IRPWind

# Integrated Research Programme on Wind Energy

Project acronym: IRPWIND
Grant agreement nº 609795
Collaborative project
Start date: 01st March 2014
Duration: 4 years

# Title: Catalogue of Facilities Available

# Work Package 3 - Deliverable number 3.1

Lead Beneficiary: CENER
Delivery date: 17 March 2015
Dissemination level: PU

The research leading to these results has received funding from the European Union Seventh Framework Programme under the agreement GA-2013-609795.

# Joint Programme on Wind Energy
# Research Facilities Catalogue

**EERA**
**EUROPEAN ENERGY RESEARCH ALLIANCE**
*Joint Programme on Wind Energy*
*RI Catalogue*


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February 27th, 2015

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| **Title: Research Facilities Catalogue**<br>**EERA IRP on Wind Energy – WP3**<br>**Authors: Pablo Ayesa / Félix Avia /Cristina San Bruno**<br><br>**Abstract (max. 2000 char.): The present contain the characteristics of the facilities for wind energy research existing at the present time in the EERA Wind JP partners.** | **Publication date March 2015** |

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# Summary

The IRPWind Work Package 3 (WP3) “Infrastructures” has the general objective of promoting alignment plus focusing of national research activities through joint experiments carried out in European research facilities and the effective joint use of European research facilities.

WP3 has the general objective of:

- Raising and optimizing the use of EU Research Infrastructures (RI) facilities
- Improving efficiency and synergy by sharing and networking RI
- Promoting alignment of member states (MS) research activities through joint experiments carried out in EU

The promotion will be provided through the creation of awareness about existing facilities and their specific characteristics, the application of common and transparent access procedures for experiment and facility selection and the required support both for the host and the guests. Synergy and effectiveness will be derived from networking for data and exchange of best practices.

By doing this, the joint use of European research facilities shall be carried out in a strategically focused and coordinated way, in which selected nationally operated facilities are employed to run specific high value carefully designed and chosen experiments, to ultimately support coordinated joint research nationally supported actions. This will, Europe-wide, lead to a more effective use of assets and better support of national R&D efforts that are alignment to a European strategy, as required by the SET-Plan and as outlined in the EERA-DOW.

Relevant, well focused and results oriented experiments require the use of state-of-the-art facilities, a high expertise and dedication for the planning, running and analysing of results to draw meaningful conclusions. The optimum use of the European facilities has been for long a clear objective of the European R&D Strategy.

The first step required is to give visibility to the facilities which are made available by the partners. The present document contain the characteristics of the facilities for wind energy research existing at the present time in the EERA Wind JP partners. Data has been provided for partners as to understand the nature of the facility and access offered. Contact persons have been added to help reader contact the operator.

A total of 30 members from the total 41 EERA Wind JP members have supplied information about their existing RI making a total of more than 140 installations.

# 1 Introduction

Most large research facilities have been promoted by single MS and are operated by institutes or universities also financed mainly by MS. This creates a scatter picture of available facilities in Europe which brings a lesser effective use of their capabilities and a less useful European investment effort than possible. Although they get used in collaborative projects, the most of its time is being devoted to national activities not necessarily matching the needs of Europe as a whole as pointed out by the SRA or EERA – DoW among others. This causes that they do not bring as much value as possible to European joint efforts.

The IRPWind Work Package 3 (WP3) “Infrastructures” has the general objective of promoting alignment plus focusing of national research activities through joint experiments carried out in European research facilities and the effective joint use of European research facilities.

Task of the WP3 Infrastructures are:

- Task 3.1 “Networking of RI
- Task 3.2 “Experiments selection and supported access to facilities”

First Task is the creation of Networking’s of Research Infrastructures. Sharing and join working are expected to create synergy and effectiveness or value of future results.

The first Networks should be created for the following priority research facility types:

- Research Wind Turbines for aerodynamics and loads study
- Wind Tunnels for wind energy research.
- Testing Facilities for Grid integration

The participants applicants must be EERA JP Wind Energy member having research facilities on the types selected. No financial support it is provided from the IRPWind to finance the work associated to the Networks creation.

The focus and alignment will be gained by means of:

- Creation of access protocols to selected European research facilities and definition of prioritization procedures for selecting the most urgent and relevant experiments in the European context.
- Implementation of a technical committee to select the experiments that will benefit the most national research activities and promote cooperation and alignment and to match experiment with the most appropriate European research facility.
- Funding of selected strategic joint experiments, including infrastructure use, at chosen national facilities supporting national R&D efforts

The RES directive and the SET Plan enforce a high rate of deployment of wind energy, on- and offshore for the European Union’s member states leading to a high challenge for research in the two priority areas: Integration and Offshore. Wind energy was therefore at an early stage identified as an area for a joint research programme where the key players are the national wind energy research institutes but open to and encouraging universities to participate in the activities.

A key objective of the joint programme is to address the research challenges of the European Industrial Initiative on Wind Energy in the "Wind Energy Roadmap"[1].

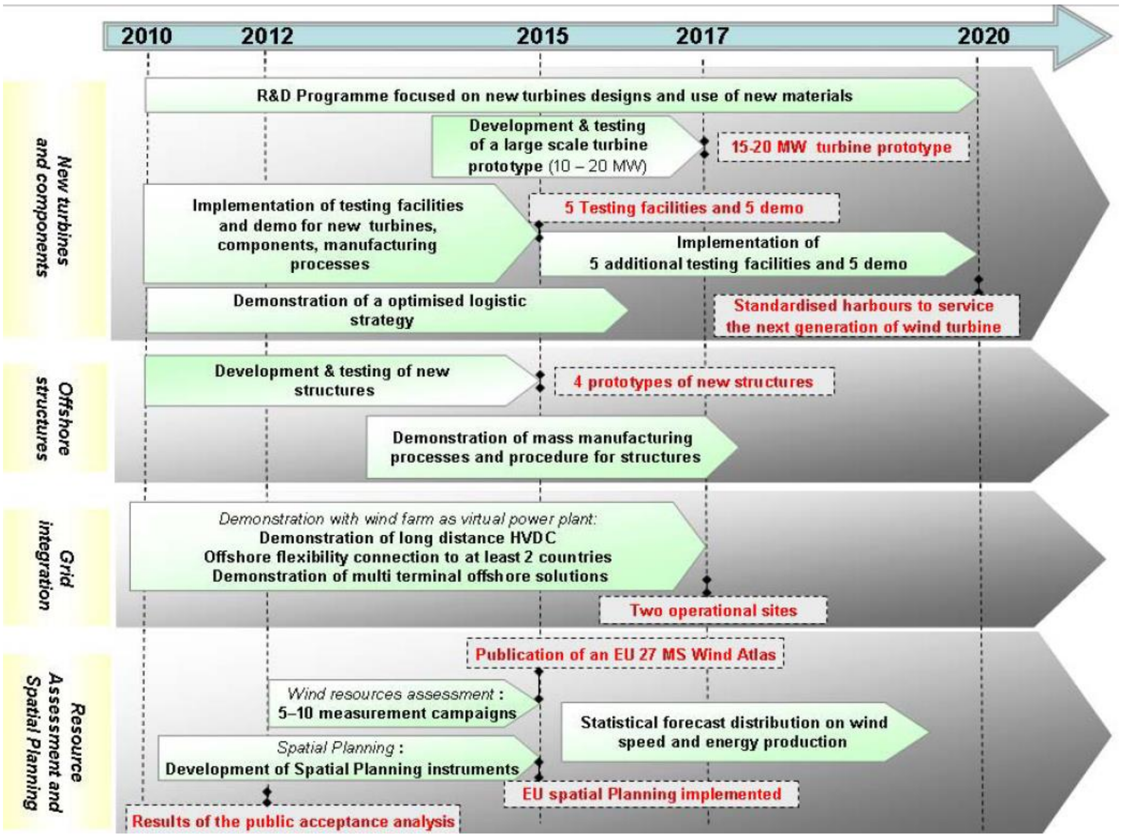



*Figure 1. European Wind Energy Technology Roadmap 2010-2020*

1SEC (2009) 1295 EU Commission Communication on Investing in the Development of Low Carbon Technologies (SET-Plan) – a Technology Roadmap. http://ec.europa.eu/energy/technology/set_plan/doc/2009_comm_investing_development_low_carbon_technologies_roadmap.pdf

The road map comprises activities during 2010-2020 on

1. New turbines and components
2. Offshore technology
3. Grid integration
4. Resource assessment and spatial planning

The European Energy Research Alliance (EERA) has as a key purpose to elevate cooperation between national research institutes to a new level, from ad-hoc participation in joint projects to collectively planning and implementing joint strategic research programmes.

The EERA Joint Programme on Wind Energy aims at accelerating the realization of the SET-plan goals and to provide added value through:

- ✓ Strategic leadership of the underpinning research
- ✓ Joint prioritisation of research tasks and infrastructure
- ✓ Alignment of European and national research efforts
- ✓ Coordination with industry, and
- ✓ Sharing of knowledge and research infrastructure.

In practical terms, the EERA Wind JP participants have agreed on organizing themselves with shared model developments, shared databases and commonly developed schemes for verification as well as sharing research facilities. The joint programme comprised six strategically important research sub-programmes.

The overall objective of the sub-programme **Wind Conditions** is to perform pre-competitive research into the fundamental understanding on how atmospheric motions affect the use of wind energy: From the design and operation of the turbines to the spatial integrated renewable energy systems, say, from dynamic inflow to regional resource assessments.

The overall objectives of the sub-programme **Aerodynamics** are to reduce the uncertainty in aero-elastic design calculations of future large wind turbines and to provide the theoretical basis for innovative steps in turbine technology for the European Industry.

The overall objective of the sub-programme on **Structures and Materials** is to reduce the uncertainty in the design of structural load carrying components as well as machinery components in order to increase cost efficiency and reliability and allow for optimization, innovations and upscaling of future wind turbines.

The overall objective of the sub-programme on **Grid Integration** is to do pre-competitive research laying a scientific foundation for cost effective wind power production and integration.

The overall objective of the sub-programme on **Offshore Windenergy** is through pre-competitive research to lay a scientific foundation for the industrial development of more cost effective offshore wind farms and enabling large scale deployment at any seas.

The overall objectives of the sub-programme on **Research Infrastructure** areto map assets and needs, develop and coordinate access to the research facilities, and contribute to the development of new joint research infrastructures and projects on testing or evaluation of results methods.

The EERA JP Wind is characterized by the four distinct dimensions which are general for solving scientific problems:

- 1)Theory and models
- 2) data acquired from well focused experiments
- 3) verification of theory and models by the data
- 4) development of new generic technology concepts

It is clear that experiments and its results are absolutely necessary for the research required by the SET-Plan objectives. It also relevant that the industry will also need testing facilities to introduce major innovations in its design which is in turn a need for the SET-Plan ambitious goals.

WP3 has two task, one on "Networking of RI" and the second on "Experiments selection and supported access to facilities". This second task contemplate the following actions:

- ✓ Mapping relevant existing facilities and creating awareness of its capabilities will increase level and effectiveness of use of EU facilities.

- ✓ Supporting well focused experiments in which MS research merges with the IRPWind to back our DoW will provide focus and alignment of the research as well as a better development of the DoW.

This document is the result of the work performed to map the existing RI inside the members of the EERA Wind JP.

In 2011 was elaborated a catalog under the umbrella of the SJP of the EERA Wind JP. Now the target was to update the existing catalog.

The process followed to get the information was to send the current data and new template to all EERA Wind JP members requesting to update the information.

From the total 41 EERA Wind JP members, 30 have supplied the requested information about their RI, making a total of more than 140 installations.

# 2 Facilities Available to EERA Wind JP

In order to facilitate to the readers to find the information about specific Research Infrastructures, the RI has been group according to the following structure:

- Wind Measurement Test Stations
- Wind Turbines Test  Sites
- Small Wind Turbines Test Sites
- Offshore Wind Test Fields
- Component Test Facilities
- Material Testing Laboratories
- Acoustic Laboratories (for Wind Energy)
- Wind Tunnels (for Wind Energy)
- Flow & Wave basins
- Electrical Test Facilities
- Applications Testing Facilities
- Other Test Facilities

Following table maps the RI of the EERA Wind JP members.

| | WMTS | WTTS | SWTTS | OWT | CTS | MTL | AL | WT | F&W | ETF | ATF | OTF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BERA | | ★ | | | | | | | | | | |
| CATAPULT | ★ | | | ★ | ★ | | | | | ★ | | |
| CENER | ★ | | ★ | | ★ | ★ | | | | ★ | | |
| CIEMAT | ★ | | | | ★ | | | | | | ★ | |
| CIRCE | ★ | | ★ | | ★ | | ★ | | | ★ | ★ | |
| CMR | | | | | | | | | | | | |
| CNR-ISAC | ★ | | | ★ | | | ★ | | ★ | | | |
| CRES | ★ | ★ | | | ★ | ★ | | ★ | | | | |
| CTC | | | | | ★ | ★ | | | | | | ★ |
| DHI | | | | | | | | | ★ | | | |
| DLR | | | | | | | | | | | | |
| DTU Wind Energy | | ★ | | | ★ | | | ★ | | | | |
| ECN | | ★ | | | | | | | | | | |
| Fraunhofer IWES | ★ | | | ★ | ★ | | | | | | | |
| ForWind Bremen | | | | | | | | | | | | |
| ForWind Hannover | ★ | | | | ★ | | | ★ | | | | |
| ForWind Oldenburg | | | | | | | | ★ | | | | |
| IC3 | | | | | | | | | | | | |
| IEn | | | | | | | | | | | | |
| IFE | | ★ | | | | | | | | | | |
| IK4-IKERLAND | | | | | ★ | ★ | | | | ★ | | |
| IREC | ★ | | | | | | | | | ★ | | ★ |
| LNEG/INETI | ★ | | ★ | ★ | | | | | | | ★ | |
| Marintek | | | | ★ | | | | | ★ | | | |
| NTNU | ★ | ★ | ★ | | | | | | | | | |
| Politecnico de Milano | | | | | | | | ★ | | | | |
| SINTEF | ★ | ★ | ★ | | | ★ | | | ★ | ★ | ★ | |
| SINTEF MC | | | | | | | | | | | | |
| TECNALIA | | | | | | | | | | ★ | | |
| Technical Univ. of Delft | | | | | | | | ★ | | | | |
| Tubitac | | | | | | | | | | ★ | | |
| Univ. of Aalbourg | | | | | | | | | | | | |
| Univ. of Athens | | | | ★ | | | | ★ | | | | |
| Univ. of Bregen | | | | | | | | | | | | |
| Univ. College of Dublin | | | | | | | | | | | | |
| Univ. of Porto | | | | | | | | | | | | |
| Univ. of Strantchclyde | | | | | | | | | | ★ | | |
| University of Stuttgart | | | | | | | | | | | | |
| VTT | ★ | ★ | | | ★ | ★ | | ★ | | | | |
| WMC | ★ | ★ | | | | | | | | | | |

# 3 Wind Measurement Test Stations (WMTS)

Wind Measurement Test Stations (WMTS) are required for a large number of reasons. To verify wind models as well as for verification of prediction models, etc …

***ISAC - CNR research area (Italy)***

Fourteen EERA Wind members from eight European countries have supplied information about their facilities related to WMTS at onshore and offshore sites

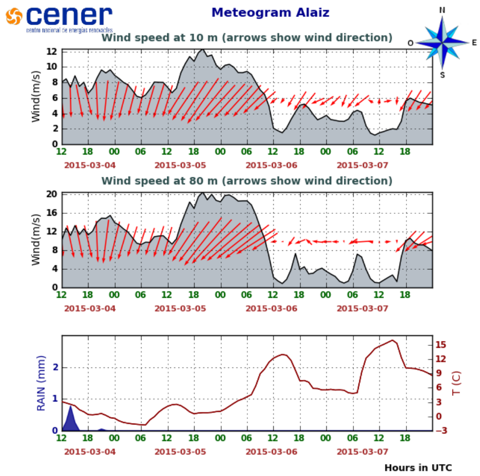
| *Member* | *Country* |
|---|---|
| *VTT (Technical Research Centre of Finland)* | *Finland* |
| *ForWind (Centre for Wind Energy Research)*<br>*Fraunhofer IWES (Wind Energy and Energy System Technology)* | *Germany* |
| *CRES (Centre for Renewable Energy Sources)* | *Greece* |
| *CNR (Consiglio Nazionale delle Ricerche)* | *Italy* |
| *NTNU (Norwegian University of Science and Technology)*<br>*SINTEF* | *Norway* |
| *LNEG (National Laboratory for Energy and Geology)* | *Portugal* |
| *CENER (National Renewable Energy Centre)*<br>*CEDER-CIEMAT (Centro Investigaciones Energéticas, Medioambientales y Tecnológicas)*<br>*CIRCE (Research Centre for Energy Resources and Consumption)*<br>*IC3 (Climate Forecasting Unit)*<br>*IREC (Catalonia Institute for Energy Research)* | *Spain* |
| *3.12 ORE CATAPULT* | *United Kingdom* |

More than thirty facilities were identified. In the following chapter it is presented information of these RI:

- CENER: The Experimental Wind Farm at Alaiz
- CIEMAT: CEDER Test Station
- CIRCE
- CNR:
  - Lamezia Terme
  - Lecce
  - Rome 1, Tor Vergata
  - Rome 2, Castel Porziano
  - ISMAR:Buoy in the Trieste Gulf
  - Oceanographic Platform, Gulf of Venice
  - Ukrania Research Vessel
- CRES:
  - 100m mast at Lavrio,
  - Long Term Mast Array
  - Remote sensing equipment (Lidar, Sodar)
- FORWIND
  - 200 m Met mast and LiDAR Systems
- IC3
- IREC:
  - Meteorological Buoy
  - Lidar Buoy Neptune
- IWES: Fraunhofer IWES Kassel: 200 m Met Mast and Lidar Systems
- LNEG
  - Urban Wind Resource Assessment
  - Offshore Buoy
  - Offshore Satellite Data
- NTNU: Met-masts with ultrasonic anemometers at the Frøya island.
- ORE CATAPULT: Offshore Anemometry Hub
- SINTEF
  - NORCOWE and NOWITECH
  - Field Instrumentation at West-Coast of Mid-Norway
- VTT:
  - Cold Climate Test Site
  - Onshore Measurement Site
  - Mobile Lidar unit.
- WMC

## 3.1 CENER (National Renewable Energy Centre)

The Experimental Wind Farm at Alaiz




**Description and main characteristics**

The Experimental WindFarm at Alaiz (EWFA) has 4x120 meter masts in a complex terrain area partially covered by thick forests. The experimental wind farm is Class IA wind.

The farm has been provided with 4 measuring masts of 120 meters. Data at 4 heights in 12 locations is available. The windfarm has an office for R&D purposes and appropriate IT systems for data management.

EWTA has been modelled and wind tunnel tested by different European groups. Correlation data with 7 additional spots would also be available.

Mast data and equipment installation will be available for EERA common projects.

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| **Contact:** | Antonio Ugarte Olarreaga<br>Head of Wind Energy Department at CENER<br>augarte@cener.com<br>Phone: +34948252800<br>www.cener.com |

## 3.2 CEDER-CIEMAT (Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas)


**Description and main characteristics**

This facility is sited in CEDER-CIEMAT that is 200 km away from Madrid in the North East direction. This facility includes the measurements in three points.

- The first is a 30 m anemometer mast with three levels of measurements and with two levels with sonic anemometer. This mast is installed upwind the building in order to know the main wind characteristics before the building. It's sited 50 m away in the predominant wind direction
- The second is a 5 m anemometer mast sited on the building rooftop that is easy to move in order to measure in different points with a simple installation. The anemometer used is a sonic one.
- The third is a 20/40 m anemometer mast with cup anemometer and wind vane.

The maximum sampling frequency is 48Hz, but the actual data are acquired at 20 Hz in the sonic anemometer and 1 Hz for the rest.

Wind measurements.

CEDER-CIEMAT has a 100 m anemometer mast with five levels to measure the wind. Each level is ready to measure wind speed and wind direction. The heights of these levels are 10, 32, 60, 80 and 100m.

| | |
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| **Contact:** | Luis Cano<br>luis.cano@ciemat.es<br>Phone: +34975281013<br>http://www.ciemat.es/CEDERportal/portal.do?TR=C&IDR=112 |

### 3.3 CIRCE - (Research Centre for Energy Resources and Consumption)


| Description and main characteristics |
| --- |
| CIRCE performs wind resource assessment and site verification through a combination of on-site measurements and wind modelling / simulation.<br>The first is made using meteorological masts, as well as by comparative analyses of LIDAR / SODAR systems and conventional anemometry. The later, by specialized software, supported by self-developed tools, such as WINDAST, a commercial software for sites characterization according to the IEC 61400-1 standard.<br>CIRCE's activities at the test stations for wind measurement consist of the following phases:<br>1. Specialized technical support in the assembly of meteorological masts and meteorological sensors.<br>2. Management of the measuring campaign: data downloading and periodic summaries.<br>3. Testing and analysis of the meteorological masts data.<br>4. Characterization of the wind at the site.<br>5. Implementation of micrositing. Verification of wind conditions and selection of the most appropriate wind turbine model according to the IEC 61400-1 standard.<br>6. Simulation with CFD models (Computational Fluids Dynamics).<br>7. Estimation of the energy produced by the wind farm.<br>8. Study of the propagation of the acoustic noise and shadows generated by the wind turbines. |

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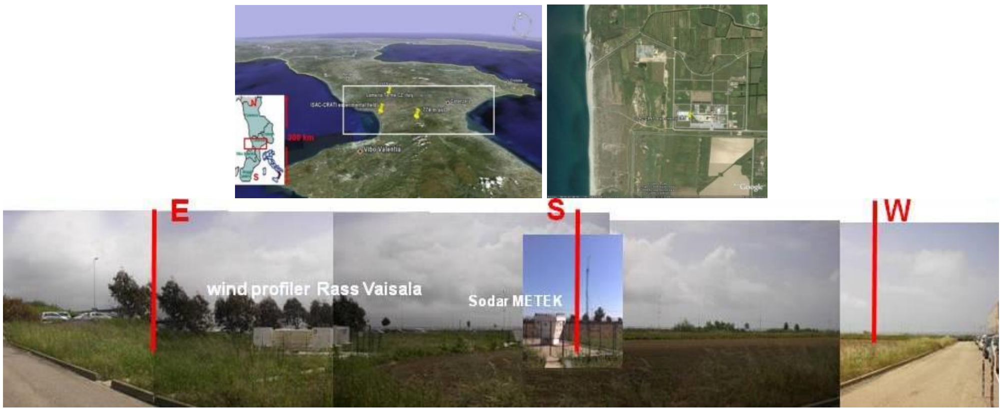
| **Contact:** | Enrique Telmo<br>Area Manager at Energy Resources Analysis (AIRE), CIRCE<br>etelmo@fcirce.es<br>Phone: +34 976 761863<br>http://fcirce.es/web/page.aspx?id=labLME |

## 3.4 CNR (Consiglio Nazionale delle Ricerche)

### LameziaTerme




**Description and main characteristics**

Coastal Experimental field located 600 m inland from the coast in the Calabrian region, a mountainous peninsula located at the southern tip of Italy about 50 km wide and 300 km long in the Central Mediterranean. The area is flat and at the end of the only west-east valley connecting the Tyrrhenian and Ionian seas. This location allows to study land sea interaction in complex terrain with convergence of sea breezes in the interior. Instruments:

Radiometric Station KIPP & ZONEN and VAISALA (pyranometer model CM11, an UV B radiometer, model UVS-B-T and a net radiometer, model CNR1 and CNR4).

Wind Lidar Zephir, model 300. Range: 10-300 m

A 10.5 m mast equipped with:

A METEK ultrasonic anemometer and a fast response Hygrometer from NOAA for Turbulent fluxes at 9.5 m

2 Temperature difference sensors (DTU Wind-DTU inhouse) DT= T5-T2 and T9.5-T2

1 Absolute temperature sensors (DTU Wind-DTU inhouse) at 9.5 m

Vaisala WTX520. (barometric pressure, humidity, precipitation, temperature, and wind speed and direction)

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| **Contact:** | Anna Maria Sempreviva<br>Head of Section at ISAC-Lamezia Terme<br>cr.calidonna@isac.cnr.it<br>Phone: 00390968209150<br>http://www.i-amica.it/i-amica/?page_id=1122&lang=en |

## Lecce.

### Description and main characteristics

The experimental facilities include an experimental field located in the Salentum peninsula (Apulia Region) in the south-east of Italy, a mobile laboratory and an urban wheatear station located in Lecce.

Equipment for the urban background site:

- Ultrasonic anemometers and fast hygrometers (turbulent fluxes).
- Fast CO2/H2O detector (Licor open path).
- Net and total radiometer, soil flux sensors.
- Thermometers and hygrometers at slow responses for air and soil.
- A complete weather station.
- Sensors for measurement of water content in soil at two levels.
- Minisodar PC-MT Sodar, developed at ISAC-CNR.
- Sodar Doppler REMTECH PA1.Additional instruments are available for studying PBL at high temporal resolution in intensive campaigns.

Additional instruments are available for studying PBL at high temporal resolution in intensive campaigns.

1. Mobile Laboratory for Environmental Research
   - Micrometeorological station with 3D ultrasonic anemometer (100 Hz) on a telescopic mast (10 meter).
2. Urban weather station
   - Urban Weather Station is operating in the old town, in Lecce

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| **Contact:** | Daniele Contini<br>Researcher, Head of Section at ISAC Lecce<br>d.contini@isac.cnr.it / +39-0832-298919 / www.le.isac.cnr.it or www.basesperimentale.le.isac.cnr.it |

## Rome 1, Tor Vergata

**Description and main characteristics**

The ISAC - CNR research area is located 100 m a.s.l. 25 km from the Tyrrhenian sea. The experimental field is equipped with ground-based remote sensing as well as in situ measurements to monitor the wind speed and temperature. Instrumentation for in situ measurements: conventional meteorological station, micrometeorological station equipped at two levels with sonic anemometers/fast response hygrometer; temperature and humidity sensors at two levels, radiation measurements (short wave and long wave radiation), temperature into the ground. Instrumentation for ground-based monitoring the wind profiles: Surface Layer mini-sodar (0-150 m), triaxial Doppler mini-sodar (0-500 m) and sodar (0-1000 m), wind profile (0-10 km)(not operative while writing). We are building a new portable sodar specially suited for monitoring winds for wind energy purposes. Instrumentation for ground-based monitoring the temperature profiles: microwave radiometer (0-600 m).

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| **Contact:** | Stefania Argentini<br>Senior Scientist at [CNR/ISAC]<br>s.argentini@isac.cnr.it / [00390649934350] / |

## Rome 2, Castel Porziano

**Description and main characteristics**

A triaxial Doppler-sodar system (investigation range 0-1000 m) is continuously operating in the Castel Porziano area.

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| **Contact:** | Angelo Viola - Senior Scientist CNR/ISAC<br>Email: A.viola@isac.cnr.it<br>Phone: 00390649934351 |

- **ISMAR:Buoy in the Trieste Gulf**

**Description and main characteristics**

PALOMA mast, 12 km offshore, bottom depth 25 m. Data: sea temperatures (0.4, 2, 15, 25 m below s.l.), air temperature, relative humidity, precipitation, solar radiation, air pressure.

