Research Activities in Wind Power

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Aalborg University

Founded in 1974

Organisation

Department of Energy Technology

- Electric Power Systems
- Power Electronic Systems
- Electrical Machines
- Fluid Power and Mechatronic Systems
- Fluid Mechanics and Combustion
- Thermal Energy Systems

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

- 50 VIP
- 60 PhD
- 10 Guest Researchers
- 10 Research Assistants
- 22 TAP

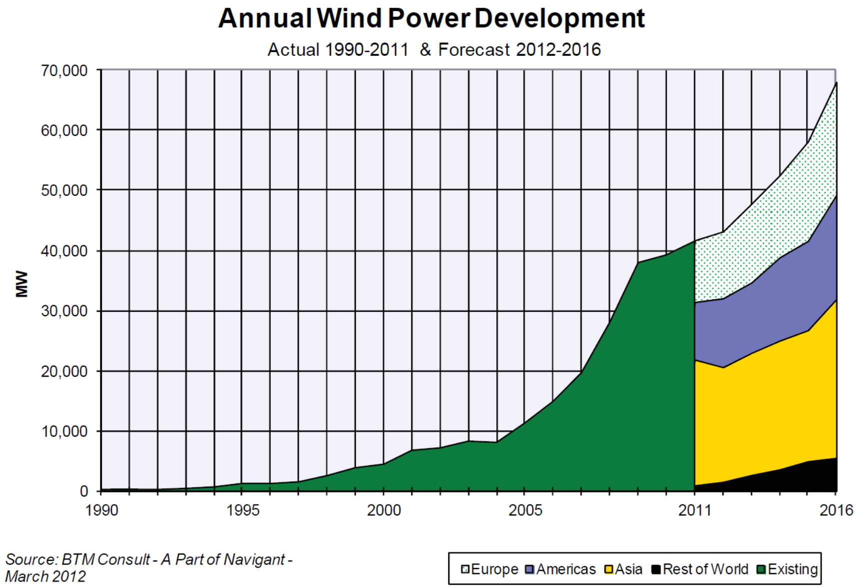
Multi-disciplinary Research Programmes

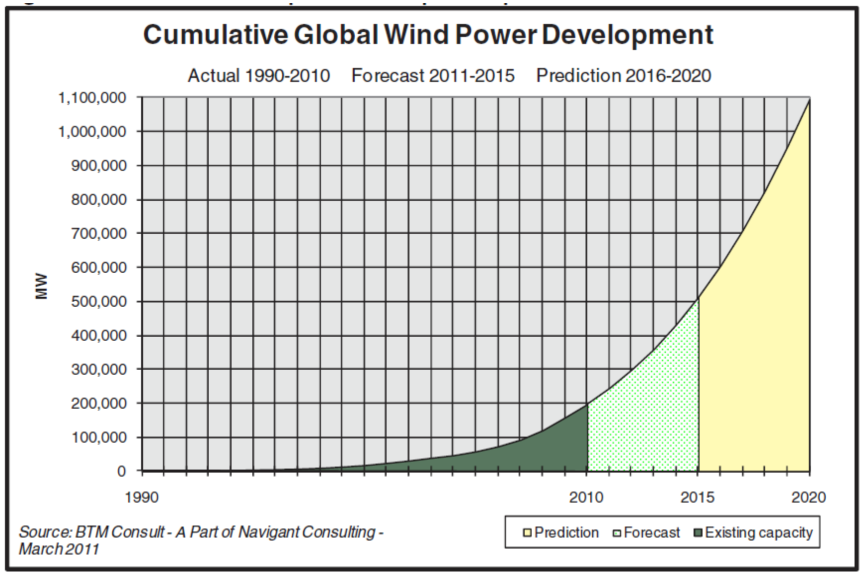
- Wind Turbine Systems
- Fluid Power in Wind and Wave Energy
- Biomass
- Photovoltaic Systems and Microgrids
- Modern Power Transmission Systems
- Smart Grids and Active Networks
- Fuel Cell and Battery Systems
- Automotive and Industrial Drives
- Efficient and Reliable Power Electronics
- Thermoelectrics
- 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

- **Power Electronics for Wind Power**
- **Grid Supports with Wind Power Plant**
- **Storage System for Grid Support**
- Grid Integration of PV

Wind Energy Systems

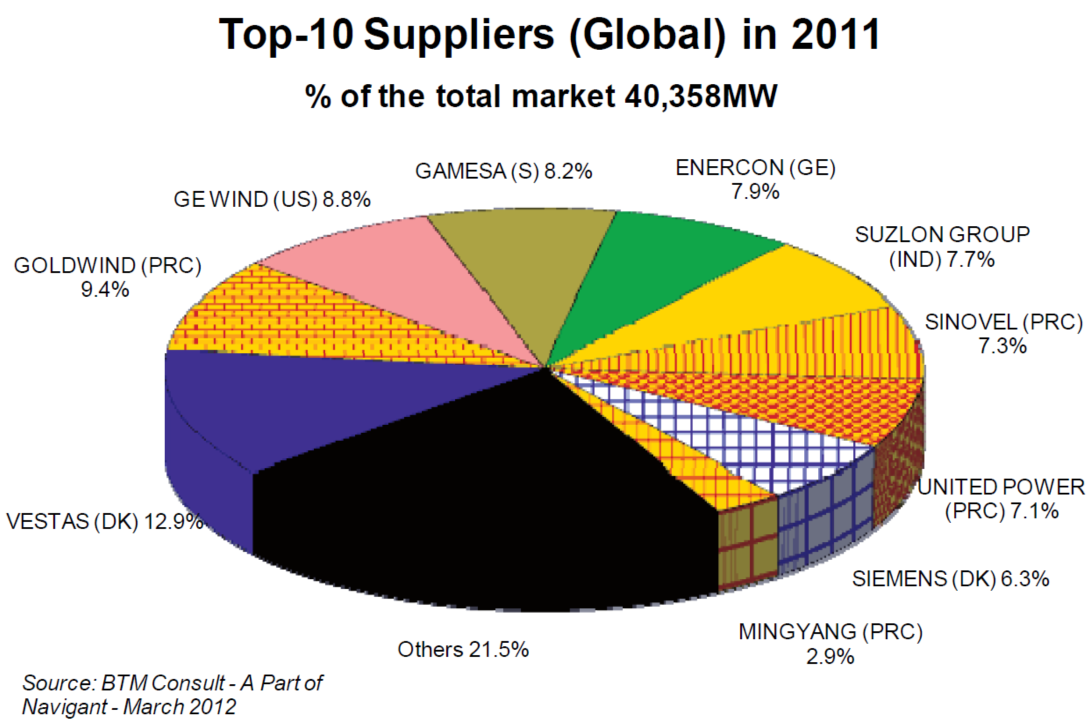




- Record installation of 41.7 GW (6% increase from 2010) in spite of the financial/economic crisis.
- The biggest annual markets in 2011 were China – 17.6 GW, Europe – 10.2 GW,followed by USA – 6.7 GW
- The cumulative worldwide installed wind power by end of 2011 was 241 GW
- The biggest cumulative market was Europe – 87.5 GW (43.7%) followed by Asia 85.3 GW and USA – 40.2 GW (20.1%)
- Offshore installations mainly in Europe was 470 MW (67.5% reduction from 2010).
- The average growth rate for 2012-2016 is 10%. In 2016 510.9 GW cumulative installation
- The worldwide accumulated installed power forecasted by 2021 is roughly 1 TW, leading to a global wind power penetration of 8%

