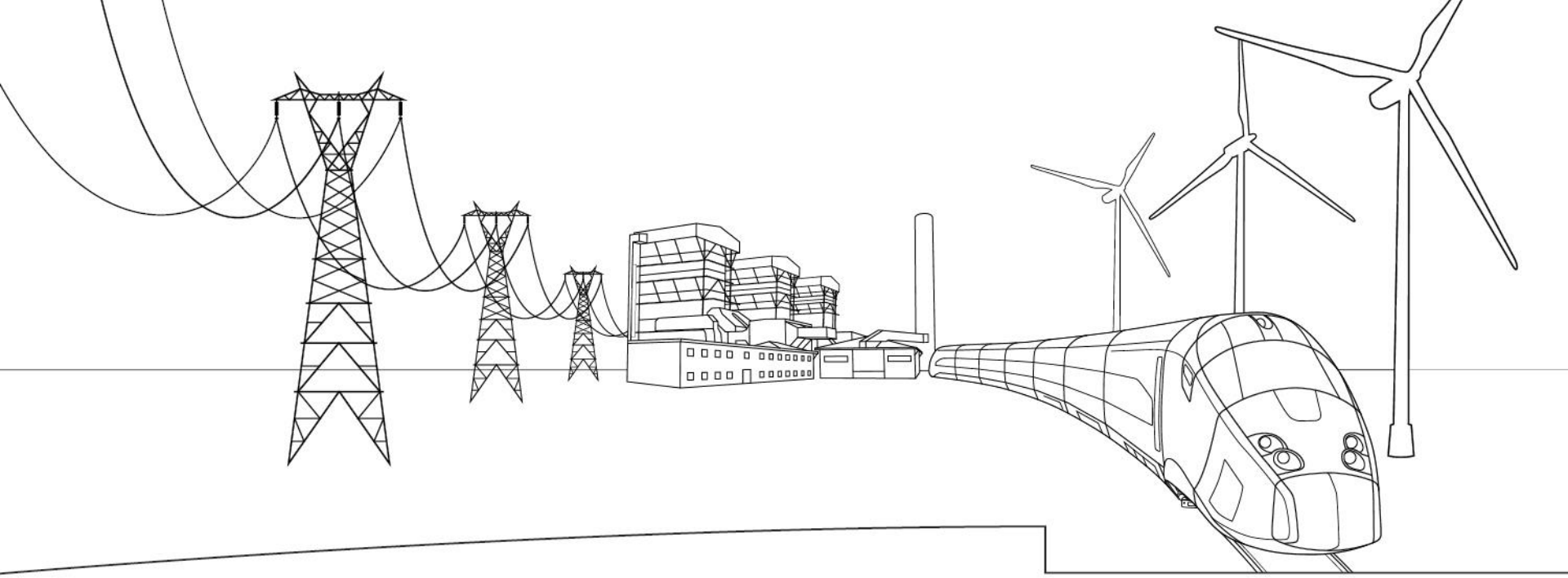


MEDOW project in Barcelona

Kevin Schönleber

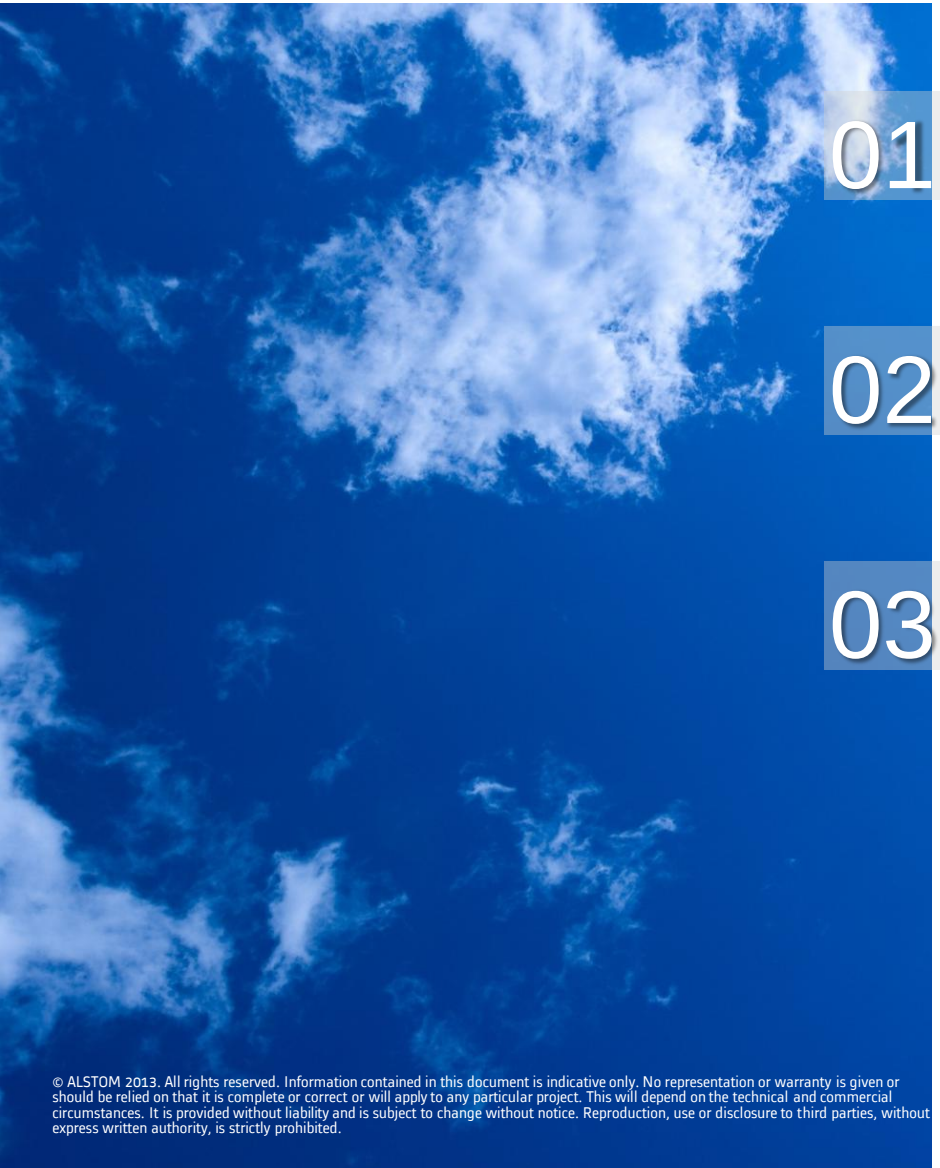
Karlsruhe, Germany

10/11/2014

ALSTOM

Shaping the future

Agenda



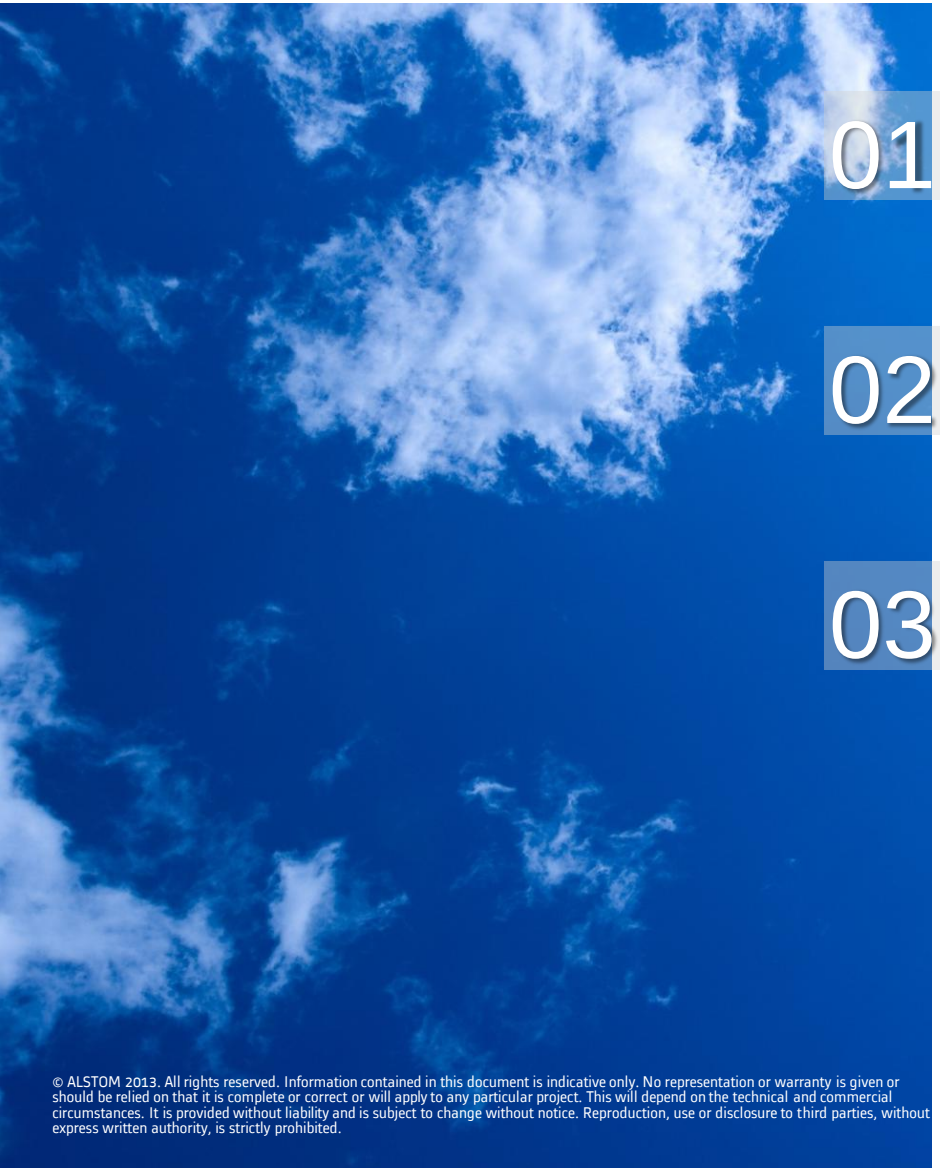
01 Alstom Wind

02 CITCEA-UPC

03 MEDOW

ALSTOM

Agenda



01 Alstom Wind

02 CITCEA-UPC

03 MEDOW

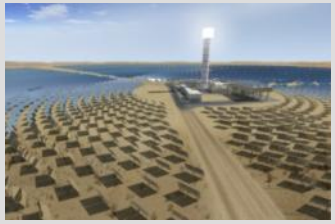
ALSTOM

Alstom Renewable Power
From single component to turnkey power plants

Alstom can provide you with integrated solutions to optimise the plant performance

