrids

Modern Power Transmission Systems

Smart Grids and Active Networks

Fuel Cell and Battery Systems

Automotive and Industrial Drives

Efficient and Reliable Power Electronics

Thermoelectrics

Green Buildings

### Lab. Facilities:

- Power Electronics Systems
- Drive Systems Tests
- Fluid Power
- Power Systems & RTDS
- Micro Grid
- High Voltage
- DSpace
- PV Converter & Systems
- Laser Systems
- Fuel Cell Systems
- Battery Test
- EMC
- Vehicles Test Lab
- Biomass Conversion Facilities
- Proto Type Facilities

# Research program focus areas



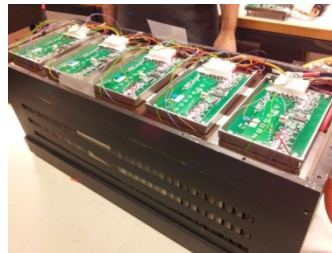
## Battery cells

Electrochemical tests  
Thermal characterization  
Degradation test and modeling  
Online diagnostics methods  
-SoC, SoH, RUL



## Battery packs

Cell balancing  
Thermal management  
Diagnostics  
-SoC, SoH, RUL



## Battery systems

Mission profile analyses  
-Backup power systems  
-Electric vehicle  
-Grid balancing and storage  
Application specific degradation



# Battery specific laboratory facilities

- **Battery test stations including FRA and temperature chambers**
  - Fuel Con
  - Maccor 4000 Series
- **FRA devices:**
  - 2 x Fuel Con FRA
  - Maccor FRA-0355
  - Gamry FRA (Reference 3000)
- **Various ovens and climatic chambers (up to 1m<sup>3</sup> DUT volume)**
- **High Power Bi-polar DC supplies (battery packs, fast charging, vehicles)**
  - Heinzinger (50kW, 800V, +-500A)
  - Regatron TopCon (up to 4x20kW, 1000V)
- **Realtime dSpace system for Battery Management System testing and emulation**
- **Various test vehicles ranging from small utility vehicles to full power automotive**



# Battery specific laboratory facilities

## Battery packs:



A123 (LFP)  
39.6V, 18.4Ah



Kokam

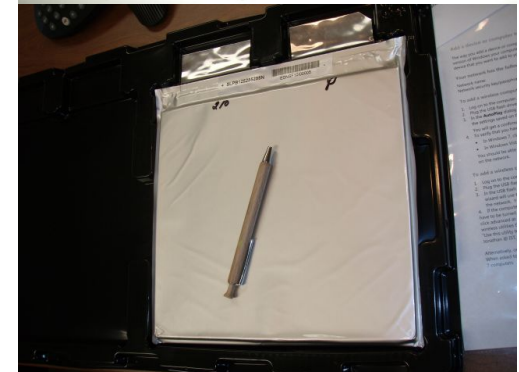
## Battery cells:

**Cylindrical**  
A123 (LFP)



## **Pouch**

Altair Nano (LTO) 50Ah  
Kokam (LCO) 25,53 Ah  
EiG (LCO,LFP)