Wind Energy Systems

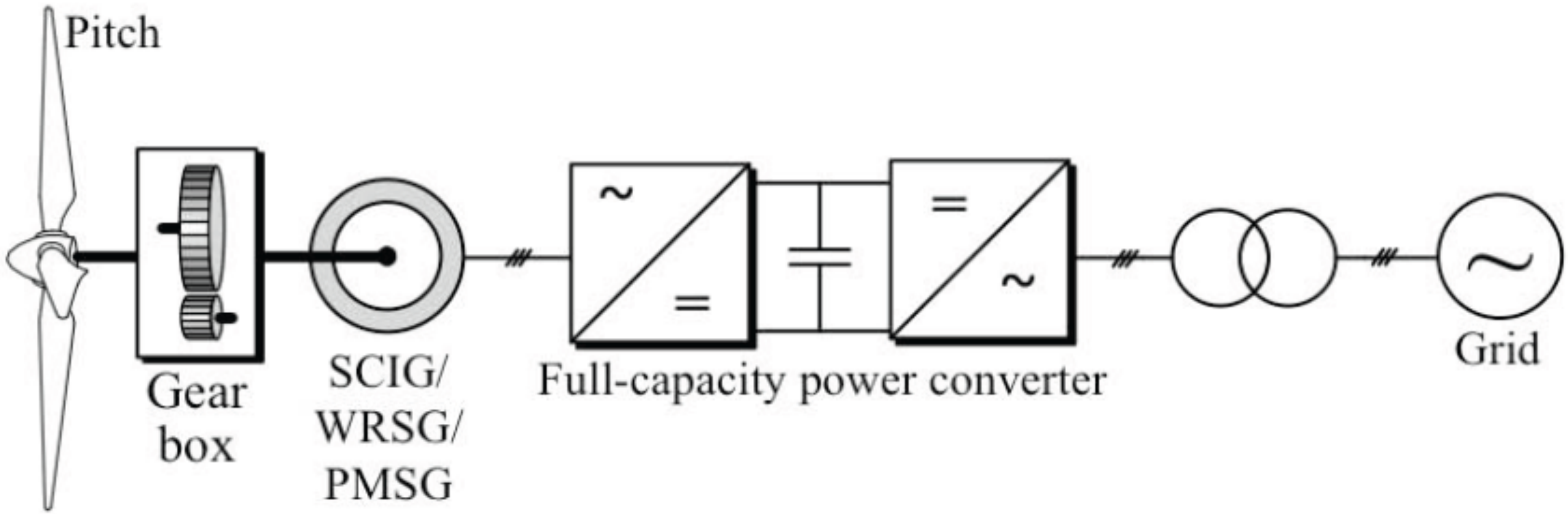
Wind Turbine development



- Vestas is nr. 1 with 12.9% (1.4% drop from 2010)
- Four chinese manufacturers are in Top 10
- Danish Vestas and Siemens Wind stand for over 20% of the worldwide market
- 2 - 3MW WT are still the "best seller" on the market!
- Averaged size on-shore in 2011 is 1.67 MW and off-shore 3.7 MW
- 3 - 7 MW WT are used for off-shore farms, ex. Vestas -8MW, Enercon – 6-7.5 MW, Siemens – 6 MW, GE – 4 MW

Wind Turbine Technology

Full power converters for WT

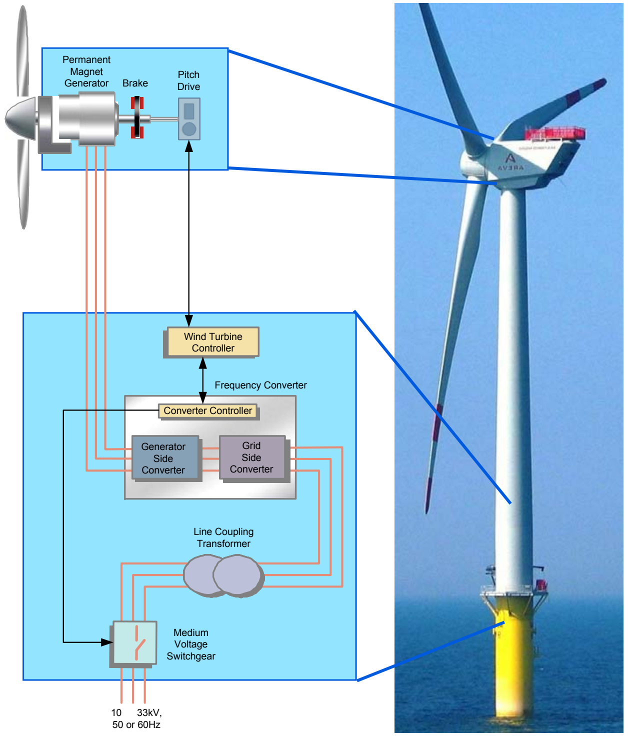


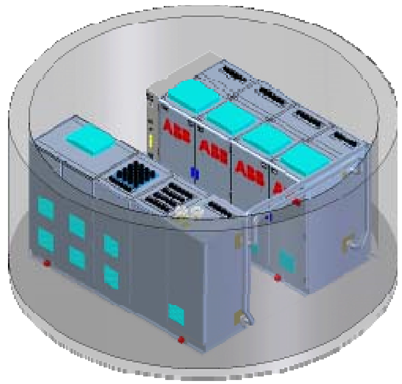
- All power goes through the power converter, full speed control
- AC-AC decoupling by means of the DC bus
- Full active/reactive power control
- Low-voltage ride-through capability
- More expensive and lager converter than in DFIG

Wind Turbine Technology

Current Developments, Areva Multibrid M5000/ABB

- Nacelle:
  - Gearbox if used
  - PM Generator
  - Mechanical Brake
  - Pitch Drive





- Lower section of the tower
  - Wind Turbine Controller
  - Power Converter
  - Main Transformer
  - Auxiliary distribution
  - MV Switchgear

MV – 3,3 kV out

Rated power: 5-10 MW

Turbine concept:1 stage- Gearbox, variable speed, variable pitch control

Generator: MV PMSM

Converter: FSC (NPC-IGCT) located at base of tower

Market - Offshore

Wind Turbine Technology

Vestas Wind Systems A/S Denmark

Vestas V164 off-shore turbine

Rated power: 8,000 kW

Rotor diameter: 164 m

Hub height: min. 105m

Turbine concept: medium-speed gearbox, variable speed, variable pitch, full-scale power converter

Generator: permanent magnet

Prototype: 2013

Wind Turbine Technology

Floating foundation

Semi-submersible multi-megawatt wind turbine

Designed by: US Principle Power

Allocation: Aguçadoura, Portugal

Turbine size: 2 MW (Vestas) (up to 10 MW)

Assambled onshore and towed and anchored offshore

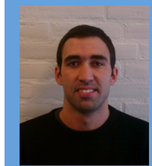
Vestas Power Program 2007 - 2012

power electronics

… converter technology and generic control features for large turbines in large wind power plants to meet high power density, efficiency and reliability targets – 5 PhD

PE 1 - High Power Density Converter for Large WT
PhD Osman Senturk
Started 1 July 2008

PE 2 -Control of Grid-Connected Converters for Large WT
PhD Hernan Miranda
Started 1 July 2008



PE 3 - Advanced Control of Grid Connected Converter for LWT
PhD Ömer Göksu
Started 15 Oct 2009

PE 4 - Modelling Life Time of Electrical Components and Systems in WT
PhD Cristian Busca
Started 1 Sep 2010

PE 5 - High Voltage Power Converter for Large Wind Turbine
PhD Michal Sztykiel
Started 1 Feb 2011

power systems

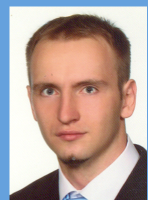
… to determine the control and operational properties required for wind power plants for optimal integration in the power system using AC or HVDC transmission – 4 PhD

PS 1 - Wind Power Plant Control for HVDC Connection
PhD Sanjay Chaudhary
Started 1 July 2008

PS 2 - Wind Power Plant Control for AC Connection
PhD Müfit Altin
Started 15 Oct 2009

PS 3 - Power system oscillation damping with augmented Wind Power Plant
PhD Andzrej Adamczyk
Started 1 August 2009

PS 4 - Optimization of VSC-HVDC Transmission in WPP
PhD Rodrigo da Silva
Started 20 Oct 2009

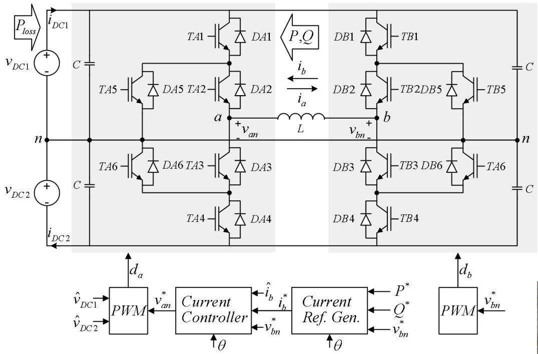


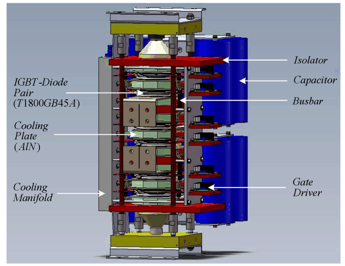
ES 2 - Storage System for Large WT Penetration
PhD Maciej Swierczynski
Started 1 August 2009

energy storage

… to determine the most suitable storage technology to be used with wind power plants meeting the reliabiliy targets – 1 PhD

