INNWIND.EU. Overview of project and recent results

Jensen, Peter Hjuler; Natarajan, Anand

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INNWIND.EU
OVER VIEW OF PROJECT and RECENT RESULTS

Peter Hjuler Jensen
Anand Natarajan
DTU Wind Energy
Background for the project

• The UpWind project completed in Feb 2011 produced many results on the technologies required for the next generation 10-20MW wind turbine.

• The UpWind project examined conventional 3 bladed upwind turbines.

• Moving deeper offshore, the need is to design and manufacture large wind turbines that are specifically designed to operate in deeper, farther offshore sites.

• This project INNWIND.EU will use the results from UpWind, but will go beyond the three bladed conventional wind turbine to conceptualize, Prioritize and put forth to the market the best innovations for offshore wind turbines.
Question 2008: Will upscaling continue?
UpWind organisation
Integrated project

with 15 technical and scientific work packages

<table>
<thead>
<tr>
<th>WP Number</th>
<th>Work Package</th>
<th>Integrated design and standards</th>
<th>Metrology</th>
<th>Training &amp; education</th>
<th>Innovative rotorblades</th>
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Support by:
Upwind participants

• 39 participants
  • 11 EU countries
  • 10 research institutes
  • 11 universities
  • 7 turbine & component manufacturers
  • 6 consultants & suppliers
  • 2 wind farm developers
  • 2 standardization bureaus
  • 1 branch organisation
UpWind:
Overall result from cost functions

- Levelised cost *increases* with scale

  - **Reasons:**
    - Rotor and nacelle costs scale ~$s^3$ (?)
    - Spare parts costs follow

- Cost of energy over lifetime increase more than 20% for increasing the Wind Turbine size from 5 to 20 MW so the power law for the rotor
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Overall UpWind results:
Case study: Blades – technology evolution with size

Innovations drive cost down in the past

![Technology Evolution with Blade Size](image_url)
INNWIND.EU
an EERA project
EERA Project - procedure

• Overall project description
• Coordinator and core group
• Call for expression of interest to all EERA members
• Expression of interest send to core group
• Core group makes project proposal
• Project proposal approved by EERA Wind management
Key Objectives

1. Beat the cubic law of weight (and cost) of classical up scaling and render a 10-20 MW offshore design cost-effective.

2. Develop innovative turbine concepts, performance indicators and design targets and assess the performance of components and integrated conceptual designs.

3. Development of new modeling tools capable of analyzing 20MW innovative turbine systems.

4. Integrate the design, manufacturing, installation, operation and decommissioning of support structure and rotor-nacelle assembly in order to optimize the structure and life-cycle as a whole.

5. Establish effective communications channels in the co-ordination of all project activities between the partners and dissemination of the knowledge gained.
## Proposal Time line 2013

<table>
<thead>
<tr>
<th>Event</th>
<th>Date</th>
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<tr>
<td>First core group meeting</td>
<td>Jan 24th</td>
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<tr>
<td>Preliminary budget and partner template</td>
<td>Jan 26th</td>
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<tr>
<td>Confirmation from all partners and feedback with deliverables</td>
<td>Feb 07th</td>
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<tr>
<td>Final decision on partners</td>
<td>Feb 10th</td>
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<td>First draft of stage 2 proposal</td>
<td>Feb 16th</td>
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<td>First meeting with all partners</td>
<td>Feb 21st</td>
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<td>Meet with EU consortium Rep</td>
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<td>Second budget revision</td>
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<td>Second draft of proposal</td>
<td>March 5th</td>
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<td>Second core group meeting</td>
<td>March 07th</td>
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<td>Partners comments on second draft</td>
<td>March 20th</td>
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<tr>
<td>Final budget and proposal</td>
<td>April 01st</td>
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Guidelines for the Proposal development

- A core group decides in coordination with all partners the details of the work packages.
- The underlying theme of the proposal is innovation in design.
- There is no requirement for demonstration of an innovation.
- Entities that wish to demonstrate a component or sub component should do so at their own expense.
- Each partner will commit to deliverables that can be tracked on a yearly basis. It is possible for a deliverable to be shared amongst partners.
- The proposal process must be transparent to all partners.
INNWIND.EU Project Overview and Consortium