Kokam (LCO)  
806V, 53Ah

**Prismatic**  
BYD 50Ah  
TS (LFP) 160Ah, 400Ah

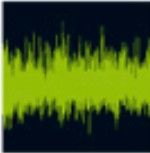


# Projects

- *Vestas Power Program – Lithium ion battery energy storage system for augmented wind power plants*  
**Partners:** Vestas
- *Highly Integrated Electric Propulsion System (EUDP)*  
**Partners:** Serenergy A/S, Lithium Balance A/S, Cemtec
- *Tomorrow's high-efficiency electric car integrated with the power supply system*  
**Partners:** NIK-VE, Cemtec, Danfoss , Silicon Power GmbH, DONG Energy, Energibyen Frederikshavn, FJ Sintermetal, KK-electronic A/S, Lithium Balance A/S, Neogrid Technologies ApS, Nordjysk Elhandel A/S, SerEnergy, Sintex A/S, Teknologisk Institut )
- *Intelligent Energy Management System for a Virtual Power Plant – Lifetime models for Lithium ion batteries in grid support applications (HTF)*  
**Partners:** Vestas, Energinet.dk, Storage Media Suppliers, Jørgens Skovgaard Invest, NOE Vestjydske Net, RAH Ringkøbing Amt Højspændingsværk, Region Midt
- *Advanced Lifetime Predictions of Battery Energy Storage (DSF)*  
**Partners:** DTU, DTI, KTH, RWTH Aachen, Lithium Balance, Leaneco, GMR maskiner a/s)
- *Batteries 2020 : Towards Realistic European Competitive Automotive Batteries*  
**Partners:** Ikerlan, Umicore, RWTH Aachen, Vrije Universiteit Brussel, Abengoa Research, Eurobat, Leclanche, Centro Ricerche Fiat)

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# Project example : Electrical Vehicle Battery Pack Design

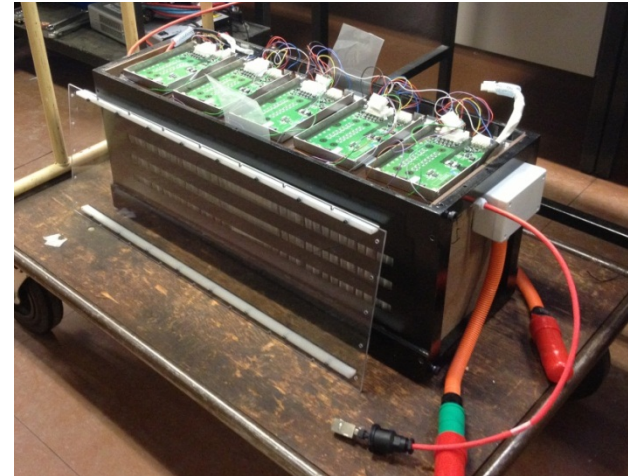
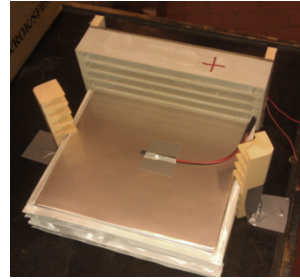
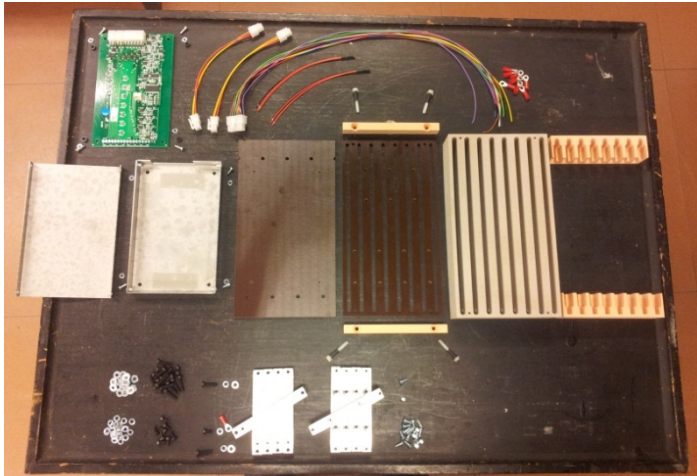
## *Tomorrow's high-efficiency electric car integrated with the power supply system*

- AAUdi EV Battery pack design and construction (geometry, BMS-integration, cell holders, cell connections, terminal connection, protection, communication, switch box, etc.).
- Influence of feasible EVs fast charging methods on Li-Ion cells performance and degradation.
- Integration of advanced EIS diagnostic features in BMS.
- Design and construction of DC-DC converters to charge 12V batteries in +800V EV applications.
- V2G applications: EVs to Support Large Wind Power penetration in Future Danish Power Systems.



- 192 Kokam SLPB 53Ah pouch cells connected in series.
- 5 sub-packs (4 x 40 cells + 1 x 32 cells).
- Voltage level up to 800V.
- 1kV Lithium Balance BMS.
- 24 LMU modules, one for each group of 8 cells.