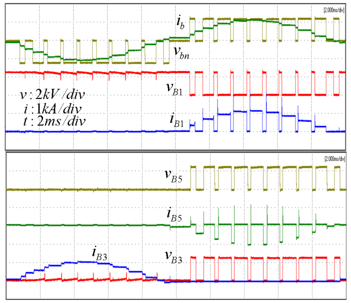
Thermal Modeling of Press-Pack IGBT 3L-NPC-VSCs for Large Wind Turbines

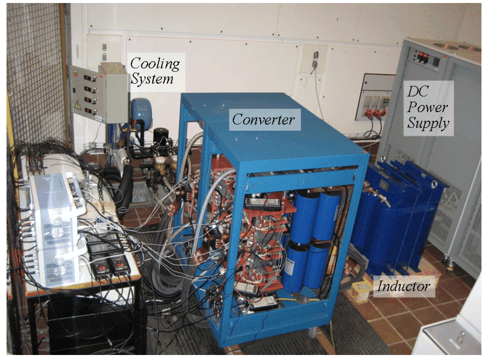




Problem

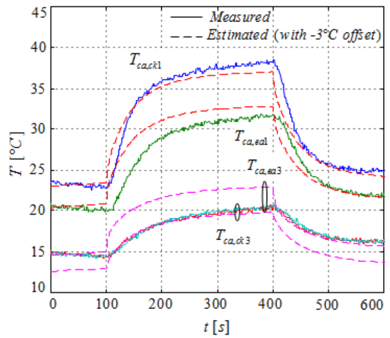
- Large wind turbines 6MW/3.3 kV
- Reliability and power density
- Need for electro-thermal models

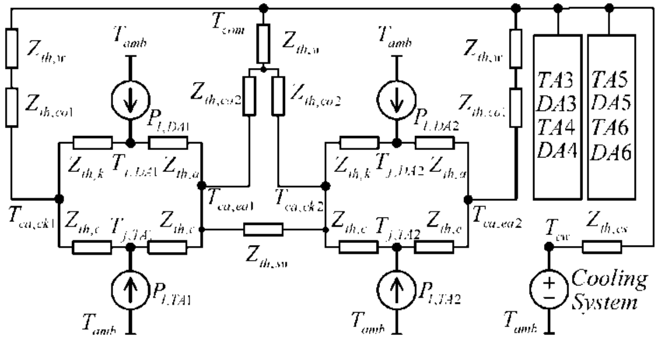




Solution

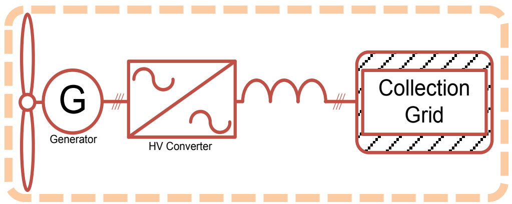
- 6MW/3.3 kV NPC with 4.5 kV/1800A PP IGBT
- Develop static an dynamic electro-thermal models taking cooling solution into account
- Simplified dynamical thermal models that can use to define overload capability online

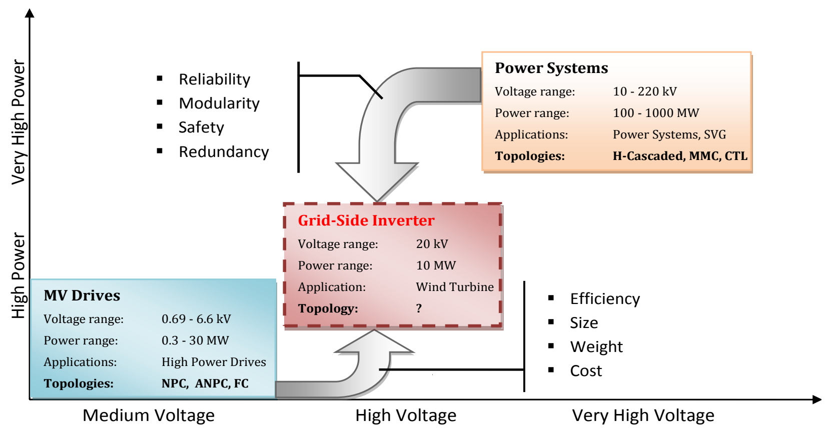




Senturk, O.; Helle, L.; Munk-Nielsen, S.; Rodriguez, P.; Teodorescu, R.; , ***"Power Capability Investigation Based on Electro-thermal Models of Press-pack IGBT Three-Level NPC and ANPC VSCs for Multi-MW Wind Turbines,"*** IEEE Transactions on Power Electronics, January 2012

High Voltage Power Converter for Large Wind Turbines



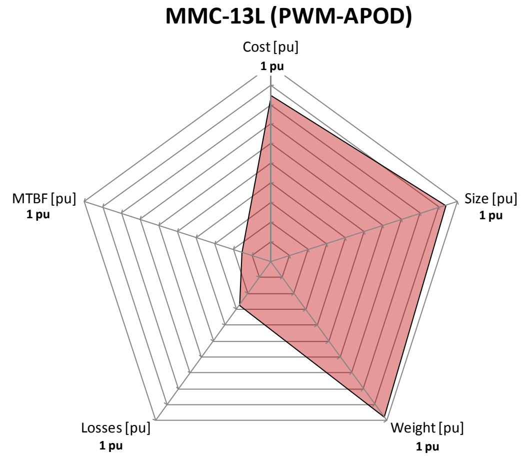


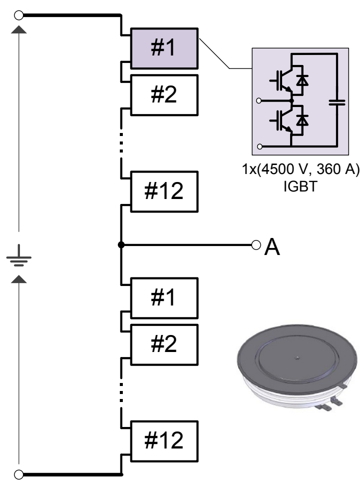
Problem

- Large wind turbines (10 MW!)
- High repair and maintenance costs (especially for offshore WTs)
- MV transformer is bulky
- Grid filters - bulky
- Generators 10kV – insulation challange

Solution

- 20kV/10MW transformerless 13L-MMC
- Reliable PP IGBTs 4.5 kV/340A





M. Sztykiel, R. Teodorescu, S. Munk-Nielsen, P. Rodriguez, L. Helle, C. Busca, *"Topology and Technology Survey on Medium Voltage Power Converters for Large Wind Turbines,"* International 10th Wind Integration Workshop, 25-26 October 2011, Aarhus, Denmark.

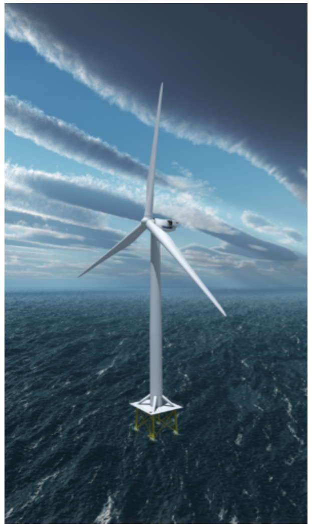
Lifetime Modelling of Press-Pack IGBTs in Wind Power Applications

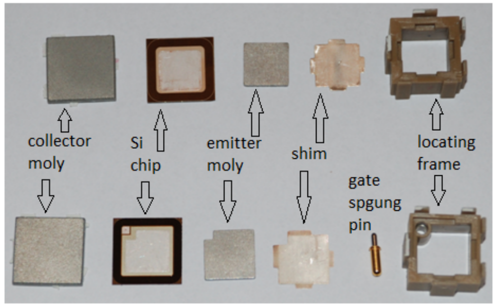
Problem

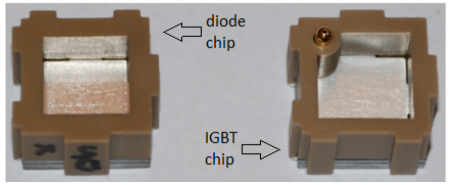
- Large wind turbines (multi-MW)
- High repair and maintenance costs (especially for offshore WTs)
- Not much experience with PP IGBTs
- PP IGBTs more reliable than wire-bonded IGBTs (longer life)
- Unequal pressure, current and temperature of individual chips