• Innwind.eu started 1. October 2013 – long negotiation period
• 5 year project, 19.6M€ overall budget
• 27 Participating organizations
• 7 Leading wind energy industries, 19 leading Universities/Research organizations, 1 trade institution
• Main Objectives:
  – a light weight rotor having a combination of adaptive characteristics from passive built-in geometrical and structural couplings and active distributed smart sensing and control
  – an innovative, low-weight, direct drive generator
  – a standard mass-produced integrated tower and substructure that simplifies and unifies turbine structural dynamic characteristics at different water depths
Innovative large offshore wind turbine design

1. **Component level innovations** integrated into the wind turbine, virtually tested and further developed.
2. Demonstrations of Innovations include **super conducting generators**, **pseudo magnetic drives** and **smart blades**.
Work Package Overview WG1

**Conceptual Design WP1**

- **External conditions Task 1.1**
  - Database of existing wind measurements at higher atmospheres. Subtask {1.1.1}
  - Modeling the external conditions at high atmospheres subtask {1.1.2}

- **Assessment of Innovation at the Subsystems Level Task 1.2**
  - Selection of PIs and target values. Subtask {1.2.1}
  - Methodology for PIs evaluation and cost models. Subtask {1.2.2}
  - Performance evaluation of selected concepts. Subtask {1.2.3}

- **Innovation and assessment at the WI Level Task 1.3**
  - Innovative turbine concepts. Subtask {1.3.1}
  - Supportive methodologies. Subtask {1.3.2}
  - Supportive methodologies. Subtask {1.3.2}

- **Integrated Innovative Concepts combined with Advanced Controls Task 1.4**
  - Innovative measurements for control. Subtask {1.4.1}
  - Control strategies. Subtask {1.4.2}
  - Quantification of turbine performance. Subtask {1.4.3}

**WP1 In Total**

| Partners | AAU | CENER | CRES | DHI | DTU | ECN | FhG | GL-GH | GL-RS | NTUA | OLD | SWE | TUD | UoS | PMs |
|----------|-----|-------|------|-----|-----|-----|-----|-------|-------|------|-----|-----|-----|-----|-----|-----|
| 18       | 11.5| 29    | 11   | 39  | 15,5| 8   | 15  | 6     | 13,5  | 26   | 8   | 42,5| 22  |     | 265 |
INNWIND Reference Wind Turbine

• The INNWIND Reference wind turbine is a 10MW turbine designed at DTU mounted on a jacket structure designed by Rambøll at 50m water depth.

• 3 Bladed Up wind, Medium speed drive, variable speed pitch controlled turbine
## Reference Turbine Parameters

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<th>Parameter</th>
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<td>Number of blades [-]</td>
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<td>Rotor Diameter [m]</td>
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<td>Blade Length [m]</td>
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<td>Transition piece mass [Tons]</td>
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Subtask 1.3.1. Innovative turbine concepts e.g.

☑ Designs aimed at a low (reduced) tower top mass, e.g.
  ➢ Lowered bedplate mass
  ➢ Two bladed down wind machines
  ➢ Lowered rated wind speeds

☑ Turbines with innovative rotors, e.g.
  ➢ 2- bladed
  ➢ High rotor speed (to reduce torque in the drive train)

☑ More than 3 bladed (braced) rotors

☑ Multi rotor concepts on single support structure.

Subtask 1.3.2. Supportive methodologies will be developed like:

☑ methodology for support structure design assessment and WT integration (in close cooperation with WP 4, a preliminary design process based on parameterized support structure models will be implemented) and

☑ a methodology and tool for integrated system reliability analysis of mechanical, electrical and structural components for innovative wind turbine systems.
New Innovations in the First Year

Kingpin Drive – Superconducting Generator in front of the rotor

Magnetic Transmission
Passive, fixed ratio gearing

Gurney Flap

Three Legged Jackets
Summary of first year objectives of WG 2:

• To investigate new aerodynamic rotor concepts and

• To benchmark the aerodynamic, aeroelastic and structural design tools that will be used in the project by the different partners for the evaluation of the innovative designs.