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| **Contact:** | Fabio Raicich<br>Scientist at CNR ISMAR<br>fabio.raicich@isac.cnr.it / 0039 040305312 / [web url] |

- **Oceanographic Platform, Gulf of Venice**

**Description and main characteristics**

"Acqua Alta" oceanographic platform, 15 km offshore, bottom depth 16 m. Meteorological data: wind speed and direction, air temperature, humidity, solar radiation, precipitation. Oceanographic data: sea temperature, sea level, ADCP currents, waves. Surface and scuba web cams Wide band intranet connection allowing real time data transmission (see.http://www.ve.ismar.cnr.it/piattaforma/)

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| **Contact:** | Mauro Sclavo<br>Scientist at CNR-ISMAR<br>Mauro.Sclavo@ismar.cnr.it / [phone] / [web url] |

- **URANIA**

**Description and main characteristics**

URANIA Research Vessel Owed by SO.PRO.MAR. Spa and operated by CNR

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| **Contact:** | Massimiliano Di Bitetto<br>Head Unit for Operative Programming at CNR headquarter, Rome<br>massimiliano.dibitetto@cnr.it / 0039 0649932650 / [web url] |

## 3.5 CRES (Centre for Renewable Energy Sources)

The following WMTS  and equipment's are operated by CRES:

- 100m mast at Lavrio
- Long Term Mast Array
- Remote Sensing Equipment (Lidar, Sodar)

### 3.5.1 100m mast at Lavrio

**Description and main characteristics**

A 100m meteorological mast is installed on CRES Test Station, situated approximately 100km SE of Athens (37° 46' 04N, 24° 03 44E) in a complex terrain site. Site elevation is 112m and the sea coast is at 1km east. The landscape, surrounded by hills with rather gentle slopes and low vegetation (more bushes, few trees), has a roughness value of about 0.15. The annual average wind speed of the site is 7.7m/s (2009-2012) with mean turbulence intensity 11% in the range 9-11m/s.
The standard instrumentation on this lattice, guy wired mast consists of five Vector A100LK cup anemometers mounted at 12m, 32m, 54m, 76m and 100m heights, five Vector W200P wind vanes, one Thies Sonic 3D anemometer, two temperature and humidity sensors, barometer and solar radiation sensors. Additional measuring instruments can be added.
Long term measurement data are available. The mast is also used for in-situ calibration of remote sensing equipment in complex terrain conditions.

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| **Contact:** | Fragiskos Mouzakis<br>Head, Wind Energy Department, CRES<br>mouzakis@cres.gr/+30 210 6603300 / www.cres.gr |

### 3.5.2 Long Term Mast Array

**Description and main characteristics**

CRES operates a number of permanent wind potential measurement stations in Greece (Long Term Mast Array). Long Term (>10 years) detailed wind potential data are available. The data base consists of 10min statistical values of wind speed and wind direction. Temperature, humidity and barometric pressure data are measured at some of the stations. Currently the array includes 5x10m mast and 5x30m masts. All masts

are remotely monitored via GSM modems. Additional equipment for deployment of new masts is available
A data base from more than 100 masts, operated for short periods (1 to 2 years) is also available.

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| **Contact:** | Nikolaos Stefanatos<br>Head, Laboratory for Wind Turbine Testing/ CRES<br>nstefan@cres.gr/+30 210 6603300 / www.cres.gr |

### 3.5.3 Remote Sensing Equipment (Lidar, Sodar)




**Description and main characteristics**

Since the early steps of the Remote Sensing technology, CRES acquired a SODAR (Scientec SFAS series) and two LIDARs (a ZephIR and a WindCube) and performed several commercial and research measurement campaigns, in complex terrain topographies.

Depending on the model, these units can reveal the wind profile up to 200m a.g.l. and provide highly correlated results to cup anemometers.

An autonomous power supply (~150W) is required for the continuous operation of LIDARs and SODARs in remote areas. Several solutions have been developed during the last years, combining PV panels, small WTs, generators, batteries and fuel cells, in order to realize these measurement campaigns.

CRES collaborates closely with LIDAR manufacturers to optimize their units when operating in complex terrain, as well as, to develop "corrections" algorithms for numerical models (WindSim, WaSP Engineering, etc.) in order to account for the LIDAR's wind speed bias.

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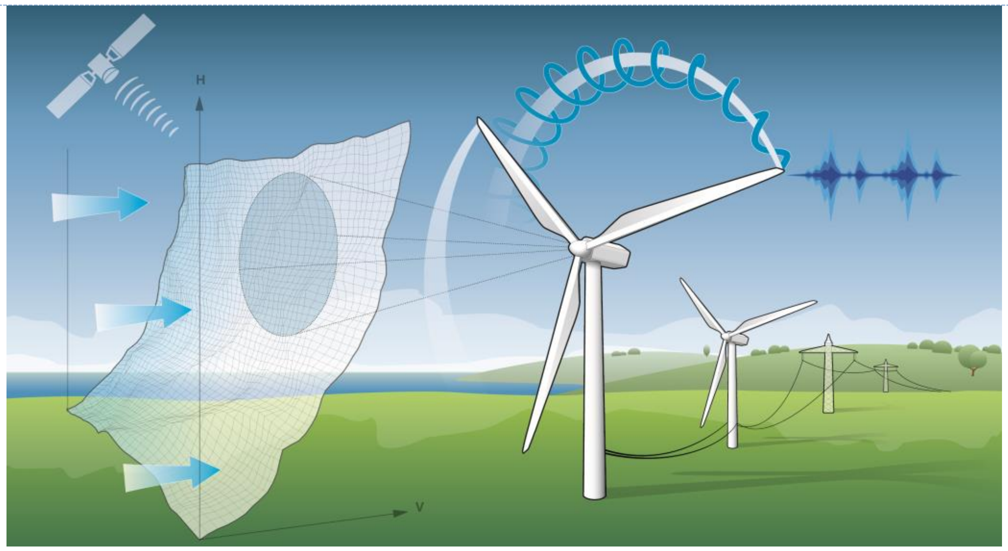
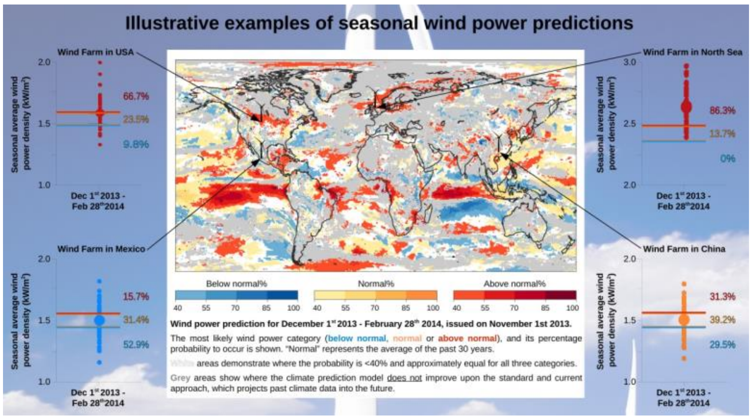
|---|---|
| **Contact:** | Dimitri Foussekis<br>Head of the Wind Testing Service, CRES<br>dfousek@cres.gr / +30 210 66033 00 / www.cres.gr |

## 3.6 ForWind (Centre for Wind Energy Research)




| Description and main characteristics | |
|---|---|
| Together with ForWind the German Aerospace Centre (DLR) will build a wind energy research platform, starting with two heavily instrumented multi MW wind turbines and several tall met masts. The platform shall be operational in 2017.<br>Next to this ForWind has access to a commercial REpower 3.4M104 research turbine (128m hub height), which is jointly operated by Deutsche WindGuard and the University of Bremen. | |
| **Contact:** | Dr. Stephan Barth<br>Managing Director ForWind<br>stephan.barth@forwind.de<br>+49 151 1578 9063 |

## 3.7 IC3 (Climate Forecasting Unit)




**Description and main characteristics**

To estimate future wind variability, current practices use the retrospective wind speed climatology, with an assumption that the past will also represent the future. Recent advances in climate predictions can provide a more informative view by modeling future wind over months to decades: they use both an analysis of the past climate system, as well as its current state at the specific time when the prediction is created, to provide a probability of different future outcomes and which will be the most likely. It has been demonstrated that climate predictions can improve upon using climatology at some spatial and temporal scales, providing a new set of climate risk management tools that can strengthen decision making.

Climate predictions represent the state-of-the-art in wind speed and power forecasting. They are based on a robust methodology: the initialisation of a large number of ensemble simulations based on one or several global climate models; post-processing using bias correction or calibration, and a full validation to assess the prediction skill over relatively long timescales in the past. This approach enables a complete understanding of the reliability and usefulness of wind predictions tailored to the energy sector, and by how much it can minimize the future wind resource uncertainty compared to current practices.

**Contact:**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## 3.8 IREC – (Catalonia Institute for Energy Research)

The following meteorological buoys are operated by IREC:

Meteorological Buoy

Lidar Buoy Neptune

### 3.8.1 Meteorological Buoy

**Description and main characteristics**

**Meteorological buoy:**

- Measurement of wind in 3m height
- Wave data
- Current data in different depths

### 3.8.2 Lidar Buoy Neptune

**Description and main characteristics**

**Lidar buoy:**

- Measurement of wind in 3m and 10-200m height at different levels
- Wave data
- Current data in different depths

| | |
|---|---|
| **Others** | Only for IREC measurements, data can be made available on request. |
| **Contact:** | Miguel Ángel Gutiérrez - Wind Energy Measurements at IREC<br>magutierrez@irec.cat / 933 562 615 |

## 3.9 Fraunhofer IWES (Wind Energy and Energy System Technology)

200 m Met mast and LiDAR Systems

| Description and main characteristics | |
|---|---|
| Fraunhofer IWES in Kassel has more than 20 years experience in measuring and assessing wind conditions. Since 2012 Fraunhofer IWES operates a 200 m high met mast in complex terrain. The mast is located at Rödeser Berg - a forested hill near Kassel, Germany. The IEC conform mast is equipped with first class cup anemometers, wind vanes, ultrasonic anemometers and further meteorological instruments - altogether about 40 sensors at 13 different heights. The mast instrumentation is complemented by a ceilometer.<br><br>Moreover Fraunhofer IWES deploys several remote sensing wind measurement LiDAR systems (Light Detection And Ranging). The LiDAR systems are equipped with autonomous power supply (diesel or fuel cell) for remote applications. The LiDAR have been applied to diverse scientific measurement campaigns in Germany. | |
| **Contact:** | Paul Kühn<br>paul.kuehn@iwes.fraunhofer.de |

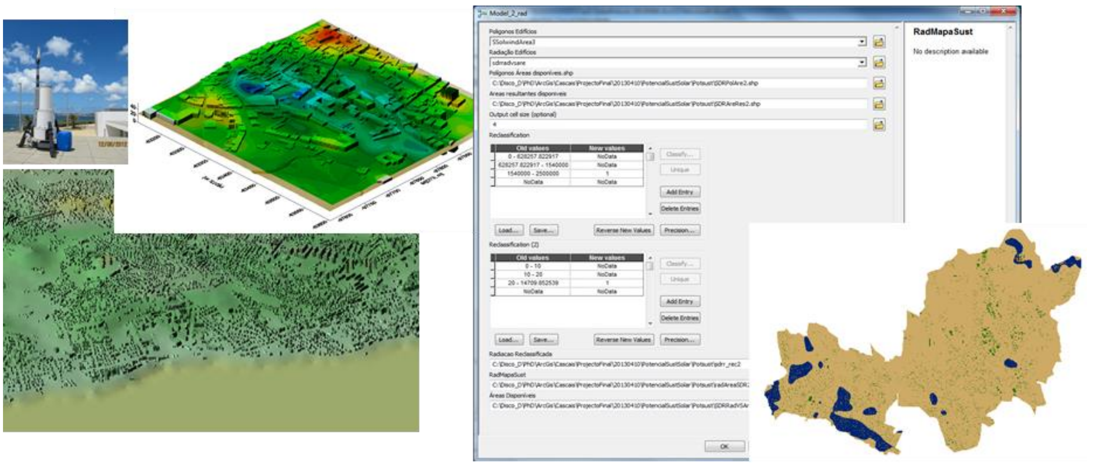
## 3.10 LNEG (National Laboratory for Energy and Geology)

**Description and main characteristics**

LNEG has monitored more than 250 anemometric stations in Portugal and in several countries around the world. These countries include Venezuela (10 station has been monitoring and 9 are in the installation phase), Mozambique (14 monitored stations), several states of Brazil (14), Republic of Serbia (2), Spain (2), Finland (10) and Poland (2). Currently, LNEG is under evaluation the installation of several anemometric stations in Bulgaria, Montenegro and Albania.

In the Portuguese territory in order to understand the wind resource variability, LNEG has in its database several stations in continuous monitoring for more than ten years.

### 3.10.1 Urban Wind Resource Assessment



**Description and main characteristics**

LNEG has worked in the previous years in the area of Wind Resource Assessment using simple and straightforward methodologies for renewable planning purposes within Smart Cities context. The developed methodologies are based on the assumption that within this context the urban fabric can be considered as a very complex terrain and simulated with models especially developed for wind energy applications. The terrain is processed with the urban geometry attributes (form, dimensions and heights) and transformed in an Urban DTM to be then introduced into a CFD developed for wind energy applications as input data to later assess the wind potential in the urban area under evaluation. The resultant resource maps are then introduced into a GIS platform along with restrictions information to the development of wind energy projects. The interactive tools are developed in order to enable the user to identify suitable areas for wind energy exploitation in urban areas.

The developed methodologies were at this date validated against experimental data – standard cup anemometry and Lidar data – installed in urban areas, with good results.

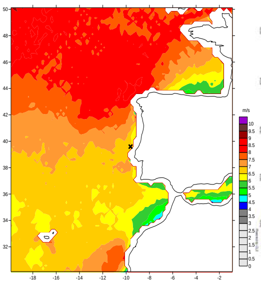
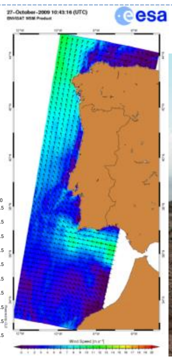
This work is a contribution for wind resource assessment in urban areas – a huge concern of the wind energy researchers in urban wind – and also for the development of renewables action plans in urban areas in a Smart cities context.

#### 3.10.2 Offshore Buoy

**Description and main characteristics**

LNEG has available a Vindicator III Lidar installed on a floating buoy in operation at open sea since July 2014. This system is located in front of Viana do Castelo (≈17 km) near the WindFloat platform ($\approx \mathbf{35\ km}$) in the nearby Viana do Castelo region. The system monitors the vertical wind profile from the sea surface up to 200m a.s.l. and it is also capable to monitor the significant wave height and currents. This system was installed in summer 2014 and since them it continues operating continuously to the present date. The main objective for use this floating buoy is the evaluation of the wind resource for the installation of the first offshore floating wind park.

### 3.10.3 <u>Offshore Satellite Data</u>

**Description and main characteristics**

LNEG has available a ZephIR/Lidar system and an anemometric mast almost in a "quasi" offshore environment, installed in the Berlengas Island, a small rocky island dominated by low roughness, located about 15 km from the Portuguese west coast line near Peniche region (10 km). This area is one of the best offshore areas in Portugal for renewable offshore wind power purposes. The ZephIR/Lidar is able to infer the evolution and behaviour of the vertical wind profile at 5 different heights from 20m to 200m a.g.l.. Regarding the meteorological mast, this able to evaluate the wind flow, temperature, humidity and mean sea surface pressure at levels, 10m and 20m a.g.l. permitting the computation of thermal fluxes and orographic turbulence in the island. LNEG also provides the processing and the assessment of long-term offshore wind satellite data collected from scatterometer (e.g. ASCAT) and SAR instrumentation satellites.  LNEG is also one of the European Laboratories with capabilities to process SAR and ASCAT raw data for wind offshore purposes in the ambit of the sentinel data provided by the Copernicus Program launched by the European Commission.

| | |
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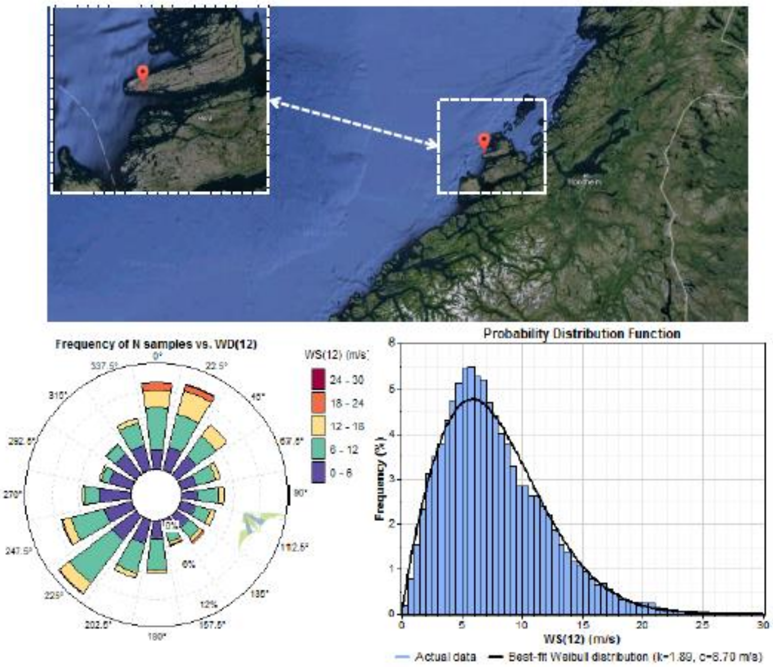
| **Contact:** | Ana Estanqueiro<br>ana.estanqueiro@lneg.pt<br>Phone: +351 210 924 773 Ext.:4773<br>Fax: +351 217 166 966 |

## 3.11 NTNU (Norwegian University of Science and Technology)




| Description and main characteristics |
|---|
| Met-masts with ultrasonic anemometers at the Frøya island. For a significant sector the incoming wind is considered as "offshore wind". 2 masts are 100m high, and 1 mast is 45m. Instrumentation: about 20 Windobserver Gill ultrasonic anamometers, one Leosphere Windcube v2, and one ZepIR 300 Lidar. |

| | |
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| **Contact:** | Lars Sætran<br>Professor at Department of Energy and Process Engineering, NTNU<br>lars.satran@ntnu.no / +47 73593716 / http://www.ntnu.edu/ept |

### 3.12 ORE CATAPULT: Offshore Anemometry Hub

**Description and main characteristics**

ORE Catapult is the UK's national research centre for accelerating grid integration of renewable energy systems and catalysing the development and deployment of offshore wind, wave and tidal energy generation technologies.

ORE Catapult's open access offshore anemometry platform located 3nm off Blyth, Northumberland offers developers and manufacturers an excellent opportunity to compare new techniques with traditional wind measurement methods. The facility enables vital testing, calibration and verification of remote sensor technologies in order to prove reliability, data availability and performance in a remote offshore environment.

**The platform can be used to:**
Validate LiDAR technology
Trial installation and monitoring of new equipment and instrumentation
Evaluate environmental conditions
Collect wildlife data
Observe marine conditions
Conduct training
Practice operation & maintenance (O&M) procedures

| **Contact:** | ORE Catapult National Renewable Energy Centre, Offshore House, Albert Street, Blyth, Northumberland NE24 1LZ<br>Ignacio Marti T +44 (0)1670 359 555 / F+44 (0)1670 359 666<br>info@ore.catapult.org.uk / ore.catapult.org.uk |
|---|---|

## 3.13 SINTEF

### 3.13.1 (NORCOWE AND NOWITECH)



**Description and main characteristics**

EFOWI (Equipment for offshore wind infrastructure) is mobile equipment consisting of three lidars, one scintillometer and two met-ocean buoys. The equipment is in operation and has been tested by installation of two lidars, one scintillometer and one met-ocean buoy in proximity to the met-masts at Frøya. Further plans for use include measurement campaigns by a) one met-ocean buoy at Havsul in proximity to 100 m offshore met-mast (to be installed by the developer) and a lidar for scanning wind field over rotor area at the NOWERI R&D installation. The equipment is owned and operated jointly between the research partners of NORCOWE and NOWITECH.Reference Access Conditions are preliminary and negotiable. **http://www.ntnu.no/ept/lab/aero**

### 3.13.2 Field Instrumentation at West-Coast of Mid-Norway


**Description and main characteristics**

There are four met-masts at Frøya, 2x45 m + 2x100 m, owned and operated by NTNU. The Norsok-standard, which specifies the wind climate for design of offshore constructions, is based on measurements from these met-masts. The masts are currently being re-instrumented. Reference Access Conditions are preliminary and to be negotiated.

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| **Contact:** | Lars Sætran<br>Professor at Department of Energy and Process Engineering, NTNU<br>lars.satran@ntnu.no / +47 73593716 /<br>http://www.ntnu.edu/ept |

## 3.14 VTT (Technical Research Centre of Finland)

The following WMTS  and equipment's are operated by VTT:

- ✓ Cold Climate Test Site
- ✓ Onshore Measurement Site
- ✓ Mobile Lidar Unit

### 3.14.1 Cold Climate Test Site


**Description and main characteristics**

VTT has been involved in cold climate field tests at Olostunturi (Muonio, Lat. 67.5 N & 23.5 E) since 1999. Top of the test site is 510 meters above sea level. Site is owned by Tunturituuli Oy and there are five Bonus 0.6 MW turbines. Winter season is spread over six months from November to April. During winter time temperature is mostly between -5 °C and  -15 °C. Occasional temperatures can rise above +0 °C or drop below -20 °C. Mean wind speed is roughly 7 m/s and up to 15 m/s is possible. During winter season the average duration of icing conditions per month can vary between 50 – 200 hours. Multitude of installations is possible: on the ground, in 40 m tall mast, in and on wind turbines. Long term data is available: wind measurement at 40 m, air pressure, temperature and icing conditions. At the test site there is a heated shelter for staff and IT equipment, electricity, 3G data connection and also surveillance camera is available.

### 3.14.2 Onshore Measurement Site

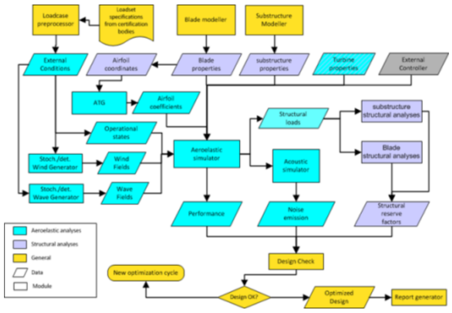
**Description and main characteristics**

VTT has had meteorological measurements in Tahkoluoto (near city of Pori) from January 2006 and still continuing. The met mast is a triangular guy-wired mast with a side length of 800 mm and 99 meter tall. Wind measurement heights are 40 m, 60 m, 80 m and 100 m. There are also other meteorological measurements and further instrumentation is possible. The mast is inside an industrial area close to the sea. The mast is surrounded by buildings, oil tanks, a power plant and a little bit farther some wind turbines. The site is prevalently flat.

### 3.14.3 Mobile Lidar Unit

| **Description and main characteristics** | | |
|---|---|---|
| With VTT Windcube LIDAR the wind profile can be remotely measured with one, compact, mobile unit. Ten different measurement altitudes can be selected from 40 meter up to 300 meters. The measurement is not disturbed by environmental conditions: the unit always provides uninterrupted and accurate data. Power requirement is reasonable, which enables deployment also to places without grid. Unit can be monitored remotely and measurement can continue for months without maintenance visits, so measurements are possible also when access to the site is limited. VTT can also offer site assessment services based on the acquired data. | | |
| **Contact:** | VTT Technical Research Centre of Finland Ltd | |
| | Tuomas Jokela | Geert-Jan Bluemink |
| | Research Scientist | Research Team Leader |
| | Tel. +358 40  8466 497 | Tel. +358 40 5500 461 |
| | tuomas.jokela@vtt.fi | geert-jan.bluemink@vtt.fi |

## 3.15 WMC (Wind Turbine Materials and Constructions)


**Description and main characteristics**

- Testing of large structures, including rotor blade testing and support structures.
- Material research
- Wind Turbine Design Software (FOCUS6).

WMC is an independent institute and carries out fundamental and applied research on materials, components and structures. WMC offers to the industry simple to complex testing in an efficient and flexible way.

WMC is partner in numerous European projects and has the larger wind turbine manufacturers among its clients. WMC contributes to national and international committees on materials and wind turbine rotor blade testing as member and convenor.

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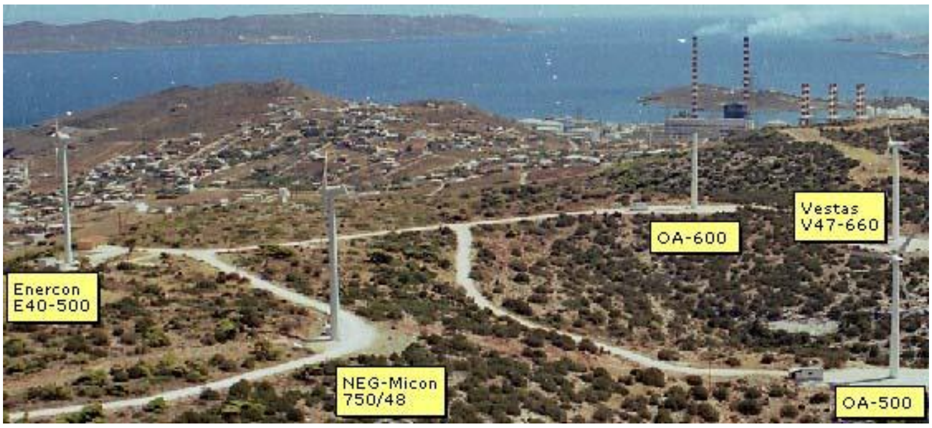
| **Contact:** | Sandra van den Outenaars. / Management Assistant<br>Kluisgat 5. 1771 MV Wieringerwerf The Netherlands<br>T: +31 227 504949 / info@wmc.eu / www.wmc.eu |

# 4 Wind Turbine Test Fields (WTTF)

Wind Turbine Test Fields (WTTF) are required to verify wind turbine models as well as for verification of wind turbine designs.

In this group are included Research Wind Turbine facilities as well as Wind Farms Test Facilities.




Five EERA Wind members from five European countries have supplied information about their facilities related to WTTF facilities.

| *Member* | *Country* |
|---|---|
| *DTU Wind* | *Denmark* |
| *CRES (Centre for Renewable Energy Sources)* | *Greece* |
| *ECN (Energy research Centre of the Netherlands)* | *The Netherlands* |
| *NTNU (Norwegian University of Science and Technology)*<br>*SINTEF* | *Norway* |
| *CENER (National Renewable Energy Centre)* | *Spain* |

In the following chapter it is presented information of the facilities related to WTTF available at the following EERA Wind members:

- CENER: The Experimental Wind Farm at Alaiz
- CRES: Wind Turbine Test Station
- DTU
  - Campus Risø, Roskilde
  - Høvsøre Test site for Large Wind Turbines at Lemvig
  - Test Centre Østerild at Thisted
- ECN: Wind Turbine Test Site Wieringermeer
- SINTEF, NTNU, IFE: VIVA – Test Centre for Wind turbines

### 4.1 CENER: Experimental Alaiz Wind Farm

**Description and main characteristics**

CENER has an experimental wind farm to install prototypes and it is suitable for certification tests in complex terrain conditions and with high wind levels.

The plant has been provided with continuous operational measurement equipment, offices for customers and meeting rooms. It has been meticulously studied, characterized and analysed to offer the best conditions for prototype

The experimental wind farm in Alaiz has 6x5MW position in a complex geography with Class IA wind. The farm has been provided with 4 measuring masts of 120 meters. Data at 4 height in 12 location is available. The windfarm has an office for R&D purposes and appropiate IT systems for data mangement.