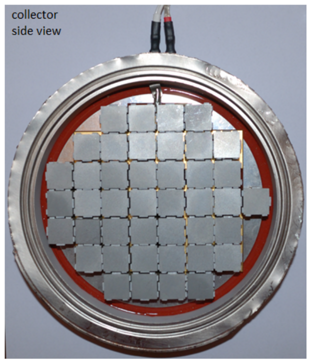
Solution

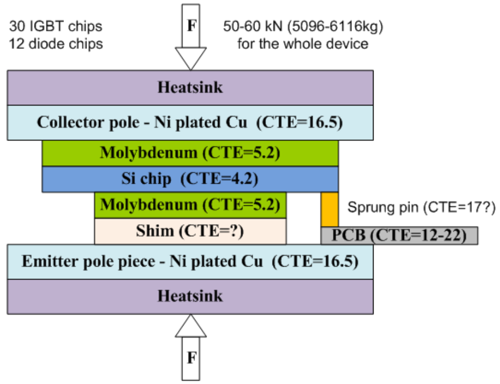
- MV converters with PP IGBTs
- Very high reliability wind turbines
- Power cycling tests
- FEM model and inside measurement of the individual chip currents and temperatures











C. Busca, R. Teodorescu, F. Blaabjerg, S. Munk-Nielsen, L. Helle, T. Abeyasekera, P. Rodriguez, ***"An Overview of the Reliability Prediction Related Aspects of High Power IGBTs in Wind Power Applications"***, ESREF 2011 (22nd European Symposium on Reliability of Electron Devices, Failure Physics and Analysis), Bordeaux, France, 3rd-7th October 2011.

Advanced Control of the Grid Side Converter for Large Wind Turbines,

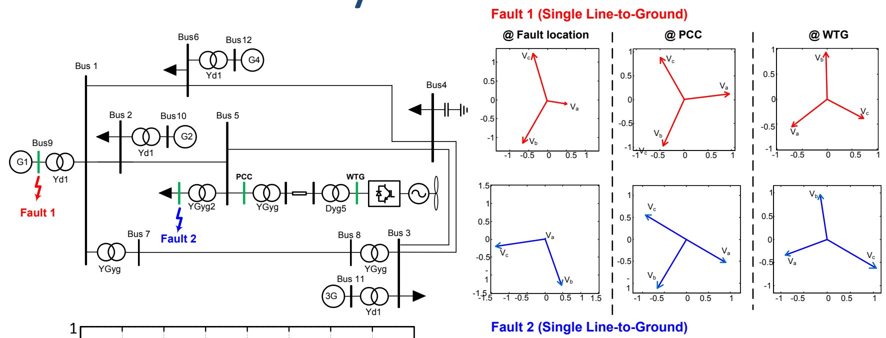
focusing on Fault Ride-Through for Asymmetrical and Symmetrical Grid Faults

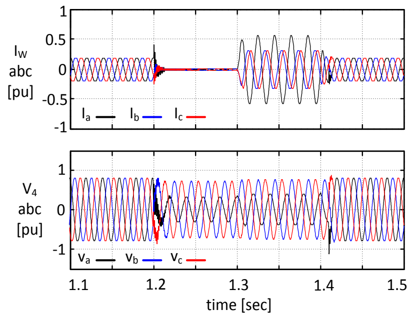
Problem: For asymmetrical grid faults, positive negative and zero sequence voltages are existing in the grid, where negative sequence voltage is harmful for power system elements.

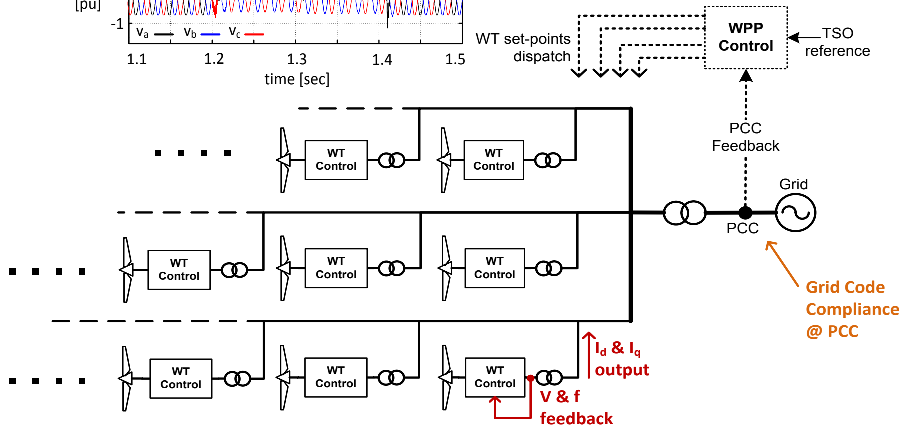
Solution: For the sake of power system; positive sequence voltage is boosted, negative sequence voltage is reduced, via injecting optimum positive and negative sequence currents by Wind Turbines.

Problem: There is a need for optimization of Fault Ride-Through for symmetrical low voltage faults, depending on the operating point of the wind turbines and grid characteristics.

Solution: Coordinated Fault Ride-Through of wind turbines at Wind Power Plant control level.







"An Iterative Approach for Symmetrical and Asymmetrical Short-Circuit Calculations with Converter-Based Connected Renewable Energy Sources. Application to Wind Power", 2012 IEEE Power Engineering Society General Meeting

Control and Protection of Wind Power Plant with VSC-HVDC Connection

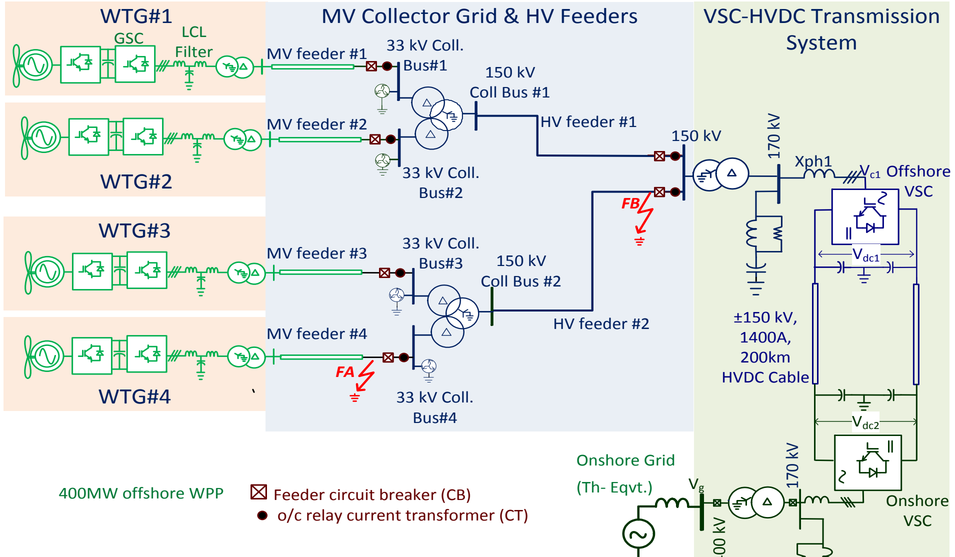
Problem

Faults in the offshore WPP-grid cause oscillations in the power-flow and dc-voltage of the VSC-HVDC. WPP generation is adversely affected.

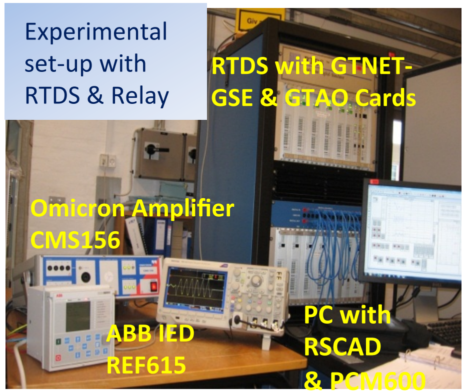
- Detection and discrimination of faults.
- DC voltage and power-flow oscillations during asymmetric faults

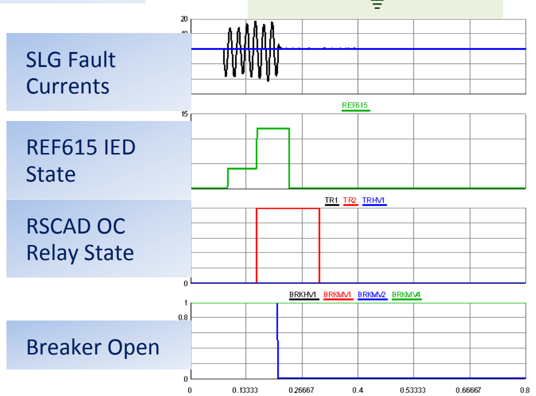
Solution

- Use of over-current relays with IEC-61850 communication.
- Negative sequence current control from the WTGs and the VSC-HVDC.