• The preliminary investigation of the influence of increased Reynolds number and compressibility effects
Summary of first year achievements

- High tip speed low induction rotors
- Targets for dedicated airfoil families
- Downwind rotor concept, tower wake influence, compressibility- and high Reynolds number effects
- Comparison of the 3 bladed 10MW reference rotor to two-bladed
Summary of first year achievements WG 2

- Structural benchmark, stiffness, strength and buckling.
- 2D and 3D Aerodynamic benchmarking.
- Aero-elastic benchmarking.
Work Package 3 Objectives

- Investigate innovative wind turbine generator systems (SC and PDD) that have the potential to beat the cubic scaling law

- PI for 10 and 20 MW reference turbine for SC and PDD compared to PMDD

- PI:
  - Size, mass, cost
  - Efficiency
  - Energy yield using Weibull distribution
  - Cost of energy
3.1. Superconducting Direct Drive (DTU)
1. SCDD models (DTU, TUD)
2. Industrial demonstration of pole pair: 2G YBCO (Siemens, DTU)
3. MgB$_2$ coil demonstration (SINTEF, DTU)

3.2. Magnetic Pseudo Direct Drive (Magnomatics)
1. Analytical model and optimization of PDD (Sheffield)
2. Industrial demonstration of PDD (Magnomatics)

3.3. Power electronics (AAU)
1. PE tailored to SCDD & PDD (AAU, Hanover & StrathClyde)
2. New components and designs (Hanover, Strathclyde & AAU)

3.4. Mechanical integration in nacelle (TUD)
1. Nacelle design (Garrad Hassan)
2. Assessment of SCDD & PDD (TUD)
3. Mechanical support of SC coils (TUD)
First year objectives and achievements (D3.42)

- Superconducting Generators
  - Overview of performance indicators
  - Model of MgB2 and YBCO
  - Definition of demonstrators (MgB2 coil + YBCO pole pair)
- Pseudo Direct Drive
  - Overview of performance indicators
  - Analytical optimization methods
  - Definition of industrial demonstrator
- Power Electronics
  - Overview of converters suitable for SC and PDD
  - Initial performance indicators (efficiency, THD)
- Mechanical integration
  - Nacelle concept defined
Integrated Design of Super Conducting Generator

- SC design 311
  SC properties
  Gen model & sizing
- 2G demo 312
  Demo & PI’s
- MgB₂ demo 313
  Wire & Coil
- Ref. Turbine (1)
  Speed + Torque
- Wind dist. (1)
  Energy prod.
- Blade design (2)
  Nacelle loads
- Nacelle integra. 34
  Kin-pin design
  Int. & Loads
- Foundation (4&1)
  Nacelle weight
  Cost of weight?
- Power electronics 32
  Electrical gen. model
  Low freq. & segment Faults
- Integrated design (1)
  PI’s, cost of capacity & cost of energy

Support by:

[European Flag]
Direct drive trains

Pseudo direct drive (Magnomatics)

10 MW superconducting (DTU)
**Innovations necessary on details of structures**

- Proof of concept in designs
- Scaled tests of innovative components

- Proof of designs in prototypes
- Real-scale tests of innovative components

- Large scale application on a cost-effective level (30% lower LoCE than 2012) and for deep water (40-50m) and large turbines (>6MW)

**Innovation: Innwind**
- Innovative joints and pipes (welded and hybrid)
- Soil-structure interaction
- Load mitigation
- Novel foundations

**Innovation: Innwind**
- Evaluation through implementation into a reference jacket
- Scaled testing of new materials and foundations

**Innovation: Innwind**
- Transfer of results into upcoming prototypes of innovative jackets
- Definition of real-scale tests of novel foundations and materials
**WG 2 TECHNOLOGY ROADMAP**

**FLOATING SUPPORT STRUCTURES**

<table>
<thead>
<tr>
<th>Year</th>
<th>Component development</th>
<th>Subsystem development</th>
<th>System development</th>
<th>Commercial application</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>Design methods and standards, incl. designs tools</td>
<td>Wave tank tests, Tool and model validations</td>
<td>Prototypes of innovative designs</td>
<td>Large scale application on a cost-effective level (30% lower LoCE than 2012) and large turbines (&gt;6 MW)</td>
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<td>2016</td>
<td>Concept development, Control strategies for FWT</td>
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<td>2020</td>
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<td>2024</td>
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<td>2028</td>
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</tbody>
</table>

**Innwind:**
- Definition of design methods and standards, incl. designs tools
- Derivation of scaled test procedures
- Development of novel floating concepts
- Tests for method and tool validation
- Evaluation of developed floater concepts and derivation of optimal solution
- Transfer of floater design into a prototype development through possible follow up projects and/or through transfer of results into industry
First Project Leaflet

Project overview

The INNWIND.EU project is about innovative wind turbine design.