# Project example : Electrical Vehicle Battery Pack Design



# Project example : Electrical Vehicle Battery Pack Design

- Tests of 192 Kokam SLPB 53Ah cells:
  - ✓ Self-discharge tests.
  - ✓ Characterization tests.
  - ✓ Capacity check.
  - ✓ EIS measurements.
- Results used to develop equivalent circuit models and statistical models.

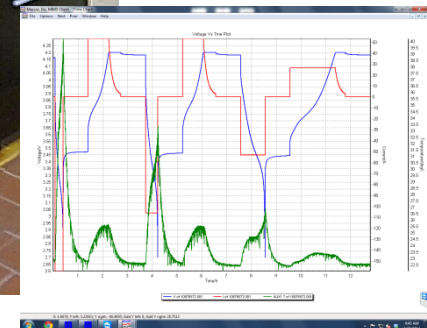
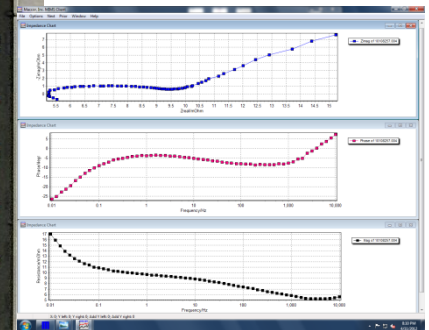
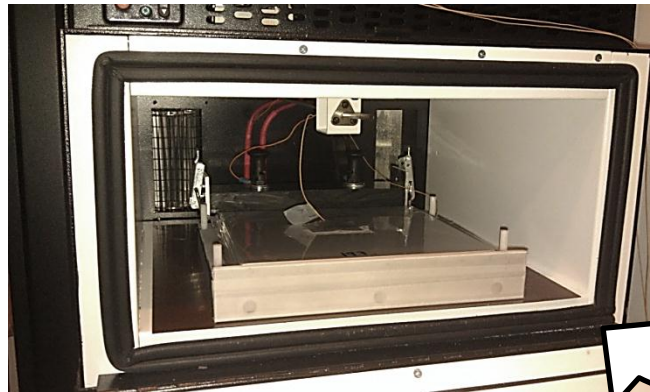
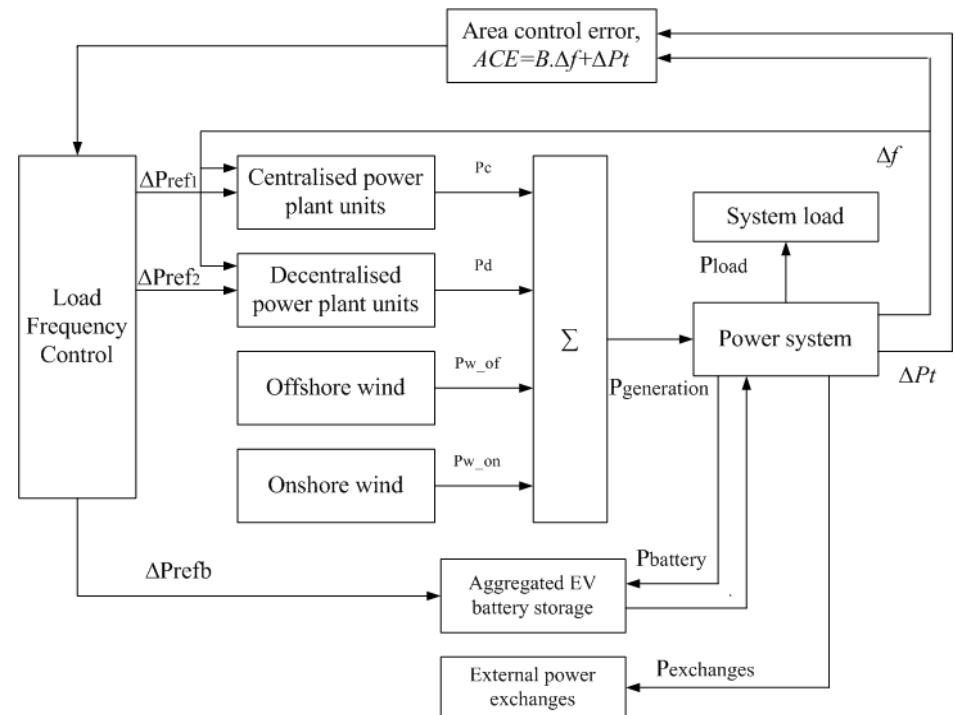
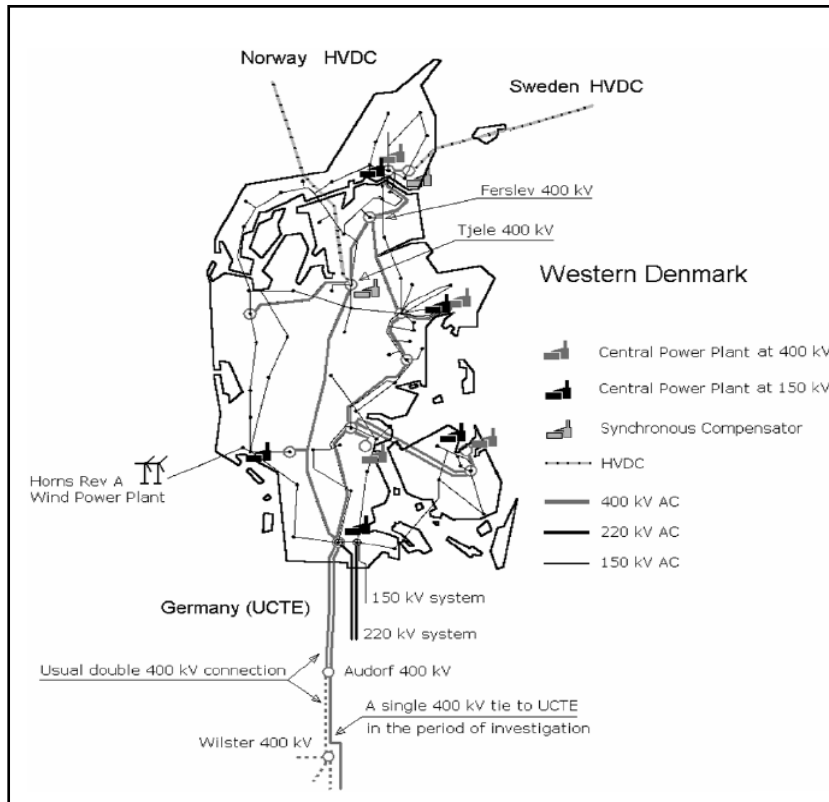


Fig. 1: MACCOR 4000 Series test station

# Project example : V2G

## *Coherent Energy and Environmental System Analysis (DSF)*

- Objective – Minimise power exchange deviations between West Denmark and the UCTE synchronous area. Nominal acceptable limits are  $\pm 50\text{MW}$ .
- Regulation reserves of power plants is determined by the insufficiency of aggregated EV based battery storages (V2G) to meet the total regulation

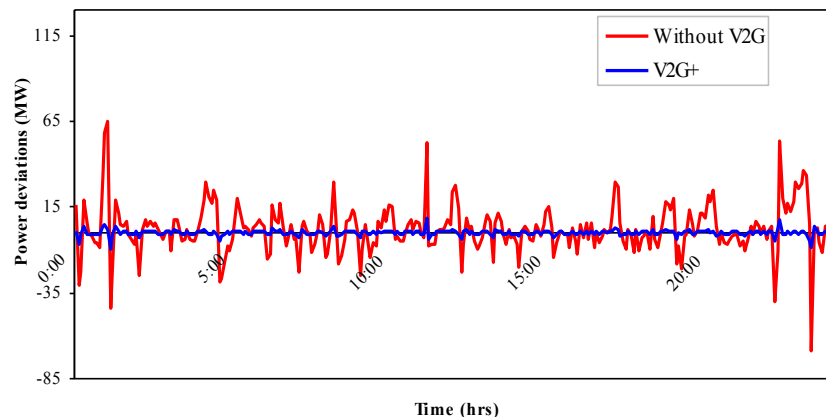


# Project example : V2G

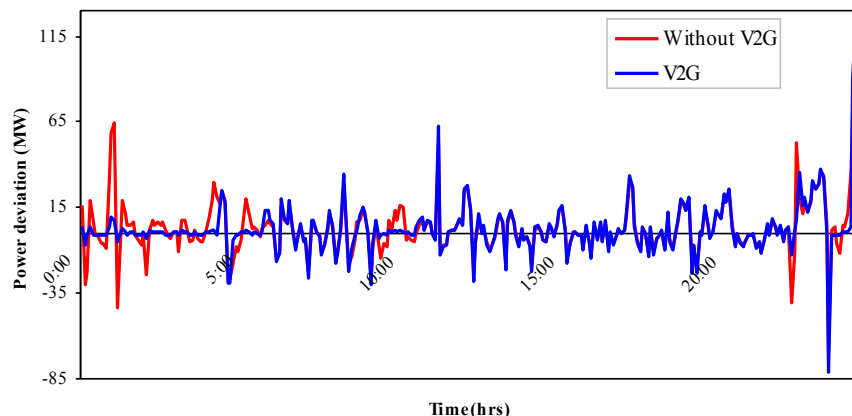
## *Coherent Energy and Environmental System Analysis (CEESA)*

### High Wind Scenario

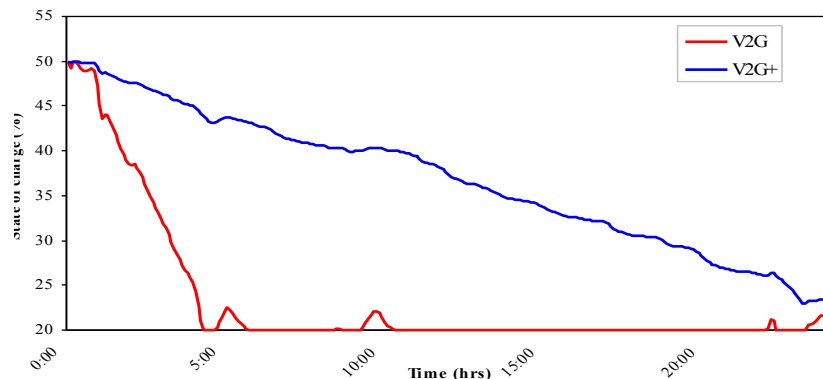
- Typical summer day in West Denmark
  - Wind power - 7% of the total demand
  - More regulation up requirement, shortage of balancing power & Instants where West Denmark –UCTE power exchange deviations greater than  $\pm 50$  MW (acceptable limits)



Minimised Power exchange deviations WDK-UCTE (MW) –with and without V2G+ (450MW, 1800MWh - 5 times V2G)



Minimised Power exchange deviations WDK-UCTE (MW) with and without V2G (90MW, 360MWh)



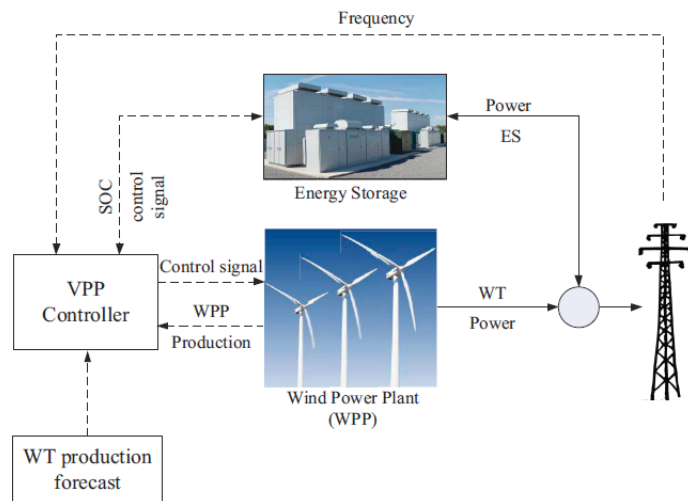
Battery state of charge (%)

# Project example : Virtual Power Plant

## *Intelligent Energy Management System for a Virtual Power Plant – Lifetime models for Lithium ion batteries in grid support applications*

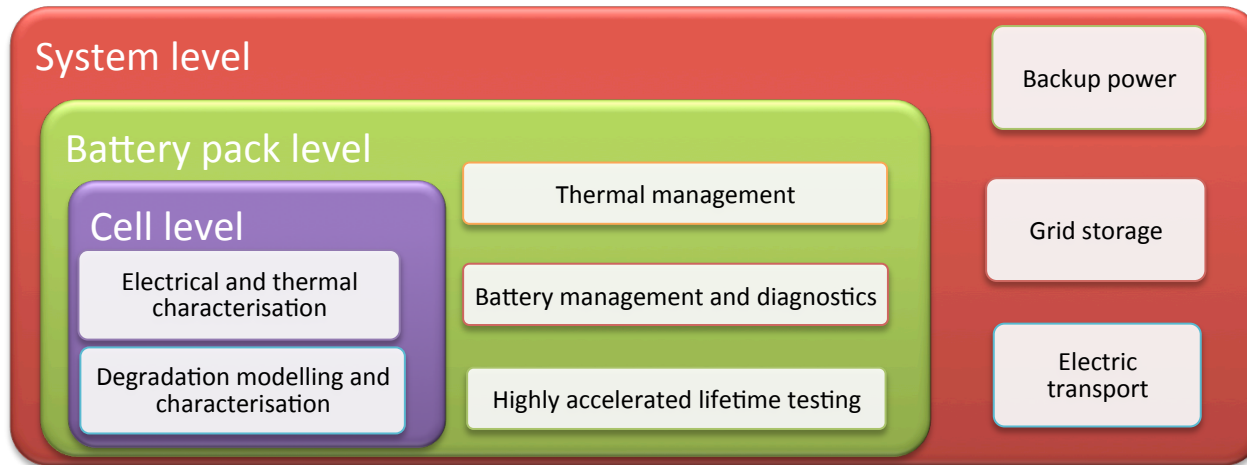
### Motivation

- Added value to Wind Turbines/Wind Farms
- Characteristics of wind power plants brought closer conventional power plants (WPP+ESS= Virtual Power Plant)
- High wind power penetration, requiring higher flexibility and power quality from the wind industry
- Various services could be offered by VPP: primary frequency regulation, forecast accuracy improvement, power gradient reduction, inertia emulation, black start, etc.
- Need for battery lifetime models for investment profitability calculations. Performance of cells is lifetime dependent.



# Project example : ALPBES

## *Advanced Lifetime Predictions of Battery Energy Storage (DSF)*



### The cell level research focus on:

Electrochemical characterization  
Electro-thermal characterization  
Battery performance models  
-Empirical and equivalent circuit models  
Mission profile specific degradation tests  
-Cycling as well as storage degradation  
Accelerated lifetime tests  
State-of-charge and State-of-Health models  
Remaining Useful Lifetime models

### The battery pack level research focus is on:

Charging and discharging algorithms  
Battery management systems  
Online diagnostics methods for  
-SoC, SoH and Remaining Useful Lifetime  
Thermal management of the battery pack  
Degradation modeling and testing including the influence from:  
-Mission profile including including cycle rate, and high and low SoC  
-Thermal imbalances and production variations in cell characteristics  
Accelerated lifetime testing  
Experimental validation of BMS algorithms on DSPACE emulator

### The battery system research focus on:

Mission profile specific performance and degradation predictions  
Laboratory simulation of application specific mission profiles  
-Detection of maintainance requirements  
-Integration with other technologies  
-Optimization of operating strategies  
Grid connection and delivery of ancillary services  
Economic feasibility studies in real applications

# Selected Cooperation Partners



# Battery activities at Department of Energy Technology, Aalborg University

Applied battery modelling, research and engineering

Søren Juhl Andreassen  
Associate Professor  
Department of Energy Technology  
Aalborg University