400MW WPP with VSC-HVDC connection





Publication: "**Application of Over-current Relay in Offshore Wind Power Plant Grid with VSC-HVDC Connection**," in 10th International Workshop on Large-Scale Integration of Wind Power into Power Systems as well as on Transmission Networks for Offshore Wind Power Plants. Aarhus, Denmark on October 25 - 26, 2011.

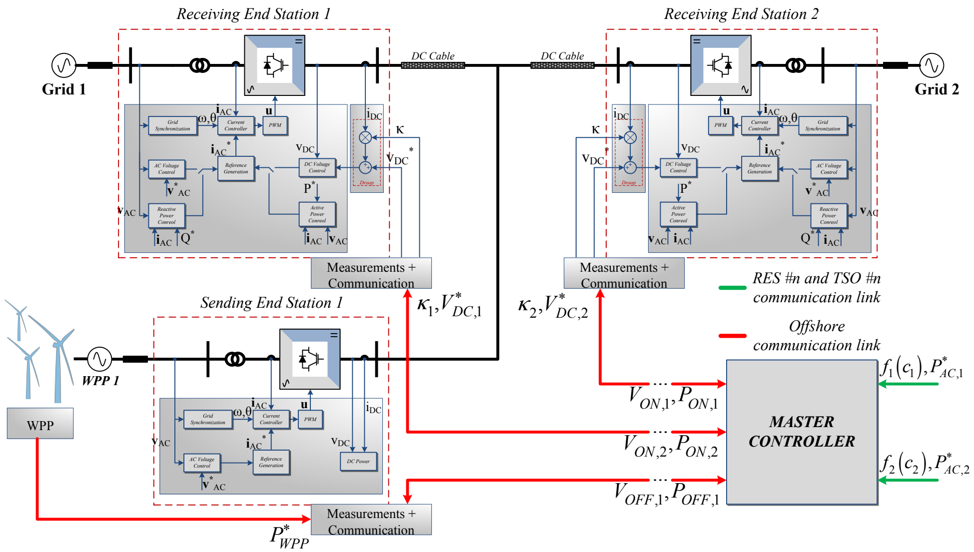
Losses Minimization in MTDC

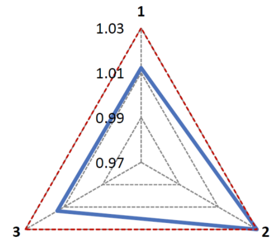
Problem

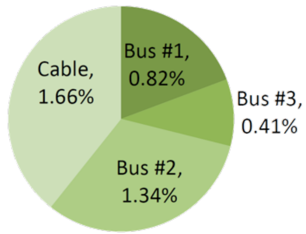
- Multiple large off-shore VSI-HVDC plants in North Sea--> MTDC
- Power management more flexible
- Voltage profile not optimized

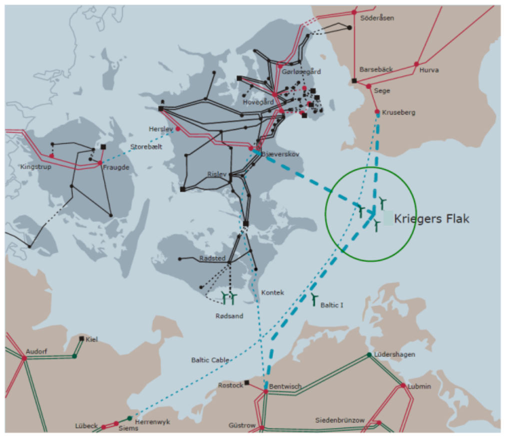
Solution

- Master MTDC Controller to optimize voltage profile and minimize losses in DC lines and converters









R. Da Silva et al "**Optimization of VSC-HVDC Transmission in Wind Power Plants**," in 10th International Workshop on Large-Scale Integration of Wind Power into Power Systems as well as on Transmission Networks for Offshore Wind Power Plants. Aarhus, Denmark on October 25 - 26, 2011.

Power Oscillation Damping with Wind Power Plant

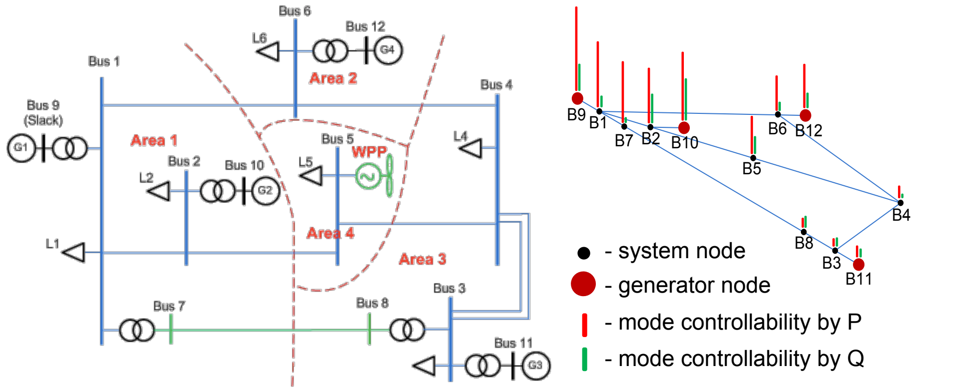
Problem

- Impact of the large scale wind power generation on oscillatory performance of the grid
- Control method for WPP to contribute to low frequency modes damping

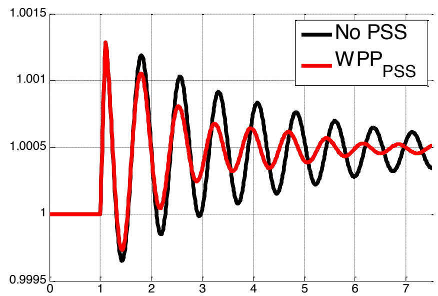
Solution

- PSS-like control loop to modulate wind turbine reactive power output
- RMS multi-bus and multi-machine grid model with relevant WPP model; small-signal analysis for different study cases

- IEEE 12-bus grid & mode controllability:



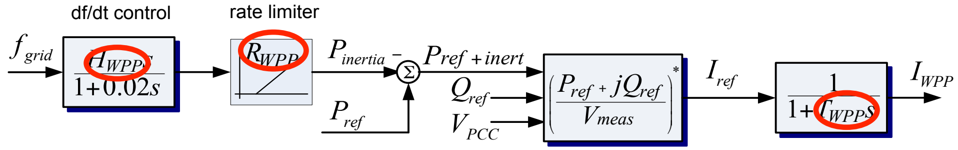
- WPP damping control:



	Damping ratio	
Mode	No PSS	WPP_PSS
1.31 Hz	3.7 %	5.9 %
1.25 Hz	9.3 %	8.6 %
1.04 Hz	3.4 %	4.9 %

Adamczyk, A.; Teodorescu, R.; Rodriguez, P.; , ***"Control of Full-Scale Converter based Wind Power Plants for damping of low frequency system oscillations,"*** PowerTech, 2011 IEEE Trondheim , June 2011

Frequency Control with Wind Power Plant

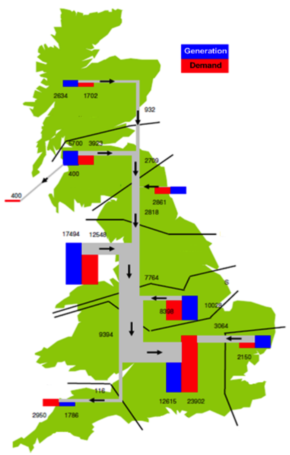


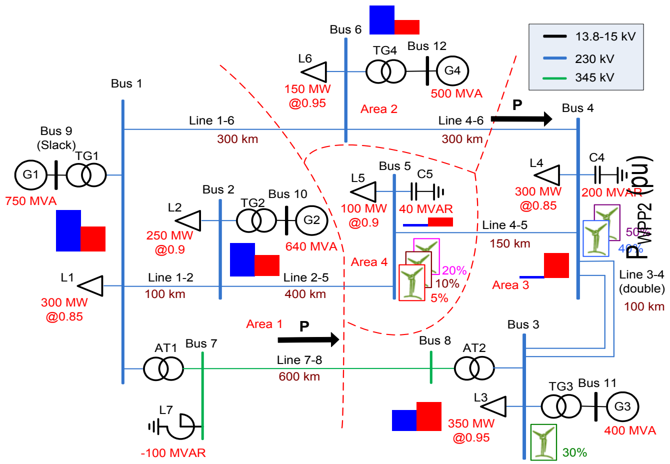
Problem:

