Low temperature compliance testing of wind turbine applications for the ‘cold climate’ market

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sirris
driving industry by technology

Vrije Universiteit Brussel

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Introduction

- **Sirris - collective technology centre in Belgium**
  - Supporting companies with implementing technology innovations
  - Multidisciplinary R&D and innovation projects in technology industry
  - Different technology sectors: Automotive, Energy, Aerospace, ICT, …
  - Different key expertise: ICT, Manufacturing, Mechatronics, Materials
  - High-tech test and R&D infrastructure

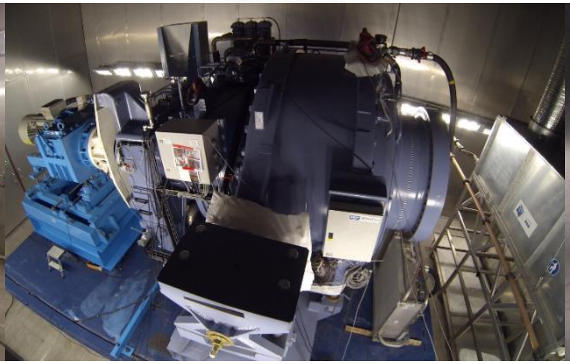
- **OWI-Lab - RD&I center for wind energy in Belgium**
  - Set-up in 2010 as a new application lab at Sirris to support wind energy R&D
  - Scope: wind energy in general - focus on '**offshore wind'** and '**cold climate'**
  - Range of new and unique test & monitoring infrastructures
  - Partnership with 3 Belgian universities for wind energy research (VUB, KU Leuven, UGent)

  - Member of IEA Wind Task19 Wind Energy in Cold Climates


Low temperature test experiences at our Climatic Test Lab

Unique test infrastructure – large climate chamber

- **Public large climatic test chamber for wind turbine applications** (+60°C to -60°C / Humidity / IR-Solar load)
- **Focus: climatic validation tests of wind turbine equipment (cold, hot-tropical and offshore climates)**



Full size small & mid-range wind turbine nacelle (or assembly) tests

Power electronics tests
Pitch & Yaw cold starts
Hydraulic brake tests
Generator tests

Smart solutions.
Strong relationships.

Functional component testing with or without wind turbine auxiliaries (forced cooling, pumps, heating, expansion tank, lubrication unit,…)

Electrical, mechanical and hydraulic components as gearboxes, transformers, switch gears, power electronics, anti & de-icing systems,…

R&D tests on the behavior of fluids, oils and hydraulics in a full functional set-up

Driver for the ‘testing topic’ within the wind power business

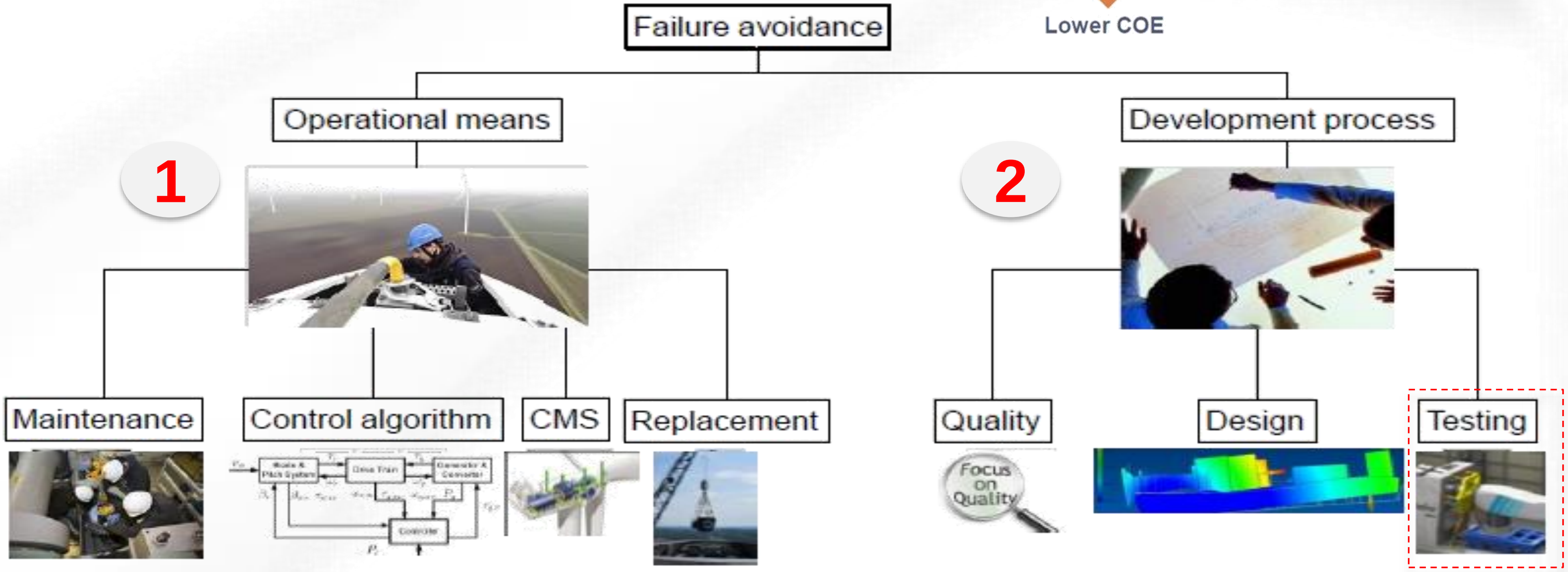
$$COE = \frac{CAPEX + OPEX}{AEP}$$

Higher reliability and better maintenance

Lower downtime

Lower OPEX and higher AEP

Lower COE

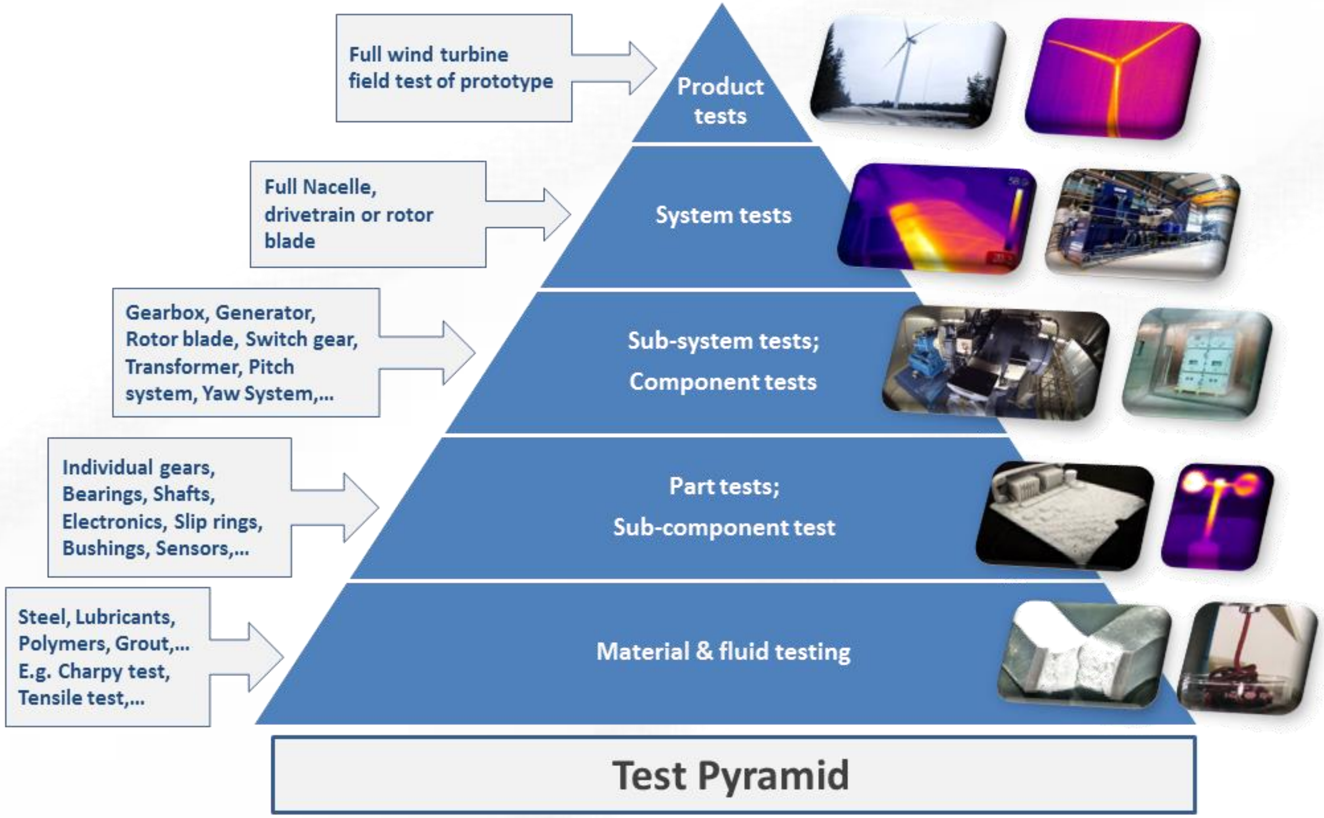


Essential part in the product development cycle

Attention point: wind turbine need to be fitted for the job to work in challenging environments:
Cold Climate, Hot Climate, Tropical Climate, Offshore

Source: Fraunhofer IWES

Different public test centers have been set-up to support R&D



Source: DTU – ØSTERILD National test center for large wind turbines

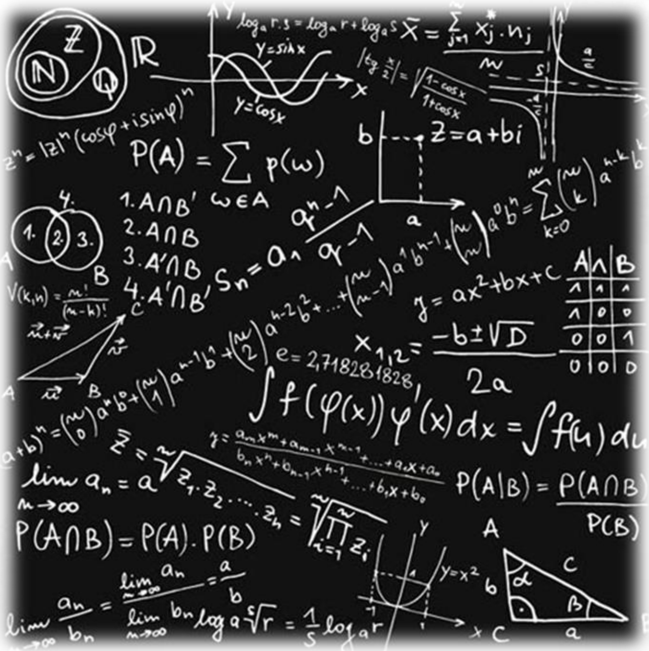
Source: Fraunhofer IWES drivetrain testbench & blade bearing test bench

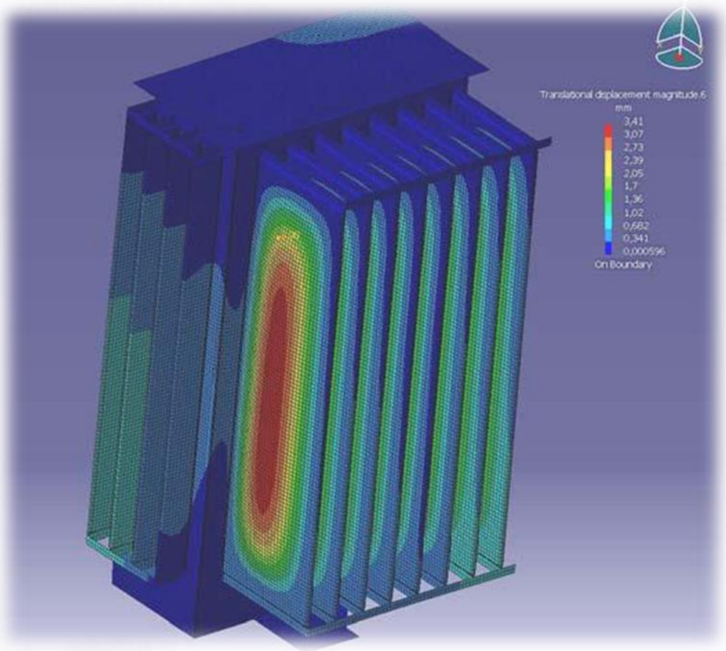
Source: ORE Catapult blade test center

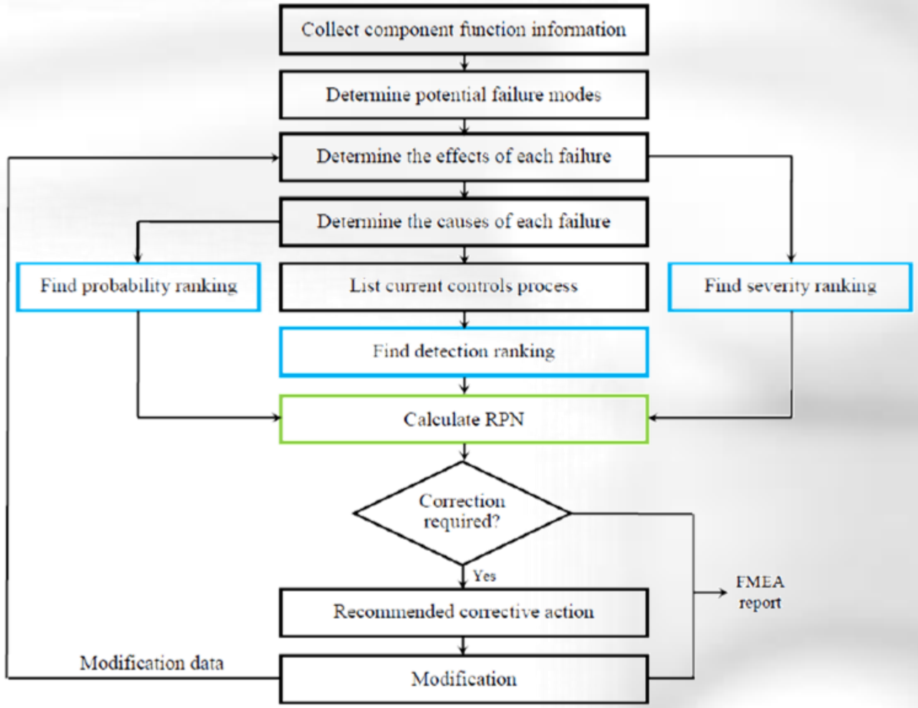
Source: Von Karman Institute for fluid dynamics

& OWI-Lab

Purpose of prototype testing in the climate chamber







FMEA Process – Pillay and Wang 2003

Design validation

Checking if simulation models are valid (model validation)

Risk mitigation

Certification

Deliver reliable machinery + shorten the time-to-market

Cold temperatures influence materials, lubrication and performance of systems
→ Some influences are difficult or time consuming to simulate

Some definitions with regard to low temperature climates to start with

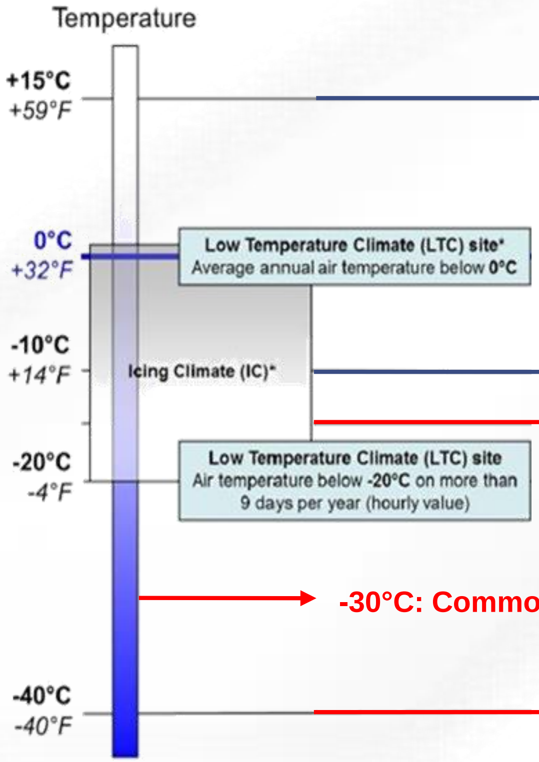
DNV·GL

'Cold climate' wind turbines

'Offshore' wind turbines

'Hot climate' wind turbines

'standard' wind turbines



Design temperature standard wind turbine (avarage annual air temperature = +15°C)

-10°C : Operational limit for standard wind turbines

< -15°C: Operational limit for Low Temperature Climate (LTC) wind turbine

-30°C: Common operational limit for LTC

Design limit for Low Temperature Climate (LTC) (structural endurance limit)

Manufacturer defines the minimum 'survival' and minimum 'operational' temperature limit of the turbine

Designed for

'Survival' temperature limit: -20°C to +50°C

'Operational' temperature limit: -10°C to +40°C

TURBINE OPTIONS

- Condition Monitoring System
- Service personnel lift
- Aviation lights
- Aviation markings on the blades
- Low temperature operation to - 30°C
- Ice detection

Source: Vestas

Some definitions with regard to low temperature climates to start with

‘Cold climate’ wind turbines

‘Offshore’ wind turbines

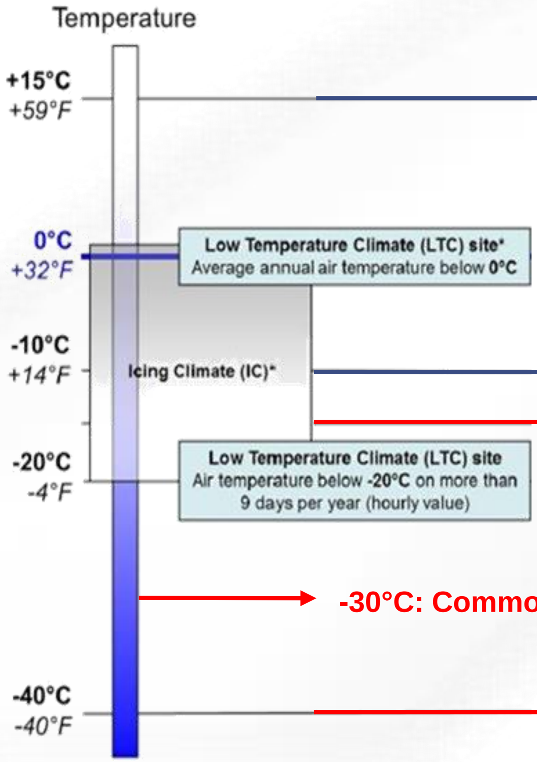
‘Hot climate’ wind turbines

‘standard’ wind turbines

Designed for

‘Survival’ temperature limit: -20°C to +50°C

‘Operational’ temperature limit: -10°C to +40°C



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Design limit for Low Temperature Climate (LTC)
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IEC 61400-1
Wind turbines –

Part 1:
Design requirements

NEN-EN-IEC 60068-2-1
(en)
Environmental testing - Part 2: Tests - Tests A: cold (IEC 60068-2-1:2007,IDT)

New trend: Cold climate & offshore meet in the Baltic sea

FINLAND

Designing to withstand Arctic conditions

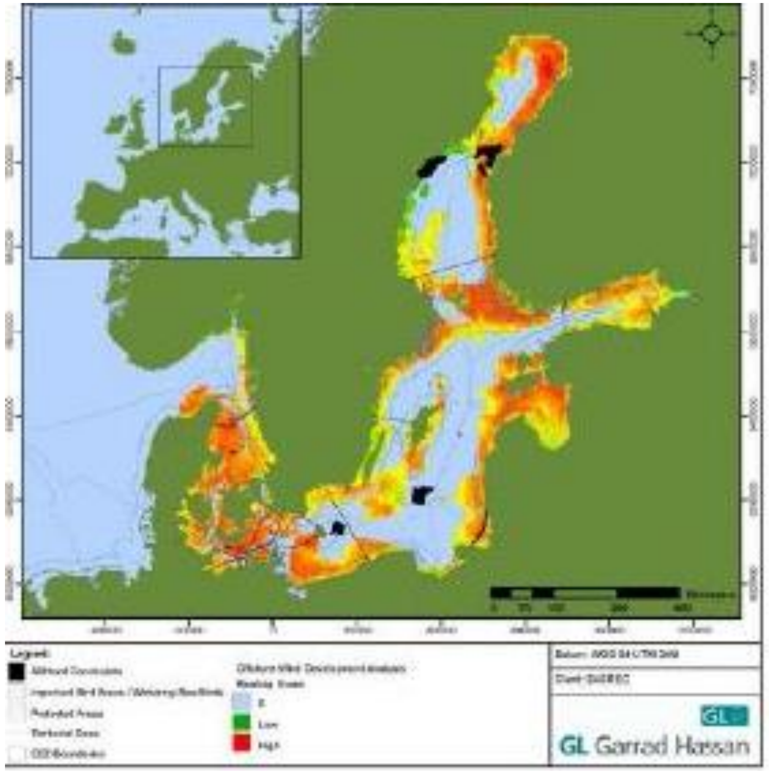
29 February 2016 by Gerard O'Dwyer , Be the first to comment

FINLAND: Much is at stake for Finland's first commercial offshore wind farm, the €120-million 40MW Tahkoluoto project in the Gulf of Bothnia, in the north of the Baltic Sea, west of Finland.

Frozen… The 2.3MW pilot turbine (right) is sited off Finland, testing the arctic weather conditions on the turbine and steel cassion foundations (left) ahead of installing the country's first commercial offshore project (top)

29/02/2016

Source: WIND POWER MONTHLY



Source: Baltic Sea Region Energy Cooperation

6.2M126 SENVION

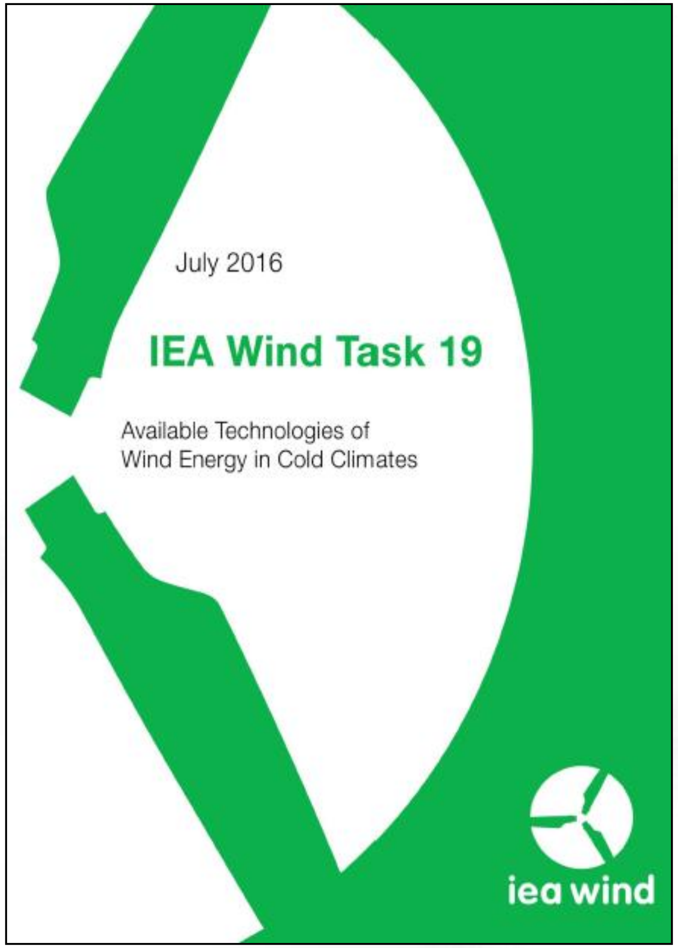
Design data

Nominal power	6,150 kW (MV-side)
Cut-in wind speed	3.5 m/s
Nominal wind speed	14 m/s 13.5 m/s
Cut-out wind speed	25 m/s 30 m/s
Restart cut-in wind speed	20 m/s 25 m/s
Operating temperature range	-20 – +35 °C

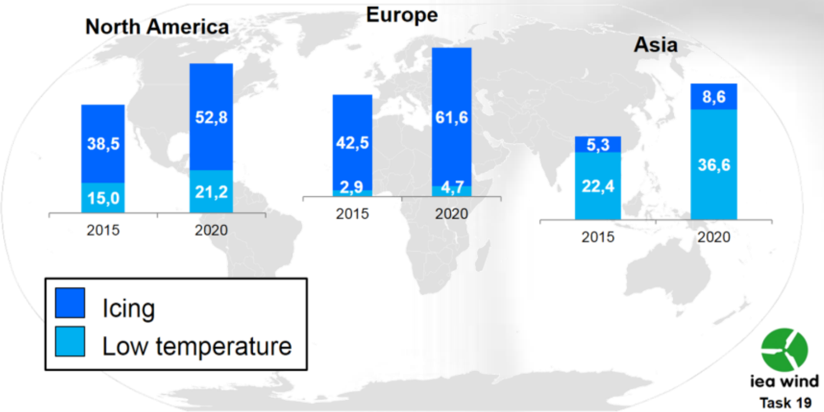
Example of temperature specification

Largest "non standard" sectors for wind energy today !

Dedicated solutions and low temperature adaptations are developed to cope with the challenges of cold climates wind farms



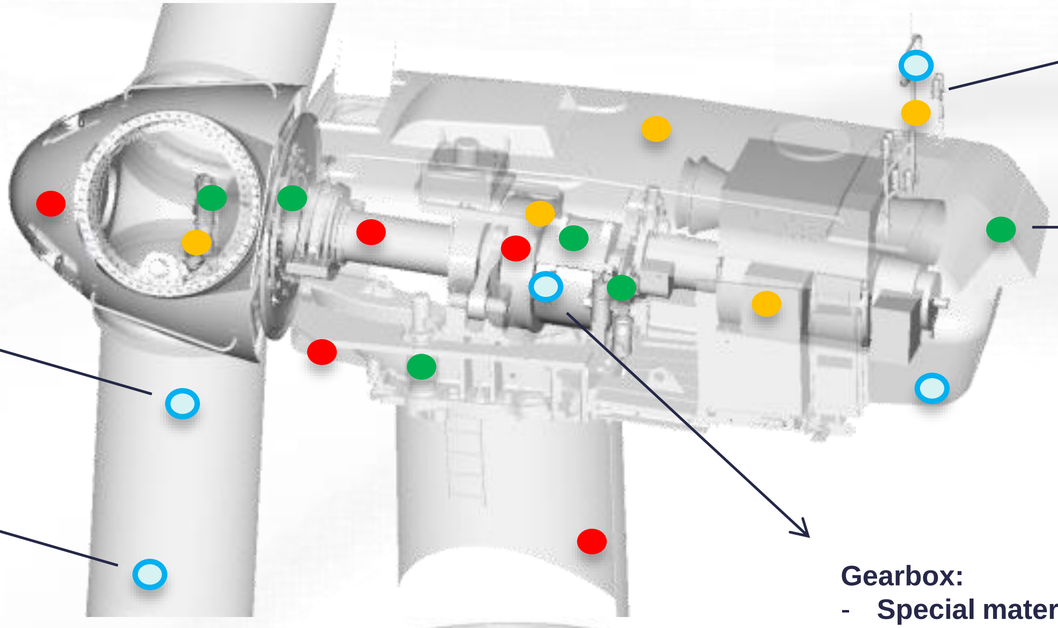
- Overview study of the 'Available technology' made by IEA Wind Task 19
- Study made public recently – July 2016 (see website)
- The study summarizes existing technologies and solutions from weather modelling, to ice detectors and turbine manufacturers that deal with wind energy in cold and icing conditions
- Low temperature adaptations chapter included



http://www.ieawind.org/task_19.html

Recent article 29/07/2016: http://www.windpowermonthly.com/article/1403504/emerging-cold

Overview of most popular measures in “cold climate package”



Ice detection
Heated anemometers

Dedicated low temperature cooling fluids and cooling circuit For gearbox, generator & converter

Ice detection / no-ice detection

Blade de-icing:

- Heating mats in composite
- Hot air system

Gearbox:
- **Special materials**
- **Special lubricants & grease**
- **Additional (pre-) heating**
- **Dedicated cold start-up procedures**

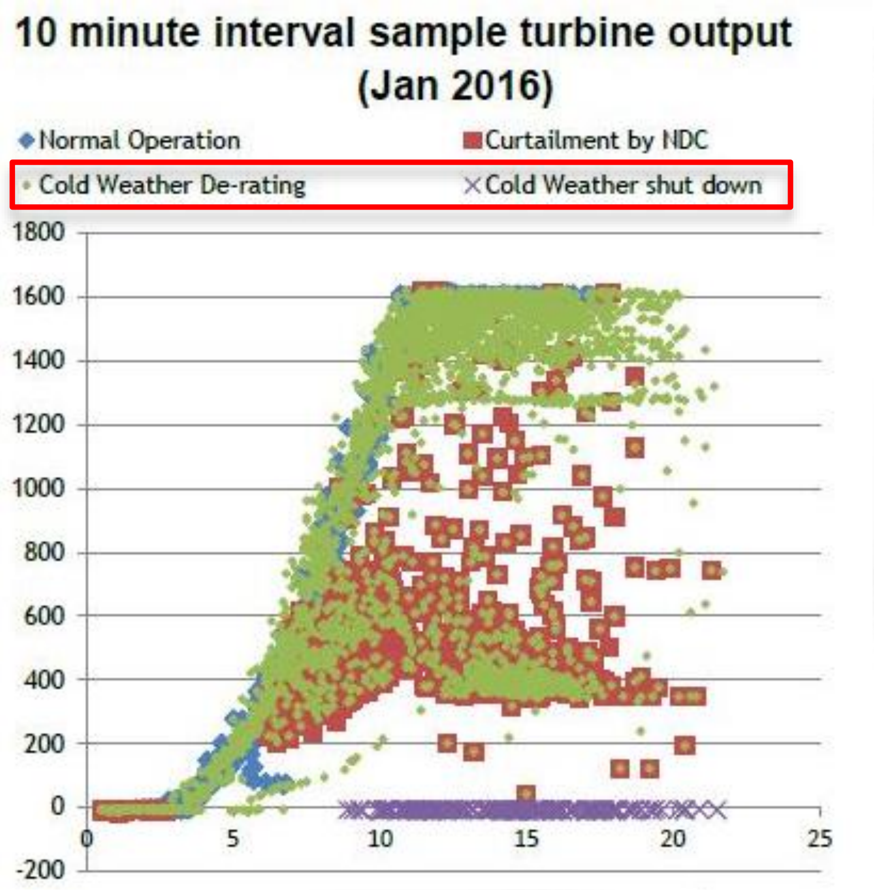
<u>HEATING:</u> Additional heaters added to switch cabinets and converters, gearboxes, hydraulics, anemometer, slip rings, nacelle space…

<u>FLUIDS:</u> ‘Low temperature’ oils & greases applied – gearbox, bearings, transformer, cooling, hydraulics,…

<u>MATERIALS:</u> ‘Low temperature’ materials applied (special steel and cast iron alloys for structures ; elastomers) - gearbox, nacelle frame, hub, main shaft, bearing housing, seals, etc…

<u>SPECIAL MEASURES:</u> Anti & de-icing solutions, improved nacelle sealing, ice-detection sensors, dedicated cold start-up procedures (cold climate controller), foundation (water ingress)

Insights in field performance in low temperatures



Source: Azure international / Clean Energy – Winterwind 2016

Location wind farm: Mongolia (cold climate)

- Dry air conditions at this location in Mongolia – almost no influence of icing on power curve, only effect of the low temperatures
- Power loss due to:
  - **Cold weather shut-downs**:

    The control system will shut the turbine down when the average temperature measured in the nacelle drops below -30°C.
  - **Cold weather de-rating**:

    When T< -15°C and >-30°C the turbine will be operating below the optimal power curve. Reasons include oil heating and limiting stress forces

Other industries: low temperatures in grid infrastructure

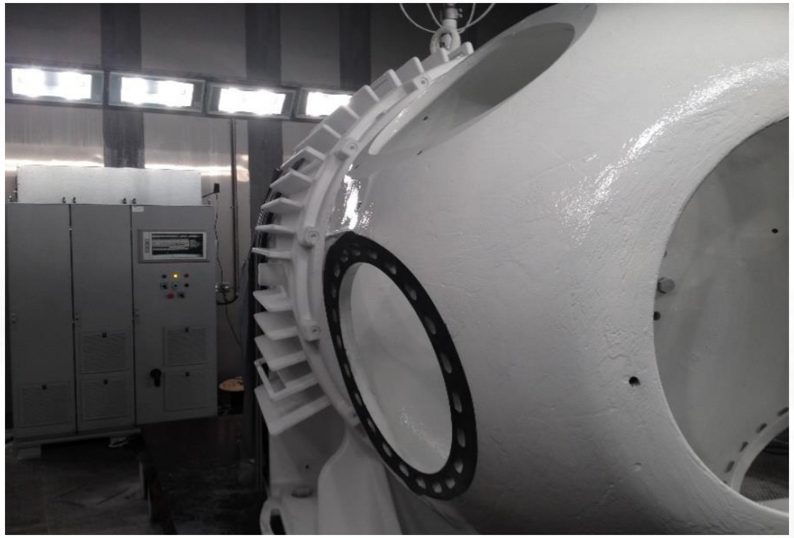
- Example of a 15MVA power transformer test campaign
- Test program at -40°C and **-50°C** for applications used in Canada, Russia, China, Mongolia and Scandinavia.
- The transformer filled with environmentally friendly, but highly viscous synthetic ester fluid.
- High viscosity at low temperatures impedes natural fluid flow and thus leads to a change of thermal performance.
- Especially relevant in case of cooling by external radiators, which is standard for power transformers. Fluid flow in the small radiator ducts is completely different from flow at the tank wall, even more so in case of high viscosity.
- Results presented at: cigré Symposium Dublin 29th May - 2nd June 2017

SIEMENS

Lessons learned when testing wind turbine machinery

1.

3.



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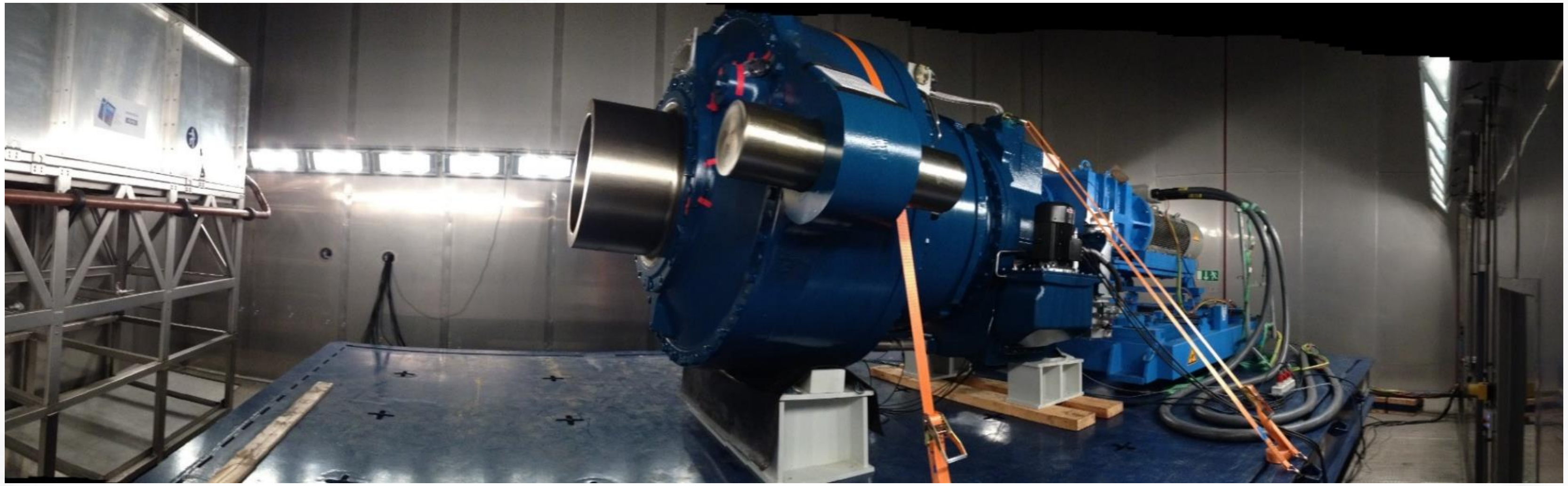
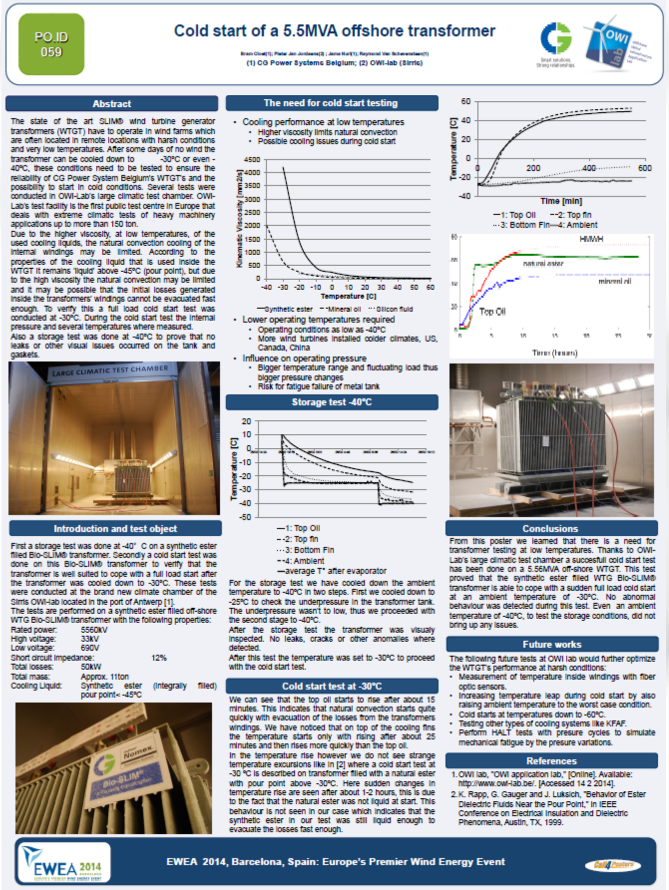


Liquid filled wind turbine transformers

- **Risks during low temperatures:**
  - Under load – no risk due to transformer losses
  - Stand-still in low temperature > 24h
    - Risk of tank underpressure and related air suction due to shrinking of the transformer oil
    - Risk of overpressure during cold start-up and warm-up in general as air can not evacuate fast enough
    - Risk of accelerated temperature rise in windings as natural cooling convection is limited at low temperature (stiff fluids)
    - Failure of auxiliaries and leakage (pumps, cooling circuits, radiators, tripping sensors, seals, etc.)



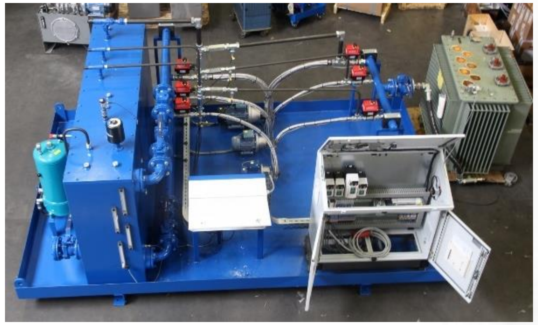
Poster and Paper available
EWEA 2014: Cold start of a 5.5MVA offshore transformer

Smart solutions.
Strong relationships.

Liquid filled wind turbine transformers

- **Lessons learned during climate chamber tests:**
  - Design of the transformer tank flexibility should take low temperature cool down and start-up into account (under- and overpressure)
  - Usage of correct type of pressure control in tank (hermetically sealed, gas cushion, breather, expansion tank)
  - The importance of seals (eliminate air suction / leakage)
  - Usage of the right auxiliaries that can work in cold climate

- **Continuous optimization and R&D effort:**
  - New fatigue tank test bench – topic under & overpressure and effect on lifetime of transformer tank
  - Field monitoring campaign of instrumented WTG transformer in cold climate



Smart solutions.
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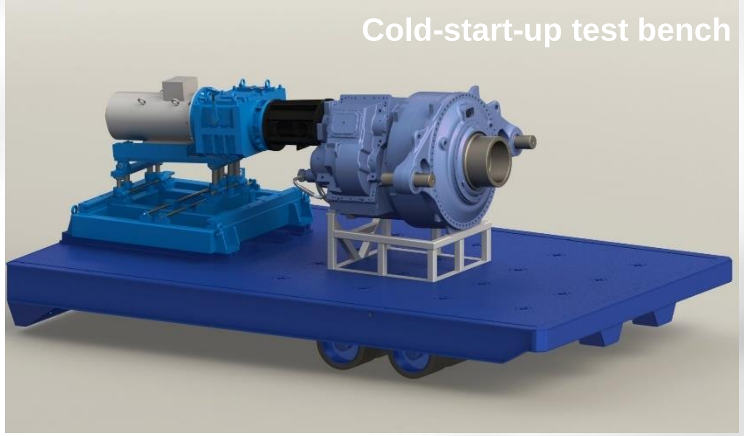
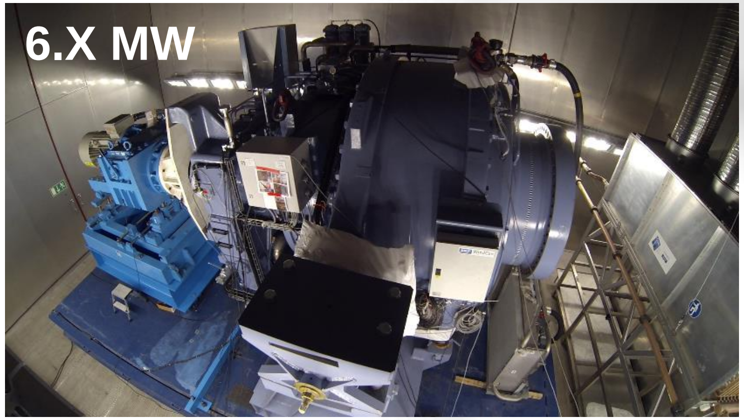
Wind turbine gearboxes – cold start-up tests

- **Risks during low temperatures:**
  - Ensure sufficient lubrication of gears and bearings during cold start-up procedure (CSP) as the oil is stiff.
  - Cold-start-up time must be within a certain allowable time limit (based on customer requirements)
  - Failure of auxiliaries and leakage (pumps, cooling circuits, filters, sensors, seals, etc.) → ensure survival limit of -40°C of all parts, even during a grid-disconnection.
  - Ensure sufficient oil flow in pumps to mitigate risk of cavitation
  - Heaters needed for pre-heating, but surface temperature of heaters should be low enough in order not to burn gearbox oil.





Wind turbine gearboxes – cold start-up tests

- **General procedure (OEM / Supplier dependent):**

Lubrication oil is heated up in separate oil tank and the gearbox oil sump from -40°C to +10°C. Friction losses from gearbox are than used to heat-up the oil quicker, next rotor speed is increased in a pre-determined procedure until partial load and full load can be applied.

- **Lessons learned during climate chamber tests:**
  - Generic lessons linked to the associated risks – example oil pumps, cavitation, seals,…
  - Climate chamber test = Standard test in validation trajectory (Cf. Automotive or off-highway vehicle tests)
  - Average cold-start-up time for gearbox: 5h – with wind

- **Continuous optimization and R&D:**
  - Testing of new lubrication oils and their performance during cold-start

Other components: pitch / yaw / brakes / converters

- Time-to-market essential
- Full scale test to proof cold climate compliance to customer
- Cold start-up procedure (CSP) of pitch ; yaw and brake systems
- Converter / generator test

Statement DNV-GL note on Engineering Details: Wind Turbine operation down to –20°C

Requirements for certification: Evidence on safe operation of the main mechanical and electrical components. At least:

1. Components of the safety system and braking systems including the pitch system and the hydraulic system
2. Blade bearing, Main bearing (s)
3. Gearbox
4. Generator
5. Yaw bearing
6. Electrical Cabinets in Hub, Nacelle, Tower
7. Medium voltage switchgear and transformer

Contact person & more information

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