Wind Power
from wind farm development to turbines services

Hydro Power
turnkey power plant or individual products

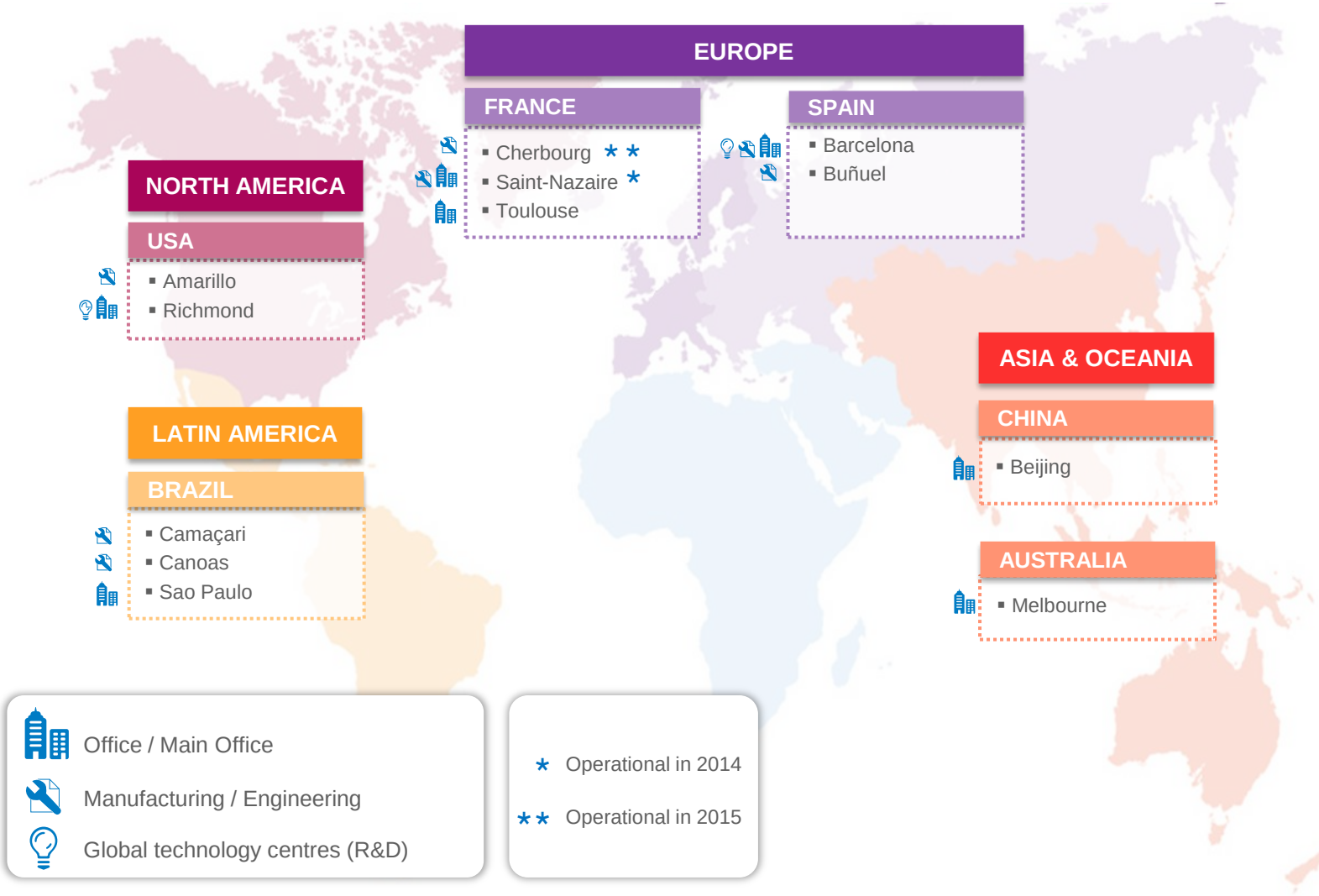


Solar Power
solar field and power block

Geothermal Power
modular and adaptable solutions from components to turnkey delivery

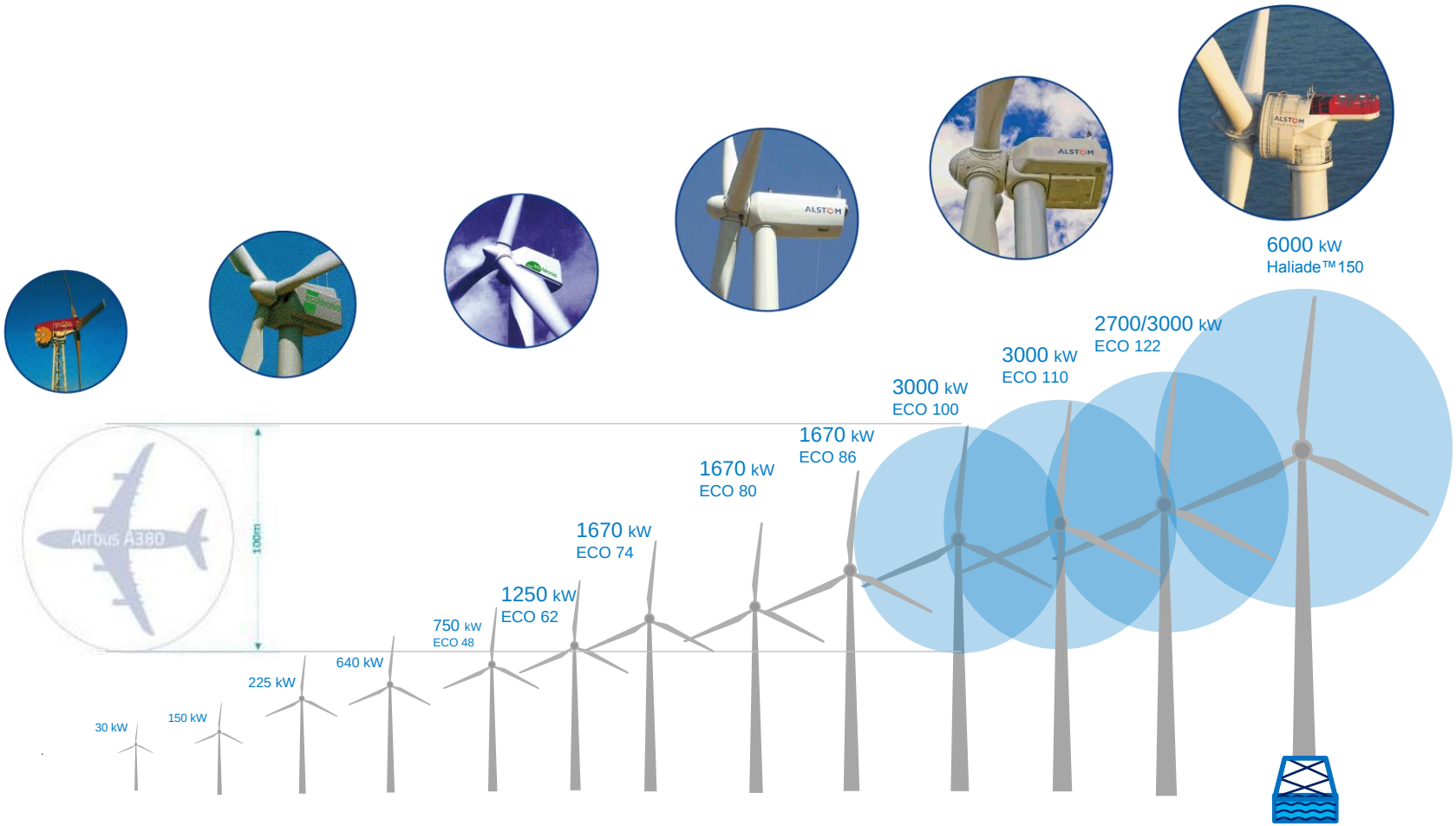
Tidal Power
from turbine to farm development