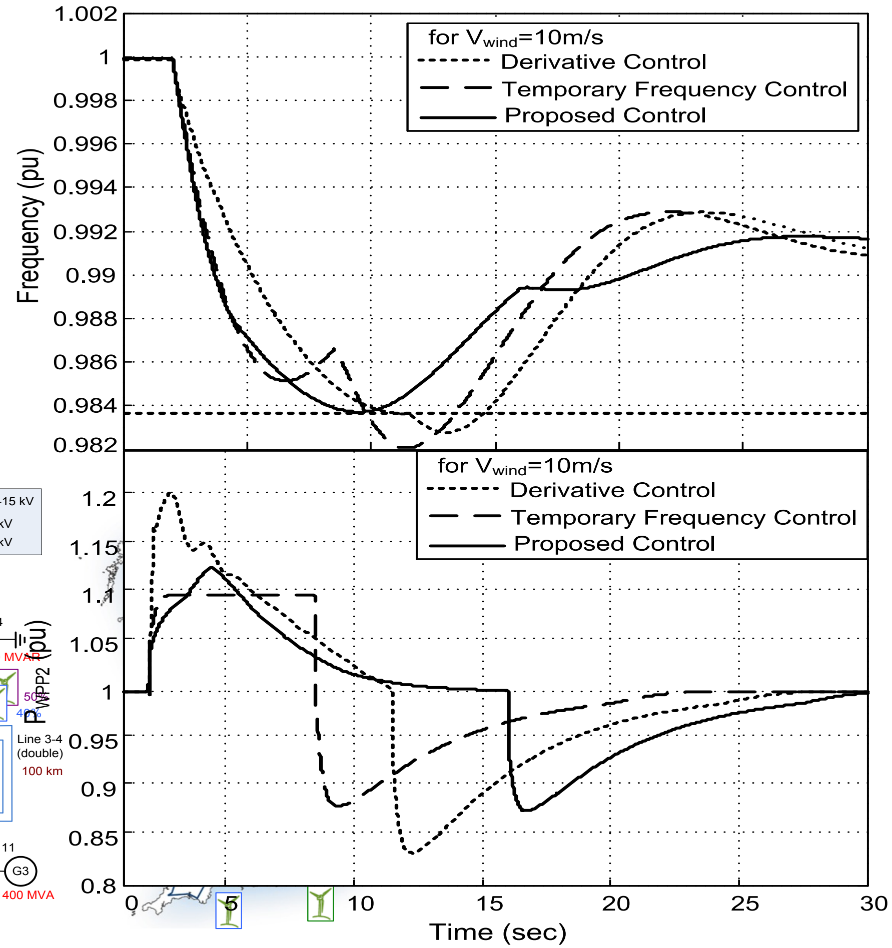
- Inertial response from WPPs
- Providing synchronizing power from WPPs

Solution:

- Adapted 12 bus test grid
- Distributed control in WPP
- Optimal power control with focus to grid frequency response
- Find the methodology for optimal H,R and T

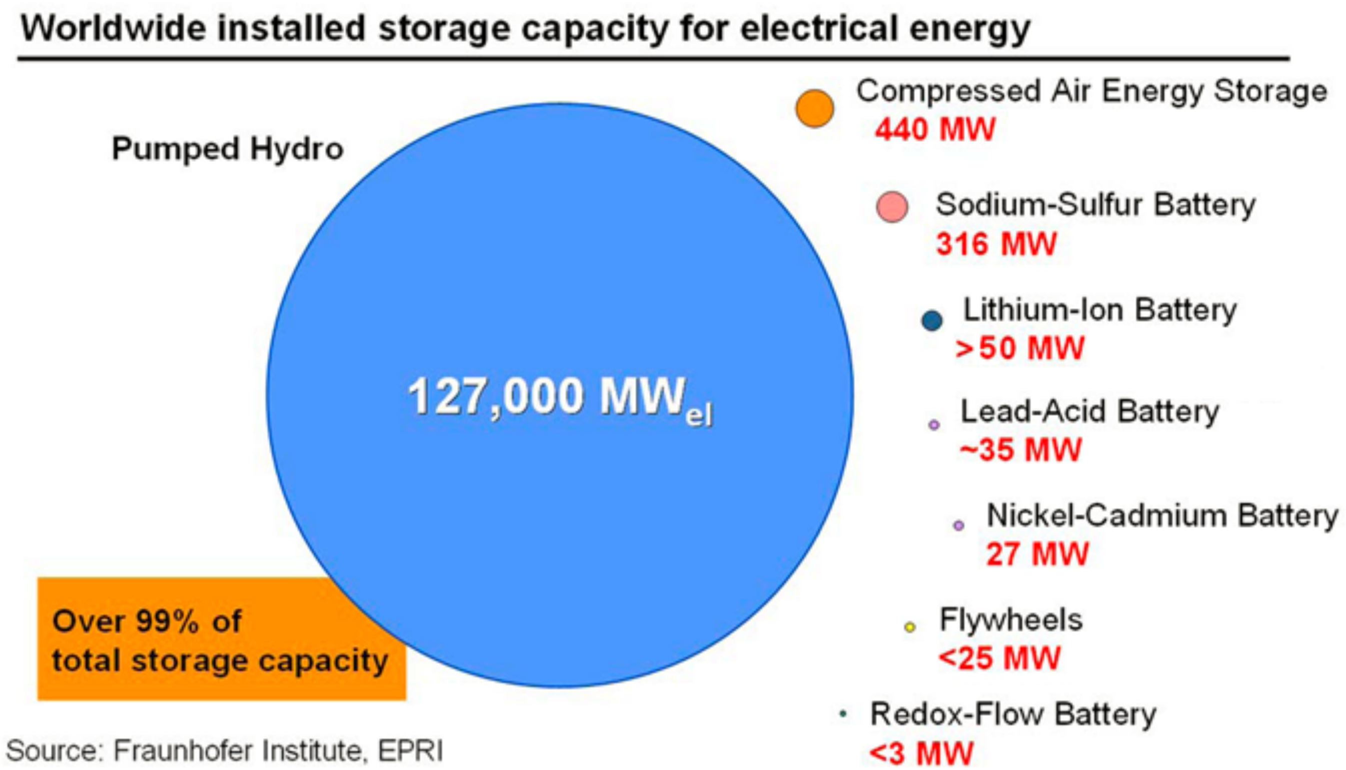






Mufiat Altin, et.al ***"Methodology for Assessment of Inertial Response from Wind Power Plants"***, PES GM 2012

Energy Storage Systems



Source: EPRI, "Electricity Energy Storage Technology Options – A White Paper Primer on Applications, Costs, and Benefits", Dec. 2010

- despite the real need for energy storage systems within the power system, very few grid-integrated storage installations are in actual operation in EU and US today;
- this landscape is expected to change around 2012, when new energy storage systems are expected to be deployed worldwide, especially in US.