Most likely all positions will be occupied for medium to long term prototype testing. Nevertheless data and remote sensing experiments can be of good use to EERA for model, procedures or equipment R&D.

Technical data sheet

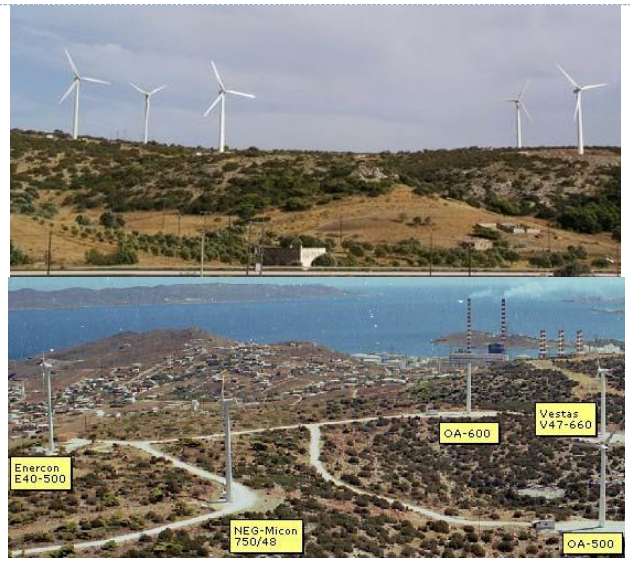
- Positions of up to 5 MWWind turbines, class I and IIA.280 m separation.
- Electrical evacuation:Sub-station: 20 kV/66 kV
- Instruments:5 sensorised masts at different heights, from 40 m to 120 m.
- Accredited tests for type certification:
- Power curve (IEC 61400-12-1).
- Energy quality (IEC 61400-21).
- Noise (IEC 61400-11).
- Mechanical loads (IEC 61400-13).

CENER has ENAC and MEASNET accreditations, required to perform the above four tests, and it is a leading member of the latter organization.

| | |
|---|---|
| **Contact:** | Antonio Ugarte Olarreaga<br>Head of Wind Energy Department at Cener<br>augarte@cener.com / +34948252800 / www.cener.com |

## 4.2 CRES (Centre for Renewable Energy Sources)

### 4.2.1 Wind Turbine Test Station




**Description and main characteristics**

CRES Test Station is situated approximately 100km SE of Athens, in a complex terrain and currently comprises 3 commercial Wind Turbines (E40-500, NEG 48/750, V47-660) and a 100m meteorological mast. Three additional Wind Turbine positions are reserved for repowering and new technology testing.

The site served continuously for various research (e.g. PROTEST, NIMO) and commercial activities, as the WTs are equipped by dedicated instrumentation for blade load measurements, gearbox monitoring, electrical power performance, power quality and condition monitoring.

The wind farm of CRES is situated in Lavrion, SE Attica, adjacent to its older wind turbine Test Station. It operates in a complex terrain site including hills up to 120m high above sea level and coastal regions. The average annual wind speed is measured 6.7m/s and the turbulence intensity approximately 12%. The energy produced from the wind turbines is fed into the interconnected 20kV electricity grid. Two meteorological masts (100m and 40m), are used to measure the reference wind conditions.

There are five wind turbines of various sizes and power control strategies. Three of these wind turbines are commercial and two are prototypes developed in Greece. The commercial wind turbines are:

- Enercon E40-500 kW gearless, synchronous, multipole, variable speed wind turbine.
- NEG Micon 750kW stall regulated, constant speed with 2 asynchronous generators wind turbine.
- Vestas V47-660 kW pitch regulated, constant speed, with one asynchronous generator wind turbine.

The two prototype wind turbines, which have been developed in Greece and manufactured by PYRKAL SA, under the tech. development of Prof. N. Athanasiadis (mechanical part) and Dr. K. Michailidis (electrical-electronic part) are:

- OA-500 kW stall regulated wind turbine, using an advanced variable speed technique (OPSC®: Opti Power Speed Control) and an active line inverter
- OA-600 kW, an otherwise identical to the above machine

| | |
|---|---|
| **Contact:** | Dimitri Foussekis<br>Head of the Wind Testing Service<br>dfousek@cres.gr / +30 210 66033 00 / www.cres.gr |

### 4.2.2 Integrated Pressure Measurements System for W/T Blades

**Description and main characteristics**

An integrated system for measurement of pressure distribution on the surface of wind turbine blades is available. The system is compact and of modular architecture and currently can support simultaneous sampling of up to 128 measurement points. Control and data acquisition units are available with capability for local/remote data storage and monitoring.

Can be used on full scale operating wind turbine blades or on blade segments tested in wind tunnels.

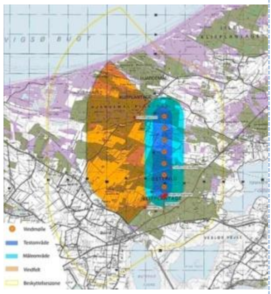
| | |
|---|---|
| **Contact:** | Nikolaos Stefanatos<br>Head, Laboratory for Wind Turbine Testing/ CRES<br>nstefan@cres.gr /+30 210 6603300 / www.cres.gr |

## 4.3 DTU Wind

**DTU Wind energy has now three wind turbine test sites in Denmark. The test sites are situated at:**

- **Campus Risø, Roskilde**
- **Høvsøre Test site for Large Wind Turbines at Lemvig**
- **Test Centre Østerild at Thisted**

**Description and main characteristics**



At Høvsøre and Østerild DTU Wind Energy has in total 8 test sites.

Test Centre Østerildwas established during 2012 and allows for erection of wind turbines of up to 210 and 250 meters respectively.

Important Facts:

- Maximum electrical power output: 16 MW
- Maximum total height of the wind turbine till blade tip in top vertical position: 250 m.
- Distance between wind turbines: 600 m.
- Distance between wind turbines and meteorology mas: 500 m.
- Average wind speed in 100 meter heights: > 8 m/s
- Terrain: flat
- Turbulence intensity: 10-14 %

| Stand | Company | Wind Turbine | Rotor (m) | Hub Height (m) | Tip Height (m) |
|---|---|---|---|---|---|
| 1 | Vestas Wind Systems A/S | V164-8MW | 164 | 140 | 222 |
| 2 | Vestas Wind Systems A/S | V126-3.3MW | 126 | 116 | 179 |
| 3 | Envision Energy | | | | |
| 4 | Siemens Wind Power GmbH | SWT-6MW | 154 | 120 | 197 |
| 5 | Siemens Wind Power GmbH | SWT-4MW | 130 | 110 | 175 |

**Contact:**

Peter Hjuler Jensen

Deputy head of Wind Energy Department

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**Description and main characteristics**

In the late 1990s was decided to establish a test centre for large wind turbines at Høvsøre, situated in Denmark on the west coast of Jutland. The main was to develop and test new wind turbine concepts and methods, gather data of tests performed on the wind turbines and document safety, operational liability, cost-effectiveness and noise/acoustic resonance. Thus safeguarding the Danish wind turbine industry's dominant position and providing them with the best possible test facilities and other facilities for basic research within meteorology and wind turbine technology. During the 10 years existence of Høvsøre an innumerable amount of tests have been performed on 19 different wind turbines and the demand for new tests and measurements on turbines at the test centre at Høvsøre will continue.

A measuring mast is standing west of each wind turbine and a meteorology mast is situated south of the test stands. Furthermore, two 165 meters high light masts have been constructed to the east of the test stands row and they mark the maximum height of the whole area.

Wind speeds, wind direction, temperatures, and atmospheric pressure are being measured on all masts, and a few of the masts provide measurements at different heights. An average wind speed of 9.3 m/s has been measured at the height of 80 meters. All data is continuously gathered, and quite a few is compared to measurements performed on the wind turbines.

| Stand | Company | Wind Turbine | Rotor (m) | Hub Height (m) | Tip Height (m) |
|---|---|---|---|---|---|
| 1 | LM Wind Power | V164-8MW | | | |
| 2 | Vestas Wind Power | V90-2 MW | 90 | 84 | 129 |
| 3 | Siemens Wind Power | SWT 4MW | 130 | 95 | 160 |
| 4 | Nordex Energy GmbH | N100-3.3MW | 100 | 75 | 125 |
| 5 | Siemens Wind Power | SWT 3 MW | 113 | 99.5 | 156 |

**Contact:**

Ole Svendgård

General Manager at VIVA

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## 4.4 ECN

### 4.4.1 Wind Turbine Test Site Wieringermeer

**Description and main characteristics**

ECN's test site is a unique facility and comprises a combination of a research wind farm, prototype test locations and a remote sensing validation facilities. The site is an onshore site near the lake IJsselmeer and consists of flat, agricultural terrain with single farm houses and rows of trees. The site has a favorable wind climate with an average wind speed of 8,3m/s at 100m height and a mean turbulence level of 8.1%; the main wind direction is South West. The site comprises six prototype locations, which enables manufacturers to test, optimize and certify prototype turbines together with ECN. Manufacturers present on the site are GE, Alstom, XMEC Darwind and Siemens where the turbines have a rated power in the range 2M to 5MW, a hub height in the range 80m to 100m and a rotor diameter in the range 100m to 120m. Supporting facilities for the prototype locations are four IEC compliant meteorological masts (a fifth is located near the research farm), grid connection and data collection. All data are gathered in the test site control centre located in the measurement pavilion. In this pavilion various offices are available for the manufacturers, maintenance and instrumentation personnel can change cloths and a meeting room is present. On a daily basis data are transferred to the ECN headquarters in Petten.

### 4.4.2 ECN Wind Turbine Test Site Wieringermeer #2

**Description and main characteristics**

The ECN Wind Turbine Test Site Wieringermeer #2 comprises a research wind farm consisting of five Nordex N80 wind turbines. The turbines have a rated power of 2.5MW, a hub height and rotor diameter of 80m. They are oriented in a line from West to East with an interturbine separation of 3.8D. In between the first two turbines from West and directly South of the line an IEC compliant meteorological mast is present with a distance of 3.5D from N5 and 2.5D from N6. This mast has wind measurements at hub height and at the lower and higher tip end (H +/- 7/10 R).

The research wind farm is crucial facility for the programme development of ECN and enables ECN to perform wind farm specific research. Innovative concepts are tested and measured data are used for model validation. Examples of the research are wind farm control strategies, power performance of wind turbines, LiDAR application, wake measurements for model validation, low cost load monitoring, innovative blade concepts, etc

| | |
|---|---|
| **Contact:** | Dr Jan Willem Wagenaar<br>j.wagenaar@ecn.nl |

### 4.5 SINTEF, NTNU, IFE: VIVA – Test Centre for Wind turbines

**Description and main characteristics**

VIVA is a test centre for wind turbines and offers access to infrastructure for test, verification and demonstration of components and full scale solutions for wind power production. The infrastructure includes prepared sites for full scale wind turbines, access to turbines for component testing and wind measurement equipment. The facilities can be used for education, research and industry purposes.

SINTEF Energy Research, Institute for Energy Technology (IFE) and the Norwegian University of Science and Technology (NTNU) are co-owners and partners sponsoring the test centre. Staff and competence from the partners will be used for scientific services and documentation when required.

VIVA operates a test station at Valsneset on the coast of Mid-Norway, prepared for full scale turbine testing. The test station is easy accessible by land and sea transportation, and has good wind condition for certification.

The test station is owned and operated by VIVA AS; **www.vivawind.no**.

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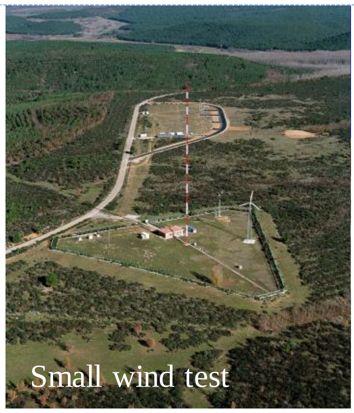
| **Contact:** | Ole Svendgård<br>General Manager at VIVA<br>ole.svendgard@vivawind.no / +47 913 83 159 / www.vivawind.no |

# 5 Small Wind Turbines Test Fields (SWTTF)

The market of small wind turbines is growing word wide  in the last years, mainly for autonomous applications but also for grid connected plants. Testing facilities for Small Wind Turbine Test Fields (SWTTF) are specifically designed for wind turbines up to 50 kW rated power. The following facilities were identified:

- CEDER-CIEMAT: Small Wind Turbine Test Plant
- CIRCE: Certification test laboratory
- LNEG: vertical and horizontal axis wind turbine

## 5.1 CEDER-CIEMAT Small Wind Turbine Test Plant




**Description and main characteristics**

<u>Small Wind Turbine Test Plant I:</u>

This facility includes, among other equipment, a 100 m meteorological tower with speed measurements and wind direction at five different heights, three small wind turbine test towers together with specific equipment for the characterization of the wind turbines, as well as specific test benches for different small wind turbine components and for various applications such as wind-powered water pumping. The main characterictics of the three points are:

Maximun power: 5 kW

Maximun height:15 m.

Average wind speed (at 15 m): 4 m/s

Batteries or grid: Both.

There are two batteries banks in this facility

The first one consists of 150 cells ($2V_{DC}$) of Lead Acid with a capacity of $C_{10}$ = 826Ah.

The second one consists of 24 cells ($2V_{DC}$) of Lead Acid with a capacity of $C_{10}$ = 425Ah.

The connection of these batteries to the grid can be made with different bi-directional converters. There are 4 converters with a maximun power of 50 kW.

Small Wind Turbine Test Plant II:

This facility that is an extension of the previous one has 5 Small Wind Turbine test positions. Tha main characteristics are:

Maximun power: 15 kW

Maximun height:22 m.

Average wind speed (at 22 m): 4.2 m/s

Batteries or AC grid: Both

There are two similar batteries banks in this facility consisting of 60 cells ($2V_{DC}$) of Lead Acid with a capacity of $C_{10}$ = 595Ah with the possibility of connection in paralell or series (240 $V_{DC}$).

The connection of these batteries to the grid can be made with different bi-directional converters. There are 2 converters with a maximun power of 20 kW.

Small Wind Turbine Test Plant III:

This facility includes 8 Small Wind Turbine test positions. Tha main characteristics are:

Maximun power: 100 kW

Maximun height: 40 m.

Average wind speed (at 40 m): 4.9 m/s

Batteries or AC grid: AC grid (only)

Small Wind Turbine Test Plant IV:

This facility includes 1 Small Wind Turbine test positions. The site is located at 45 km away from the three previous ones. Tha main characteristics are:

Maximun power: 7 kW

Maximun height: 15 m.

Average wind speed (at 15 m): 7.5 m/s

Batteries or AC grid: AC grid (only)

Small Wind Turbine Test Plant V:

This facility includes 2 Small Wind Turbine test positions. The site is located at 50 km away from the three previous ones. Tha main characteristics are:

Maximun power: 30 kW

Maximun height: 25 m.

Average wind speed (at 25 m): 7.5 m/s

Batteries or AC grid: AC grid (only)

Technological capacities Accredited laboratory in the standard ISO 17025 for the next tests:

- Power performance (in accordance with the Standard IEC 61400-12-1.)
- Duration (in accordance with the Standard IEC 61400-2.)
- Noise emission (in accordance with the Standard IEC 61400-11.)
- Safety and function (in accordance with the Standard IEC 61400-2

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| **Contact:** | Luis Cano<br>luis.cano@ciemat.es<br>Phone: +34975281013<br>http://www.ciemat.es/CEDERportal/portal.do?TR=C&IDR=112 |

## 5.2 CIRCE: Certification test laboratory

| Description and main characteristics |
| --- |
| CIRCE runs the Electrical Metrology Laboratory (LME-CIRCE), which is accredited by the Spanish National Accreditation Organization (ENAC), for conducting SWT certification tests according to international standards: IEC 61400-12-1:2005, IEC 61400-2:2012 and IEC 61400-11:2012.<br><br>Power performance tests: CIRCE carries out the wind turbine power curve verification according to the standard IEC 61400-12-1:2005. These measurements are made with specific devices and systems that bring solutions in both DC and AC configurations. Additional devices allow the verification and execution of tests remotely, by means of GSM / GPRS technologies.<br><br>Acoustic tests: The study and analysis of noise emissions is made onsite, following the international standard IEC 61400-11:2012, Measnet:2011 procedure, Renewable UK Small Wind Turbine Standard:2014(UK) and AWEA:2009(US) standards. Systems used in these tests are based in high-accuracy DAQ devices with 802.11 wireless connectivity. It allows an easy, remote and unattended data acquisition process where 24/7 monitoring is needed.<br><br>Duration tests: This test regarding the service life of the SWT is made under IEC 61400-2:2013 standard. The equipment used includes meteorological sensors and DC and AC power measurement systems.<br><br>At its facilities the LME-CIRCE has three small wind turbines ranging from 0.2 kW to 4 kW to conduct scientific tests and work on R&D. Additionally, CIRCE complements its test site with one advanced meteorological tower. This met mast includes traditional sensors such as cup anemometers or wind vanes but also incorporate some advanced sensors such as a sonic anemometer for 3D wind measurements.<br><br>In addition, CIRCE works together with the company Medano Ingenieros in a small wind turbine testing platform in the Canary Islands. At this facility, worldwide manufacturers and providers can certified the performance of their turbines under ENAC conformity. |

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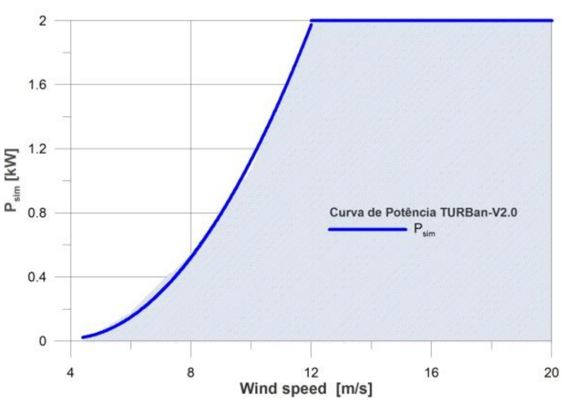
| **Contact:** | Jorge Bruna<br>Director of Electrical Tests Group at Energy Resource Analysis (AIRE), CIRCE<br>jbruna@fcirce.es /34 976 761863/ |

## 5.3 LNEG

### 5.3.1 Vertical Axis Wind Turbine

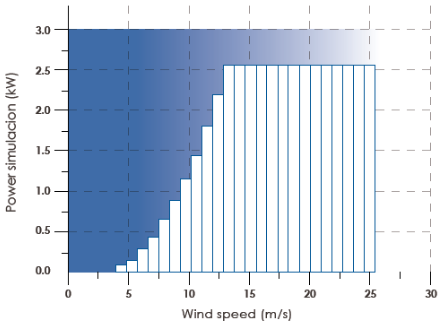



**Description and main characteristics**

The LNEG designed and produced one prototype of a vertical axis wind turbine (T.Urban V2.0 – 2.0 kW).

Currently this wind turbine is installed on the Solar XXI roof (LNEG installations) for characterization of its power curve according the standard IEC 61400-12-1.

### 5.3.2 Horizontal Axis Wind Turbine




**Description and main characteristics**

LNEG designed and produced two prototypes of horizontal axis wind turbine (T.Urban H1.8 – 1.8 kW and H2.5 – 2.5 kW). Currently, one of the prototypes has been testing on the LNEG installations. The other prototype is installed in the Portuguese Prime Minister's official residence and it has been operating and connecting to the public electric grid for about 4 years.

The T.Urban was developed to achieve a high efficiency and low production cost in order to get a profitable investment for use in urban and built-up environments.

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| Contact: | Ana Estanqueiro<br>ana.estanqueiro@lneg.pt<br>Phone: +351 210 924 773 Ext.:4773<br>Fax: +351 217 166 966 |

# 6 Offshore Wind Test Fields (OWTF)

Offshore wind research is one of the priority sectors in the last years. Offshore Wind Test Fields (OWTF) for development and demonstration of this new technology are very expensive and usually require high investments. The owners of ready existing demonstration plants are industrial companies and promotors, not member's of the EERA Wind JP. For this reason was not easy to get information of the existing OWTF, like Alpha Ventus Wind Farm, HyWind Plant, Aguacadora WindFloat Plant, etc. However, seven EERA Wind members from six European countries have supplied information about their facilities related to OWTF facilities:

| *Member* | *Country* |
|---|---|
| *Fraunhofer IWES (Wind Energy and Energy System Technology)* | *Germany* |
| *CNR (Consiglio Nazionale delle Ricerche)* | *Italy* |
| *ECN (Energy research Centre of the Netherlands)* | *The Netherlands* |
| *NTNU (Norwegian University of Science and Technology)*<br>*SINTEF* | *Norway* |
| *LNEG (National Laboratory for Energy and Geology)* | *Portugal* |
| *ORE CATAPULT* | *United Kingdom* |

- CNR ISSIA: Spar Buoy
- ECN Offshore wind measurements platforms
- Fraunhofer IWES: Offshore Free Field Weathering Locations
- LNEG: Offshore buoy, nacelle and satellite data
- NTNU
- ORE CATAPULT: Offshore Anemometry Hub
- SINTEF, NOWITECH and NORCOWE: NOWERI

## 6.1 CNR ISSIA

| **Description and main characteristics** | |
|---|---|
| The "ODAS Italia 1" (Oceanographic Data Acquisition System) spar buoy is moored at the centre of the Gulf of Genoa at 009° 06.71' E 43° 49.42' N, about 80 Km off-shore on a 1200 m bottom depth, without any shield for winds and waves. The buoy was specifically developed as a stable measuring platform: its design allows for negligible sensitivity of sea heave and height.<br>The buoy is equipped with a set of meteorological sensors. Wind measurements are collected from a 2D and a 3D sonic anemometers installed at 12 and 8 meters above the mean sea level, respectively.<br>The acquired data are available in near-real time at the receiving station ashore.<br>Taking into account the constraints related to the availability of space and power supply, the platform can host additional instrumentations that can be integrated into the onboard acquisition and control system. | |
| **Contact:** | Roberto Bozzano<br>Researcher at ISSIA<br>roberto.bozzano@cnr.it / +39.010.6475656 / www.odas.ge.issia.cnr.it |

## 6.2 ECN Offshore wind measurements platforms


### Description and main characteristics

In the framework of the Dutch research program "Far and Large Offshore Wind energy (FLOW)" RWE owns the offshore IEC compliant meteorological mast, which is operated by ECN. This mast is located about 85km West from the coastal city IJmuiden; the water depth is around 28m. The meteorological mast is 100m high and has booms at 25.5m, 57m and 86.5m pointing in 46.5 degrees, 166.5 degrees and 286.5 degrees. These booms contain cup anemometers and wind vanes; sonic anemometers are located on the booms at 86.5m. At the top there are two additional cup anemometers and a Zephir 300 LiDAR is placed inside the mast. The mean wind speed at 90m is 9.9m/s and the main wind direction is Southwest.

### Description and main characteristics

In the framework of the same FLOW program ECN operates a Leosphere WindCube V2 LiDAR on the offshore platform 'Lichteiland Goeree'. This platform is owned by 'Rijkswaterstaat' and is about 30km Southwest of Hoek van Holland. Originally this platform is meant to collect atmospheric and wave impact data. In addition it contains a lighthouse. Lately, ECN installed a LiDAR on the platform for detailed wind measurements for wind resource assessments for nearby offshore wind farm development areas.

In this same FLOW program and similar to 'Lichteiland Goeree' ECN is contracted to operate a LiDAR on the Euro platform as well. This Euro platform is a monopod about 55km West of Hoek van Holland and is situated at the beginning of the 'Eurogeul'. This 'Eurogeul' is a pathway for large ships to enter the harbour of Rotterdam. In this respect relevant data are collected at the Euro platform. The additional LiDAR data again are for the detailed wind measurements for offshore wind farm development.

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| **Contact:** | Hans Verhoef<br>verhoef@ecn.nl |

## 6.3 IWES

### 6.3.1 Offshore Free Field Weathering Locations

**Description and main characteristics**

At four test locations – Wilhelmshaven, Sylt, Helgoland and at the mouth of the River Weser – materials and components are being tested under offshore conditions in order to acquire new knowledge about the long-term stability of sensor systems. As the environmental conditions at the locations differ, so do the damage profiles. Accordingly, customized strategies for protection are being developed. Sensors are being increasingly used in offshore wind turbines for recording material fatigue data. They can detect very small changes in the material structure and report these to the system. The results are used for validation and improvement of current laboratory test methods.

-Free field weathering of specimens in real offshore environments, e.g. tests of coatings, components, new materials, sensors, if required over a longer period of years

- Free field weathering in several application zones: permanent under water zone, alternating water zone, splash water zone and atmospheric weathering
- Variable design of the specimens for atmospheric weathering up to large seizes or components possible
- Partial real time Online-Monitoring of specimens possible
- semi-annual inspection and documentation of specimen on-site

The facilities are also part of the Marinet network, which builds a synergy among Marine Renewable Energy test sites across the European Union. This also enables foreign customers to use them free of charge under conditions. Detailed information are available on the project website: **http://www.fp7-marinet.eu/**

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| **Contact:** | Bernhard Lange<br>Bernhard.Lange@iwes.fraunhofer.de<br>+49 471 14290-350 |

### 6.3.2 Wind Lidar Buoy

**Description and main characteristics**

The Fraunhofer IWES Wind LiDAR Buoy offer a great potential to assess offshore wind resources, and is a cost-effective and flexible alternative to offshore meteorological (met.) masts. It is an accurate, robust, reliable and flexible system for long-time offshore wind measurements, especially for yield assessment.

Main characteristics are:
- Measurements of the wind speeds using LiDAR technology up to 200 m above sea level
- Buoy 7.2 m high, 2.5 m Diameter, 4.7 t Weight
- Redundant and self-sufficient power supply with Batteries
- High accuracy achieved by correcting measurements for buoy movements
- Robust design assures for high availability
- two different LiDAR-systems available
- LiDAR- systems fully enclosed
- simultaneous Wave and current measurement
- adaption to wave climate and water depth
- 2nd Buoy: Available Q1/ 2015

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### 6.3.3 Multichannel Shallow Water Seismic for Geological Soil Surveys


**Description and main characteristics**

The use of a new, fully digital, multichannel seismic streamer allows high-resolution data to be acquired for drawing up detailed subsurface structural models with a high vertical coverage (100 - 200 m). This modern seismic data acquisition system is specially designed for collecting acoustic data in shallow marine environments. In combination with suitable seismic sources it is possible to gain structural information with a resolution of approximately 1 m.
Main characteristics:
- Digital multichannel seismic with using a Micro-GI-Gun as seismic source
- Especially suitable for shallow waters (<100m Water depth)
- Penetration into the soil up to 200 m

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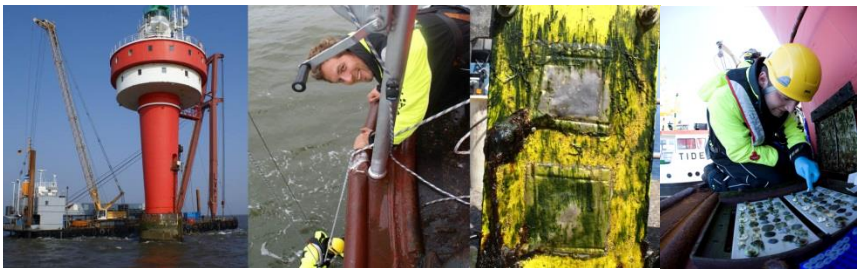
| **Contact:** | Florian Meier<br>Florian.Meier@iwes.fraunhofer.de<br>+49 421 218 - 65380 |

## 6.4 IWES: Offshore Free Field Weathering Locations



### Description and main characteristics

Materials are subjected to extreme conditions offshore: temperature fluctuations, increased UV radiation, exposure to seawater, biologically induced corrosion and mechanical loads. At four test locations – Wilhelmshaven, Sylt, Helgoland and at the mouth of the River Weser – materials and components are being tested under offshore conditions in order to acquire new knowledge about the long-term stability of sensor systems. As the environmental conditions at the locations differ, so do the damage profiles. Accordingly, customized strategies for protection are being developed. Sensors are being increasingly used in offshore wind turbines for recording material fatigue data. They can detect very small changes in the material structure and report these to the system. The results are used for validation and improvement of current laboratory test methods.

-Free field weathering of specimens in real offshore environments, e.g. tests of coatings, components, new materials, sensors, if required over a longer period of years

- Free field weathering in several application zones: permanent under water zone, alternating water zone, splash water zone and atmospheric weathering

- Variable design of the specimens for atmospheric weathering up to large seizes or components possible

- Partial real time Online-Monitoring of specimens possible

- semi-annual inspection and documentation of specimen on-site

The facilities are also part of the Marinet network, which builds a synergy among Marine Renewable Energy test sites across the European Union. This also enables foreign customers to use them free of charge under conditions. Detailed information are available on the project website: **http://www.fp7-marinet.eu/**

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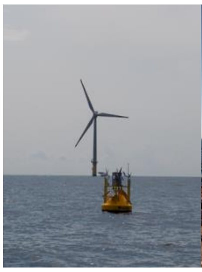
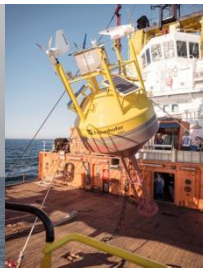
Bernhard.Lange@iwes.fraunhofer.de
+49 471 14290-350

## 6.5 IWES: Wind LiDAR Buoy

] 

### Description and main characteristics

The Fraunhofer IWES Wind LiDAR Buoy offer a great potential to assess offshore wind resources, and is a cost-effective and flexible alternative to offshore meteorological (met.) masts. It is an accurate, robust, reliable and flexible system for long-time offshore wind measurements, especially for yield assessment.

Main characteristics are:
- Measurements of the wind speeds using LiDAR technology up to 200 m above sea level
- Buoy 7.2 m high, 2.5 m Diameter, 4.7 t Weight
- Redundant and self-sufficient power supply with Batteries
- High accuracy achieved by correcting measurements for buoy movements
- Robust design assures for high availability
- two different LiDAR-systems available
- LiDAR- systems fully enclosed
- simultaneous Wave and current measurement
- adaption to wave climate and water depth
- 2nd Buoy: Available Q1/ 2015

| **Contact:** | Claudia Rudolph<br>Claudia.Rudolph@iwes.fraunhofer.de<br>+49 471 14290-351 |
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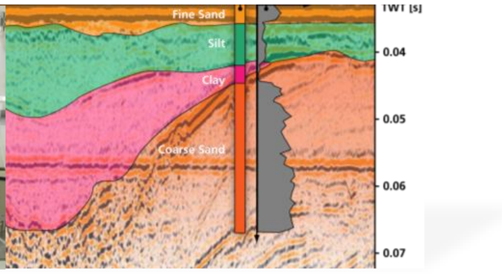
## 6.6 IWES: Multichannel shallow water seismic for geological soil surveys




### Description and main characteristics

The use of a new, fully digital, multichannel seismic streamer allows high-resolution data to be acquired for drawing up detailed subsurface structural models with a high vertical coverage (100 - 200 m). This modern seismic data acquisition system is specially designed for collecting acoustic data in shallow marine environments. In combination with suitable seismic sources it is possible to gain structural information with a resolution of approximately 1 m.

Main characteristics:
- Digital multichannel seismic with using a Micro-GI-Gun as seismic source
- Especially suitable for shallow waters (<100m Water depth)
- Penetration into the soil up to 200 m

**Contact:**

Florian Meier
Florian.Meier@iwes.fraunhofer.de
+49 421 218 - 65380

## 6.7 LNEG

### 6.7.1 AguacadoraWindFloat - Portugal

**Description and main characteristics**

A semi-submerssible type floating offshore wind turbine foundation call the WindFloat operating at rated capacity (2MW) approximately 5km offshore of Agucadoura, Portugal.

## Offshore Nacelle

**Description and main characteristics**

LNEG has available a Wind Iris Lidar, manufactured by Avent Lidar Technology, mounted on a nacelle of a Vestas turbine installed on the Windfloat platform. It is an offshore floating platform located in front of Aguçadoura (≈6 km), Póvoa de Varzim, Portugal.

This system is based on the pulsed LiDAR technology and allows to infer horizontal wind speed at distances of 80 to 440 meters upwind of the turbine, with a distance of 40 m between two measurement points

.In order to validate the wind data registered with this unit, and according IEC61400-12-1. Ed. 1, LNEG has installed a met mast onshore located at Aguçadoura sand dunes

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## 6.8 NTNU

### 6.8.1 HyWind

**Description and main characteristics**

Hywind is the world's first full-scale floating wind turbine. In 2009. Statoil invested around NOK 400 million in the construction and further development of the pilot, and in research and development related to the wind turbine concept. The public corporation Enova SF, whose aim is to promote the transition to environmentally friendly energy use and energy production in Norway, has granted NOK 59 million in support for the project.
Through the first two years of testing, the concept has been verified, and it continually exceeds preforms beyond expectations. With few operational challenges, excellent production output, and well-functioning technical systems the Hywind concept could revolutionize the future of offshore wind.
The Hywind concept is a door opener for completely new renewable energy business opportunities, unlocking huge offshore areas for clean energy production. This is a direct result of Statoil's extensive offshore oil and gas experience. Our next step will be the development of small pilot parks. We are currently assessing possible locations for a future pilot park of 3-5 turbines, Statoil is focusing on identifying sites in US and UK.

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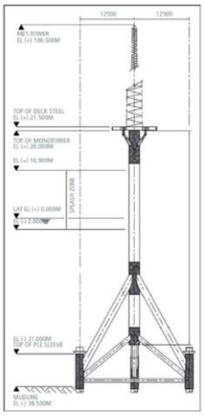
| **Contact:** | Lars Sætran<br>Professor at Department of Energy and Process Engineering, NTNU<br>lars.satran@ntnu.no / +47 73593716 / http://www.ntnu.edu/ept |

## 6.9 ORE - CATAPULT

### Description and main characteristics



ORE Catapult is the UK's national research centre for accelerating grid integration of renewable energy systems and catalysing the development and deployment of offshore wind, wave and tidal energy generation technologies.

The Offshore Anemometry Hub is installed three nautical miles off Blyth, Northumberland. It provides wind resource and environmental data to validate turbine demonstrations with the instrumentation and data management capability to be made available for future research collaborations.

| | | | | |
|---|---|---|---|---|
| **Platform features** | **Platform Height**<br>18m AMSL | **Access**<br>Conventional offshore turbine service vessel access | **Foundation Design**<br>Tripod | **Primary Power**<br>Wind |
| | **Mast Tip**<br>104m AMSL | **Deck Size**<br>$10m^2$ | **Design Verification**<br>DNV | **Back-up Power**<br>Diesel generator and PV |
| | **Main Structure**<br>Monopile | **Crane**<br>1 tonne capacity | **Design Service Life**<br>25 years | **Telemetry**<br>Fixed microwave datalink |

| | | |
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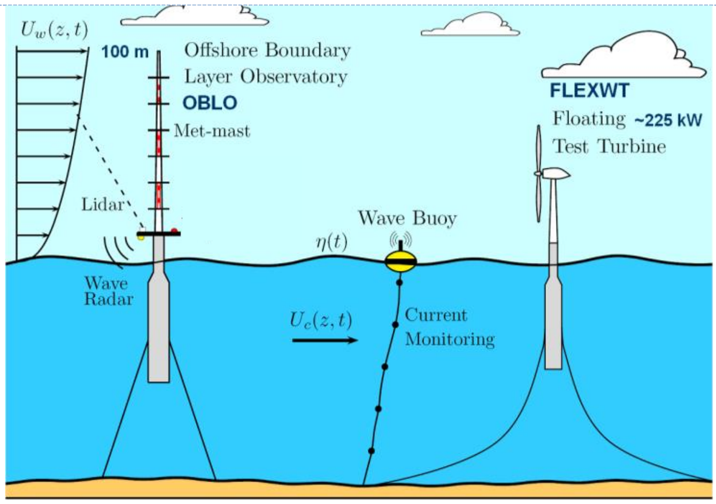
| **Wind Instrumentation** | **Wind Speed**<br>• Class 1 Anemometers, calibrated to MEASNET procedures<br>• Height of vanes and anemometers - 35m, 52m, 69m, 86m and 103m AMSL<br>• Anemometry mast compliant to IEC 61400-12<br>• LiDAR system validated to NORSEWInD criteria | **Environment**<br>• Temperature and humidity<br>• Atmospheric pressure<br>• Air quality monitoring<br>• Present weather system Data Logging<br>• Redundant system, backed up onshore & offshore |
| **Environmental Instrumentation** | • Sea State by Doppler Current Profiler<br>• Marine Mammal Acoustic Detector<br>• Bat Monitoring | • Avian RADAR<br>• Vessel RADAR with AIS<br>• Turbidity Monitoring |

**Contact:** ORE Catapult- National Renewable Energy Centre, Offshore House, Albert Street, Blyth, Northumberland NE24 1LZ/ Ignacio Marti-T +44 (0) 1670 359 555/ F+44 (0)1670 359 666/ info@ore.catapult.org.uk/ ore.catapult.org.uk

## 6.10 SINTEF, NOWITECH and NORCOWE: NOWERI




| **Description and main characteristics** | |
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NOWERI (Norwegian Offshore Wind Energy Research Infrastructure) includes OBLO (Offshore Boundary Layer Observatory) and FLEXWT (Floating Experimental Wind Turbine).

OBLO is a ~100 m tower on a slender floater complete with instrumentation for met-measurements, wave radar, oceanic environmental conditions, etc.

FLEXWT is a moderate size (~225 kW) wind turbine on a slender floater. It will be used as a) a source of data and measurements for validation of numerical models, b) a platform for experimental research, testing and demonstration of new technology and c) testing and experimentation for improved O&M schemes.

Expected to be in operation by 2015.

The equipment is owned and operated jointly between the research partners of **NORCOWE** (Norwegian Centre for Offshore Wind Energy) and **NOWITECH** (Norwegian Research Centre for Offshore Wind). Reference Access Conditions are preliminary and negotiable

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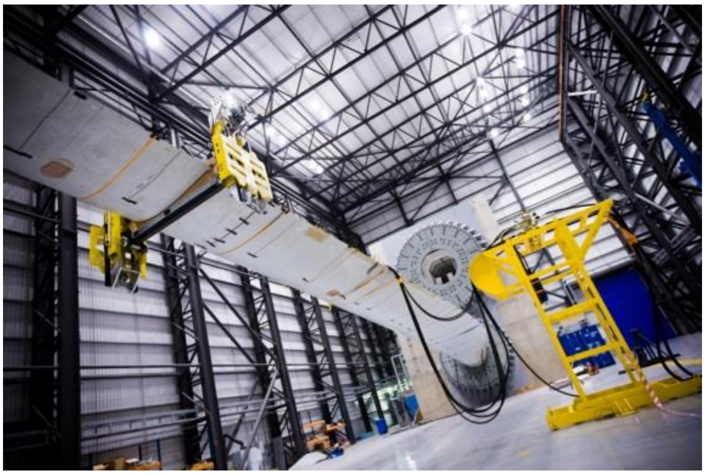
| **Contact:** | Lars Sætran<br>Professor at Department of Energy and Process Engineering<br>lars.satran@ntnu.no / +47 73593716 / http://www.ntnu.no/ept/lab/aero |

# 7 Components Test Facilities (CTF)

There are several facilities for Components Test Facilities (CTF) mainly developed for research development and to supply services for the industry.



Ten EERA Wind members from six European countries have supplied information about their facilities related to CTF:

| *Member* | *Country* |
|---|---|
| *DTU Wind* | *Denmark* |
| *VTT (Technical Research Centre of Finland)* | *Finland* |
| *ForWind (Centre for Wind Energy Research)* | *Germany* |
| *CRES (Centre for Renewable Energy Sources)* | *Greece* |
| *LNEG (National Laboratory for Energy and Geology)* | *Portugal* |
| *CENER (National Renewable Energy Centre)*<br>*CEDER-CIEMAT (Centro Investigaciones Energéticas, Medioambientales y Tecnológicas)*<br>*CIRCE (Research Centre for Energy Resources and Consumption)*<br>*IK4 -IKERLAND* | *Spain* |
| *ORE - CATAPULT* | *United Kingdom* |

In the following paragraphs it is presented information of these facilities related to CTF available:

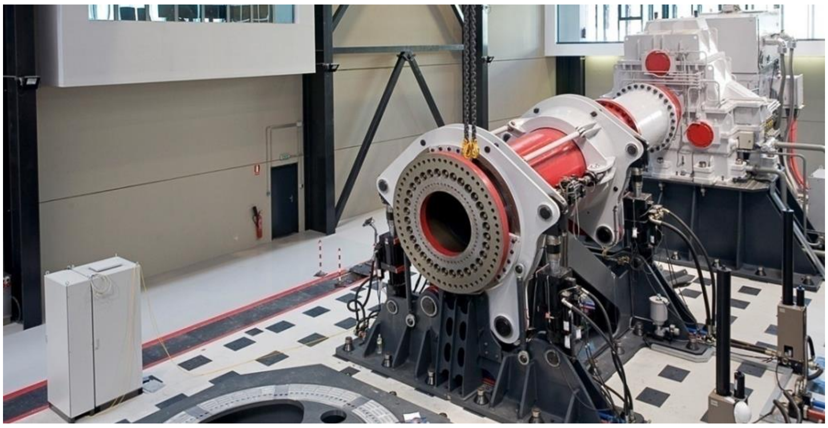
- ✓ CENER:
  - Drive Train Test Lab
  - Blade Test Lab
  - Generator Test Bench
- ✓ CEDER-CIEMAT Blade Test Bench and generator test bench
- ✓ CIRCE: Real Time Digital Simulator (RTDS)
- ✓ CRES: 25m blades Test Bench
- ✓ DTU:
  - Drive Train Test Centre
  - Blade Test Centre
- ✓ FORWIND:
  - GEOLAB
  - Test Centre Spport Structures
  - IMKT Largue BearingTesting
- ✓ IK4: Lab test scaled tower for structural health monitoring purposes
- ✓ IWES:
  - Rotor Blade Testing
  - Rotor Blade Component Testing / Material Testing
  - IWES: DYNALAB – Dynamic Nacelle Laboratory
  - Rotor Shaft Test Stand
  - Offshore Climate Chamber and Halt/Hass Tests for accelerated testing of Mechanics and Electronics
  - Test Centre Support Structures Foundation Test Pit
  - Test Centre Support Structures Span
- ✓ ORE CATAPULT:
  - Blade Test Facilities,
  - 15MW Wind Turbine Nacelle Test Facility and 3MW Tidal,
  - Turbine Nacelle Test Facility
- ✓ VTT: Expert Services Ltd test laboratory

## 7.1 CENER Component Test Lab

CENER Component Test Laboratory is located in Sangüesa, Navarra and has the following facilities:

- Drive Train Test Lab
- Blade Test Lab
- Generator Test Bench
-

### 7.1.1 Drive Train Test Lab



**Description and main characteristics**

The Drivetrain Lab comprises two test benches. The first one is a full featured 6 DoF dynamic test bench with a power of 8 MW. The second one is a 1 DoF test bench with a power of 8 MW.

The actuation system can be force and position controlled. Time series of forces and positions can be applied. The 6 DoFtestbench can be operated using the actual generator or an external generator to act as an 8MW brake.

Both test benches have been provided with automatic supervision of alarms both coming from specimen and machinery, UPS and complex acquisition and analysis of data systems.

### 7.1.2 Blade Test Lab


**Description and main characteristics**

The blade test lab has two test stands. Both can be configured to run fatigue testing and only one is able to test for extreme loads. The lab also characterizes the mechanical properties of the blade. All tests get run under IEC 61400 – 23. The maximal length to be tested is limited to 75 meters. However actuators and stands have design so that clipped tip blades of reference length of 100 m can be tested.
The lab has been provided with acquisition systems based in electrical and optical strain gauges. As relevant feature the lab has 8 resonance actuators giving it multi-axes multi-point actuation for fatigue.

### 7.1.3 Generator Test Bench


**Description and main characteristics**

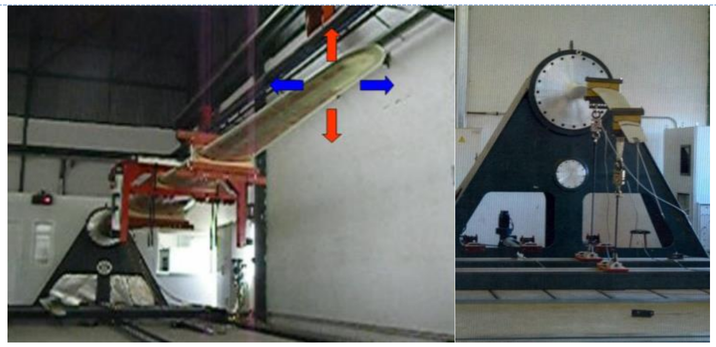
The Generator Test Bench consists of an motor of 8MW applying velocity and torque to a generator and its corresponding power converters.The motor and power converters form a close loop so that energy can be recovered. The systema can sectioned from the grid to operate in 60 Hz conditions.

The test bench is also capable of running Voltage Fault-Ride-Through.

| | |
|---|---|
| **Contact:** | Antonio Ugarte Olarreaga<br>Head of Wind Energy Department at Cener<br>augarte@cener.com / +34948252800 / www.cener.com |

## 7.2 CEDER-CIEMAT:

### 7.2.1 Blade Test Bench



**Description and main characteristics**

The blade test laboratory of CEDER-CIEMAT is prepared to perform structural tests of wind turbine blades up to 12 meters length. Full scale blade tests provide information to optimize and validate manufacturer's designs, and the completion of some of these tests is a requirement to get the complete wind turbine certification in many standards.

Tests available:

- Blade properties tests
- Static tests
- Fatigue tests
- Collapse test

TECHNICAL SPECIFICATIONS

General

*(max. values)*

Blade length: ≅11 m. (for guidance)

Blade tip deflection: 2.5 m.

Mounting plate

axis bolt diameter: 550 mm.

root diameter: 700 mm.

Properties tests

Dynamic signal analyser.

Determination of the centre of gravity, natural frequencies and structural damping factors.

Static tests

Maximum static bending moment: 445 kN·m

Electric winches: 3 available

24.7 kN x 1

24.7 kN x 2

24.7 kN x 3

Pulling method: Vertical downward direction

(optionally pulling up to ±45º from vertical direction)

Maximum pulling distance from root: 8 m.

Fatigue tests

Forced actuator 1 to 5 m. blade length (for guidance)

Maximum frequency: 1 Hz.

Maximum amplitude: ± 400 mm.

Vertical uniaxial excitation

Resonance actuator 5 to 11 m. blade length (for guidance)

Maximum frequency: ≅3 Hz.

Two axial (flap- and edge-wise) and/or torsional excitation

INSTRUMENTATION CAPABILITIES

- Automated static and fatigue pulling control system
- 82 channels for strain gauges
- 4 channels for accelerometers or force sensors
- 8 Measurement of blade airfoils displacements
- Thermography camera
- Thermo-hygrometer
- Video record for tests

### 7.2.2 Generator Test Bench

**Description and main characteristics**

The Generator Test Bench of CEDER-CIEMAT is prepared to perform electrical test in accordance with the IEC 60034 Standard. The main characteristics are:

General

*(max. values)*

| | |
|---|---|
| Power: | 100 kW |
| Rotational speed: | 3000 rpm (for small generators) |
| Torque | 20 kNm |

Available tests

Short-circuit tests.

No-load tests.

Determination of main parameters of synchronous machines.

Determination of Voltage-current curve.

Efficiency.

Thermal.

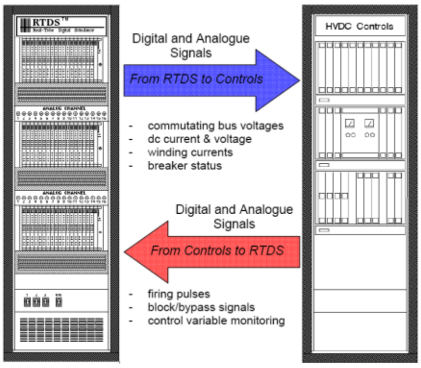
Vibrations

INSTRUMENTATION CAPABILITIES

- 3 Torque transducers
- 48 channels for measurements
- 8 channels for accelerometers
- Thermography camera
- Video record for tests

| | |
|---|---|
| **Contact:** | Luis Cano<br>luis.cano@ciemat.es<br>Phone: +34975281013<br>http://www.ciemat.es/CEDERportal/portal.do?TR=C&IDR=112 |

## 7.3 CIRCE: Real Time Digital Simulator (RTDS)




### Description and main characteristics

The RTDS is a fully digital electromagnetic transient power system simulator, and a cost-effective replacement for transient network analysers and analogue/hybrid simulators. This equipment allows testing protections and controls in real time, and is the best tool for devices and prototypes validation, since it makes it possible to verify their response against all kinds of tests and transient phenomena.

Since the simulation runs in real time, the physical protection equipment can be connected in closed-loop with the power system model. The controlled and flexible environment of the digital simulation allows protection equipment to be subjected to virtually all possible faults and operating conditions. The closedloop interaction of the protection system with the network model provides insight on both the performance of the relay scheme as well as its affect on the power system.

At the RTDS laboratory, CIRCE reproduces the real-time behaviour of complex electrical power networks according to different conditions: Steady-state / Electromechanical transients / Electromagnetic transients, and develops several types of tests and studies:

At this facility, CIRCE develops, tests and studies:

- Smart grid applications. Evaluation and selection of the optimal, cost-effective and most replicable solution for the distributed intelligence on MV and LV networks.
- Distributed generation. Wind and solar energy.
- True real time response for closed-loop testing.
- Protective devices testing - line, transformer, busbar, generator, fault location, prevention of outages or complete failure.
- Control system and algorithms testing - HVDC, SVC, FACTS... optimal voltage control, congestion management, optimal network configuration/topology.
- Integrated protection and control systems testing.
- General AC and DC system operations, behaviour and interaction.
- Interaction of various electrical installations (e.g. between two HVDC systems).
- Large scale real time simulations.
- Modelling of electricity grids and simulations.
- Testing and validating the interoperability of the solutions developed..

**Contact:**


Susana Martín
Manager at Electrical Power Systems (GISEP), CIRCE
smartin@fcirce.es /+34 876555286 /
http://www.fcirce.es/web/page.aspx?id=labrtds

## 7.4 CRES: 25m blades Test Bench


**Description and main characteristics**

The Blade Testing Service of the Laboratory for Wind Turbine Testing of CRES, operating since 1994, can accommodate blades up to 25m long. Through the use of computer-controlled hydraulic actuators Modal, Static and Fatigue full-scale tests are performed. All tests are performed following IEC 61400-23. Strains, deflections, inclinations and accelerations exhibited by the blade, imposed loading and environmental conditions are monitored during each testing to define blade's performance.

For these tests, the Blade Testing Service has a hydraulic power supply of 360 l/min capacity at 210bar driving 4 hydraulic cylinders of various capacities (±25kN – 500mm, ±100kN – 1500mm) for static and dynamic loading and 2 cylinders of 100kN, 2000mm for static loading. A 64 channel acquisition system collects data from force, displacement, strain, inclination, acceleration, temperature and humidity sensors. A 4 channel optical fibre system, along with non-destructive equipment (10-channel Acoustic Emission system, Ultrasonic thickness and flaw detection system for composite material structures, a vibration exciter and a 3D digitizer for quality control of the blade's geometry supplement the capacity of the laboratory.

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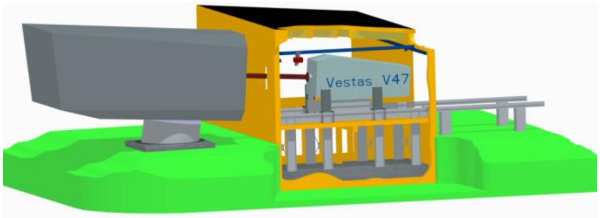
|---|---|
| **Contact:** | D. Lekou<br>Head of Blade Testing Service at CRES, Laboratory for Wind Turbine Testing<br>dlekou@cres.gr / +30 210 6603300 / www.cres.gr |

## 7.5 DTU WIND – RISO Campus

### 7.5.1 DRIVE TRAIN TEST CENTRE




| **Description and main characteristics** | |
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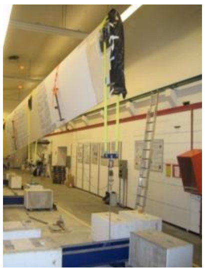
| **Contact:** | |

### 7.5.2 BLADE TEST



| **Description and main characteristics** | |
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| **Description and main characteristics** | |
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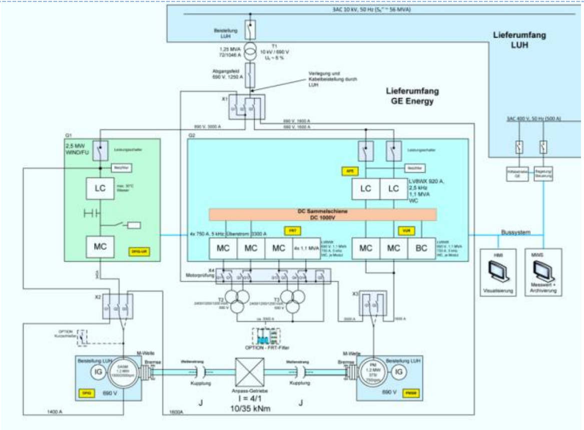
| **Contact:** | |

## 7.6 FORWIND Components Testing Laboratories:

### 7.6.1 GECOLAB




| Description and main characteristics |
|---|
| 1.2 MW test bench with permanent magnet synchronous machine coupled to a doubly-fed induction generator by gearbox. A 3 MW grid emulator will be able to simulate all important grid situations. Research focus are generator converter interactions, grid supporting strategies for wind turbines (converter control) and generator aspects (fault tolerant operation, bearing currents… ). The expected start of operation is in Summer 2015. |

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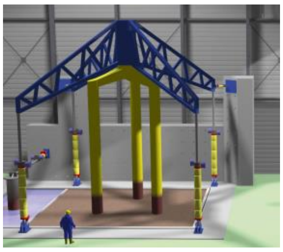
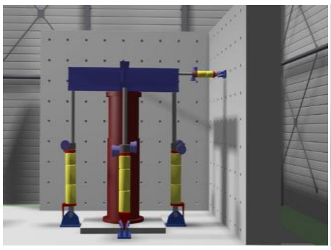
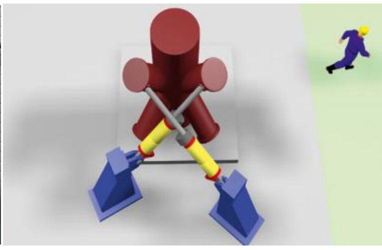
| **Contact:** | Dr. J. Steinbrink<br>Chief Engineer at Institute for Drive Systems and Power Electronics<br>Steinbrink@ial.uni-hannover.de/ +49-(0)511-762-2864 / www.ial.uni-hannover.de |

### 7.6.2 Test Centre Support Structures

**Description and main characteristics**

The Test Centre Support Structures offers a geotechnical test pit with a thick abutment wall (dimension pit: 14m x 9m x 10m) and a span (dimension: 18.5m x 9.5m [horizontal field] and 8.5m x 10m x 8m [vertical field]) for the large-scale experimental investigation of models or real support structures of offshore and onshore wind turbines. This research facility contributes to the optimization of wind turbines. Partners from industry and research are supported by an experienced team of structural engineers, process engineers, material developers and geologists.

Investigation and evaluation of foundation structures and affiliated construction methods for their offshore installation in 1:10 scale and larger can be executed. The bearing behaviour and soil -structure– interaction can be investigated by performing axial and lateral cyclic or static loading tests on model structures in the geotechnical test pit. In the span experimental investigations of structures will be executed under real multiaxial loading for determination of inspection intervals and fatigue life of critical items. Additionally, the Test Center Support Structures offers various laboratories and workshops, e.g. a Structural Health Monitoring (SHM) and a composite laboratory (also see www.tth.uni-hannover.de).

| | |
|---|---|
| **Contact:** | Prof. Dr.-Ing. habil. Raimund Rolfes<br>Prof. Dr.-Ing. Peter Schaumann<br>Test Centre Support Structures Hannover www.tth.uni-hannover.der.rolfes@isd.uni-hannover.de +49 511 762 3867<br>schaumann@stahl.uni-hannover.de +49 11 762 3781 |

### 7.6.3 IMKT, Large Bearing Testing

**Description and main characteristics**

The large size bearing test rig at the Institute for Machine Design and Tribology (IMKT) of Leibniz University Hannover is intended for experimental investigations with large size bearings under various conditions, especially those that may cause unexpected bearing damages or failures in practical applications. One single test bearing can be operated with radial and axial forces as well as tilting moments and misalignment, both static and dynamic as well as with different speeds. Different bearing sizes and types such as spherical roller bearings (both radial and axial), cylindrical roller bearings, deep groove ball bearings or taper roller bearings can be operated either with a rotating inner ring or a rotating outer ring. The dimensions of the test rig allow for a maximum bearing outer diameter of about 800mm and a maximum width of about 430mm. In addition to the temperatures of the bearing and the oil, the speeds of the rotating parts, forces and displacements of the components, the axial position of the rolling elements and their slip values as well as strains and vibrations can be monitored.

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| **Contact:** | Roman Böttcher<br>Resarch assistant at Institute of Machine Design and Tribology<br>boettcher@imkt.uni-hannover.de / +49 511 762 3691 / www.imkt.uni-hannover.de |

## 7.7 IK4: Lab test scaled tower for structural health monitoring purposes


**Description and main characteristics**

Lab test scaled tower for structural health monitoring purposes:

- Monitored tower with many physics measured: Vibration, environmental conditions, etc

Many monitoring systems:

- Pulse Reflex (B&K)
- Luna fiber optic system
- OROS (noise and vibration analyser)
- Load cells up to 300KN
- Accelerometers

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|---|---|
| **Contact:** | Aron Pujana-Arrese<br>apujana@ikerlan.es<br>IK4-IKERLAN |

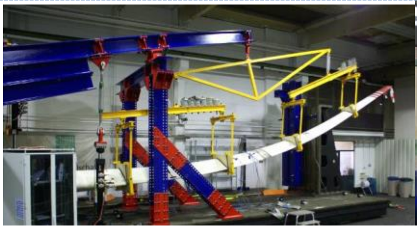
## 7.8 IWES:

- Rotor Blade Testing
- Rotor Blade Component Testing / Material Testing
- IWES: DYNALAB – Dynamic Nacelle Laboratory
- Rotor Shaft Test Stand
- Offshore Climate Chamber and Halt/Hass Tests for accelerated testing of Mechanics and Electronics
- Test Centre Support Structures Foundation Test Pit
- Test Centre Support Structures Span

### 7.8.1 Rotor Blade Testing

| Description and main characteristics | |
|---|---|
| Static and fatigue tests on full-scale rotor blades make it possible in a few months to predict the performance of a rotor blade, according to certification standards, over its 20 year life-span.<br>- 70m Rotor Blade Test Facility: hydraulic actuators for static and dynamic blade tests<br>- 90m Rotor Blade Test Facility: hydraulic actuators for static and dynamic blade tests<br>- Maximum static bending moment: 115,000 kNm<br>- Maximum static blade tip deflection: 30 m (however, block can be tilted 20° during the static test for a much higher effective maximum blade deflection).<br>- Maximum dynamic bending moment: ± 30,000 kNm<br>- Maximum dynamic blade tip deflection: ± 9.5 m<br>The application of the loads using hydraulic cylinders permits precise control of the loading. Fatigue testing is accomplished through cyclic loading at (or near to) the natural frequency of the rotor blade, which provides an ideal load distribution along the blade. This is a fast testing method, with low energy consumption. Biaxial loading is possible as well, either at natural frequencies or quasi-static in one or both directions. Through measurement and frequency analyses, the rotor blade natural frequencies can be determined. Over 250 strain gauges along with load cells, cable sensors, angle sensors and acceleration/temperature/humidity sensors provide a wealth of meaningful data. | |
| **Contact:** | Eric Putnam<br>Eric.Putnam@iwes.fraunhofer.de<br>+49 471 14 290 328 |

### 7.8.2 Rotor Blade Component Testing / Material Testing




**Description and main characteristics**

In addition to the testing of full-scale rotor blades, the laboratory infrastructure consists of facilities for coupon and component testing, providing characteristic values for the evaluation and development of rotor blade substructures. For standard material characterization, uniaxial coupon test machines, 3 - 4 point bending jigs, antibuckling devices and a climate chamber are available. For structural characterization, an adaptable test bench of 12 m x 3 m with versatile loading capabilities, i.e. hydraulic cylinders up 100 kN and an excenter with 20 kN at 2 Hz, is utilized, e.g. for beam testing.

- Clamping plate for Component testing: 2 strong floors of 3x12 m with 3 strong walls 1.5x3 m, 1000 kNm cap.
- Material and subcomponent test stands: at capacities of 25, 50, 100, 250, 1000 and 2500kN.
  Tension-torsion: 100 kN, 2 kNm
- Laboratory for material tests: static, dynamic characterisation of fibre reinforced plastics
- Rain erosion test stand (helicopter-principle)
- Laboratory for manufacturing of fibre reinforced plastics plates or subcomponents
- BladeMaker-Democenter: automated manufacture of rotor blades, 25x 8m, Available: Q4/2015

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|---|---|
| **Contact:** | Florian Sayer<br>florian.sayer@iwes.fraunhofer.de<br>+49-471-14290-329 |

### 7.8.3 IWES: DYNALAB – Dynamic Nacelle Laboratory


**Description and main characteristics**

The DyNaLab is Germany's first test stand for complete Nacelles of wind turbines. It offers a realistic test facility for testing and optimising both existing and future MW Nacelles

- Mechanical dynamical loads: 20,000 kNm Bending moment, ± 2,000 kN Shear forces
- Nominal torque: 8,600 kNm
- Overload torque: 13,000 kNm
- Prime mover: 10 MW Twin Direct Drive (15 MW overload capability up to 6min.)
- Artificial grid: 44 MVA converter capacity
- Measurements: over 600 synchronous, high-definition measurement channels

**Hardware in the loop**

Due to the missing rotor and tower, the nacelle has different system characteristics on the test stand than those in the field. In order to simulate real conditions in the laboratory occurring loads and the interactions between nacelle and rotor are calculated and applied. The necessary wind turbine real-time models and the appropriate control algorithms are developed and the necessary hardware components specified in order that the test stand including specimen can operate in the Hardware in the Loop (HiL).In addition, wind energy turbine reliability and availability can be increased and, at the same time, maintenance and repair costs reduced.

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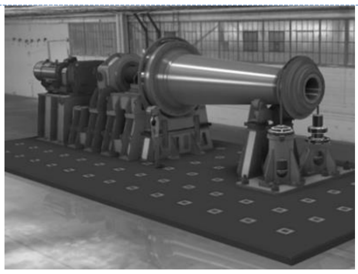
| **Contact:** | Martin Pilas<br>martin.pilas@iwes.fraunhofer.de<br>+49 471 14290-410 |

### 7.8.4 Rotor Shaft Test Stand



**Description and main characteristics**

Rotor shaft test stand, Location: Bremerhaven, Available: Q2/2015

- For main shafts of 2-5MW Wind turbines
- testing of various main shaft geometries in under realistic boundary conditions for accelerated fatigue tests
- Modifications of the test set-up also allows for testing of the main bearing of the rotor shaft, blade bearings and machine frame.
- Hydraulic actuators for shear forces up to 4,000 kN and bending moments up to 12,000 kNm
- 400kW drive with a maximum torque of 50 kNm
- Rotational speed up to 60 rpm

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|---|---|
| **Contact:** | Martin Pilas<br>martin.pilas@iwes.fraunhofer.de<br>+49 471 14290-410 |

### 7.8.5 Offshore Climate Chamber and Halt/Hass Tests for Accelerated Testing of Mechanics and Electronics

**Description and main characteristics**

HASS/HALT-Tests

- Accelerated Mechanical and Thermal Aging of test specimens
- Accellerations: 5 –70 gRMS
- Temperature ramp-up: -100°C –200 °C; ΔT = 70–100 K/min
- Frequency excitation broad spectrum up 10 kHz

Offshore-climate chamber (3), Location: Bremerhaven

- Accelerated Weathering of test specimens by parallel loads spectra and climatic influences
- Temperature: -30°C – 100°C, (salt) water spray, Surge water (4°C – 20°C)
- Bending moments up to 200Nm for reference test plates
- UV, Relative Air Moisture: 10-95%
- 12 test plates 200x580 mm can be tested in parallel- Free definable test programs allowing combinations of the various influences

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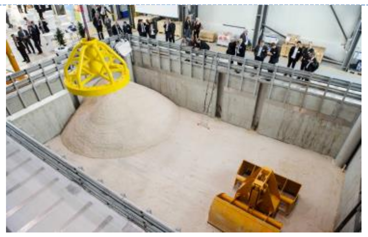
|---|---|
| **Contact:** | Claus Kupferschmidt<br>claus.kupferschmidt@iwes.fraunhofer.de<br>+49 471 14290-367 |

### 7.8.6 Test Centre Support Structures Foundation Test Pit



**Description and main characteristics**

The foundation test pit (FTP) measures 14 m length x 9 m width x 10 m depth which makes it the world's largest testing facility of its kind. Here, it is possible to perform realistic load
tests with cyclic load application in order to examine the dynamic behaviour of large-scale structural models. The force can be applied from above and from the side. An adjustable load
cross at the head of the model simulates the base of the wind turbine tower and can initiate any loads in the test specimens through four vertically and two orthogonally arranged horizontal hydraulic cylinders. Simultaneously, the soil behaviour in the area

of the foundation elements and the interaction of soil and support or foundation structure are examined. For
this purpose the structure models are based in water-saturated sand. The water content in the soil can be adjusted by six wells. Additionally to the examination of the soil-structure
interaction, the planned pit dimensions allows the testing of installation methods such as piling procedures

- Dimensions horizontal field: 14 x 9 x 10 m, zoning possible
- Vertical load: 2,000 kN tension, 500 kN compression, horizontal: ± 500 kN, up to 50 Hz
- Anchor points (vertical span): ± 500 kN, 270 kN shear load.
- Pit filling material: 1250 $m^3$ soil, about 48 h needed to fill/drain the pit
- Designed for pile driver impact up to 20 kJ

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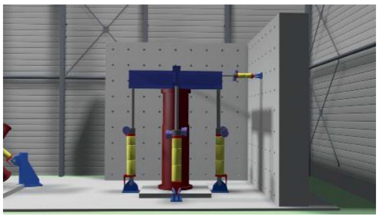
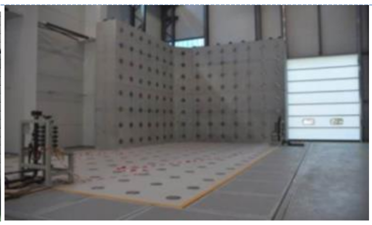
|---|---|
| **Contact:** | Maik Wefer<br>maik.wefer@forwind.uni-hannover.de<br>+49 511 7629279 |

#### 7.8.7 Test Center Support Structures Span

**Description and main characteristics**

Span: The large-scale testing facility consists of a large span with rigidly attached rectangular abutment angles. Here, the structural behaviour of components or large-scale wind turbine support structure models can be tested and evaluated regarding their technical reliability and economic efficiency. The geometry of the floor plan and the height of the abutment walls (8 m) have been de-signed for testing large-scale entire structures as well as different reference test pieces of components like steel nodes, hybrid connection elements (Grouted Joints) or junctions of heavyweight foundations. Additionally to the massive abutment angles, flexible steel angles or alternatively steel wall segments can be relocated at will to facilitate multi-axial examination of any given test piece. The load is applied through anchor points in the span and abutment angles. Large vertical loads can be applied through portal frames. The span makes it possible to test large-scale entire structures horizontally and vertically and is unique in Europe, concerning its specifications.

- - Dimensions horizontal field: 18.5 x 9.5 m, vertical field: 9.5 x 10 x 8 m
- - Load: 14 cylinders, up to 2,000 kN, up to 50 Hz
- - Anchor points: 1,000 kN tension/compression, 420 kN shear load.

Additional test facilities:

- Resonance test machine, up to 1,000 kN, up to 120 Hz.
- climate chamber
- SHM laboratory
- Soil mechanics, concrete, composite laboratories

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|---|---|
| **Contact:** | Maik Wefer<br>maik.wefer@forwind.uni-hannover.de<br>+49 511 7629279 |

## 7.9 ORE CATAPULT:

ORE CATAPULT has the following facilities for wind turbine component testing:

- Blade Testing Facilities
- 15MW Wind Turbine Nacelle Test Facility
- 3MW Tidal Turbine Nacelle Test Facility

### 7.9.1 Blade Testing Facilities

**Description and main characteristics**

ORE Catapult is the UK's national research centre for accelerating grid integration of renewable energy systems and catalysing the development and deployment of offshore wind, wave and tidal energy generation technologies.

ORE Catapult has undertaken independent testing of wind turbine blades up to 50m in length for a number of leading manufacturers since opening its first facility in 2005. A new 100m facility opened in 2012 and has been developed to accommodate larger blades for offshore wind turbines.

ORE Catapult performs structural testing of blades in accordance with IEC and ISO standards or customer requirements. Both Blade Test Facilities are accredited to ISO17025 by The United Kingdom Accreditation Service (UKAS). Dynamic and static tests are undertaken and can include the determination of natural frequencies, modal analysis, post-fatigue and collapse assessments.

| Facility Capability | Facility 1 | Facility 2 |
|---|---|---|
| Maximum blade length | 50m | 100m |
| Number of static winches | 7 | 6 |
| Hub height | 4.2m | 3.25m or 10m |
| Hub inclination angle | 1 deg on both hubs | 5.75 deg on 3.25m hub 1 or 3.5 deg on 10m hub |
| Maximum lift | 30Te | 90Te |
| Dynamic testing | Hydraulic resonant mass | Hydraulic resonant mass |
| Maximum hub moment | 50MNm | 140MNm |
| Maximum static tip deflection | 13m | 50m |
| Dynamic tip-to-tip deflection | 10m (vert), 8m (horiz) | 24m (vert), 16m (horiz) |
| DAQ (strain gauge channels) | 128 | 384 |
| Slew drive capability | Rotate blade on test hub | Rotate blade on test hub |

**Contact:**

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Ignacio Marti T +44 (0)1670 359 555 / F+44 (0)1670 359 666
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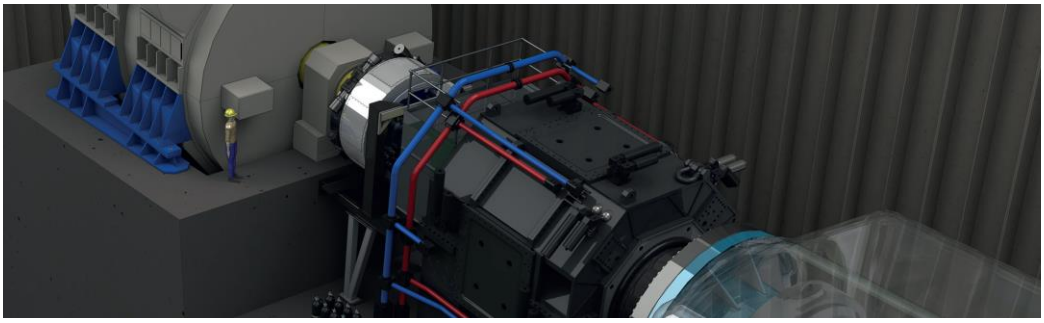
### 7.9.2 15MW Wind Turbine Nacelle Test Facility



**Description and main characteristics**

ORE Catapult is the UK's national research centre for accelerating grid integration of renewable energy systems and catalysing the development and deployment of offshore wind, wave and tidal energy generation technologies.

The facility is capable of performing independent performance, validation, functionality, endurance and compressed life testing of components, subassemblies, sub-systems and full systems (including the generator and converter) dynamically in a controlled onshore environment up to 15MW rating.

The test stand will help to improve the understanding of turbine performance, identifying any potential assembly and design issues in a relatively short time period compared to field tests. Ultimately, it will help to reduce time to market, improve reliability and mitigate the associated costs and risks of deployment.

**Typical Testing Activities**

- Highly Accelerated Lifetime Testing (HALT)
- Complete nacelle test capability (system or major component within system)
- Power curve assessment
- Design verification of control system
- System performance and endurance
- New supplier validation testing (major component)
- Internal manufacturing conformance testing (system or major component within system)
- Improvements to models physical and numerical – condition monitoring validation
- Research and development

The test rig is capable of replicating the real-life loads such as dynamic wind conditions in accordance with IEC and ISO standards or customer requirements. Testing capability includes dynamic torque, axial and radial force application and bending moment application to emulate operational conditions. Unbalanced rotor, brake emulations, condition monitoring and control system validation tests can also be conducted.

**Contact:** ORE Catapult National Renewable Energy Centre, Offshore House, Albert Street, Blyth, Northumberland NE24 1LZ
Ignacio Marti T +44 (0)1670 359 555 / F+44 (0)1670 359 666
info@ore.catapult.org.uk / ore.catapult.org.uk

### 7.9.3 3MW Tidal Turbine Nacelle Test Facility

**Description and main characteristics**

ORE Catapult is the UK's national research centre for accelerating grid integration of renewable energy systems and catalysing the development and deployment of offshore wind, wave and tidal energy generation technologies.

ORE Catapult's 3MW turbine drive train test stand performs accelerated lifetime testing of integrated turbine nacelle systems and the individual drive train components. It is equipped with a Force Application System (FAS) which simulates the environmental loads likely to be experienced by tidal devices and wind turbines offshore. This facility allows ORE Catapult to carry out reliability and performance appraisals in a controlled environment, helping to identify any potential assembly and design issues in a relatively short time period compared to field tests. This helps to reduce the financial risk and improve reliability for developers.

**Typical Testing Activities**

- Highly Accelerated Lifetime Testing (HALT)
- Power curve assessment
- Design verification of control system
- System performance and endurance
- New supplier validation testing (major component)
- Internal manufacturing conformance testing (system or major component within system)
- Improvements to models physical and numerical condition monitoring validation
- Research and development

The facility performs testing of turbines in accordance with IEC and ISO standards or customer requirements. Testing capability includes dynamic torque, axial and radial force application and bending moment application to emulate operational conditions. Unbalanced rotor, brake emulations, condition monitoring and control system validation tests can also be conducted.

| | |
|---|---|
| **Contact:** | ORE Catapult National Renewable Energy Centre, Offshore House, Albert Street, Blyth, Northumberland NE24 1LZ<br>Ignacio Marti T +44 (0)1670 359 555 / F+44 (0)1670 359 666<br>info@ore.catapult.org.uk / ore.catapult.org.uk |

## 7.10 VTT

**Expert Services Ltd test laboratory**


**Description and main characteristics**

VTT Expert Services Ltd test laboratory is fully equipped for large scale structures testing. The test laboratory has a 500 m2 strong floor system with configurable framing and support system. The floor includes an anchorage-point grid with movable hydraulic cylinders and support frames for various test configurations.

- Full scale, assembly, component and sub-component testing
- Servohydraulic loading cylinders from 1 kN up to 1000 kN for static or dynamic loading. Multiaxial loading is also possible.
- Loading frames with a capacity up to 2000 kN (static tests) and 1000 kN (dynamic tests and fatigue)
- Versatile data acquisition systems for monitoring of load, displacement, strain, temperature etc. during the test
- Large 450 kN- 2000 kN universal servo-hydraulic test machines for component testing
- Extreme conditions applicable
- Field measurements
- Earth quake testing

| | |
|---|---|
| **Contact:** | VTT Expert Services Ltd<br>Juha Halme<br>Product Manager<br>Tel. +358 40 569 4717<br>juha.halme@vtt.fi |

# 8 Material Testing Laboratories for Wind Energy (MTL)

There are several ongoing projects related to the development and use of new materials for different windturbine components (blades, generators, etc)

Five EERA Wind members from three European countries have supplied information about their facilities related to MTl. In the following paragraphs it is presented information of the available facilities related to MTL:

- CENER Component Test Lab
- CRES: Material & Small component Testing
- CTC: Advanced Materials and Metallurgical Laboratory
- IK4
- VTT: Material testing laboratory

## 8.1 CENER


| Description and main characteristics | |
|---|---|
| The lab comprises two units. The first is destined to characterize materials as well as composite coupons or medium metallic components. The second one aim for process development and composite manufacturing.<br><br>The lab can be complemented by other labs at CENER offering environmental aging, chemical and optical characterization.<br><br>The mechanical testing can reach 600 kN and 250 kN for extreme or fatigue testing. The process model shop is able to produce composite by infusion, prepreg or mold processes. | |
| **Contact:** | Antonio Ugarte Olarreaga<br>Head of Wind Energy Department at Cener<br>augarte@cener.com<br>/ +34948252800 / www.cener.com |

## 8.2 CRES (Centre for Renewable Energy Sources)

Material & Small component Testing

**Description and main characteristics**

Within CRES, static and fatigue tests in tension & compression, as well as 3- and 4-Point Bending Tests are performed on composite material specimens on a universal ±250kN fatigue testing machine (150mm stroke). Tests on subcomponents, such as blade joints can be also performed through use of the special table of the testing machine and fixtures specifically designed for such purpose. Load, strain, displacement, etc. are monitored continuously along with temperature on the specimen (for fatigue tests) through an 8-channel dedicated data acquisition system. Tests can be performed under load, displacement or strain control. Fatigue tests can be performed under constant amplitude or variable amplitude load application scenarios. Both static and fatigue tests. Optionally, mechanical testing can be combined with non-destructive testing (2-channel Acoustic Emission system, Ultrasonic testing system). A 4-channel Optical Fibres System is also available for relevant measurements. LWTT is accredited as a Testing Laboratory according to ISO/IEC 17025:2005 and the accreditation scope includes tests according to ISO 527-4, ISO 527-5, ISO 14126 and ISO 14129.

| | |
|---|---|
| **Contact:** | D. Lekou<br>Head of Blade Testing Service at CRES, Laboratory for Wind Turbine Testing<br>dlekou@cres.gr<br>/ +30 210 6603300 / www.cres.gr |

## 8.3 CTC (Technological Centre of Components)

### 8.3.1 Advanced Materials and Nanomaterials Laboratory

**Description and main characteristics**

Advanced Materials and Nanomaterials Laboratory is equipped with specific equipment to carry out projects and services in this activity area. This facility has laboratory general equipment (all kinds of glassware, muffle, oven, hot plates, viscometer, mechanical stirrer, precision balance, thermostatic bath, homogenizer, incubator, Vicat needle, hydrometer …) and specific equipment, which include:

- Atomic Force Microscope (AFM): High resolution technique to analyse materials at nanometric scale. Morphological images and topographic profiles. Electrical, magnetic, thermal and mechanical properties. Nanolithography.
- Three Roll Mill: Nanomaterials dispersion in different media (high shear forces technique).
- Mini Spray Dyer: (advanced technique of drying): Microencapsulation of materials, atomization of liquids, production of solid particles at microscale, transformation of liquids (solutions, emulsions) into dry micro powder, dispersion of nanomaterials into microparticles, etc.
- Thermal conductivity analyser, specific heat, diffusivity and effusivity of any kind of material, whether solid, liquid, paste or powder.
- Inverted metallurgical microscope: Microstructural analysis of materials.
- Universal Mechanical Testing Machine. Tensile, bending and compression tests.
- Ultrasound homogenizer. Nanomaterials dispersion en different liquid media.

http://ctcomponentes.es/en/advanced-materials-and-nanomaterials-lab/

| | |
|---|---|
| **Contact:** | Dr. Ángel Yedra<br>Head of the Advanced Materials Area at CTC<br>ayedra@ctcomponentes.com / +34942766976 /<br>www.ctcomponentes.es |

### 8.3.2 Corrosion Laboratory And Marine Corrosion Test Site El Bocal


**Description and main characteristics**

The CTC has developed a corrosion and metallographic laboratory where tests are performed for materials characterization. It assesses how it affects the behaviour of materials and coatings in artificially generated atmospheres (under ISO, NORSOK and ASTM test standards) and in real environment under climatic agents (either in marine environment or air).

The Marine Corrosion Test Site "El Bocal" is a Marine Laboratory placed in open water and located at the shoreline of the Cantabrian coast, few kilometres away from Santander, whose main purpose is to test, study and analyze the behaviour of different materials and coatings against marine biofouling and corrosion. The facility has been designed to test specimens under realistic conditions of exposure in any of the three different exposure zones (submerged, tidal and splash). In addition to materials and coatings, pieces of other components with marine requirements, such as fishing nets, ropes, steel wires offshore chains or materials for aquaculture cages can be placed and tested.

- Salt fog chamber.
- Climate chamber for exposure to UV/condensation/spray cycles.
- Alternate immersion machine in saline solution.
- Climate Chamber with Temperature and RH control.
- Weathering exposure sites (in marine and atmospheric environment).
- Dry film thickness measurement tester.
- Adhesion Tester.
- Surface Roughness tester
- Metallographic light microscope.
- Stereomicroscope.
- Micro indenter.
- Atomic Force Microscope (AFM).

*http://ctcomponentes.es/en/corrosion-lab/* *http://ctcomponentes.es/en/mcts-marine-laboratory-el-bocal-2/*

| | |
|---|---|
| **Contact:** | Raúl Rodríguez Arias<br>Head of the R&D Projects at CTC<br>rrodriguez@ctcomponentes.com / +34942766976 /<br>www.ctcomponentes.es |

## 8.4 IK4-IKERLAND

- Tensile Test And Fatigue Test Universal Machines For General Purposes
- Accelerated Fatigue Test Machine for characterisation of Fatigue Properties of Plates:
- Optical Microscopy for Material Analysis:
- Material Characterisation and Model Validation

### 8.4.1 <u>Tensile Test And Fatigue Test Universal Machines For General Purposes</u>

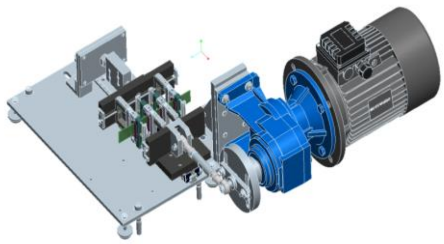

**Description and main characteristics**

Tensile test up top 300KN

Fatigue test up to 160KN

Facilities to characterise materials

### 8.4.2 <u>Accelerated Fatigue Test Machine for characterisation of Fatigue Properties of Plates:</u>



**Description and main characteristics**

Suitable for 3, 4, 5 point bending test

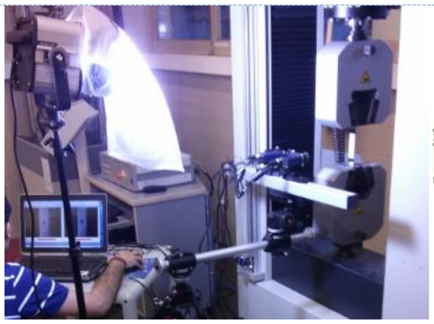
Up to 30Hz frequency range

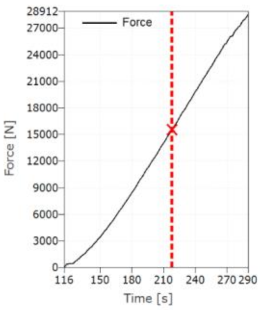
Up to 20mm stroke

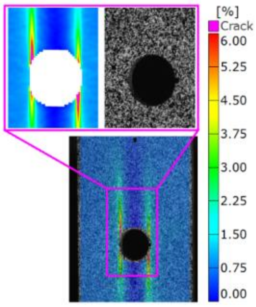
### 8.4.3 Optical Microscopy for Material Analysis:

| Description and main characteristics |
|---|
| ▪ Scanning optical electron microscope (SEM and STEM).<br>▪ Contact and confocal profilometers.<br>▪ Optical microscope LEICA DM-ML with lens Leica 50x,100x,200x,500x,1000x and digital camera C9100 Hamamatsu EM-CCD |

### 8.4.4 Material Characterisation and Model Validation






| Description and main characteristics | |
|---|---|
| Digital image correlation system VIC 3D | |
| **Contact:** | Aron Pujana-Arrese<br>apujana@ikerlan.es<br>IK4-IKERLAN |

## 8.5 TECNALIA

### 8.5.1 Corrosion Laboratory & Natural Exposure Site for Material Degradation Testing: Marine Corrosion and Protection



**Description and main characteristics**

- **Natural outdoor (i.e. marine) exposure sites for material degradation testing:** Facility for research, development, testing & evaluation in the field of marine corrosion.
- Estimate the corrosion resistance of materials in seawater.
- Assesses corrosion protection, material selection and prevention depending on the aggressivity of the environment.
- Continuous measurement (environment & corrosion).
- Accelerated corrosion (aging) chambers
  - Salt spray fog corrosion chambers
  - Climatic chamber (-70ºC a 180ºC with humidity control)
  - UV chamber
  - Erosion apparatus (ASTM G76).
- Electrochemical testing (i.e. Potentiometric, Impedance)
- Stress corrosion cracking: Evaluation of the resistance of materials to stress corrosion cracking & Development of testing methods used for the valuation of the resistance of materials to stress corrosion cracking (SSC).
- Evaluate the resistance of materials to corrosion fatigue.
- Corrosion monitoring
- Coatings selection and characterization
- Training

| | |
|---|---|
| **Contact:** | Pablo Corengia. Manager of Materials for Energy Area.<br>ENERGY AND ENVIRONMENT DIVISION.<br>TECNALIA RESEARCH & INNOVATION.<br>pablo.corengia@tecnalia.com / 902 760 004 / www.tecnalia.com |

## 8.6 VTT

| Description and main characteristics | |
|---|---|
| The mechanical properties of fibre reinforced laminates can be characterized by variety of tests. For instance, the following standard tests are conducted:<br>• Tension and compression tests<br>• Bending tests<br>• Interlaminar shear strength tests (ILSS)<br>• Flatwise and out-of-plane tensile tests<br>• Impact tests<br>• Tests for sandwich structures<br>• Heat Distortion Temperature (HDT) measurements.<br>• The glass transition temperature with Differential Scanning Calorimetry (DSC).<br>• Chemical composition of the polymer can be determined with Fourier Transform Infrared Spectroscopy (FTIR)<br>• Surface studies with Scanning Electron Microscopy (SEM)<br>• Energy Dispersive X-ray Spectroscopy (EDS) is used for analysing the chemical element composition<br>• Thermogravimetric Analysis (TGA)<br>Tension, compression and bending tests can be static or dynamic (fatigue tests). Environmental exposure or different ageing programs are also available within our laboratory. A variety of 5 kN- 2000 kN universal test machines for material testing. | |
| **Contact:** | VTT Expert Services Ltd<br>Juha Halme<br>Product Manager<br>Tel. +358 40 569 4717<br>juha.halme@vtt.fi |

# 9 Acoustic Labs for Wind Energy (ALWE)

The following installations have been identified:

- CIRCE: Electrical Metrology Laboratory
- CNR-IDASC Istituto di Acustica e Sensoristica "Orso Mario Corbino"

Specific information about these research infrastructures is included in the following pages.

### 9.1 CIRCE: Electrical Metrology Laboratory

**Description and main characteristics**

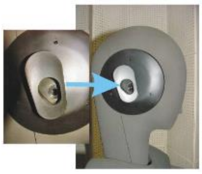
The Electric Metrology Laboratory (LME-CIRCE) is accredited by the Spanish Accreditation Body (ENAC) to conduct tests for acoustic noise emission measurements on wind turbines.

This laboratory performs the acoustic tests according to international standards, such as IEC 61400-11:2012, Measnet:2011 procedure and other specific standards from other countries, (Renewable UK Small Wind Turbine Standard:2014 and AWEA:2009).

The DAQ platform used by LME-CIRCE takes advantage of 802.11 wireless capabilities where easy, remote and flexible data acquisitions are needed. Besides, the use of a multichannel DAQ card for simultaneous vibration and acoustic measurements makes possible the research beyond the actual state-of-art.

| | |
|---|---|
| **Contact:** | Jorge Bruna<br>Director of Electrical Tests Group at Energy Resource Analysis (AIRE), CIRCE<br>jbruna@fcirce.es /34 976 761863 / http://fcirce.es/web/page.aspx?id=labLME |

## 9.2 CNR-IDASC Istituto di Acustica e Sensoristica "Orso MarioCorbino"

| | | |
|---|---|---|
| In field measurement equipment |  In field calibrated binaural recorder |  Sound proof room for audio-video subjective tests |
| |  Head and torso calibrated simulator |  Control room |

**Description and main characteristics**

The "in field" measurement equipment enables to record and analyse the immission sound level due to wind turbine according to international standards. Binaural recordings in field and in laboratory are required for a hearing-related measurements representative of sound perception. Laboratory facilities enable to perform subjective tests on "in field" recordings and on virtual scenarios.

| | |
|---|---|
| **Contact:** | Giovanni Brambilla<br>Scientist at CNR IDASC<br>giovanni.brambilla@idasc.cnr.it / +390645488030 / www.idasc.cnr.it |

# 10 Wind Tunnels for Wind Energy (WTWE)

Ten EERA Wind members from nine European countries have supplied information about their facilities related to WTWE.

| *Member* | *Country* |
|---|---|
| *CRES (Centre for Renewable Energy Sources)* | *Greece* |
| *DTU Wind* | *Denmark* |
| *ForWind (Centre for Wind Energy Research)* | *Germany* |
| *LNEG (National Laboratory for Energy and Geology)* | *Portugal* |
| *METUWIND* | *Turquey* |
| *NTUA (Univ. of Athens)* | *Greece* |
| *NTNU (Norwegian University of Science and Technology)* | *Norway* |
| *Politecnico di Milano* | *Italy* |
| *Delft University of Technology* | *The Netherlands* |
| *VTT (Technical Research Centre of Finland)* | *Finland* |

The following Wind Tunnels used for Wind Energy research are described in the following pages:

- CRES Wind Tunnel (Greece)
- DTU Wind Tunnel (Denmark)
- FORWIND: Oldemburg Wind Tunnel (Germany)
- LNEG Wind Tunnel (Portugal)
- METUWIND Wind Tunnel (Turquey)
- NTNU Wind Tunnel (Norway)
- Politecnico di Milano Wind Tunnel (CIRIVE) (Italy)
- TUDelft: Delft University of Technology Wind Tunnel (The Netherlands)
- VTT: Icing Wind Tunnel (Finland)

Specific information about these research infrastructures is included in the following pages.

## 10.1 CRES: Wind Tunnel

| Test Sections characteristics | | | | |
|---|---|---|---|---|
| Type | Width (m) | Height (m) | Length (m) | Speed range (m/s) |
| Closed walls | 2.2 | 2.2 | 3.0 | 1.0 - 3.5 |
| Open jet (no walls) | 0.8 | 0.8 | 1.8 | 3.0 - 25.0 |
| Closed walls | 1.4 | 1.4 | 11.0 | 2.0 - 8.5 |

**Description and main characteristics**

The wind tunnel of CRES is a closed loop wind tunnel with total wind run 45m. It includes three test sections. Test Section 1 (Closed walls, 2.2mx2.2m) is equipped with a rotating turntable and is suitable for wind flow modelling around buildings and structures (max. speed 3.5m/s). The open jet Test section 2 has an upstream contraction section with surface ratio 1:7.5. Maximum wind speed at Section 2 is 25m/s. This section is suitable for anemometer calibrations, fulfilling requirements of IEC 61400-12-1/2005, Annex F and MEASNET guidelines. Test Section 3 (closed walls, 1.4mx1.4m, length 11.0m) has maximum speed of 8.5m/s and is suitable for atmospheric boundary layer simulations.

CRES wind tunnel is mainly used for calibration of anemometers forming one of the Laboratories accredited according to ISO 17025 services since 1999.

**Contact:**

NikolaosStefanatos

Head, Laboratory for Wind Turbine Testing, CRES

nstefan@cres.gr/+30 210 6603300 / www.cres.gr

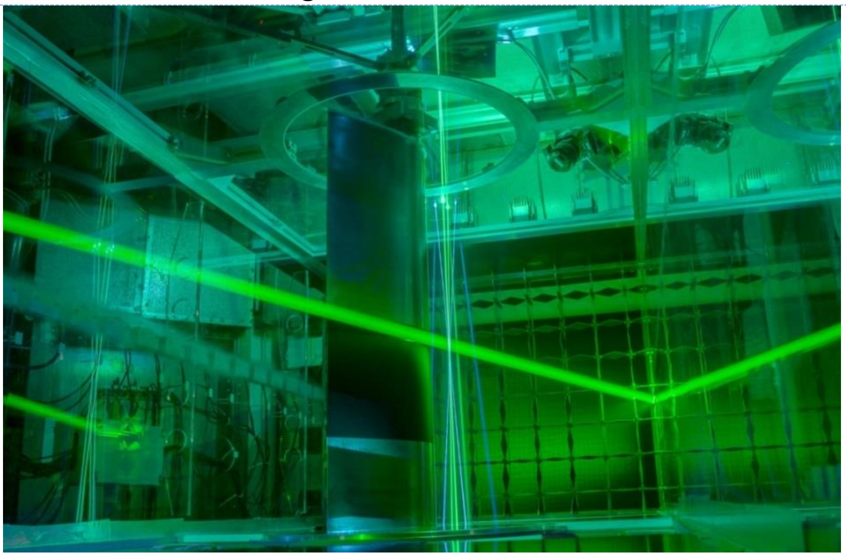
## 10.2 DTU Wind Tunnel

**Description and main characteristics**

Based on e.g. the wind tunnel experience at DTU, with the DTU wind tunnel with closed test section dimensions 0.5m x 0.5m and maximum flow speed of 60m/s, with the VELUX wind tunnel with open test section dimensions of 3.4m x 3.4m and maximum flow speed of 40m/s and tests in international wind tunnels, a national research infrastructure is planned and is now in the design process to be finalized end 2015. The tunnel is a closed wind tunnel with test section dimensions H x W x L=2.2m x 3.3m x 10.0m, maximum flow speed of 105m/s and turbulence intensity at maximum 0.1%. The tunnel will be dedicated to wind turbine airfoil tests, where also the ability to carry out aeroacoustic tests will be possible. Thus, the standard chord for the airfoil tests will be 1.1m and will result in Reynolds numbers of maximum 7.7x106, but bigger chords will be possible to test to obtain even bigger Reynolds numbers. However, tests of other models than airfoils will also be possible..

| | |
|---|---|
| **Contact:** | Christian Bak<br>chba@dtu.dk |

## 10.3 FORWIND: Oldemburg Wind Tunnel



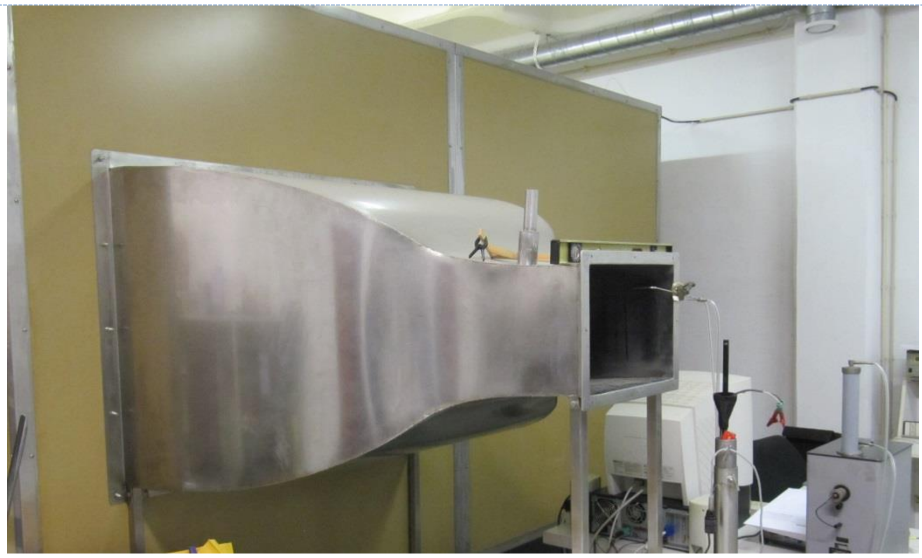
**Description and main characteristics**

The new turbulent wind tunnel in Oldenburg will be opened to researchers in the course of 2016. With an outlet of 3 meters x 3 meters and a measurement test section with a length of 15 meters in the open and 30 meters in the closed configuration, the whole wind tunnel is optimized for investigations on wind turbine models, with respect, for example, to wake effects and the flow field within wind farms. Turbulent wind fields will be generated by means of an active grid at a maximum velocity of 30 m/s, where typical characteristics of atmospheric wind fields e.g., gustiness can be realized.

Next to this two smaller wind tunnels (0.8 m x 1.0 m outlet, max velocity 50 m/s) are available for aerodynamic investigations of blade elements, development of anemometry technologies, etc. Oldenburg wind tunnels are equipped with state-of-the-art measurement techniques, e.g. high-speed stereo PIV, LDA, hot-wire anemometers.

| **Contact:** | Dr. Michael Hölling<br>Wind Tunnel Experiments<br>ForWind – University of Oldenburg<br>michael.hoelling@forwind.de<br>+49 441 798 3951 |
|---|---|

### 10.4 LNEG Wind Tunnel



**Description and main characteristics**

The LNEG wind tunnel is a subsonic and jet tunnel type where the section work is outside the wind tunnel. The free opening where the section work starts has an area of 0.4m x 0.3m. This wind tunnel was designed to perform anemometer calibrations in accordance the standard IEC6100-12-1 Ed.1.

The measurements of dynamic pressure are obtained by an accuracy Betz pressure manometer. The electrical parameters are recorded by precision equipment which was calibrated in national reference laboratories.

| | |
|---|---|
| **Contact:** | Ana Estanqueiro<br>ana.estanqueiro@lneg.pt |

## 10.5 METUWIND Wind Tunnel

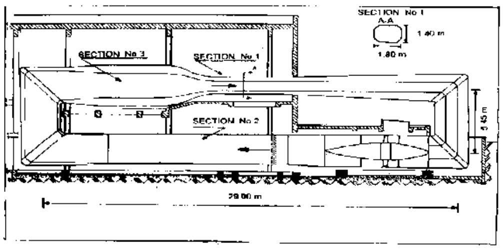
**Description and main characteristics**

METU Centre for Wind Energy operates several wind tunnels (WT).These includes several small to medium scale WT as well as a large-scale multi-purpose WT that will be operational in the summmer of 2015. The measurement instrumentation included 2D/Stereoscopic High-Speed PIV, CTA, 128-channel pressure measurement system, load balances, etc.

MMETUWIND Large Scale Wind Tunnel: Closed loop, 54m x 18m footprint.

| | |
|---|---|
| **Contact:** | Prof.Dr. Oguz Uzol<br>uzol@metu.edu.tr |

## 10.6 NTUA Wind Tunnel




| Test Sections | | |
|---|---|---|
| Width (m) | Height (m) | Max. speed (m/s) |
| 4.5 | 3.5 | 9.5 |
| 3.5 | 2.5 | 17.0 |
| 1.8 | 1.4 | 60.0 |

### Description and main characteristics

CRES has access to the NTUA wind tunnel, through joint R&D projects with the Aerodynamics Section of the Mechanical Engineering faculty. The low speed (subsonic) closed circuit wind tunnel is a high precision measuring facility which can be used in a broad range of experimental applications.

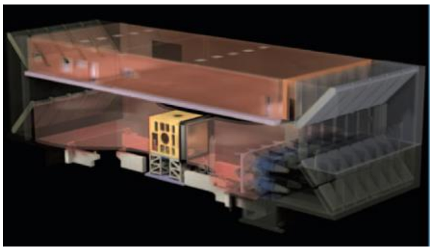
The wind tunnelhas a total length of 32m, comprising three test sections, and is powered by a seven blade axial fan of 350 hp. The maximum speed in the smallest section is 60m/s and the turbulence level 0.2%. Available measuring systems include a PIV system, allowing velocity field measurements on a plain, Laser Doppler Apparatus, hot-wire velocimetry and 7 hole Pitot tubes. Multiple channels pressure scanners are available for measuring static pressure distributions on aerodynamic bodies. Load measurements are performed using a 6 component balance and a 6 component load pad.Flow visualizations are performed using smoke and a Laser source, liquid crystals and TiO2-oil compound.

| | |
|---|---|
| **Contact:** | Lars Sætran<br>Professor at Department of Energy and Process Engineering<br>lars.satran@ntnu.no / +47 73593716 / http://www.ntnu.no/ept/lab/aero |

## 10.7 NTNU Wind Tunnel

| Description and main characteristics | |
|---|---|
| The wind tunnel has a test section of 11.0 x 2.7 x 1.8 m and a maximum velocity of 30 m/s.<br>It is suitable for scaled experiments, and has been applied for studying various blade profiles, flow over terrain / wind farm models, wake-effects etc.<br>The wind tunnel is owned and operated by NTNU. Reference Access Conditions are preliminary and to be negotiated. | |
| **Contact:** | Lars Sætran<br>Professor at Department of Energy and Process Engineering<br>lars.satran@ntnu.no / +47 73593716 / http://www.ntnu.no/ept/lab/aero |

## 10.8 Politecnico di Milano Wind Tunnel

**Description and main characteristics**

POLIMI Wind Tunnel is located in the academic environment of Politecnico di Milano University, operating since 2001. The facility has two missions, being both a purely research tool and, secondly, a modern instrument for high-technology industrial applications, offering advantageous reciprocal synergies.
Politecnico di Milano Wind Tunnel has two different test rooms that allow to offer a very wide range of test arrangements and alternatives.
**Low Speed / Boundary Layer Test Section.** The low speed test section is 14m wide and 4m high, having a maximum wind velocity of 16m/s and turbulence intensity < 2 %. The 35m long, constant section test room enables to set up upstream passive and active turbulence generators to simulate the atmospheric boundary layer or highly correlated large scale turbulence. The test section is equipped with a 13m diameter turntable.
**High Speed / Low Turbulence Test Section.** The high speed test section is 4m wide, 4m high and 6m long. It is possible to perform tests in confined-flow and in open jet configuration. The maximum wind velocity is 55m/s and the turbulence intensity is less than 0.15 percent. The test section is equipped with a turntable (diameter 2.5m) and a traversing system behind the model's location, suitable for making wake measurements.
The availability of two test sections, having different and complementary performances, allows to perform a wide set of tests in wind energy research.
The low turbulence and high Reynolds characteristics of the 4x4m test section makes it eligible of high Reynolds static and dynamic airfoil testing.
Thanks to the dimensions of the test sections, full scale prototypes of small vertical axis wind turbines (VAWT) can be tested. A fully equipped computer controlled test rig allows for complete characterization of VAWT (all the mechanical and fluid dynamics parameters of interest).
A well established technology is available for horizontal axis wind turbine scale aeroelastic models design, production and testing. The scale models, fully equipped with rotor velocity control and blades independent pitch control, can be tested in a scaled atmospheric boundary layer flow. Allowance for wake effects testing is given by the very wide (14m) test section, with capability to investigate the rotor, tower and blades dynamic behaviour in turbulent wind and in the wake of upwind wind turbines. All of that within controlled inflow conditions (all state of the art flow measuring instrumentation available).
Also, the designed 6-DoF robotic platform is currently being tuned for simulating the motion of a floating offshore wind turbine (FOWT) scale model. This rig serves as wind tunnel / hardware-in-the-loop hybrid testing of FOWT scale model due to combined effect of hydrodynamic and aerodynamic loads. This is useful to study the performances and control strategies of floating offshore wind farms.

| | |
|---|---|
| **Contact:** | Prof. Alberto Zasso<br>Wind Tunnel Director-Department of Mechanical Engineering<br>alberto.zasso@polimi.it<br>Ph: +39 02 2399 8434 |

## 10.9 Delft University of Technology Wind Tunnel


**Description and main characteristics**

- Low-speed Low-turbulence Wind Tunnel (maximum velocity 110 m/s, test section size 1.25m x 1.80m). This tunnel is extensively used for airfoil measurements up to Reynolds numbers of 4x106. Turbulence intensity about .07% at 75 m/s
- Open Jet Facility (octagonal open jet, 2.85m x 2.85m). Suited for rotor model tests with rotors up tot to 1.8 m in diameter. Maximum velocity 30 m/s. Longitudinal turbulence intensity 0.24% at 15 m/s
- Boundary layer Wind Tunnel (30 m/s, 1.5m x 0.25m test section). The test section has a 6m long adjustable back wall to create pressure gradients.
- Aero-acoustic Vertical Wind tunnel with a square open jet of 0.6m x 0.6m.
- Several small 0.4m x 0.4 m wind tunnels, which can be used either in the open or closed test section configuration.

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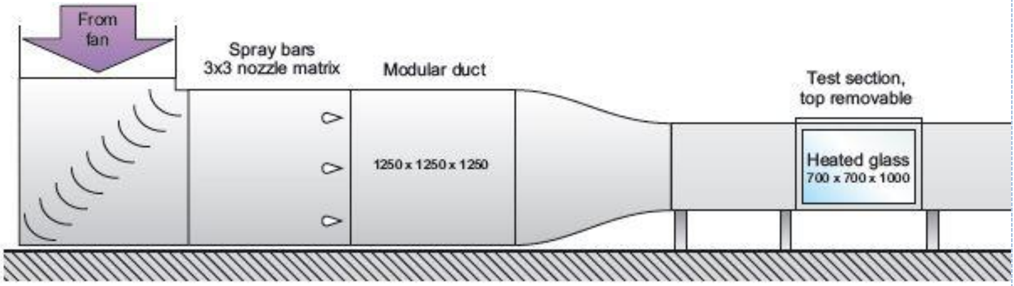
| **Contact:** | Nando Timmer<br>w.a.timmer@tudelft.nl<br><br>Carlos Simao Ferreira,<br>c.j.simaoferreira@tudelft.nl |

## 10.10 VTT Icing Wind Tunnel




| **Description and main characteristics** |
|---|
| VTT icing wind tunnel in Espoo, Finland serves testing and verification of products and concepts. The tunnel is located inside a climate chamber which allows wide variety of testing conditions based on customer needs. The combination of low running costs and high competence of personnel make this facility a unique possibility for trying out new ideas, functionality of prototypes, design optimisation, and verification of products in controlled environment. Droplet size and wind speed profile have been verified using shadow imaging method. |

| **Contact:** | |
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# 11 Flow & Wave Basins (FWB)

The following installations have been identified:

- CNR: INSEAN-CNR Towing Tank Basin no. 1, no.2 and circulating water channel
- DHI: Shallow and deep water wave basins
- SINTEF/MARINTEK: Ocean Basin Laboratory and Ship Model Tank Labor

Specific information about these research infrastructures is included in the following pages.

## 11.1 INSEAN-CNR

### 11.1.1 TOWING TANK BASIN NO. 1

**Description and main characteristics**

The Towing-Tank Basin No.1 is a research facility devoted to the load and flow analysis of floating or underwater bodies. It allows investigations on streamlined bodies subjected to airflows at high Reynolds numbers due to the combination of water density and carriage speeds up to 15 m/s. The basin section is 13.5 m wide and 6.5 m deep whereas its length is 470 m.

Simple captive tests are possible as well as forced motion imposed to the bodies by means of actuators. Instrumentation include dynamometers and an underwater Particle Image Velocity system to provide data about loads and downstream wake evolution, respectively.

In the facility experimental techniques are used also to determine and optimize the performance of power generators able to collect energy from currents.

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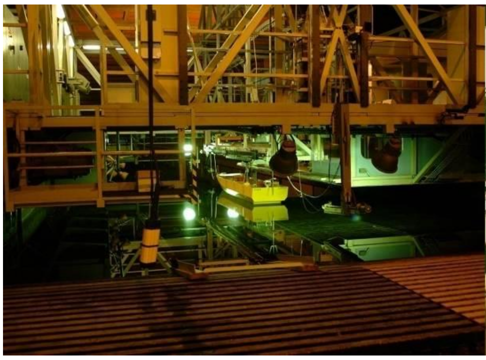
### 11.1.2 TOWING TANK BASIN NO. 2




**Description and main characteristics**

The Towing-Tank basin no. 2 is devoted to the analysis of offshore platforms for wind energy farms. The basin length, width and depth are 220 m, 9 m and 3.5 m, respectively. The basin allows to create an artificial bottom for tests in shallow water conditions. It is equipped with a wave maker that allows to study the response of moored floating structures to deterministic (sinusoidal wave trains) or stochastic (wave spectra) sea excitation.

The in-house design and assembling of experimental set-ups include the possibility of structural scaling of full-scale constructions. Optical systems for motion sensing of multi-platforms, dynamometers for load measurement, strain-gage arrays as well as accelerometer for elastic deformations can be integrated in the physical model.

Typical experimental activities in this facility are: measurements on marine current turbines, measurements on wave energy conversion systems, assessment of marine energy devices power out capability, etc.

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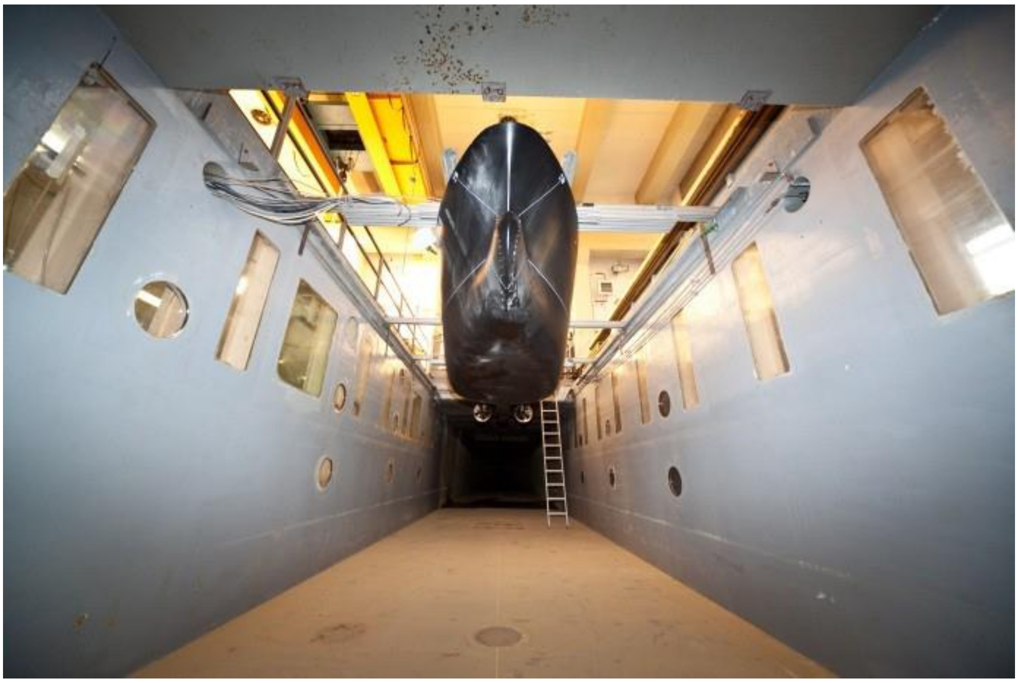
### 11.1.3 Circulating Water Channel



**Description and main characteristics**

The facility is the largest free surface cavitation lab in the world with the test section having the cross-section area of 3.6 x 2.25 m2 and length of 10 m. Two 1 MW main pumps provide the power needed to achieve a maximum velocity over 5 m/s in the test section. The facility can be depressurized down to 30 mbar allowing the simulation , at model scale, of the cavitation behaviour of full scale ship. A maximum ship model of 7 m length can be tested in the facility to study the cavitation on propeller and ship appendages. Typical tests are for example: hydrodynamic characterization of surface and submarine vessels and structures, assessment of marine propulsor performance, assessment of marine current turbine performance, hydroacoustics characterization of marine devices (noise emission and radiation), characterization of complex flow field structures through correlated velocimetry, pressure, and flow visualization analyses.

The facility is equipped with several type of dynamometers and balances for the measurement of the forces and moments; advanced laser velocimetry techniques as LDV, PIV and Stero-PIV able to survey the propeller wake; state of the art imaging techniques with high speed cameras and high resolution cameras for the quantitative visualization of cavitation phenomena; hydrophones with a dedicated high frequency data acquisition system for hydroacoustic testing.

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## 11.2 DHI: Shallow and deep water wave basins


| **Description and main characteristics** |
|---|
| DHI is one of the world's leading hydraulic laboratories with the most advanced physical modelling facilities currently available. DHI has pioneered the enhancement of modelling technologies and techniques and our laboratory technology is used by more than 50 laboratories around the world. DHI's Shallow Water Basin for combined waves, current and wind is 35m long and 25m wide with an overall depth of 0.8m. The basin is ideal for model testing when the effects of combined waves, current and wind are of major importance, for instance scour around structures, and loads on fixed or floating coastal and offshore structures. The size of the facilities ensures efficient operation and maximum flexibility with minimum of operational staff required. Our deep water basin has recently been used for testing various floating wind turbine foundation concepts. |

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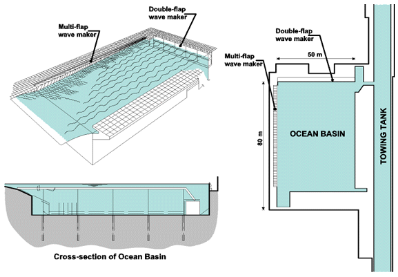
## 11.3 SINTEF/MARINTEK

### 11.3.1 OCEAN BASIN LABORATORY




**Description and main characteristics**

It is used for studying basic as well as applied ship and offshore problems. A total environmental simulation including wind, waves and current offers unique testing conditions for models of all types of fixed and floating structures.

**Ocean basin laboratory data**

Length: 80 m - Width: 50 m - Depth: 0-10 m. Maximum current velocity approx. 0.2 m/s at 5 m water depth. Down at 7.5 m water depth maximum current velocity is approx. 0.15 m/s.

**Double flap wave maker:** Hydraulic driven, hinged double-flap type.

*Wave characteristics:*Regular waves. Maximum wave height: 0.9 m.; Wave periods: 0.8 s and above; Wave spectra: Computer generated or from magnetic tape.

**Multiflap wave maker:** Electrically driven, hinged single-flap type. 144 individually controlled flaps.

*Wave characteristics:*Regular waves: Maximum wave height: 0.4 m. ;Wave periods: 0.6 s and above; Wave spectra: Computer generated shortcrested or longcrested waves of specified direction.

**The carriage system** follows free running models with no constraints at speed up to 5 m/s, at any heading to the waves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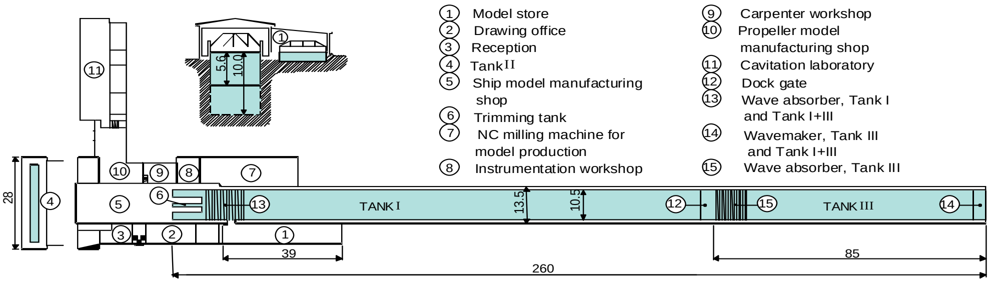
### 11.3.2 Ship Model Tank Laboratory




| Tank I | Tank II | Tank III | Tank I+III* |
|---|---|---|---|
| 175 m | 25 m | 85 m | 260 m |
| 10.5 m | 2.8 m | 10.5 m | 10.5 m |
| 5.6 m | 1.0 m | 10 m | 5.6/10.0 m |
| 0.02-10 m/s | 0.05-1.75 m/s | 0-0.9 m/s | 0.02-10 m/s |
| 1 m/s² | 1 m/s² | 1 m/s² | 1 m/s² |

| | | | |
|---|---|---|---|
| 8 m | 1 m | - | 8 m |
| | Single flap | Double flap | Double flap |
| | Regular and irregular waves | Regular and irregular waves | Regular and irregular waves |
| | 0.3 m | 0.9 m | 0.9 m |
| | 0.25-3 sec. | 0.8-5 sec. | 0.8-5 sec. |

* Tank I and III can be used separately and also as one long tank (Tank I + III) by removing the gate (12) and wave absorber (15). In Tank I + III either of the two carriages can be used.

**Description and main characteristics**

The Ship Model Basin Laboratory is used for studying basic as well as applied ship and offshore problems. The basin is equipped with two carriages: One for towing up to 10 m/s for traditional calm water tests and a second carriage for seakeeping tests and other tests performed with fixed or free-running models. The main activity of the towing tank is related to studies of resistance and propulsion of ships. Other important activities are seakeeping in head and following seas, and directional stability tests with free running models and testing of tidal turbines. The tank is equipped with a wave maker.

The seakeeping carriage is custom made for seakeeping tests and other tests performed with free-running or fixed/towed models. The test-space, which is surrounded by the carriage structure, gives excellent control of the model and a good view for observation and video from all directions. The two fully movable work platforms provide excellent access to the models at the test location. The crane that spans the entire test space enables lifting most models out of the water for inspection or repair without disconnecting the test set-up. The carriage is designed and built by MARINTEK.

The multi-purpose carriage includes a 6 degrees-of-freedom motion platform, enabling the possibility of performing forced oscillation tests. Wind batteries can be fitted.

**Instrumentation**

All dynamometers compatible with computerized data collection and reduction. Strain gauge based dynamometers for:

- Towing force
- Open water tests
- Propulsion tests

Test equipment for fixed and floating structures measuring:

- Pressure
- Forces and moments in six degrees of freedom
- Displacement in six degrees of freedom

Modular force gauges give flexibility for special instrumentation requirements.

3-dimensional wake measurements by use of 5-holes pitot tubes.

6 component dynamometer for measurement of forces and moments of propellers and tidal turbines.

Marine track motion capture system for motion measurements in six degrees of freedom.

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## 11.4 FORWIND Hannover

### 11.4.1 Multidirectional Wave Basin (Franzius-Institute)

**Description and main characteristics**

The 3D wave machine (servo driven snake wave maker with 72 individual piston wave paddles) allows answering many questions related to basic research, as well as the study of practical engineering problems such as scour development, wave loads, offshore problems, revetment stability, stability of breakwater heads and research with oblique wave attack. The system is unique in the German research landscape.

**System Characteristics:**

| | |
|---|---|
| basin dimensions: | 25 m x 40 m |
| max. water depth: | 0 - 1.0 m |
| max. wave height: | 0.47 m (regular waves), 0.32 m (significant wave height) |
| wave spectra: | computer generated long- and short crested waves (theoretical, in-situ measured, focused waves, …) |
| wave generation direction: | 5° to 175° |
| active absorption control: | up to 6 Hz |

**Additional Instrumentation:** wave gauges,3DPIV, 2D and 3D current meter, pressure transducer, force transducer, ultrasonic sensors, displacement probes, video documentation

**Contact:**

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Managing Director and Chair at Franzius-Institute for Hydraulics, Waterways and Coastal Engineering

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### 11.4.2 FORSCHUNGSZENTRUM KÜSTE (FZK) - Large Wave FLUME (GWK)

**Description and main characteristics**

The Large Wave Flume (GroßerWellenkanal, GWK) is the core facility of Forschungszentrum Küste (FZK) and with 5 m width, 7 m depth, about 300 m length and wave heights up to 2.0 m one of the largest facilities of this kind worldwide. The huge dimensions of GWK are necessary to perform unique large-scale experiments for the investigation of certain phenomena, like e.g. breaking wave impact on or scour around structures, which cannot be arbitrarily downscaled. Results from the large-scale experiments fill the knowledge gaps of small-scale experiments and provide an ideal basis for the development or validation of theoretical approaches and numerical models in coastal and ocean engineering.

The data acquisition system at GWK has 144 channels with a maximum digitizing rate of 100 kHz per channel. The standard measurement equipment includes:

- Capacitive wire gauge for water surface elevation measurements,
- one-, two- and three-dimensional current meters,
- pressure transducers for wave impact pressures and pore-water pressure measurements,
- strain gauges, load cells, displacement meters and accelerometers for structural dynamics,
- single beam and multi beam echo sounders for under water detection,
- ultrasonic sensors for for water level measurements
- a synchronized video camera system,
- 2D and 3D laser scanner.

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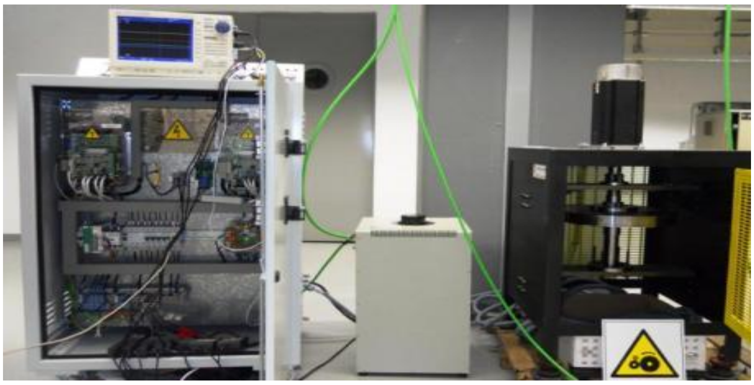
# 12 Electrical Test Facilities for Wind Energy (ETF)

The growing of penetration of wind energy is posing growing challenges on the electrical grid. The spread of the grid codes and the need to start providing ancillary services raises the priority of grid integration. New designs of generators and converters add even more interest to it. Europe is known for safe and demanding standards in most fields. However when it comes to wind testing the situation is not that clear.



Eight EERA Wind members from four European countries have supplied information about their facilities related to ETF.

| *Member* | *Country* |
|---|---|
| *NTNU (Norwegian University of Science and Technology)*<br>*SINTEF* | *Norway* |
| *CENER (National Renewable Energy Centre)*<br>*CIRCE (Research Centre for Energy Resources and Consumption)*<br>*IK4 - IKERLAND*<br>*IREC (Catalonia Institute for Energy Research)*<br>*TECNALIA* | *Spain* |
| *TUBITAK* | *Turkey* |
| *ORE CATAPULT* | *United Kingdom* |

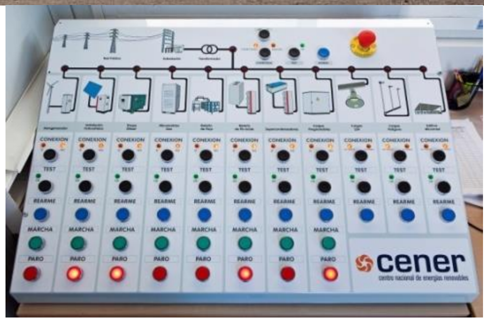
The following installations have been identified:

- CENER: Microgrid for industrial application
- CIRCE:
    - Renewable energy integration lab
    - Electrical Metrology Laboratory
    - Power quality analyser
    - Small power converter
- IK4: Medium Voltage Power Electronics Laboratory
- IREC: Network of testing facilities of wind turbines /wind farms for grid integration

- ORE CATAPULT: Electrical Systems and Materials
- SINTEF: Renewable energy/SmartGrid lab
- TECNALIA RESEARCH & INNOVATION:
    - Smart Grids Lab
    - Communication protocols lab
    - Electrical equipment laboratories
    - Electrical PTO lab
- TUBITAK: Electrical dynamometer test lab
- University of Strathclyde: Power Networks Demonstration Centre

Specific information about these research infrastructures is included in the following pages.

## 12.1 CENER: Microgrid for industrial application




### Description and main characteristics

It is a microgrid for industrial application, designed to supply part of the electrical loads of the specific facilities of the LEA.

The main objectives of the installation are to: manage the power generated at any given moment so that the energy supply to the assigned loads is always guaranteed; ensure that the power consumed by the loads comes, whenever possible, from renewable sources; protect the existing facilities from faults both from the electrical grid and from the microgrid; be able to send the energy surplus produced to the electrical grid, so that the microgrid does not operate isolated from the distribution grid but as an active part of it and act as a test bench for new equipment, generation systems, energy storage and control strategies, as well as microgrid protection.

The microgrid currently has the following major equipment at its disposal:25kWp photovoltaic installation, full-converter type 20 kW nominal power wind turbine, 55 kVA rated power diesel genset generating set, lead acid gel technology battery bank, able to supply 50 kW uninterruptedly for 2 hours, 120 kVA three-phase loads bank and a Vanadium Flow Battery with capacity to provide 50 kW for approximately 4 hours.

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## 12.2 CIRCE

### 12.2.1 Renewable Energy Integration Lab


**Description and main characteristics**

CIRCE runs the Renewable Energy Integration Laboratory, which consists of a micro-grid that includes four asynchronous squirrel-cage benches between 22 kW and 90 kW and two permanent magnet generator benches (4 and 50 kW) and energy storage systems based on supercapacitors and Ion-lithium batteries.
They are used to optimize renewable energy generation systems, reversible pumping systems, energy storage and connection to the grid. In addition, control policies for AC and DC micro-grids are tested.
Near the laboratory it is placed a vertical windmill with a 4 kW permanent magnet generator and an electric vehicle charging point that includes: three electric vehicle charging points with different working modes (mode 2, 3 and 4-CHAdeMO), electric energy storage system and a 1 kW photovoltaic generator. In front the laboratory it is also placed a 50 kW inductive charging point for electric vehicles. There are also two real electric vehicles (with conductive and inductive charging capabilities (CHadeMO + mode 2 charge / mode 1 + inductive) and an electric vehicle emulator to tests the performance of different charging systems.
The laboratory also includes a 2 and a 30 kW inductive coupling prototype for research activities into power transfer by an inductive coupling field. A high-efficiency power electronics configuration has been added to the transformer station, to provide the FACTS functionality (Flexible Alternating Current Transmission System) and FAP (Active Power Filter).
More research activities are conducted at a Laboratory in the dam of Valdabra; The "Valdabra Laboratory" is located in a real size pumping facility formed by three pumps of 200 kW connected to a weak electrical grid. The laboratory consists of a DC micro-grid, connected to the pumping station, composed of a 250 kW wind turbine, a reversible hydraulic pump of 160 kW and 7 MJ of energy storage based on super-capacitors. The micro-grid is able to work connected to the grid or isolated. The installation has a SCADA system for remote controlling.
Technical applications;

1. Power electronics configurations.
   - Technology upgrading of wind turbines, changing generators from fixed speed to variable speed, able to support dips according to PO12.3.
   - Variable speed hydroelectric generation systems and reversible pumping. Hydropumping with wind energy support, both grid-connected and isolated.
2. Improvement of grid quality and security of supply in weak grids.
   - Development of FACTS (Flexible Alternative Current Transmission Systems) and FAP (Active Power Filtering).
   - Distributed generation: integrated management of generation and storage systems for the connection to weak grids.

- Research and development in direct current micro-grids and smart managing.
- Reduction of the harmonic levels in the electrical grid, optimization of energy balances, reactive power compensation.

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| **Contact:** | José Francisco Sanz<br>Director at Integration of Renewable Energy (IER), CIRCE<br>jfsanz@fcirce.es /34 976 761863/<br>http://www.fcirce.es/web/page.aspx?id=labier |

### 12.2.2 Electrical Metrology Laboratory

**Description and main characteristics**

The Electrical Metrology Lab (LME-CIRCE) began its activity in 1983. LME-CIRCE complies with all the specifications of the UNE-EN ISO/IEC 17025 regulations. In 1997, it received accreditation from ENAC (Spanish National Accreditation Body) in direct current and low frequency electricity, and received accreditation in 2007 for measurement tests in Wind Turbines and Distribution networks. Since November 2011 it is also member of MEASNET (Measuring Network of Wind Energy Institutes), an international organization created for the collaboration of different institutions specialized in wind energy. Its objective is to ensure the quality of measurements, unify standards and recommendations and ensure the interchangeability of results.

There are three lines of activity:

- Electrical calibration area: With the accreditation of ENAC (Spanish Accreditation Body) to realize electrical calibration both in the laboratory as well in the client´s installation
- Electric testing area: With MEASNET accreditation to execute test of power curves in wind turbines and ENAC accreditation for testing wind turbines and electrical distribution grids
- High Tension Lab: Dielectric test of the protection equipment and on-site calibration of wind turbines and high voltage divider.
- The LME-CIRCE uses an own developed measurement system that separately measures voltage and current values in each phase at a sampling rate of 6.4 kHz. These data is instantaneously synchronizes with those provided by the meteorological mast. This measurement device includes a GSM/GPRS communication module in order to allow the test completion to be remotely checked and several digital entries. It allows the equipment to easily record all required wind turbine’s status signals.

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### 12.2.3 Power Quality Analyzer (QUALIZER)


**Description and main characteristics**

FORES is a technology-based company born in 2010 as a spin-off from CIRCE, dedicated to optimizing renewable energy to make it more efficient and ensure its safety. CIRCE/4fores has different recording devices "**QualiZer**" with remote access with which can perform tests and collect information about field-tests without the need of having technicians in the site. The main characteristics of the equipment are:

- Fast and wide reconfiguration of parameters.
- Possibility of remote control.
- Automatic generation of daily, weekly or monthly reports.
- Variable sampling frequency.
- Simple and friendly interface.

**QualiZer** is smart recorder equipment capable of acquiring and processing signals with a high flexibility and easy handling. This device has been designed, developed and manufactured to measure in real time the most important electrical.

This is achieved by implementing fast math functions in software and displayed by automatic reports which will allow the customer to save much time. In such a manner the client could always know how their generation plant is working and get the following benefits:

- Optimization of the production by controlling system´s parameters.
- Fulfilling of requirements of the international grid codes.
- Quick Detection of errors.
- Several types of communication´s interfaces.
- Ad-hoc software solution.
- Data storage and process for each type of test according different standard in the same time.
- Possibility to configure free test with the parameters that customer needs.

Within this facilities, CIRCE/4fores, as part of the Electric Metrology Laboratory, can perform accredited tests for the most extended regulations and standards:

- P.O. 12.3, P.O. 12.2. (Spain)
- FGW TG3 and FGW TG4 (Germany)
- IEC 61400-21 Ed. 2. (Europe)
- MEASNET (power curve)

In the same time, CIRCE/4fores has carried out tests and reports according to different Grid Codes:

- Europe: UK, Poland, France (ERDF and RTE), E.O.N. (Italy), Croatia
- North America: EEUU, Canada
- South America: Ecuador, Brazil
- Asia: China

Furthermore, CIRCE/4fores have also carried out specific customer´s requirements such as:

- Precertification and validation tests.
- External audit in power plants with failures in their electrical behavior.

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### 12.2.4 Small Power Converter Lab

**Description and main characteristics**

FORES is a technology-based company born in 2010 as a spin-off from CIRCE, dedicated to optimizing renewable energy to make it more efficient and ensure its safety.

In 2015, an agreement between the municipality of Maria de Huerva, in the province of Zaragoza (Spain), and CIRCE/4fores is achieved. This deals with the use of municipal lands for the implementation of an experimental testing site for hybrid generation systems.

The purpose of this testing site is to carry out tests in different generation and control systems (converters) for both off-grid and on-grid applications, to verify that this equipment comply with the requirements demanded by each grid code and have technical values acceptable by customers and market.

This outdoor laboratory shall have a system capable of:

- Managing different loads and modes of operation (off-grid, on-grid, batteries,...)
- Monitoring grid quality
- Performing low voltage ride through testing according to different grid codes
- Analyzing production values of active and reactive energy
- Communicating references points to the system (values, ramps, etc.) in order to check the good tracking of the generation systems

CIRCE/4fores has promoted this experimental park taking into account adequate gust and speed wind and solar conditions. This will allow the validation of the prototypes in order to facilitate the process of certification of new small generation systems.

CIRCE/4fores, as a promoter of the park, has the authority to grant the authorization in order to be user and install such facilities within the site and to provide for priority to companies that use or have used their services in a stable manner.

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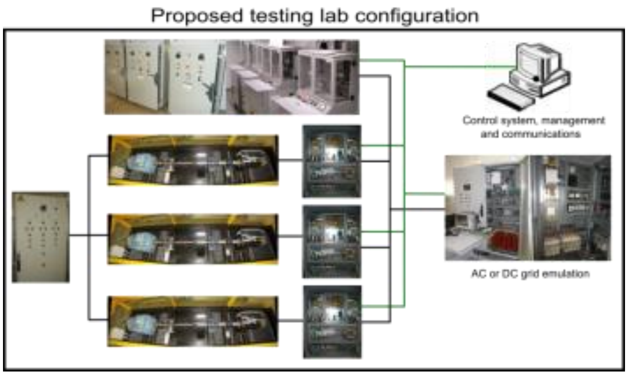
| **Contact:** | Susana Martín<br>Manager at Electrical Power Systems (GISEP), CIRCE<br>smartin@fcirce.es /+34 876 555286/<br>http://www.fcirce.es/web/page.aspx?id=innovase |

## 12.3 IK4-IKERLAND

**Medium Voltage Power Electronics Laboratory**

| Description and main characteristics | |
|---|---|
| IK4-IKERLAN's Medium Voltage Power Electronics Laboratory allows electrical tests to be conducted for low voltage (400V AC) and medium voltage (up to 4kV DC) power electronic converters and storage systems in grid connected or drive oriented applications. It's fully equipped with: 2 Adjustable DC power sources up to 4 kV and 150 kW, 2 ABB ACS800 110 kW regenerative drives, 150 kW three-phase 400 V transformers, a 20 kW water cooling system, and a modular dSPACE control system for monitoring and converter/storage system integration testing through the emulation of real consumption profiles. | |
| **Contact:** | Aron Pujana-Arrese<br>apujana@ikerlan.es<br>IK4-IKERLAN |

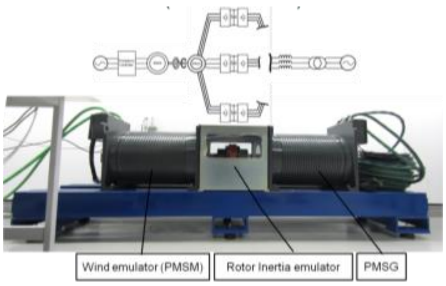
## 12.4 IREC: Network of testing facilities for grid integration




**Description and main characteristics**

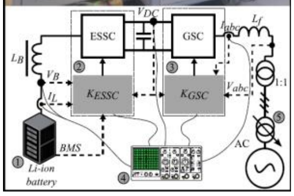
In IREC, we have laboratory facilities especially developed for grid integration studies. This equipment provides the user with a versatile tool capable to reproduce a wide type of scenarios and different levels of similarity to the reality, always focused on electrical issues. IREC's electrical lab is currently operating with a number of configurable units. Some of the units can be configured to work as wind turbines, energy storage nodes or energy consumption nodes. Also, real storage systems (flywheel, super-capacitors and batteries), wind emulators (SCIG, DFIG, PMSG and Multiphase PMSG) and PEV charging point are integrated. Finally, there is also a grid emulator allowing studying different grid perturbations and configurations. They can be combined forming different possible configurations. An example of possible combination obtaining an offshore wind power plant is shown in the previous figure.

In the electrical laboratory there is also a scale platform of a full equipped multi three-phase generator based wind turbine. It can be also connected to the grid emulator for testing grid faults.



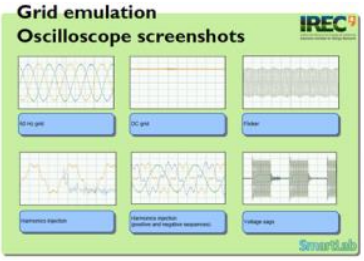

Moreover, the research infrastructure includes three different types of energy storage systems namely Fly-wheel, ultracapacitors and Li-ion batteries connected to the rest of the laboratory by means of back to back converters. The energy storage systems can be controlled independently or together with any of the other generators. From the joint connection of emulators and energy storage, for example, power smoothing techniques can be validated, for increasing power quality of the power delivered.






Also, IREC’s laboratory includes emulated devices (referred to as emulators) which are flexible units that can generate variable active and reactive power. Emulators can be configured to behave as wind turbines or PV arrays, batteries, variable loads, electric vehicle (EV) chargers, etc. In IREC’s laboratory there are 5 of these units. The emulators are capable to reproduce any P and Q profile to reproduce the behaviour of the desired energy conversion technology. The emulators are also integrated in the whole laboratory infrastructure, allowing reproducing a whole wind farm, and see how they would respond for a grid disturbance generated by the grid emulator.


In the electrical laboratory of IREC, there is, as said before, a grid emulator. It is an AC/DC-DC/AC power converter. It is capable to generate configurable voltage supply at the terminals, including: Voltage disturbances (sags, flicker, frequency deviations, amplitude, etc), control and generation of voltage harmonics, DC voltage supply, be used as a hardware in the loop (HIL) equipment, among other capabilities.



In IREC we have been working in several projects related to grid integration of wind power plants in the last years. We are very interested in participating in the Research facilities Network for wind turbine grid integration studies. Our research group works in electrical and grid integration aspects validating research carried out experimentally in our research infrastructures. The laboratories have been widely used for experimental validation of various research and industrial projects.

| | |
|---|---|
| **Contact:** | Dr. Oriol Gomis-Bellmunt<br>Group Leader Power Electronics at IREC<br>ogomis@irec.cat / 933 56 26 15 / www.irec.cat |

### 12.5.1 Electrical Systems and Materials (Electrical Test Facilities)

## Description and main characteristics

ORE Catapult is the UK's national research centre for accelerating grid integration of renewable energy systems and catalysing the development and deployment of offshore wind, wave and tidal energy generation technologies.

We provide specialist consulting and test services, assisting clients to develop products to cater for the needs of the developing power systems and exploring life extension opportunities for ageing assets. The Charles Parsons UKAS accredited laboratories are equipped with specialist test and measurement facilities used to carry out component development, materials selection, system certification, electrical grid integration and accelerated lifetime test programme delivery.

**Capabilities**

- **Electrical Test Laboratories:** High voltage, high current, lightning impulse, partial discharge, RIV, corona protection, thermal stability, temperature rise and power quality test facilities.
- **Materials Test Laboratories:** Metallurgy services, mechanical failure investigations, HV insulation materials characterisation, corrosion assessment, paint and other coating assessments, organic and inorganic analysis, characterisation and performance tests on oils, polymeric and composite materials, $SF_6$ handling and oil processing capability.
- **Environmental Test Laboratories:** Environmental chamber (-40 °C to +180 °C & 10% to 98% RH) with internal HV live testing capability, high humidity/salt corrosion assessment/studies, IP and wet testing for HV tests.
- **Mechanical Test Laboratories:** Vibration test facility (shaker table), mechanical lift, impact testing.
- **Low Voltage Power Network:** Investigation, demonstration and emulation of a wide range of intelligent network elements, including prime mover and load elements, configured to represent the effects of generators in the field.

| | |
|---|---|
| **Contact:** | ORE Catapult National Renewable Energy Centre, Offshore House, Albert Street, Blyth, Northumberland NE24 1LZ<br>Ignacio Marti T +44 (0)1670 359 555 / F+44 (0)1670 359 666<br>info@ore.catapult.org.uk / ore.catapult.org.uk |

## 12.6

## 12.7 SINTEF & NTNU: Renewable energy/SmartGrid lab

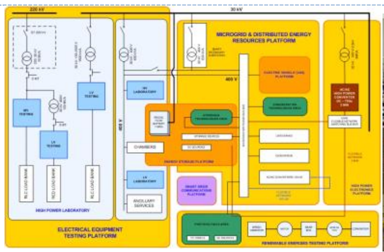
| **Description and main characteristics** | |
|---|---|
| The joint SmartGrid lab of NTNU and SINTEF is designed as a flexible structure where passive electrical components, electrical machines and power electronic converters up to 70 kVA power range can be tested.<br><br>The Renewable Energy/SmartGrid lab is suited for scaled experiments regarding research on novel generators, power electronics, control systems and their interaction in a strong, weak or isolated grid. Short-circuit fault emulation can also be done.<br><br>The lab has three generator sets rated at 100, 50 and 17kVA that have significantly different inertia. A new addition to the lab includes a 10kHz bandwidth grid emulator controlled by an OPAL-RT, thus enabling Power-Hardware-in-the-Loop (PHIL) testing. The lab is owned and operated jointly by SINTEF Energy Research and NTNU. | |
| **Contact:** | Salvatore D'Arco salvatore.darco@sintef.no<br>Ole Christian Spro OleChristian.Spro@sintef.no<br>www.sintef.no/energylab<br>Ole Christian Spro<br>OleChristian.Spro@sintef.no |

## 12.8 TECNALIA

The following electrical laboratories are operated by TECNALIA:

- INGRID-Smart Grids Laboratory
- Communication Protocols Laboratory
- EMC Laboratory
- Electrical Equipment Laboratories
- Electrical PTO Laboratory

### 12.8.1 INGRID-Smart Grids Laboratory



**Description and main characteristics**

TECNALIA Research & Innovation test facilities for smart grids are organised around it. The key research and testing activities of this lab are: advanced power system architectures, microgrids for buildings and districts, new power converters for grid connection, smart metering and grid automation, electric mobility (infrastructure, V2G), demand side management and demand response

In practical, the facilities consist basically on a set of interconnected testing platforms which are shown in the attached layout and listed below :

1. Electrical equipment testing platform (includes high power lab and MV&LV lab)
2. Microgrid and Distributed Energy Resources (DER) testing platform
3. Energy storage platform
4. Smart grids communication platform
5. Renewable energy testing platform
6. Electric Vehicle testing platform
7. 7. Power electronics and energy conversion platform

| | |
|---|---|
| **Contact:** | Angel Díaz Gallo<br>Director of Smart Grids Business Unit<br>angel.diaz@tecnalia.com / + 34 946 430 850 / www.tecnalia.com |

### 12.8.2 Communication Protocols Laboratory

**Description and main characteristics**

TECNALIA Research & Innovation develops testing tools and certification services to ensure the correct implementation of the communication protocols. According to the

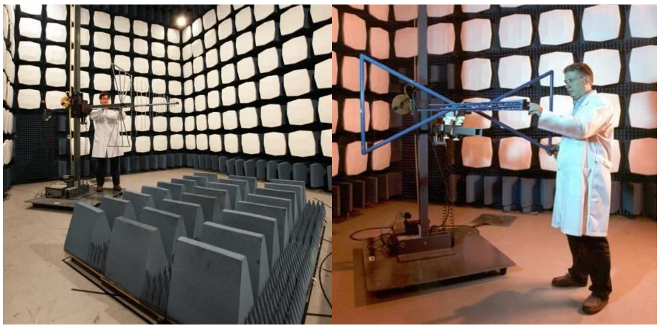
Smart Grid Co-ordination Group hundreds of protocols are implemented in the Smart Grids. TECNALIA is recognized internationally and specialized in the communication and telecommunication protocols for:

- PRIME PLC communications
- DLMS/COSEM data storage
- Meters & More PLC communications
- IEC 60870-5-104
- GPON FTTH
- …

Our testing tools are used by laboratories like DNV GL (KEMA), ITE and LABELEC.

| | |
|---|---|
| **Contact:** | Ibon Arechalde<br>EMC & Telecom Lab Manager at TECNALIA RESEARCH & INNOVATION<br>Ibon.arechalde@tecnalia.com / 902 760 020/ www.tecnalia.com |

### 12.8.3 EMC Laboratory



**Description and main characteristics**

**Main Features**

- Compliance with CISPR 16-1 y EN 55022
- EMI Measurements at 3 m
- Lightning Level in compliance with IEC 61000-4-3
- Levels of residential and industrial Immunity
- Rotating platform of 2 m diameter
- Range of Frequencies from 9 kHz to 18 GHz
- 

**Equipment to be tested**

- Electrical Equipment
- Measurement, Protection and Control Equipment
- Smart Meters and Smart Data Concentrators
- Inverters & Professional Electronics
- ICT & Telecom Equipment
- Transformers
- Switchgear&Control gear
- Household Appliances

| | |
|---|---|
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### 12.8.4 Electrical Equipment Laboratories

**Description and main characteristics**

**Power Laboratory**

**Ratings**

- At Low Voltage (≤ 1000 V): Up to 200 kA
- At Medium Voltage (≤ 36 kV): Up to 8 kA

**Tests**

- Ability to withstand Shortcircuits
- Short-time and Peak Withstand Current Tests
- BreakingCapacity
- Making and Breaking
- InternalArcing

**High VoltageLaboratory**

**Ratings**

- PowerFrequency (550 kVrms)
- Lightning Impulse (800 kVpeak)

**Tests**

- Power Frequency Withstand Voltage (dry and wet conditions)
- InducedVoltage
- Lightning Impulse
- PartialDischarges and RIV
- Tan delta &Capacitance
- Instrument Transformers Temperature-rise
- AgeingwithPollution
- Voltage-CurrentcombinedTests

**Low Voltage Laboratory**

**Tests**

- Temperature-rise (up to 12.000 A)
- Dielectrics
- Degree of Protection (IP and IK)
- Tracking, Flammability
- MechanicalEndurance
- InsulationResistance
- ThermalCycles
- Transformers: No-load, Shortcircuit, Ratio, etc
- Functional

**Environmental Tests Laboratory**

**Tests**

- Cold
- Dry and Wet

- Thermal Shock
- Temperature and HumidityCycles
- Salt Mist
- Resistance to Corrosion ($SO_2$)
- Vibrations and Shock
- Free Fall
- Hammer

**Power Electronics Laboratory**

**Ratings**

- LV Microgrid powered with AC and DC buses
- AC power supply: 165 kW
- DC power supply: 150 kW

**Tests**

- PV Inverters
  - Functionaltests
  - Anti-islanding
  - Voltagedips
- Smart Meters
  - PRIME Protocol Certification
  - CENELEC EN 50065-1, EN 50065-2-3, EN 50065-7
  - DLMS
  - Interoperability
  - Efficiency
  - EMC
  - Climatic & mechanical
- Other electronic equipment: CHP, UPS, batteries, etc

| **Contact:** | Luis Martínez<br>Researcher & Lab Manager at TECNALIA RESEARCH & INNOVATION<br>Luis.martinez@tecnalia.com / 902 760 020/ www.tecnalia.com |
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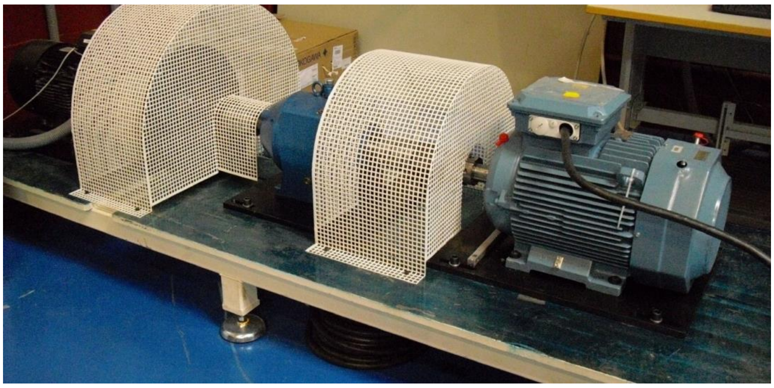
### 12.8.5 Electrical PTO Laboratory



**Description and main characteristics**

**Turbine emulator to simulate the mechanical output of an ocean energy device/wind turbine. It allows to:**

- Validation of the concept from the electrical point of view
- Tuning, comparison and validation of speed/torque control of the generator. Comparison of the behaviour of the system and control in non-ideal conditions
- Compare different control laws in terms of efficiency and power quality

- Grid connection
- Different sea-states, repeatability. Repeat sea/wind working conditions (based on field measurements) which lead to failures to debug the system.
- Validate the device models

**in a controlled lab environment, reducing risks and development time before the deployment of the system.**

**Test bed features:** 12 kW nominal power and 768 rpm rated speed

- Motor
  - Performed by a PC control board. Fully controllable torque or speed commands
  - Programmable user defined turbines characteristics under arbitrary sea states/sea currents/wind conditions can be programmed.
- Generator: Induction generator
- Generator control
  - Performed by a PLC. Torque or speed commands updated every 10 ms
  - Fully controllable in speed or torque control modes. Arbitrary torque or speed waveform references
  - Programmable user defined control softwareInertia
- Inertia: Currently installed with a 1 kgm2 flywheel
- Grid connection
  - Direct grid connection
  - Grid connection through a full power back-to-back power converter
  - Fully configurable grid available for the grid connection

| | |
|---|---|
| **Contact:** | Eider Robles<br>Researcher at TECNALIA RESEARCH & INNOVATION<br>eider.robles@tecnalia.com / 902 760 004 / www.tecnalia.com |

## 12.9 University of Strathclyde – Power Networks Demonstration Centre

**Description and main characteristics**

The PNDC at Strathclyde is an environment for accelerated testing, demonstration and validation of existing and novel operation, control, protection and automation technologies aiming to facilitate the deployment of distributed generation and renewable energy.

In summary, the Centre consists of an outdoor compound containing overhead and underground 11 kV equipment, comprising pole- and ground-mounted transformers and substations with associated protection and control equipment. There are test points at which devices to be demonstrated can be connected directly to the 11 kV network. An LV network is also available, supplied via several transformers from the 11 kV system. The LV network can be loaded using a variety of programmable load banks, and contains points for connections of devices under test. An industry-standard supervisory control and data acquisition (SCADA) system with control room, a real time power system simulator (RTDS), a large indoor LV laboratory and several other laboratories, along with comprehensive high-fidelity monitoring and data historian facilities are also available and complement the primary system hardware existing at the Centre.

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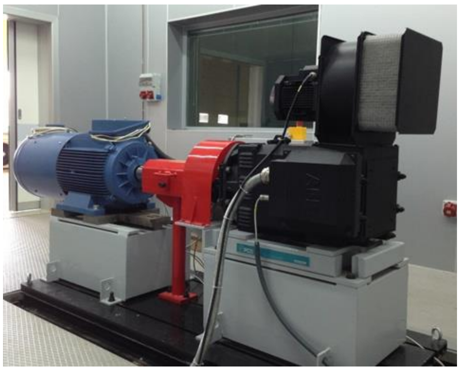
|---|---|
| **Contact:** | Prof. William Leithead / Dr. Olimpo Anaya-Lara<br>w.leithead@strath.ac.uk |

## 12.10 TUBITAK: Electrical Dynamometer Test Lab

**Description and main characteristics**

Up to 500 kW powered generators, industrial type motors and their drivers can be tested.

2 dynamometers:

- 500 Kw
- 90 kW

4500 Nm, 3000 rpm, 500 kW (500 kW); 700Nm, 3000 rpm, 90 kW (90 kW)

Real time data acquisition;

- Torque
- Speed
- Temperature
- Current
- Electircal and mechanical power

| | |
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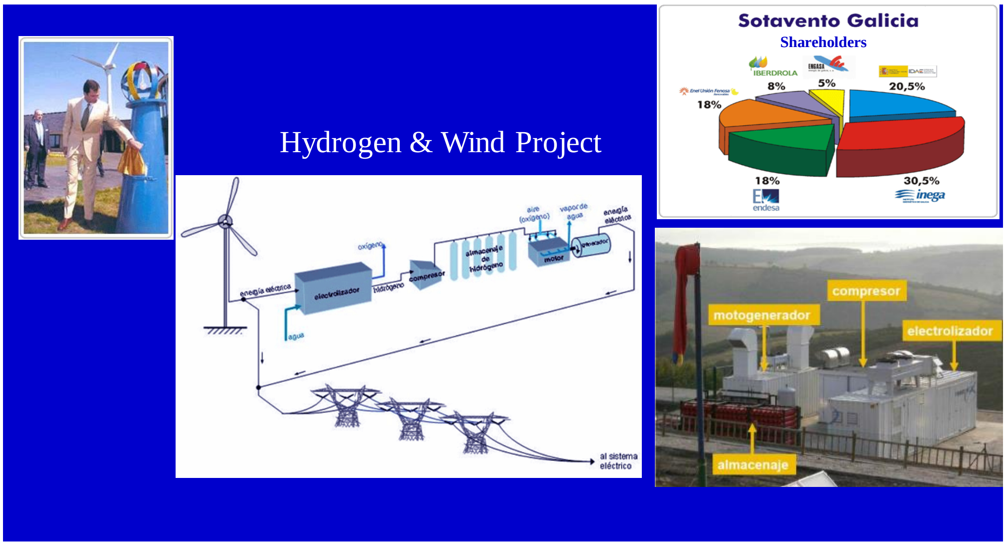
| **Contact:** | Ersen AKDENİZ<br>ersen.akdeniz@tubitak.gov.tr<br>+90 262 677 27 67 |

# 13 Applications Test Facilities (ATF)

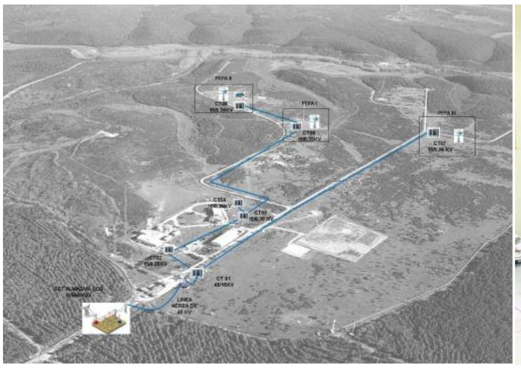



The following installations have been identified:

- CEDER-CIEMAT: Distributed Energy test facility
- CIRCE: Voltage dip tests mobile laboratory and quality test for energy systems lab
- LNEG
- SINTEF: ETEST

Specific information about these research infrastructures is included in the following pages.

### 13.1 CEDER-CIEMAT: Distributed Energy test facility




**Description and main characteristics**

It is the aim of CIEMAT to use the installations at CEDER (Soria) as an experimental facility for micro-grids testing. These installations include:

- **Electrical infrastructure:**
    - Several buildings, operating as loads for the microgrid
    - Transformers
    - Renewable generators (solar 15kW, wind 100kW, 30 kW mini-hydro)
    - Diesel generator set (50 kVA) with a clutch to allow the synchronous generator to work as a synchronous capacitor in order to regulate reactive power
    - Storage systems (100+50 kWh Lead-acid batteries, 50 kWh Li-ion battery, flywheel, hydrogen, supercapacitors)
    - Dump load (40 kW controllable loads)
- **Communication infrastructure:**
    - Distributed cable and OF network
    - Distributed monitoring, supervisory control and communication functions through distributed nodes for each component of the micro-grid
    - Distributed smart-meter network
    - Full external internet access
- **Cold / Heat infrastructure**
    - Central District Heating already working for building temperature conditioning
    - Biomass boilers forming the core of the District Heating system
    - Controllable electric boiler (up to 100 kW) included in the District Heating
- **Hydrogen infrastructure**
    - Biomass gasifier (0.5 MWt)
    - Some hydrogen loads from HYCHAIN project
    - Possibility of collaboration with the Fuel Cell Group in CIEMAT-Madrid

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|---|---|
| **Contact:** | Luis Arribas - lm.arribas@ciemat.es<br>Luis Hernández - luis.hernandez@ciemat.es<br>Phone: +34 975281013<br>http://www.ciemat.es/CEDERportal/portal.do?TR=C&IDR=112 |

### 13.1.1 CEDER-CIEMAT: Flywheel Test Laboratory

 

**Description and main characteristics**

CEDER-CIEMAT has the only laboratory in Spain which is equipped to carry out all types of rotary flywheel tests for their application in kinetic energy storage systems, at high speed (up to 63,000 rpm), with modular equipment to test rotors and other vertical axis components. The system allows for the testing of fatigue cycles and over speeding as well as of destructive testing for the failure of flywheels manufactured in metal or composite materials.

Technical specifications

- Metallic Flywheel
  Weight: 400 kg
  Diameter: 990mm
  Length: 950mm
- Composite Flywheel
  Weight: 2-3 kg
  Diameter: 260 mm
  Length: 300mm

Available tests

- Stress test: maximun speed and 63000 rpm and maximun aceleration 9999 rad/s².
- Burst Test. Overspeed burst test.


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|---|---|
| **Contact:** | Oscar Izquierdo<br>Oscar.izquierdo@ciemat.es<br>Phone: +34975281013<br>http://www.ciemat.es/CEDERportal/portal.do?TR=C&IDR=112 |

## 13.2 CIRCE

### 13.2.1 Voltage DIP Tests Mobile Laboratory

| **Description and main characteristics** |
|---|
| In 2007, the first electrical test device was designed, built and put into use to verify compliance with Spanish P.O.12.3: the voltage dip mobile laboratory – CIRCE's MEGHA.<br>The MEGHA electrical test system, acting as a mobile electric substation, makes it possible to carry out tests on wind turbine behaviour when faced with 5MW voltage dips. For the verification of P.O.12.3, the AEE's (Spanish Wind Energy Association) Verification and Validation Process is applied.<br>This system is interconnected with the evacuation line for electrical power generated by wind turbine(s) in the wind farm and the specific wind turbine being tested.<br>Voltage levels up to 20 kV and power levels up to 5 MW.<br>Voltage dips generator in accordance with the international standards, being able to select the length of the dip, the depth up to 100% with adjustable variation steps and as many depth levels as desired, to address several failure types.<br>The equipment is able to generate three-phase, two-phase (isolated or to ground) and single-phase dips.<br>It is also capable of controlling the power of the short circuit that affects the wind turbine and isolates the rest of the grid from the induced faults.<br>http://fcirce.es/web/page.aspx?id=labMEGHA |

### 13.2.2 Quality Test For Energy Systems Lab

| **Description and main characteristics** | |
|---|---|
| QuEST Lab is designed to test equipment up to 10MW (depending on network conditions) and also electrical networks up to 20 kV. Due to having more than 10,000 settings combinations, QuEST Lab is perfectly adaptable to any required test condition. By using the new QuEST Lab we were able to minimize the aloud disconnection time, reaching almost no generation losses during the process. The generator would be disconnected only at the exact time when the serial connection between the electrical network and the tested equipment through the QuEST Lab is turned on.<br>Before completing the essays, the necessary simulations are performed to determine the most appropriate parameters, configurations and adjustments for the QuEST Lab, depending on the electrical grid layout and the required tests. Once this is done, the automated setup process does the rest to make sure the QuEST Lab is ready to start all the essays. QuEST Lab has a protection system for any undesired disturbance event that could happen; which in this case would be activated and thus protect the facility tested as the portable laboratory.<br>Test characteristics:<br>• Testing swells up to 30% above rated voltage.<br>• Voltage dips in the entire range of voltages from nominal voltage to zero.<br>• Phase shifts of up to 35º | |
| **Contact:** | Susana Martín<br>Manager at Electrical Power Systems (GISEP), CIRCE<br>smartin@fcirce.es/ Phone: +34 876555286/<br>http://www.fcirce.es/web/page.aspx?id=labquest |

## 13.3 LNEG


| Description and main characteristics | |
|---|---|
| The cluster computing is based on a SGI Altrix system, equipped with a head node and eight node servers linked together via Infiniband connection at 40Gbits. The system has a total 16TBytes of hard disk space and share 144 Intel Xeon E52680 cores and 320GBytes RAM. The system is controlled by the CentOS linux system version 6.5 and has available libraries for MPI and OpenMPI applications and different C and C++ and Fortran Compilers. The system runs different atmospheric mesoscale models such as the MM5, WRF, ARPS and RAMS. It will be also expected, in a near future the implementation of the oceanic model WW3 and its coupling into mesoscale models. The system also has been running the CFD model OPENFOAM in order to analyse turbulence effects and wind flow disturbance in complex orography and obstacle influences under the study area. | |
| **Contact:** | Ana Estanqueiro<br>ana.estanqueiro@lneg.pt<br>Phone: +351 210 924 773 Ext.:4773<br>Fax: +351 217 166 966 |

## 13.4 SINTEF: ETEST

| Description and main characteristics | |
|---|---|
| ETEST is a mobile low voltage fault ride through test laboratory for testing the response of voltage dips on full scale wind turbines, up to 8 MVA. ETEST will be available for testing from Q2 2013 on.Reference Access Conditions are preliminary and negotiable. | |
| **Contact:** | Helge Seljeseth<br>Research Scientist at SINTEF Energy Research<br>Helge.Seljeseth@sintef.no / +47 73597200 / www.sintef.no |

# 14 Other Testing Facilities (OTF)

In this group has been included other research infrastructures used for wind energy research that does not fir in the others groups. The following installations have been identified:

- CTC: Navigation Systems Laboratory
- IREC: Semi-virtual dynamic testing laboratory

## 14.1 CTC: Navigation Systems Laboratory


**Description and main characteristics**

The Navigation Systems Laboratory is oriented to the development of Navigation Systems, Stabilized Platforms as well as other applications which demand the utilization of navigation sensors.

The GNSS test equipment comprises a wide variety of test and validation systems ranging from high accuracy Navigation Systems that can be used as reference systems, to external clocks, GNSS antenna splitters and "mass market" low-cost sensors.

It is remarkable the relevance of the equipment intended for the characterization and modeling of sensors and systems:

- ACUTRONIC SIMEX TWO 2-axis motion simulator with removable temperature chamber and 45 kg maximum payload for modeling and calibration of MEMS inertial sensors and stabilized platform testing (Hardware-in-the-loop).
- Test-bed for the development of GNSS attitude determination systems and antenna calibration (Phase Center Variation). It includes a high accuracy 2-axis rotary table.

http://ctcomponentes.es/en/navigation-systems-lab/

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|---|---|
| **Contact:** | María Campo-Cossío Gutiérrez<br>Head of the Industrial Automation and Robotics Area at CTC<br>mcampo@ctcomponentes.com/ +34942766976 / www.ctcomponentes.es |

## 14.2 IREC: Semi-virtual dynamic testing laboratory

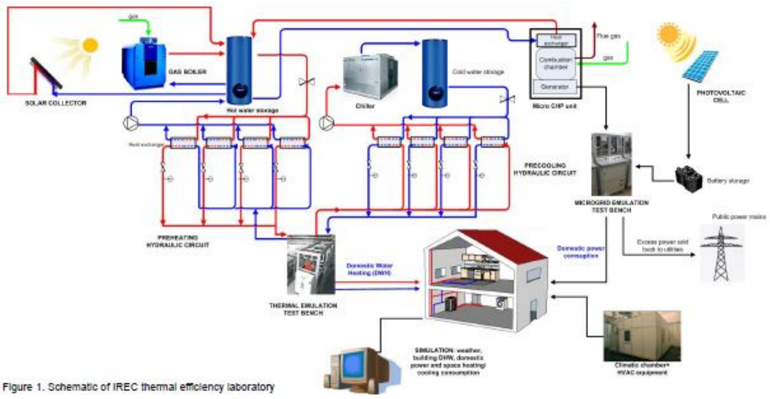

Figure 1. Schematic of IREC thermal efficiency laboratory

### Description and main characteristics

It has recently been set- up to assess the integration of diverse thermal and electrical equipment for the development of the concept of Net Zero Energy Buildings (NZEB). The laboratory is provided with cutting-edge technology comprising diverse systems for the generation and storage of heat and power, an active network system for DWH (domestic water heating), facilities for testing HVAC equipment and microgrid interaction. These elements are integrated and driven by the energy loadings from a numerically-simulated virtual building developed with the software TRNSYS. The laboratory is pioneer in addressing the smart integration of electrical and thermal components and aims to become a leading experimental facility for improving the development of Net Zero Energy Buildings.The objectives of the IREC thermal efficiency laboratory are to optimise the efficient usage of energy in buildings by investigating:

- The performance of active hydraulic systems for DWH, space heating and cooling and/or combined heat and power equipment in buildings.
- The integration of NZEB and smart grid concepts including electrical systems or combined thermal and electrical systems.

| | |
|---|---|
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# 15 Contact Points

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Denmark

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This document will be yearly updated by the Research Infrastructures Group and will be submitted for approval to the Steering Committee.


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