Alstom Wind business
Our international presence



ALSTOM

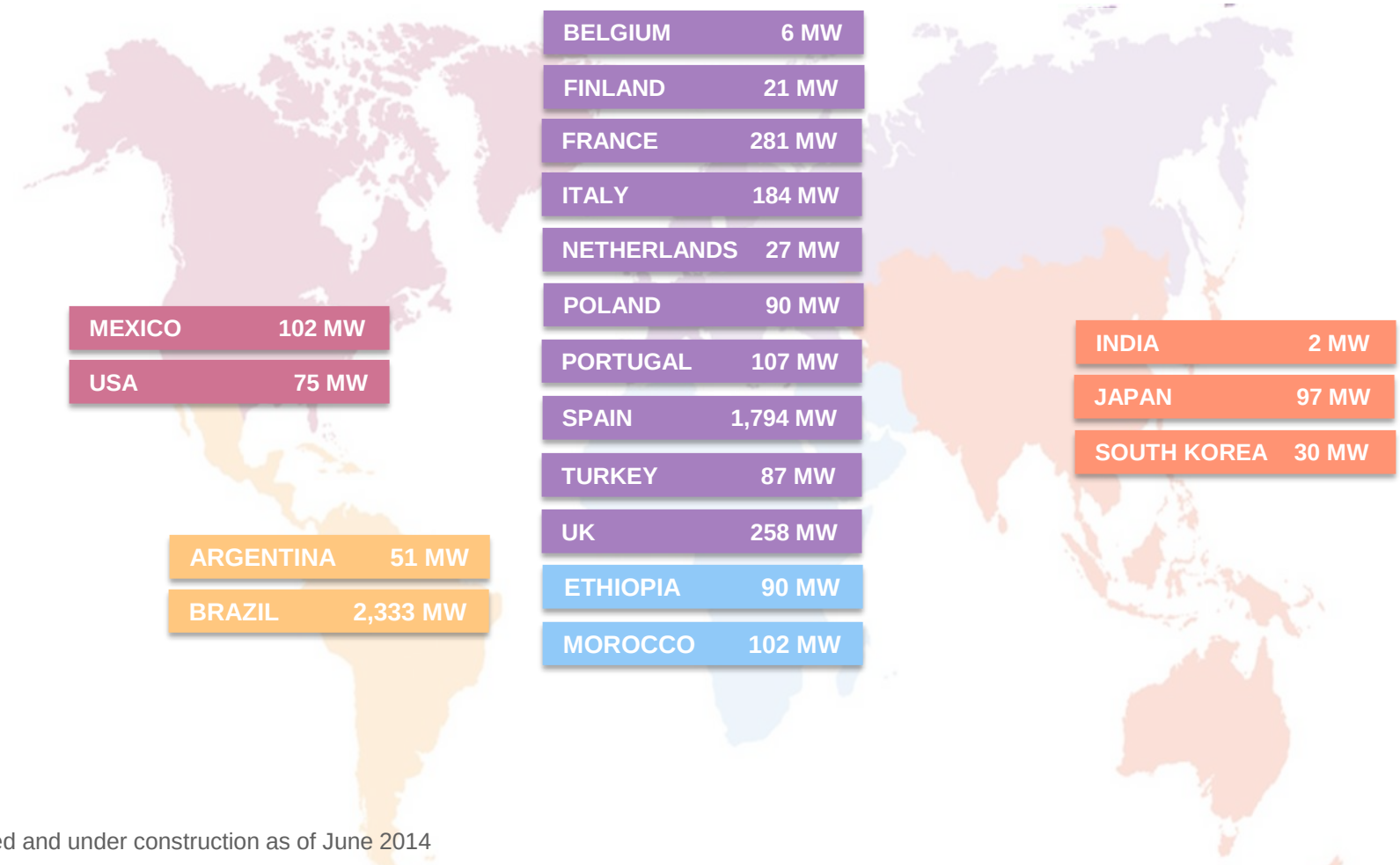
Alstom Wind
Your partners in wind power solutions



30 years of experience in wind technology

ALSTOM

Powering the world
Our references in Wind

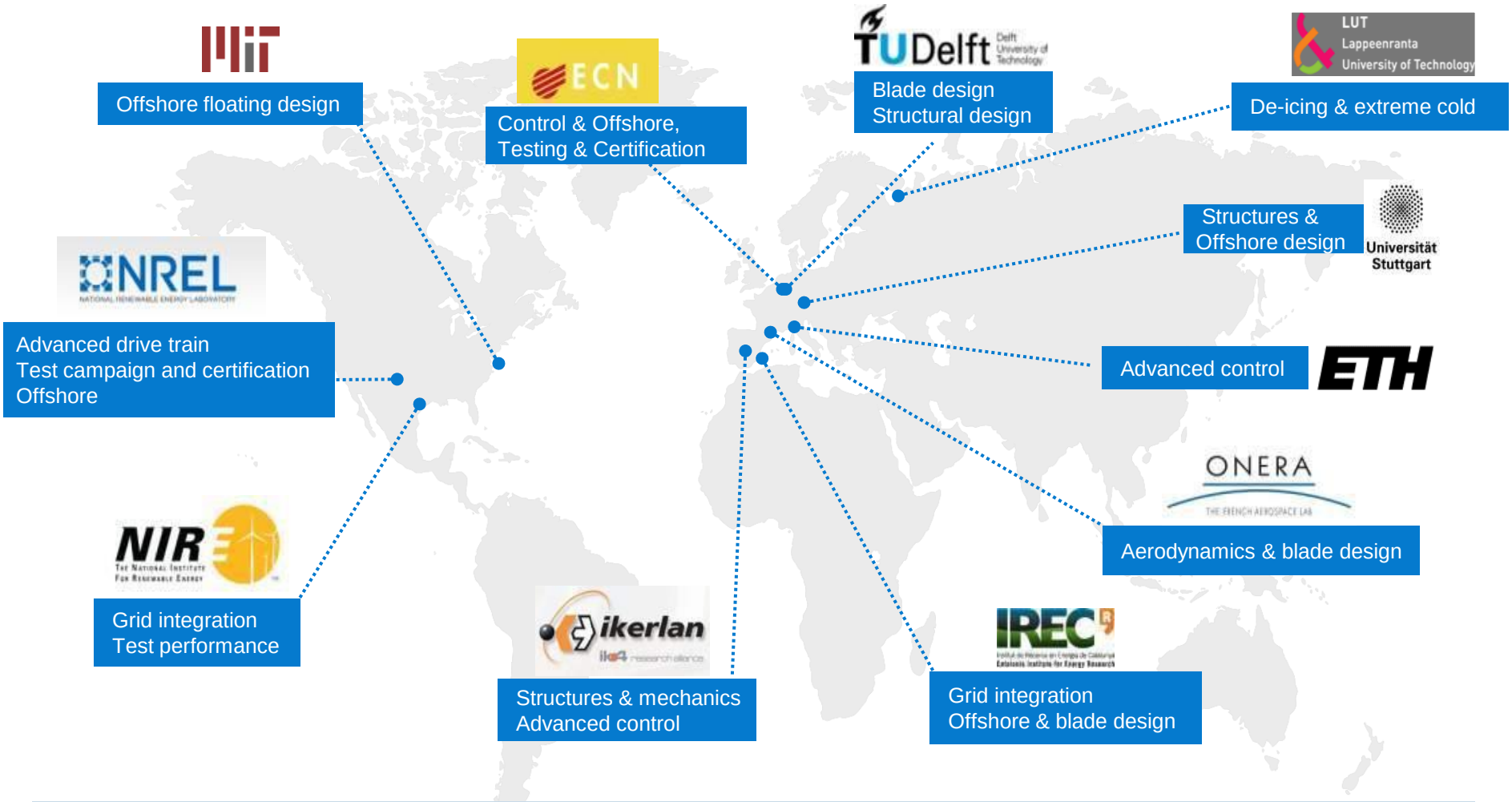


* Installed and under construction as of June 2014

Over 5.7 GW installed/ under construction in more than 200 wind farms

ALSTOM

Alstom Wind business
Our strong innovation partnerships



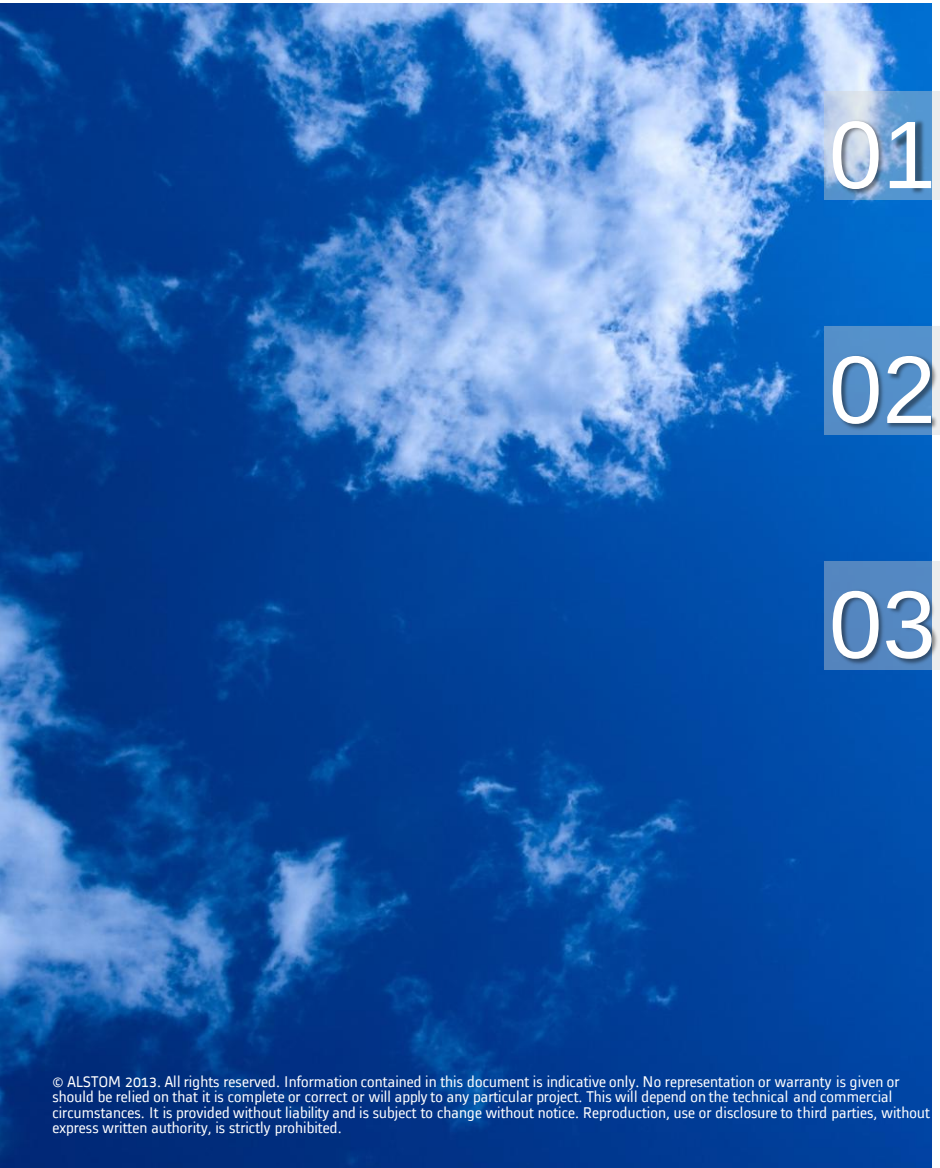
Over 250 people involved in R&D activities with leading research institutions

Alstom, your partners in wind power solutions

- **Haliade™ 150-6MW**
  - Innovative technology, reliable and efficient
  - Completion of first onshore unit commissioning at full 6MW output
  - Certification underway
  - First offshore unit installed
- **Alstom Grid**
  - Over 130 years of grid expertise
  - 50 years of HVDC experience
  - 2.9 GW offshore wind substation references

ALSTOM

Agenda



01 Alstom Wind

02 CITCEA-UPC

03 MEDOW

ALSTOM

CITCEA-UPC

CITCEA-UPC

Wind Power and **HVDC grids**

www.citcea.upc.edu

Technology and Knowledge transferred from University to Industry

TECNIO
Be tech. Be competitive

CIT UPC
Centre d'Innovació i Tecnologia

CITCEA-UPC is a centre for research and technology innovation born in 2001 inside the Technical University of Catalonia (UPC) supported by the Government of Catalonia.

12 years' experience, 70 people, 110 customers, 197 projects, 8,5 M€ turnover, 9 patents, 1 spin-off (teknoCEA), more than 200 conference papers; more than 100 journal paper.

Activity fields

MECHATRONICs:

Power electronics and electrical drives.
Automation, industrial ICTs.

ENERTRONICS:

Generation, transmission and distribution of electrical energy.
Economics, market and regulation of electrical energy.

LIFE LONG LEARNING

LLL Masters in Mechatronics and Enertronics. Courses and Seminars for professionals

Expertise

Mechatronics

Power electronics and converters, special for applications in wind and PV
Digital control with DSP
Industrial communications
Data acquisition and signal processing
Process automation and Motion control
Electric vehicles and battery chargers
Design of electrical machines

Enertronics

Electrical generation from renewables and distributed generation
Wind generator design
Distribution and transmission grids
Control of wind generators and wind farms
Offshore wind farms and HVDC
Microgrids and smart grids
Condition monitoring and PQ

TECNIO Be tech. Be competitive

CIT UPC Centre d'Innovació i Tecnologia

teknoCEA. Our spin-off

- Created in 2012
- Industrial branch of CITCEA-UPC
- Commercialization of CITCEA-UPC designs
- Example products:
  - Voltage Source Converter (VSC) for grid connection of renewable energy and storage systems (Modular converters from 1 kW to 200 kW, Single-phase / Three-phase, Grid code compliant)
  - Bidirectional electrical vehicle chargers with V2G capability
  - Isolated bidirectional DC/DC converters
  - Energy management systems for microgrids
  - Multiple purpose control boards for smart grids
  - Industrial communications systems
  - Industrial emulators (Grid, renewable, batteries, loads, etc…)
  - Scaled platforms for research
  - Educational boards and test beds

Main topics

- Wind turbine technology
- Grid integration of wind power
- Offshore wind power plants
- Transmission systems for offshore wind
- HVDC grids

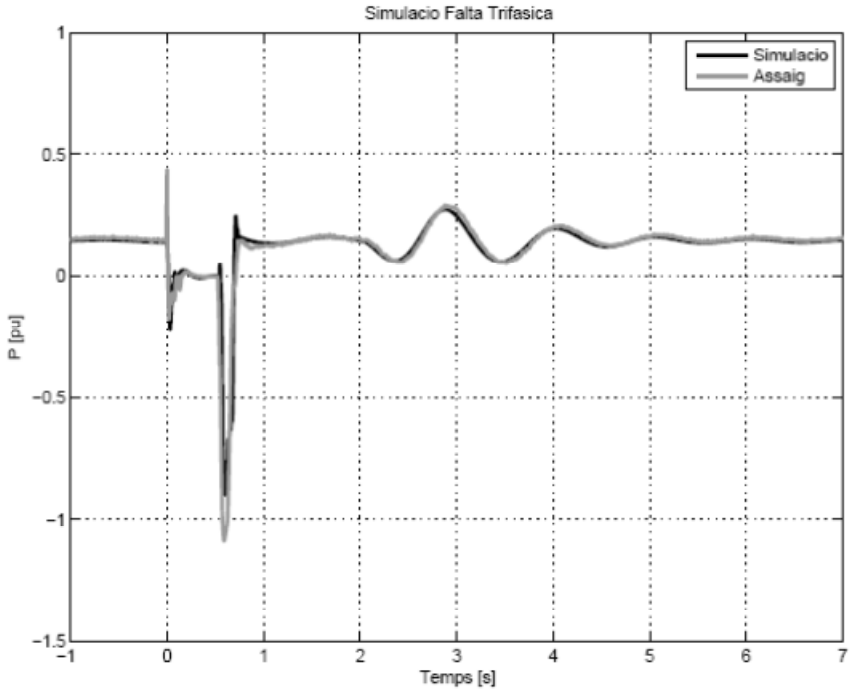
Industrial Projects

- Wind turbine manufacturers
- Wind farm developers
- Component manufacturers
- Transmission system operators
- Distribution system operators

Research projects

Drive train - Generators

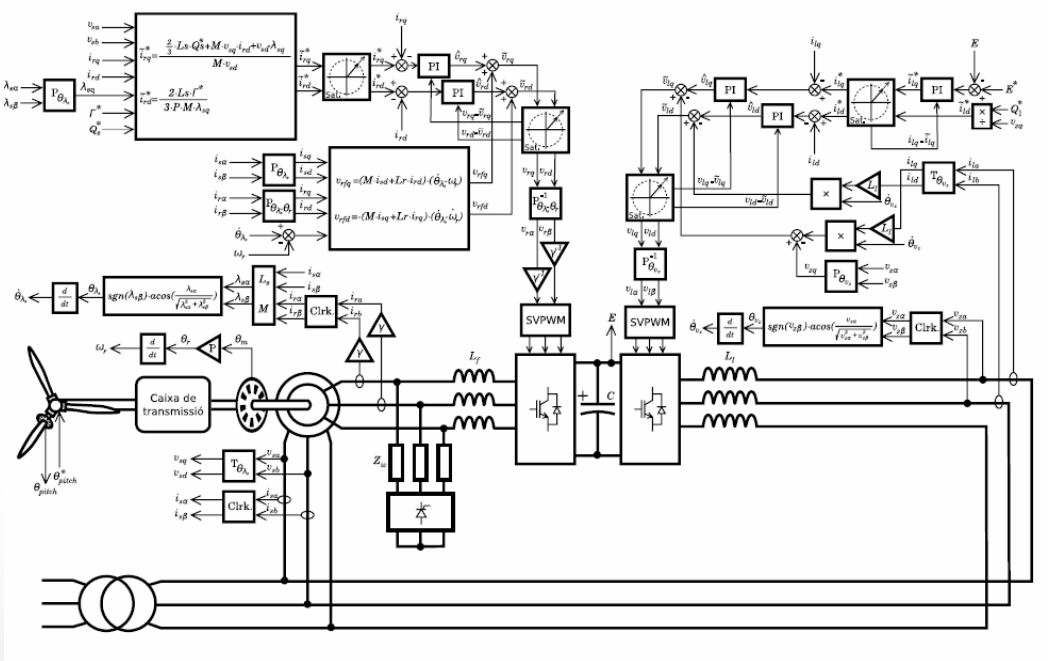
- ✓ **Wind turbine technology**
- ✓ Grid integration of wind power
- ✓ Offshore wind power plants
- ✓ Transmission systems for offshore wind, multiterminal HVDC

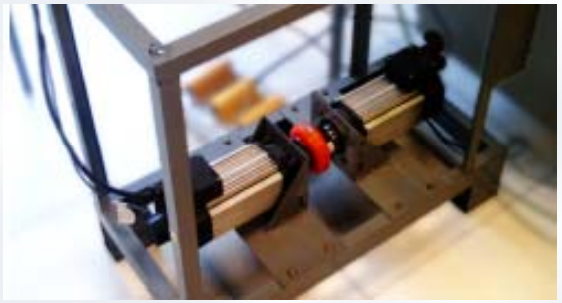


- ❑ Doubly fed induction generators (DFIG)
- ❑ Synchronous generators (SG)
- ❑ Design
- ❑ Modeling
- ❑ Model validation with real measurements

Power electronics and control

- ✓ **Wind turbine technology**
- ✓ Grid integration of wind power
- ✓ Offshore wind power plants
- ✓ Transmission systems for offshore wind, multiterminal HVDC

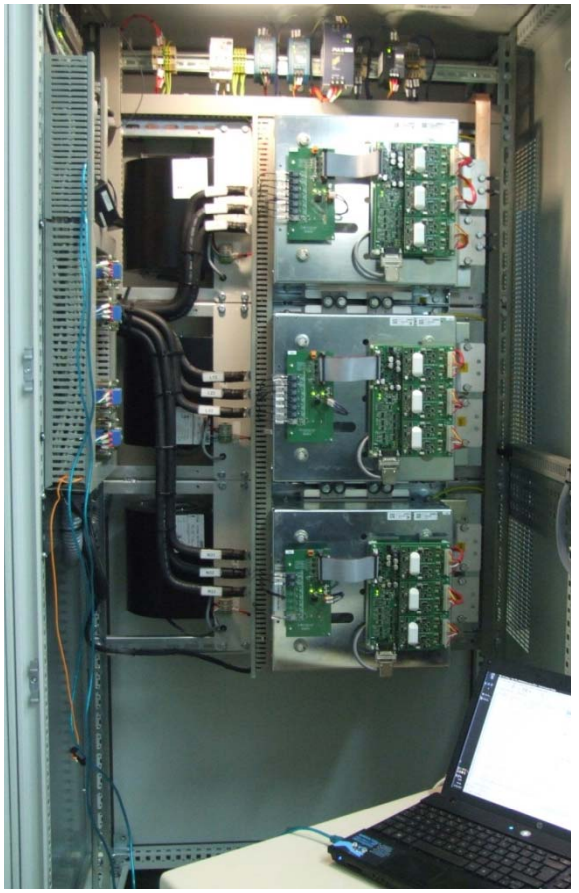




- ❑ Converter topologies
- ❑ Generator and converter control
- ❑ Operation under faults
- ❑ Experimental validation
- ❑ Modeling and simulation

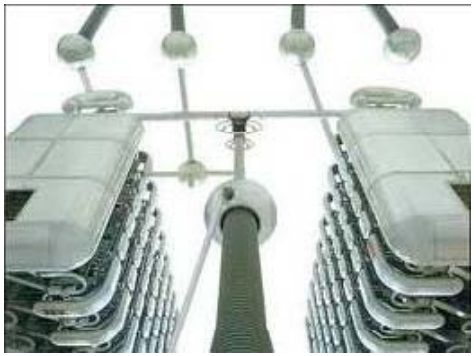
Previous and current activities related to wind turbine generator and power converter

- For *Alstom Wind*:
  - DFIG model development
  - DFIG control scheme under unbalanced faults and frequency excursions
  - DFIG model validation with field measurements
  - PMSG model development. PMSG control scheme design
  - Grid and transformer modeling and simulation
  - DLL generation to interact with Bladed.
- teknoCEA (CITCEA start-up):
  - Power converter design (up to 200 kVA)
  - Wind turbine control design
  - Scaled laboratory platforms for SCIG, DFIG and PMSG



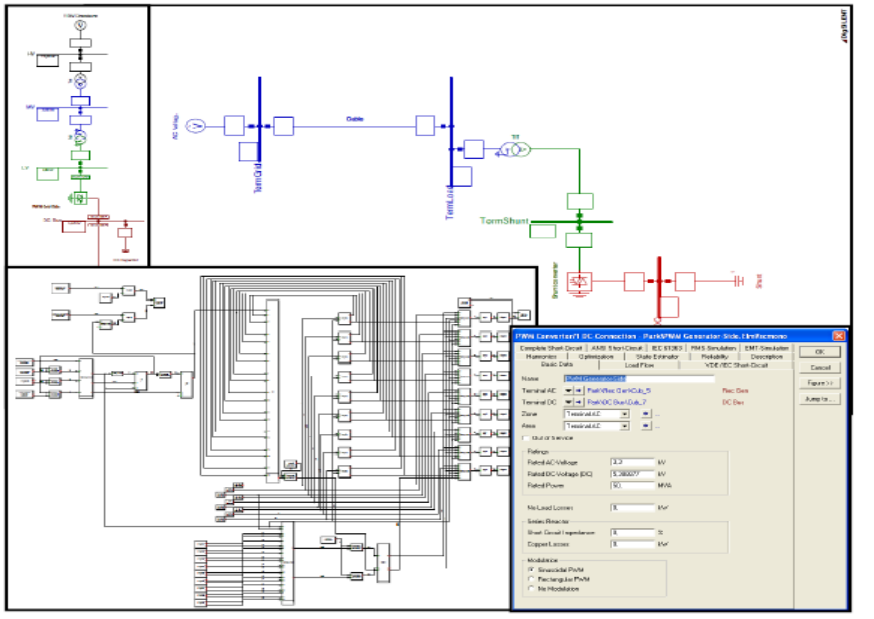
Wind power plants

- ✓ Wind turbine technology
- ✓ **Grid integration of wind power**
- ✓ Offshore wind power plants



ABB

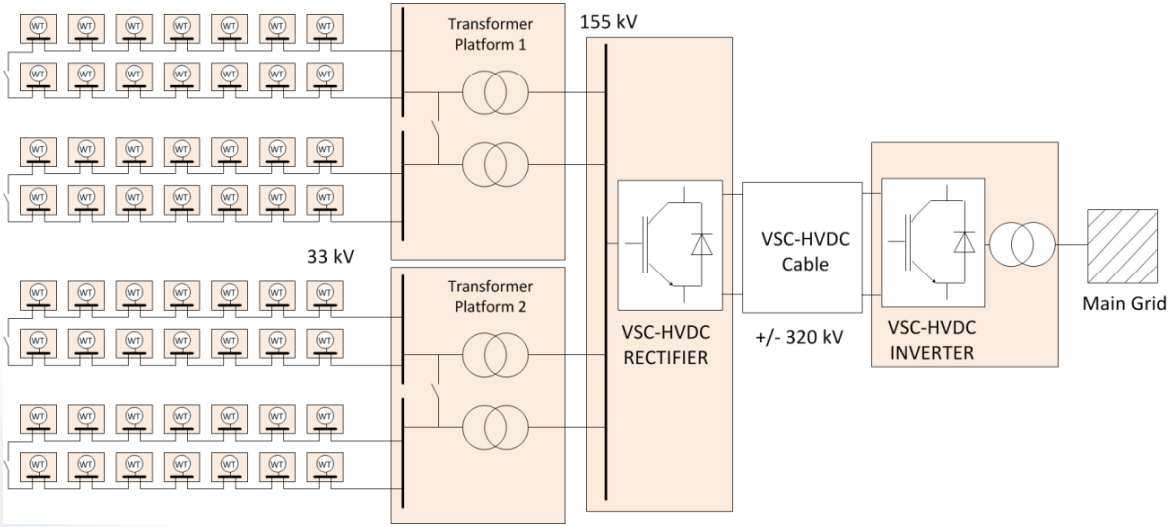
Beacon

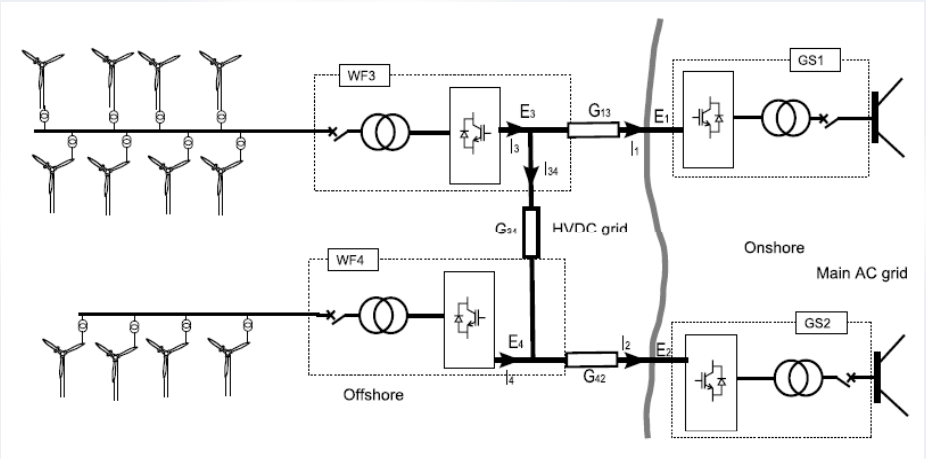


- ❑ Wind farm control
- ❑ Power system support
- ❑ Energy storage
- ❑ FACTS
- ❑ Grid codes
- ❑ Voltage sags and frequency perturbations
- ❑ Modeling and Simulation with DigSilent Power Factory, PSS/E, etc...

Offshore wind power plants

- ✓ Wind turbine technology
- ✓ Grid integration of wind power
- ✓ **Offshore wind power plants**
- ✓ Transmission systems for offshore wind, multiterminal HVDC





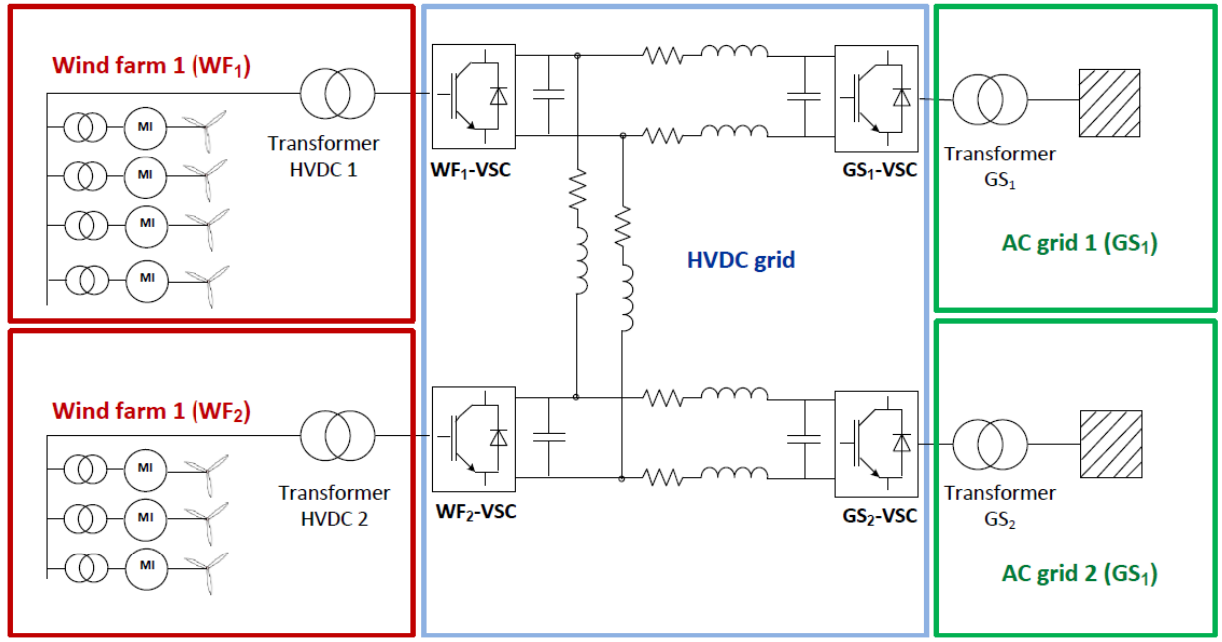
- ❑ Modeling and control for HVAC and HVDC connections
- ❑ Stability analysis
- ❑ Wind power plant operation and control
- ❑ New topologies and control concepts

Previous and current activities related to grid integration and offshore wind power plants

- KIC Offwindtech
  - Offshore wind power plant design and optimization
  - Power flow studies of wind power plants
- For *Endesa Red*
  - Wind power integration in the Spanish network
  - Static and dynamic analysis of the overall network with different wind penetration levels.
- For *Alstom Wind*:
  - Active and reactive power dispatch algorithms for wind farms
  - Studies of utilization of FACTS and energy storage in wind farms
  - Grid support from wind farms
  - Wind farm modeling with DIgSILENT Power Factory.

Multiterminal HVDC

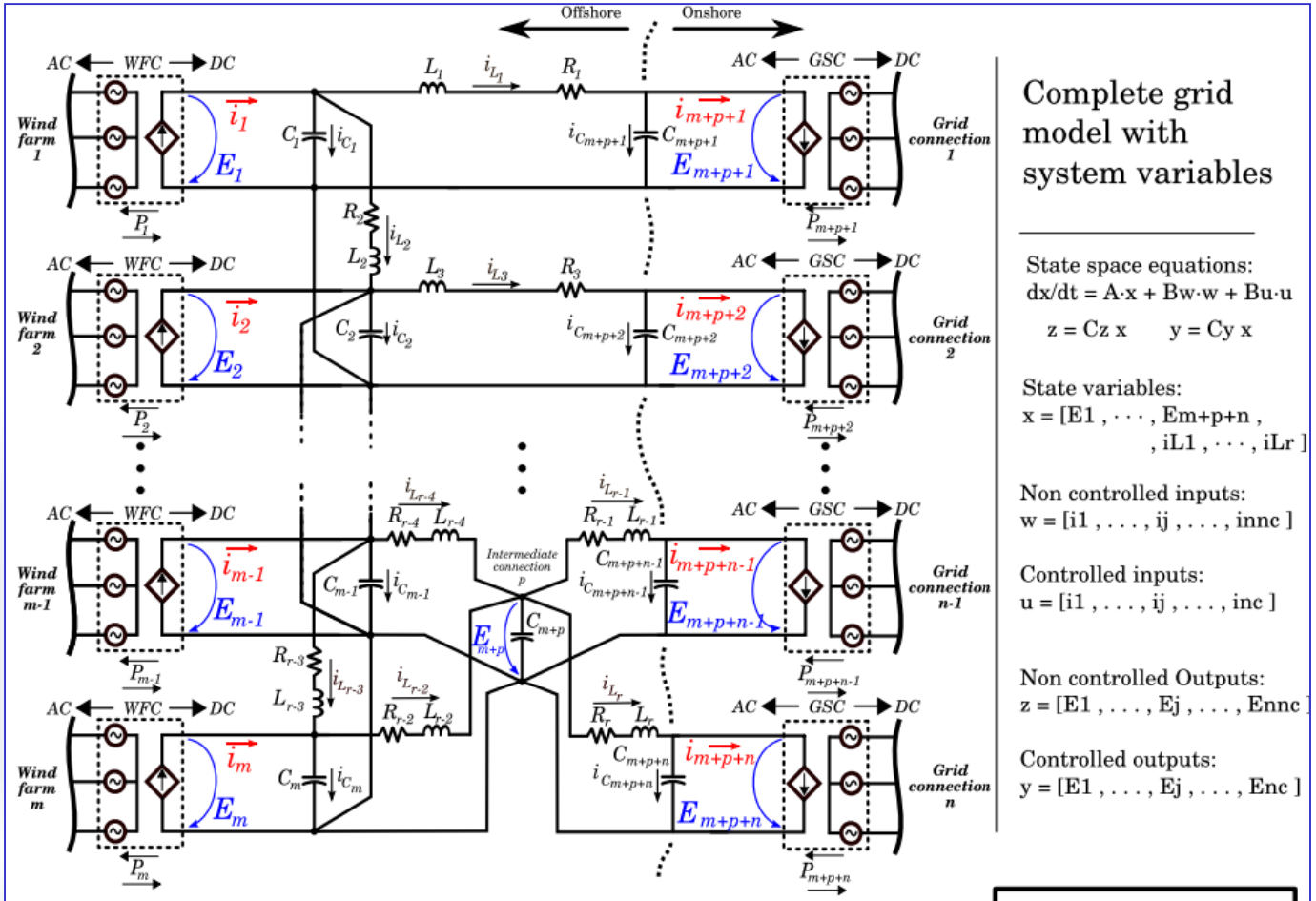
- ✓ Wind turbine technology
- ✓ Grid integration of wind power
- ✓ Offshore wind power plants
- ✓ **Transmission systems for offshore wind, multiterminal HVDC**



- ❑ HVDC
- ❑ Multiterminal systems
- ❑ Operation and control
- ❑ Operation under faults
- ❑ Dynamic simulation
- ❑ Experimental validation

Multiterminal HVDC

Control of VSC-HVDC grids for offshore wind power plants



Complete grid model with system variables

State space equations:
dx/dt = A·x + Bw·w + Bu·u

z = Cz x y = Cy x

State variables:
x = [E1 , · · · , Em+p+n , , iL1 , · · · , iLr]

Non controlled inputs:
w = [i1 , . . . , ij , . . . , innc]

Controlled inputs:
u = [i1 , . . . , ij , . . . , inc]

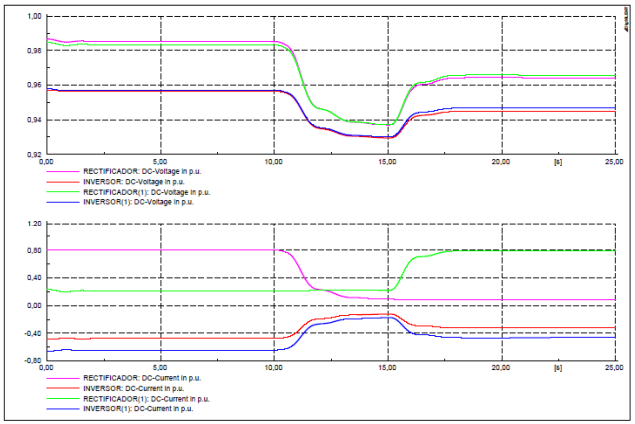
Non controlled Outputs:
z = [E1 , . . . , Ej , . . . , Ennc]

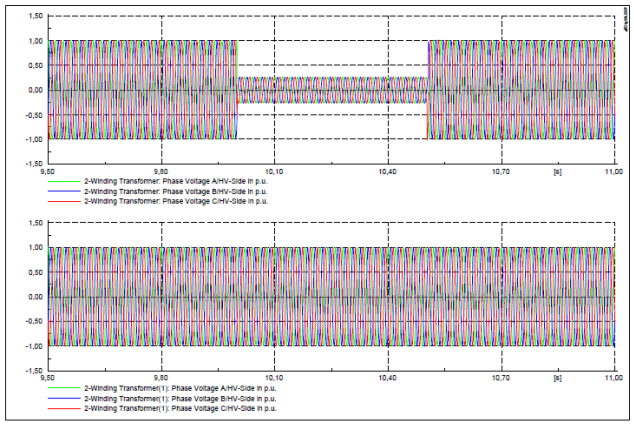
Controlled outputs:
y = [E1 , . . . , Ej , . . . , Enc]

Transfer function matrices: Relations between all inputs and outputs either controlled or non controlled

	Outputs	
Inputs	Non Controlled (z)	Controlled (y)
Non Controlled (w)	G_{zw}	G_{yw}
Controlled (u)	G_{zu}	G_{yu}

DIgSILENT Power Factory® simulations

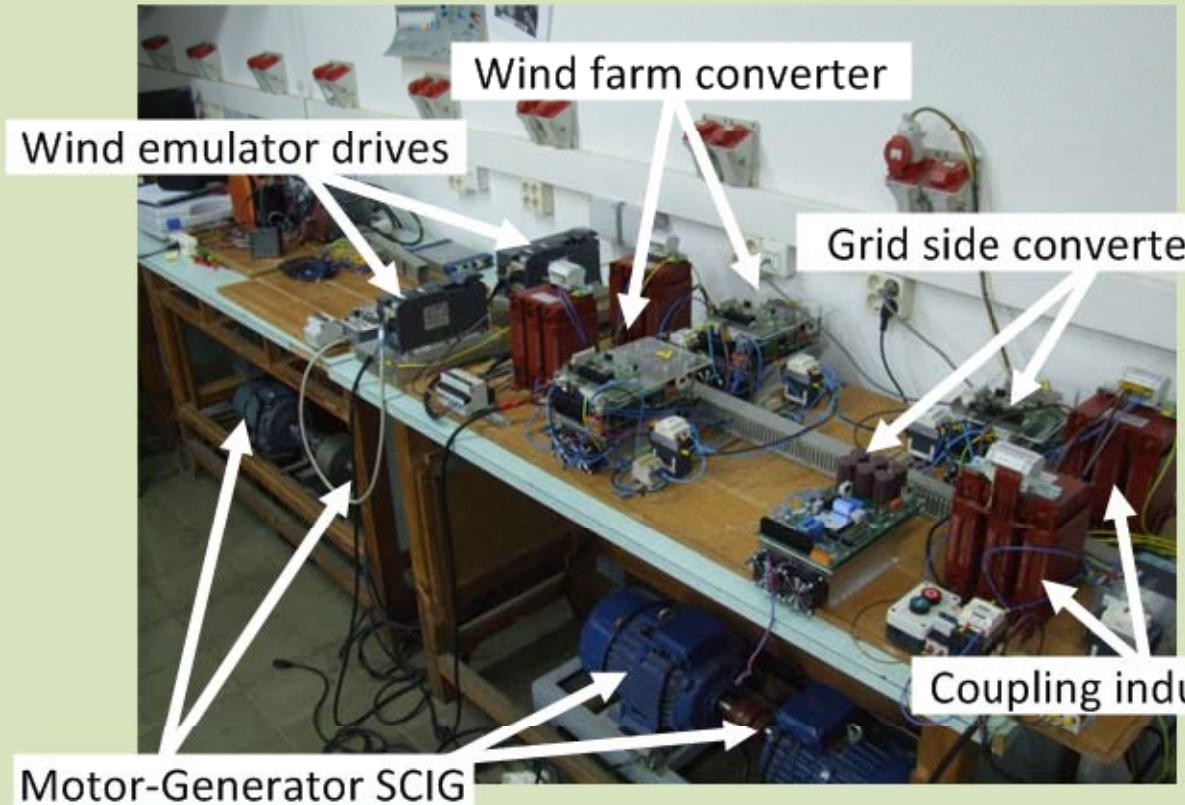




Multiterminal HVDC

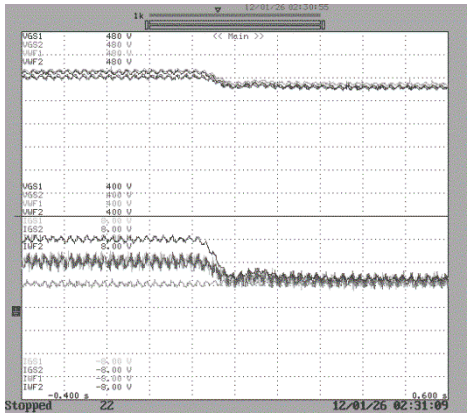
Scaled platform for testing the control and operation algorithm for the studied DC grid

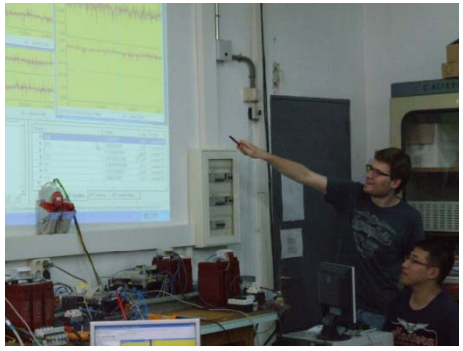
M-VSC-HVDC test bench



M-VSC-HVDC TB main characteristics

- Nominal power: 10 kVA (each converter)
- Maximum DC Voltage: 800 V
- Nominal AC voltage: 400 V_{RMS}
- Maximum current: 15 A_{RMS}
- Two SCIG as a wind farm (2.2 kW and 7.5 kW)
- DSP programable microcontroller





Previous and current activities related to HVDC

- Multi-terminal DC grid for offshore wind (MEDOW), Marie Curie Initial Training Networks (ITN) Call: FP7-PEOPLE-2012-ITN
  - Modeling and control of M-HVDC systems including wind power
  - WP1 and WP6 leaders
- KIC SmartPower
  - Optimum power flow of mixed AC-DC grids
  - Voltage and power control of M-HVDC including experimental validation with scaled platform.
- ENE2012-33043 Sistemas de transporte eléctrico para grandes centrales eólicas marinas.Ministerio de Economía y Competitividad.
- ENE2009-08555 Sistemas multiterminal de corriente continua en alta tensión (HVDC) para la integración de energías Renovables a la red eléctrica, Ministerio de Ciencia e Innovación

2nd HVDC Doctoral Colloquium in CITCEA-UPC July 7th and 8th, 2011

2nd HVDC DOCTORAL COLLOQUIUM â€“ BARCELONA 2011

July 7th and 8th, 2011

Scope Program Committee Registers Location Collaborators CITCEA CERIEN ETSEIB

english

Scope

After the first edition of the HVDC doctoral colloquium (http://paginas.fe.up.pt/~hvdc/) celebrated last June 14th and 15th, 2010 in Universidade do Porto, Faculdade de Engenheria, we have the pleasure to invite you to the second edition in the Universitat PolitÃ¨cnica de Catalunya - BarcelonaTech (UPC) next July 7th and 8th, 2011. The colloquium will be organized by the Centre of Technological Innovation in Static Converters and Drives (CITCEA-UPC) in collaboration with Cardiff University, Catalonia Institue for Energy Research (IREC), Universidade do Porto, Katholieke Universiteit Leuven (KUL), China Electric Power Research Institute (CEPRI) and Imperial College London.

The colloquium will allow researchers and PhD students to discuss the research they are doing in the field of HVDC transmission systems applied to large offshore wind power plants connection. The colloquium will include topics relevant to HVDC or wind power, as HVDC circuits and power converter topologies, power flow analysis, protection schemes, operation and control and scaled laboratory experiences.

Electronic Registration

CITCEA UPC

Càtedra endesa d'innovació energètica UPC

IREC Institut de Recerca en Energia de Catalunya Catalonia Institute for Energy Research

CARDIFF UNIVERSITY

Universidade do Porto FEUP Faculdade de Engenharia

KATHOLIEKE UNIVERSITEIT LEUVEN

国家电网 STATE GRID 中国电力科学研究院

Imperial College London

TECNIO Be tech. Be competitive

CIT UPC Centre d'Innovació i Tecnologia

http://www.cerien.upc.edu/jornades/index.php?id=28

Industrial Projects

8 projects since 2006 including projects with Alstom Wind and Endesa.

Research Projects

- Multi-terminal DC grid for offshore wind (MEDOW), Marie Curie Initial Training Networks (ITN) Call: FP7-PEOPLE-2012-ITN
- KIC Offwindtech
- KIC SmartPower
- ENE2012-33043 Sistemas de transporte eléctrico para grandes centrales eólicas marinas. Ministerio de Economía y Competitividad.
- ENE2009-08555 Sistemas multiterminal de corriente continua en alta tensión (hvdc) para la integración de energías Renovables a la red eléctrica, Ministerio de Ciencia e Innovación

Patents

- WO/2012/016585, Reactive power regulation (Alstom Wind)
- P2236EP00 Method for avoiding voltage instability in an electrical grid of an offshore wind park (Alstom Wind)
- P201330058 Asynchronous electric generator control procedure and corresponding system (CITCEA-UPC)

PhD Thesis on field related to wind power and HVDC grids

Completed

- Adrià Junyent. Control of power electronic converters for the operation of wind generation. 2011.
- Marcela Martinez. Reactive power dispatch in wind power plants using heuristic optimization techniques. 2011.
- Paola Pezzini. Optimization Techniques to improve energy efficiency and to mitigate line overloads. 2011
- Tomas Skocil. Interconnection Optimization of Power Units with Renewable Power Sources to Distribution Network. 2010.
- Roberto Villafafila-Robles. Probabilistic modeling in Normal Operation and the Control of Distribution Systems with Renewable Source based DG units. 2009
- Andreas Sumper. Dynamic performance of fixed speed wind turbine generating systems during system fault events. 2008
- Daniel Montesinos. Modeling and control of electrical drives. 2008

Ongoing

- Mònica Aragüés. Control and operation of offshore wind power plants.
- Eduardo Prieto. Advanced control of renewable power systems.
- Agustí Egea. Multiterminal HVDC transmission systems for offshore wind.

Selected publications

Wind turbine technology

Lluis Trilla, Oriol Gomis-Bellmunt, Adria Junyent-Ferre, Montserrat Mata, Javier Sanchez, Antoni Sudria-Andreu, Modeling and validation of DFIG 3 MW wind turbine using field test data of balanced and unbalanced voltage sags, IEEE Transactions on Sustainable Energy, Vol 2, Num 4, pag 509 - 519 , 2011

Alba Colet-Subirachs, Oriol Gomis-Bellmunt, Daniel Clos-Costa, Guillermo Martin-Segura, Adria Junyent Ferre, Laia Ferrer Marti, Electromechanical Modelling and Control of a micro-wind generation system for isolated low power DC micro grids, EPE Journal, Vol 20, Num 2, pag 42-48, 2010

Adria Junyent-Ferre, Oriol Gomis-Bellmunt, Andreas Sumper, Marc Sala and Montserrat Mata, Modeling and Control of the Doubly Fed Induction Generator Wind Turbine, Simulation Modelling Practice and Theory, Vol 18, Num 9, pag 1365-1381, 2010

Oriol Gomis-Bellmunt, Adria Junyent-Ferre, Andreas Sumper and Joan Bergas-Jane, Ride-through control of a doubly-fed induction generator under unbalanced voltage sags, IEEE Transactions on Energy Conversion, Vol 23, Num 4, pag 1036-1045, 2008

Andreas Sumper, Oriol Gomis-Bellmunt, Antoni Sudria-Andreu, Roberto Villafafila-Robles and Joan Rull-Duran, Response of Fixed Speed Wind Turbines to System Frequency Disturbances, IEEE Transactions on Power Systems, Vol 24, Num 1, pag 181-192, 2009

Adria Junyent-Ferre, Eduardo Prieto-Araujo, Oriol Gomis-Bellmunt , Fernando Bianchi. Voltage sag ridethrough of PMSG wind turbines using droop control stabilization in EPE'11 ECCE Europe 14th European Conference on Power Electronics and Drives Birmingham, United Kingdom 2011

Grid integration of wind power

Francisco Diaz-Gonzalez, Andreas Sumper, Oriol Gomis-Bellmunt, Roberto Villafafila-Robles, A review of energy storage technologies for wind power applications, Renewable and Sustainable Energy Reviews, Vol 16, pag 2154-2171, 2012

Marcela Martinez-Rojas, Andreas Sumper, Oriol Gomis-Bellmunt, Antoni Sudria-Andreu, Reactive Power Dispatch in Wind Farms using Particle Swarm Optimization Technique and Feasible Solutions Search, Applied Energy, Vol 88, Num 12, pag 4678-4686, 2011

Adrià Junyent-Ferre, O. Gomis-Bellmunt, T. Green, D. Soto-Sanchez, Current control reference calculation issues for the operation of renewable source grid interface VSCs under unbalanced voltage sags, IEEE Transactions on Power Electronics, Vol 26, Num 12, pag 3744-3753, 2011

Paola Pezzini, Oriol Gomis-Bellmunt and Antoni Sudria-Andreu, Optimization Techniques to improve Energy Efficiency in Power Systems, Renewable and Sustainable Energy Reviews, Vol 15, Num 4, pag 2028-2041 , 2011

Eduardo Valsera-Naranjo, Andreas Sumper, Oriol Gomis-Bellmunt, Adria Junyent-Ferre, Marcela Martinez-Rojas, Pitch Control System Design to Improve Frequency Response Capability of Fixed-Speed Wind Turbine Systems, European transactions on electrical power, Vol 21, Num 7, pag 1984–2006, 2011

Selected publications

Offshore wind power plants

Mikel de Prada Gil, Oriol Gomis-Bellmunt, Andreas Sumper, Joan Bergas-Jane, Analysis of a multi turbine offshore wind farm connected to a single large power converter operated with variable frequency, Energy, Vol 36, Num 5, pag 3272-3281, 2011

JL Domínguez-García, DJ Rogers, CE Ugalde-Loo, J Liang, O Gomis-Bellmunt, Effect of non-standard operating frequencies on the economic cost of offshore AC networks, Renewable Energy, Vol 44, Num , pag 267-280, 2012

Oriol Gomis-Bellmunt, Adria Junyent-Ferre, Andreas Sumper and Joan Bergas-Jane, Control of a wind farm based on synchronous generators with a central HVDC-VSC converter, IEEE Transactions on Power Systems, Vol 26, Num 3, pag 1632 - 1640 , 2011

Mikel de Prada Gil, Oriol Gomis-Bellmunt, Andreas Sumper, Joan Bergas-Jane, Analysis of a multi turbine offshore wind farm connected to a single large power converter operated with variable frequency, Energy, Vol 36, Num 5, pag 3272-3281, 2011

Oriol Gomis-Bellmunt, Adria Junyent-Ferre, Andreas Sumper and Samuel Galceran-Arellano, Maximum generation power evaluation of variable frequency offshore wind farms when connected to a single power converter, Applied Energy, Vol 87, Num , pag 3103-3109, 2010“

Transmission systems for offshore wind, multiterminal HVDC

Monica Aragues-Penalba, Agusti Egea-Alvarez, Oriol Gomis-Bellmunt, Andreas Sumper, Optimum voltage control for loss minimization in HVDC multi-terminal transmission systems for large offshore wind farms, Electric Power Systems Research, Vol 89, Num 8, pag 54-63, 2012

Jun Liang, Tianjun Jing, Oriol Gomis-Bellmunt, Janaka Ekanayake, and Nicholas Jenkins, Operation and control of multi-terminal HVDC transmission for offshore wind farms, IEEE Transactions on Power Delivery, Vol 26, Num 4, pag 2596 - 2604 , 2011

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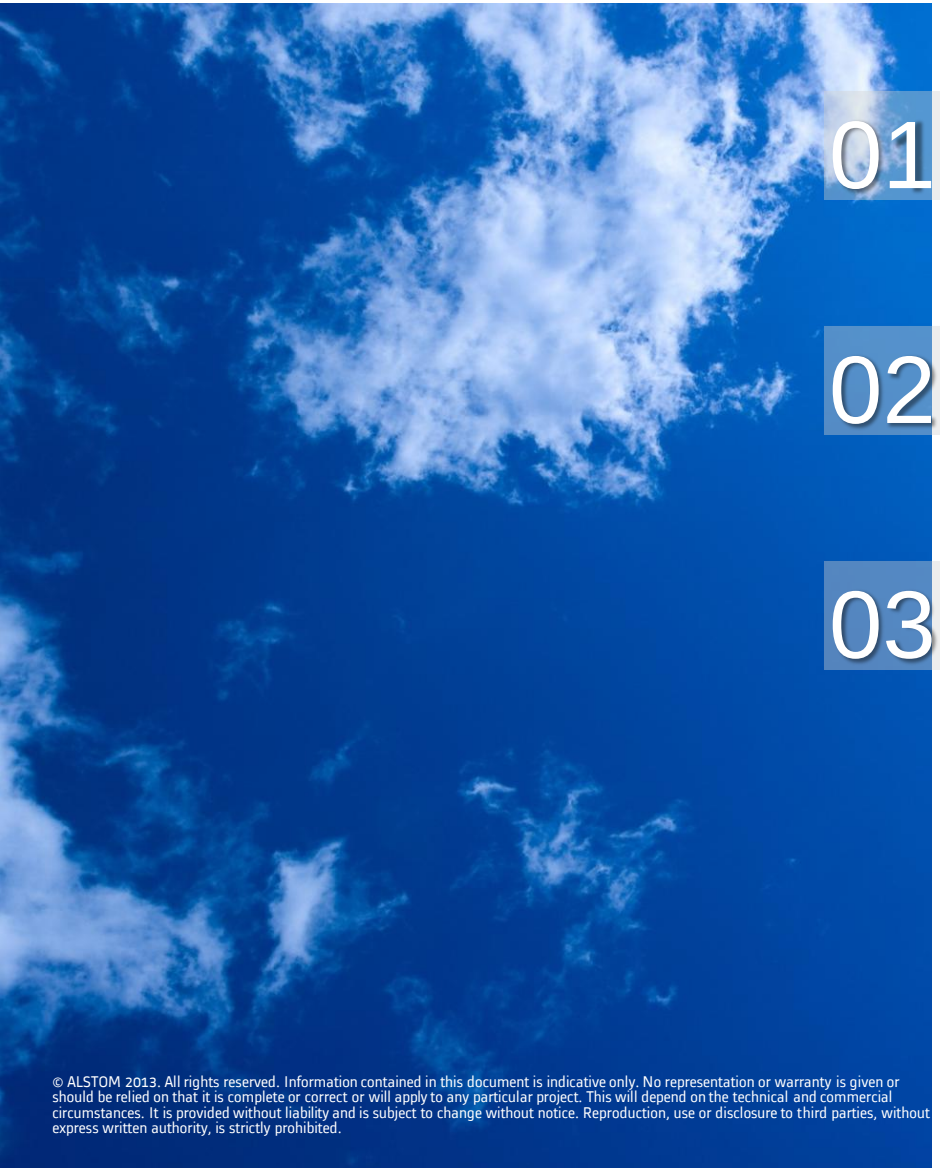
Agenda



01 Alstom Wind

02 CITCEA-UPC

03 MEDOW

ALSTOM

Multi-terminal DC grid for offshore wind

- Start date: 1 April 2013 until 31 March 2017
- FP7 funding: 3.9 M€
- EU FP7 Marie Curie Initial Training Network
  - opportunity to improve research skills
  - join established research teams
  - enhance career prospects
- 12 Early-Stage Researchers (ESR)
  - 3 years, with PhD enrolment
- 5 Experienced Researchers (ER)
  - 1 year, Postdoc

Multi-terminal DC grid for offshore wind

MEDOW
MULTI-TERMINAL DC GRID FOR OFFSHORE WIND

- Cardiff University (Co-ordinator)
- Universitat Politècnica de Catalunya
- Control Intel.ligent de l'energia
- Alstom Renovables España
- Universidade do Porto
- EFACEC Engenharia e Sistemas
- Katholieke Universiteit Leuven
- Elia System Operator
- Danmarks Tekniske Universitet
- China Electric Power Research Institute
- National Grid (Associated Partner)

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH

cinergia

ALSTOM

Universidade do Porto
FEUP Faculdade de Engenharia

efacec

KU LEUVEN

elia

DTU

国家电网
STATE GRID
中国电力科学研究院
CHINA ELECTRIC POWER RESEARCH INSTITUTE

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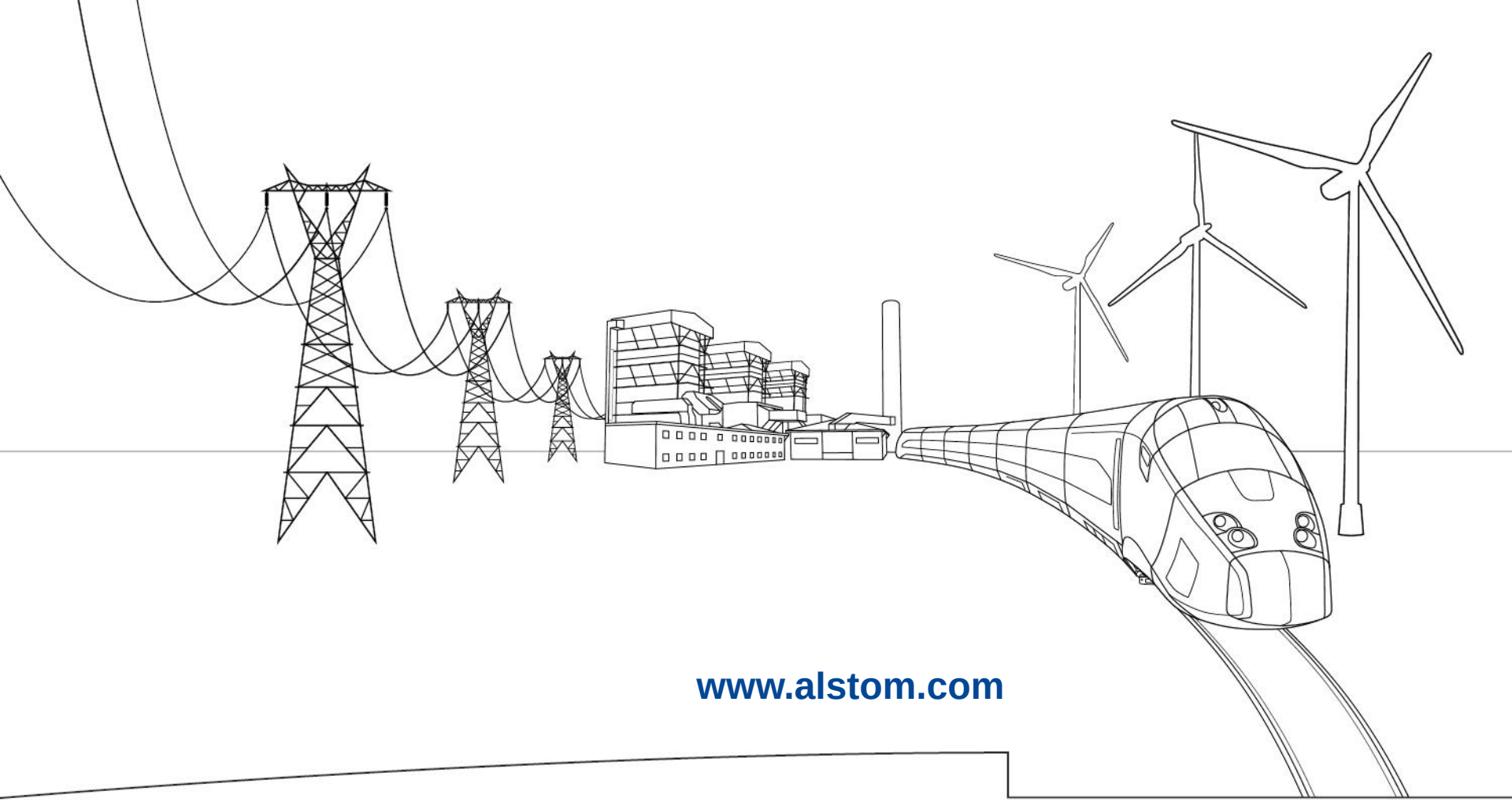
Research objectives

WP1: Connection of offshore wind power to DC grids:
O1: Design and analyse the topologies of offshore DC grids
O2: Determine steady state operation characteristics
O3: Develop dynamic control systems for offshore DC grids

WP2: Investigation of voltage source converters for DC grids:
O4: Design and compare various voltage source converters
O5: Investigate power flow control in DC grid
O6: Develop tools for analysing and simulating converter stations

WP3: Relaying protection:
O7: Analyse DC grid faults
O8: Develop DC protection algorithms and post-fault restoration schemes
O9: Investigate AC protection with DC grids

WP4: Interactive AC/DC grids:
O10: Develop simulation and experimental platforms for the integrated DC/AC system.
O11: Investigate impact between AC and DC grids
O12: Validate integrated DC/AC systems using simulation and experimental platforms



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