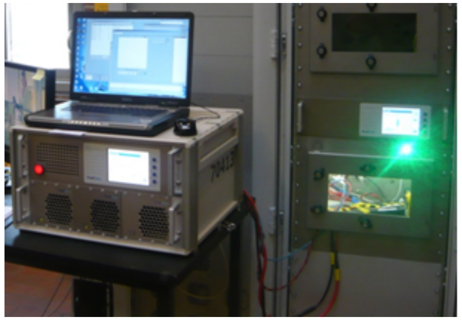
Life-Time Models for Li-Ion Batteries in Grid Support Applications

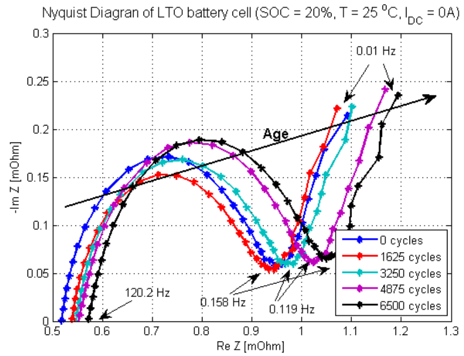
Problem

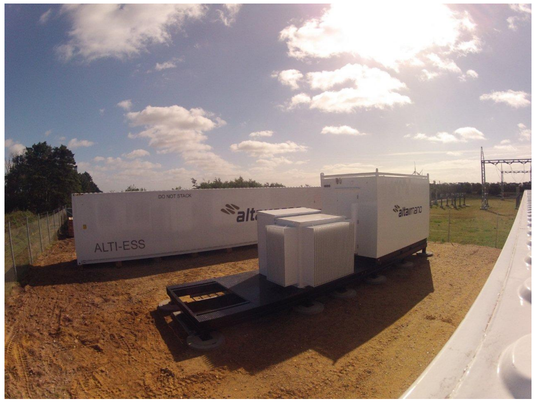
- Estimation of RULfor Li-ion batteries

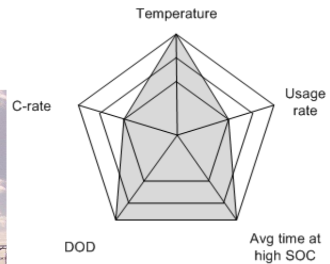
Solution

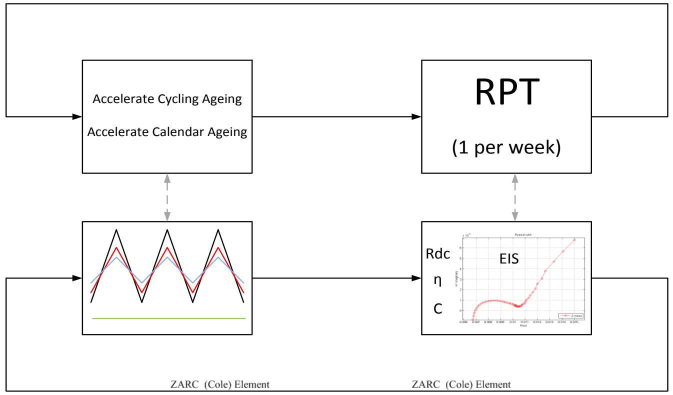
- Accelearate ageing tests
- Electrochemical Imped. Spectroscopy
- Curve-fitting
- Thermal Impedance Spectroscopy

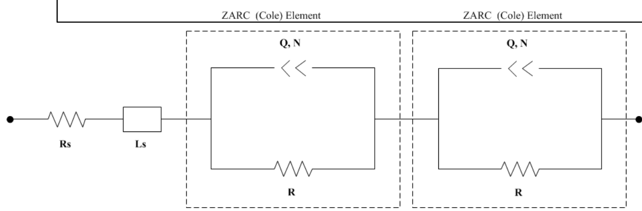












Publication: "**Impedance-based model for $LiFePO_4$ batteries in grid support applications**," in Advanced Battery Development for Automotive and Utility Applications and their Electric Power Grid Integration. Münster, Germany on March 6-7, 2012. (accepted for presentation in the poster session)

Research output – State-of-the Art facilities

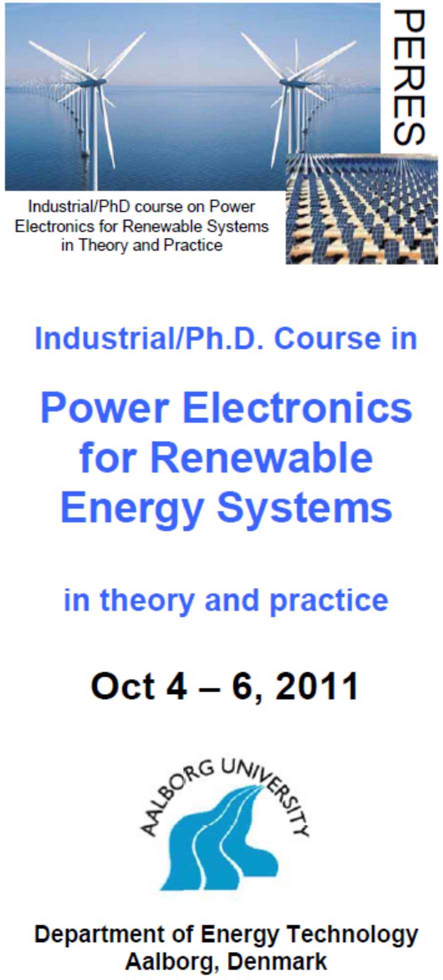
MV lab for testing 6MW 3.3 kV converter

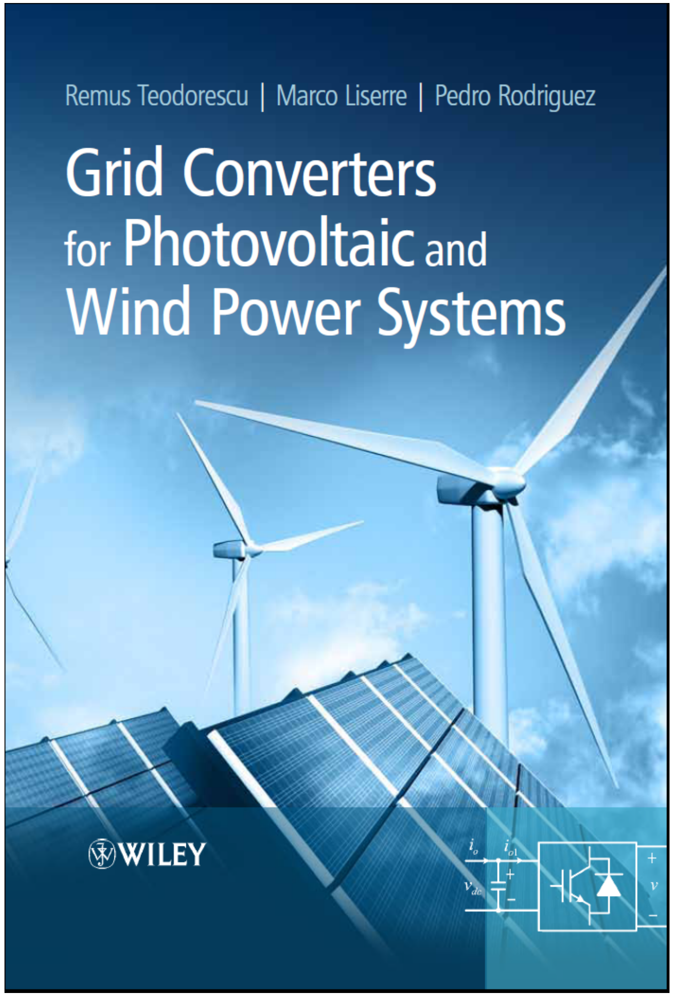
Battery tester with 2 ch, including EIS

Multi-level grid converter grid including grid simulator lab

RTDS system with 20 cores

Research output

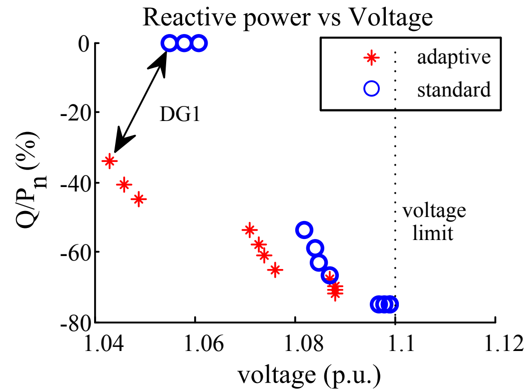




- 60+ Publications and 5 patent applications, Annual Symposium since 2008

- Power Electronics for Wind Power
- Grid Supports with Wind Power Plant
- Storage System for Grid Support
- **Grid Integration of PV**

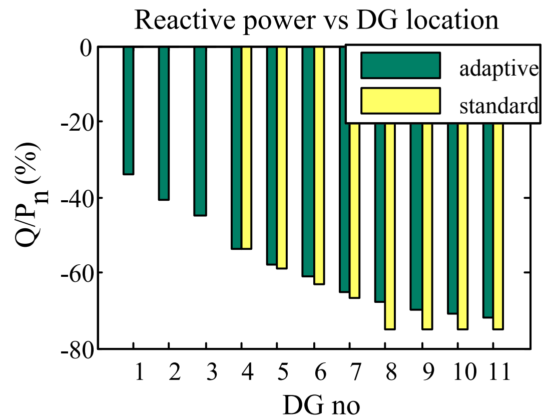
Control of Grid Interactive PV Inverters for High Penetration on LV Distribution Networks



Problem

Limited PV penetration level on LV networks

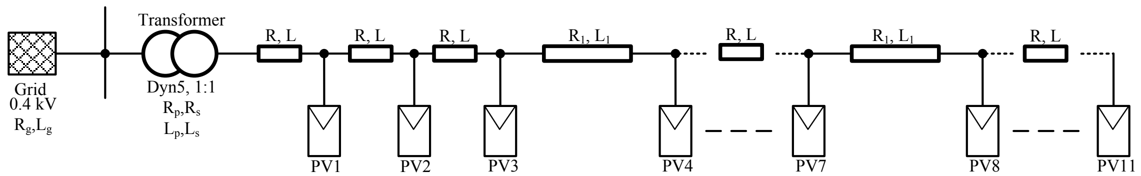
- Voltage rise
- Transformer overloading



Solution

New ancillary services by PV inverters

- Real power curtailment
- Reactive power support (adaptive Q(U))



Demirok, E., Gonzalez, P., Frederiksen, K.H.B., Sera, D., Rodriguez, P., Teodorescu, R., *"**Local reactive power control methods for overvoltage prevention of distributed solar inverters in low voltage grids**," IEEE Journal of Photovoltaics*, vol. 1, issue. 2, p. 174-182, 2011.

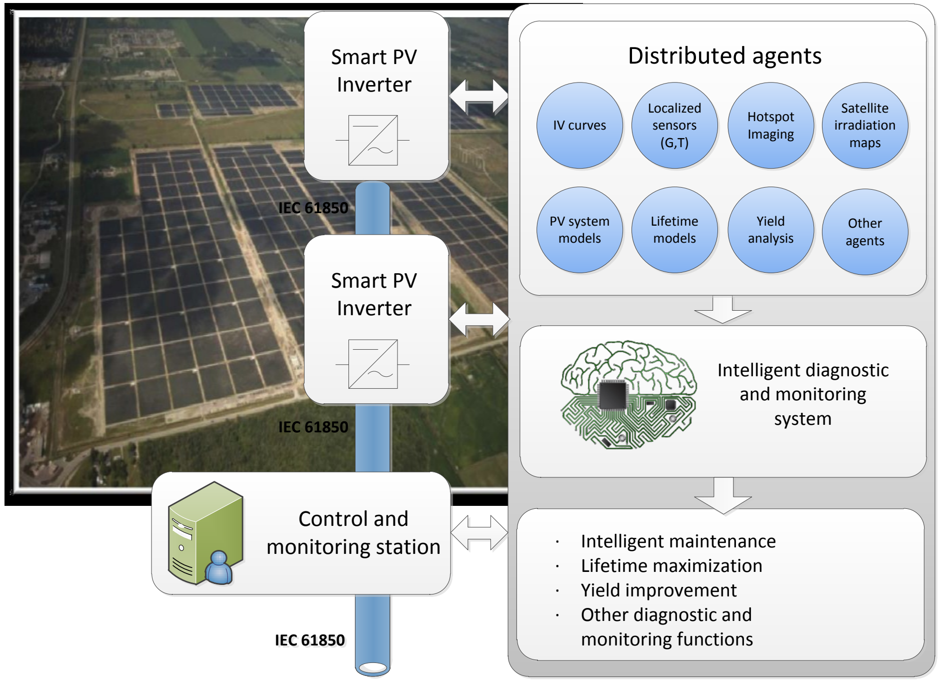
Diagnostic and Condition Monitoring in PV Power Systems

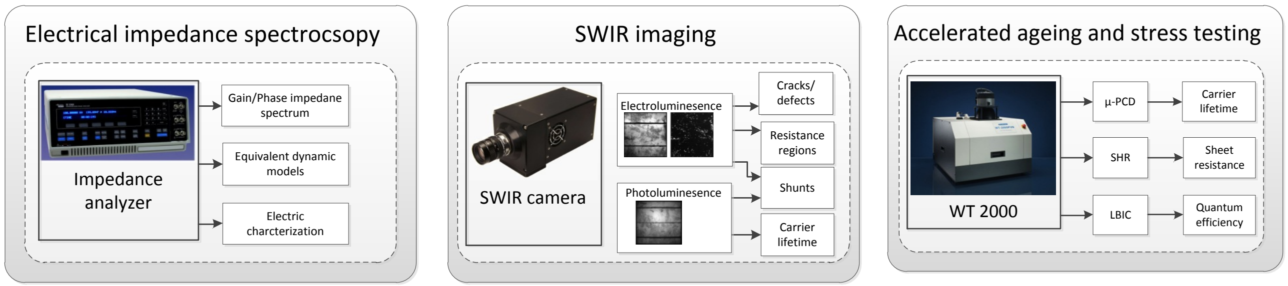
Problem

- Large PV plants utility scale
- Diagnostic and condition monitoring functions
- Reliability and lifetime models

Solution

- Intelligent modelling and diagnostic systems based on machine learning
- IV, dark IV characteristics
- Impedance spectroscopy
- SWIR imaging
- Accelerated solar cell ageing
- Carrier lifetime
- Diffusion length





Publication: "**Sensorless Diagnostics for Residential PV Systems**"; S. Dezso, S. Spataru, M. Laszlo, T. Kerekes, R. Teodorescu In: 26th European Photovoltaic Solar Energy Conference and Exhibition (EUPVSEC 2011). Hamburg, Germany : ETA-Renewable Energies and WIP-Renewable Energies, 2011. p. 3776-3782.

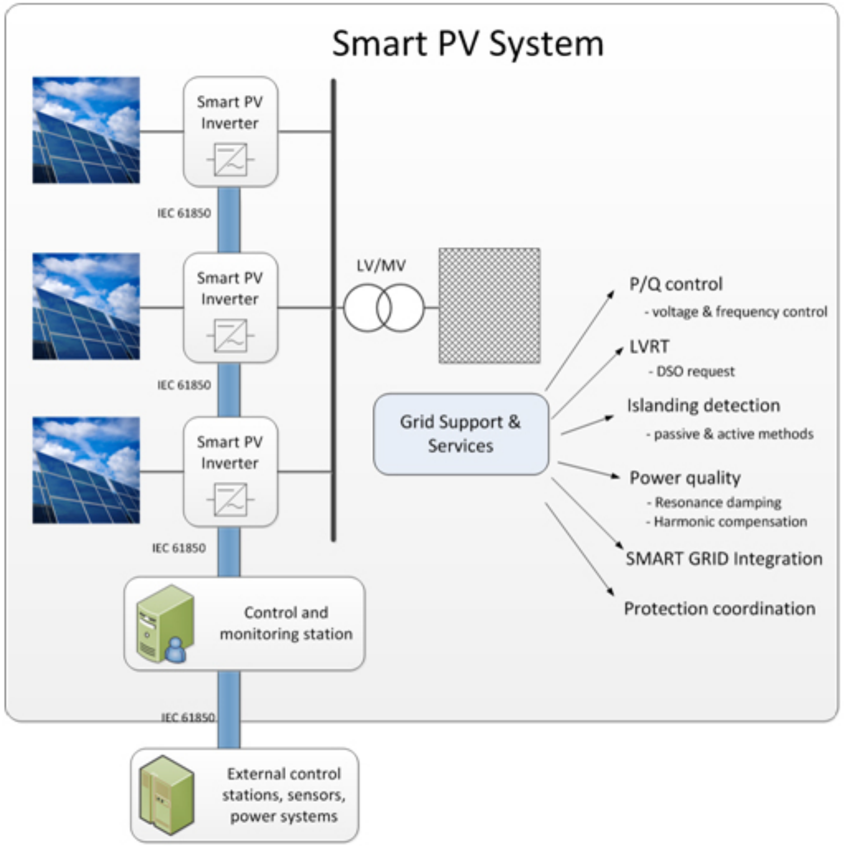
Grid Support and Condition Monitoring for PV Systems

Problem

- Increased PV penetration causes grid stability concerns (Ex."50.2 Hz problem")
- Decrease of conventional generation require PVPPs to perform VPP actions
- Need for PVPPs to offer reliable services on ancillary power markets
- Attractive feed-in tariffs led to profitable businesses

Solution

- Development of frequency stabilization functions using coordinated control and communication
- Create Virtual Power Plant functions for PVPP and compliance with future grid codes
- Participation of PVPP on the ancillary power markets and prove the economical benefits



Overview of Recent Grid Codes for PV Power Integration – Bogdan Craciun, Remus Teodorescu, 13th International Conference on OPTIMIZATION OF ELECTRICAL AND ELECTRONIC EQUIPMENT (Optim 2012). Brasov, Romania