- It will:
  - Investigate and demonstrate new designs for 10-20 MW offshore wind turbines and their components.
  - Develop methodologies for assessing innovative sub-system and turbine system designs.

Introduction

Commercial offshore wind turbines are, currently, predominantly bottom fixed, mainly through monopile, tripod or gravity based sub-structures in waters up to 40 metres deep.

Moving into waters 50 metres deep or more opens huge opportunities for offshore wind power generation and is an important step in meeting Europe’s offshore wind energy targets. Ensuring this innovative technology’s reliability and cost-effectiveness requires new alternatives to the conventional design of wind turbine components.

A previous EU-funded project, UPWIND (www.upwind.eu), demonstrated that the development of large wind turbines (10 MW) is technically feasible but not yet cost-effective. To develop offshore wind farms in deep waters and further from shore, it is more cost-efficient to install turbines with a high rated capacity, 10 MW or more.

INNWIND.EU will build on the UPWIND project to increase cost-effectiveness of deep offshore wind farms by investigating and demonstrating new technologies.

The project in more detail

INNWIND.EU will investigate and demonstrate innovative designs for large wind turbines of rated capacities between 10 MW and 20 MW and their key components.

The project will also develop methodologies for assessing innovative designs at the turbine and sub-system levels.

The Integrated wind turbine concept will be supported by innovations and demonstrations of the key components of the 20 MW wind turbine.

Lightweight direct drive generators

- Superconducting Direct Drive and Magnetic Pseudo Direct Drive (PDD) generators can offer high power density and, thereby, more light weight and compact machines compared to conventional direct drive generators.
- Key performance indicators such as size, weight, efficiency and cost will guide the development of a 10-20 MW offshore turbine by striving for decreasing the cost of energy. Demonstrations of downscaled superconducting poles and a PDD generator are also part of the project.

Lightweight rotor

- with a combination of adaptive characteristics from passive built-in geometrical and structural couplings and active distributed smart sensing and control.

Integrated design

- Innovative sub-structures with modular construction for mass production;
- Advanced controls for load mitigation;
- Water depths of 50 m and beyond.

Standard mass-produced integrated tower and substructure

- Simplifying and unifying turbine structural dynamic characteristics at different water depths.

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UPWIND

- 5 MW reference Wind Turbine (WT) design
- Upscaling challenges and barriers identified
- New modelling and design tools for large WT

INNWIND

- 10 MW reference WT, 10-20 MW offshore WT designs
- Investigating innovative concepts for WT’s and key component technologies
- Application of UpWind modeling tools on components and WT
- Explore synergies at component and WT level

Components

- Modular blades, 1st generation active flow control on small scale adaptive blade
- Conventional Drive train optimization (Radial and transverse flux permanent magnet - RFP, TFPM)
- Monopile optimisation and jacket concept evaluation for deep sea

- Advanced active/passive flow control and new structural concepts. Validation on 2.5 MW adaptive rotor
- Superconducting and Magnetic Pseudo Direct Drive Generators validated through prototypes
- Steel and hybrid-type jacket support structures design, towers design for 10 MW horizontal and vertical axis wind turbines

Support by:
INNOVATIVE WIND CONVERSION SYSTEMS (10-20MW) FOR OFFSHORE APPLICATIONS

The proposed project is an ambitious successor for the UpWind project, where the vision of a 20MW wind turbine was put forth with specific technology advances that are required to make it happen. This project builds on the results from the UpWind project and will further utilize various national projects in different European countries to accelerate the development of innovations that help realize the 20MW wind turbine. DTU is the coordinator of this large project of 5 years duration and with a total of 27 European partners.

The overall objectives of the INNWIND EU project are the high performance innovative design of a beyond-state-of-the-art 10-20MW offshore wind turbine and hardware demonstrators of some of the critical components.

The progress beyond the state of the art is envisaged as an integrated wind turbine concept with:

- a lightweight rotor having a combination of adaptive characteristics from passive built-in geometrical and structural couplings and active distributed smart sensing and control
- an innovative, low-weight, direct drive generator
- a standard mass-produced integrated tower and substructure that simplifies and unifies turbine structural dynamic characteristics at different water depths

Support by: