



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

pieterjan.jordaens@owi-lab.be



www.owi-lab.be

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)

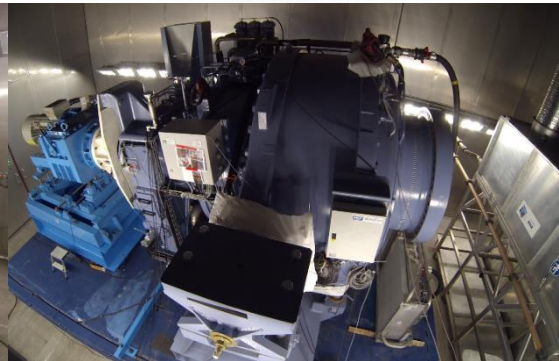


Full size small & mid-range
wind turbine nacelle (or assembly)
tests

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



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

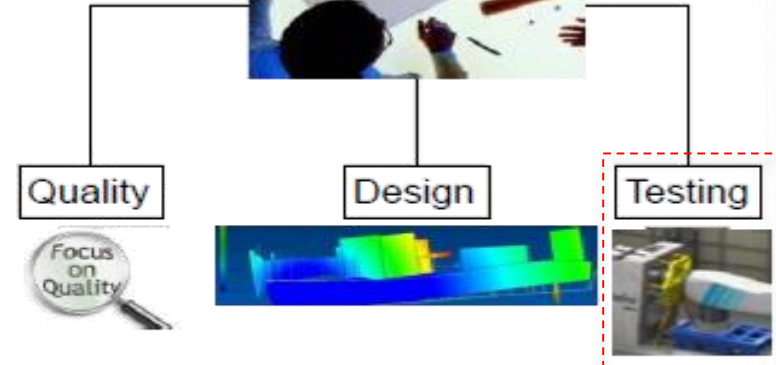
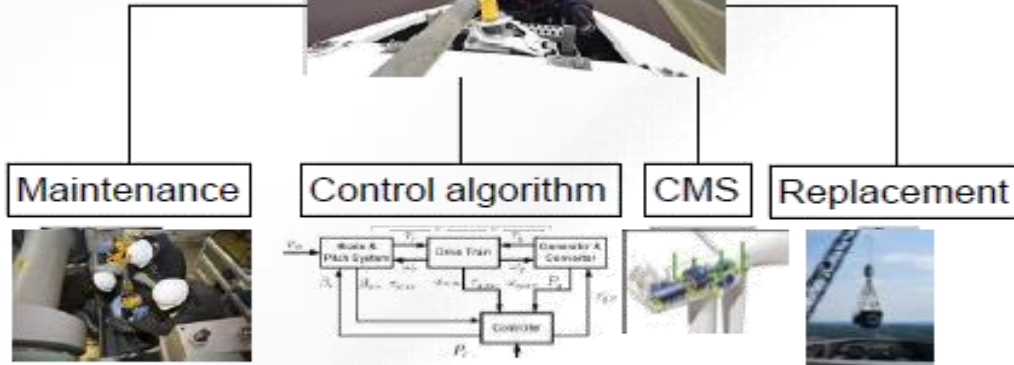
Failure avoidance

Operational means

Development process

1

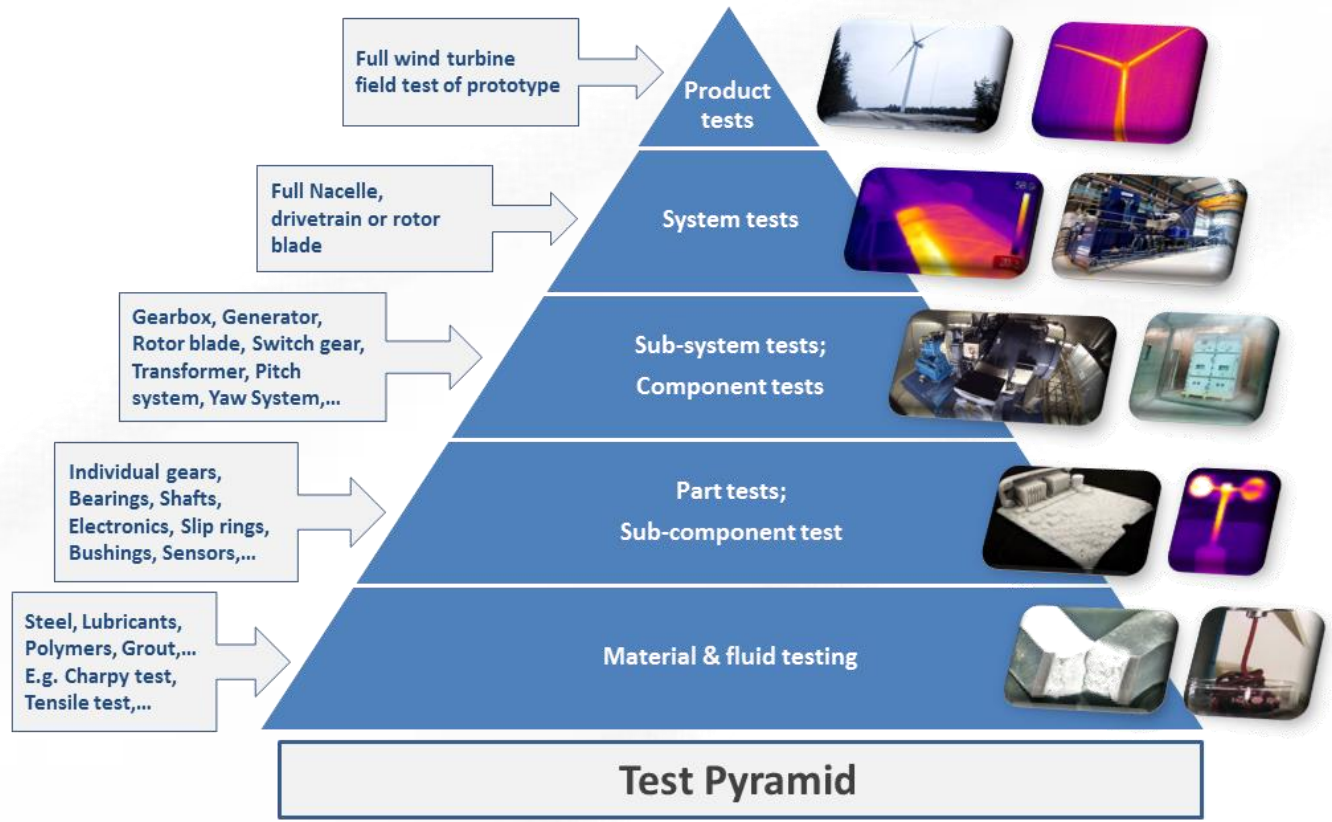
2



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

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

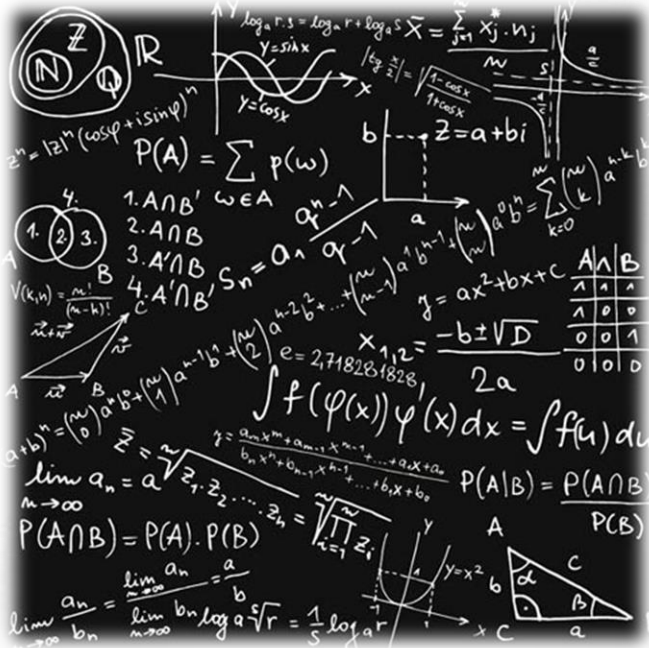


Source: Von Karman Institute for fluid dynamics

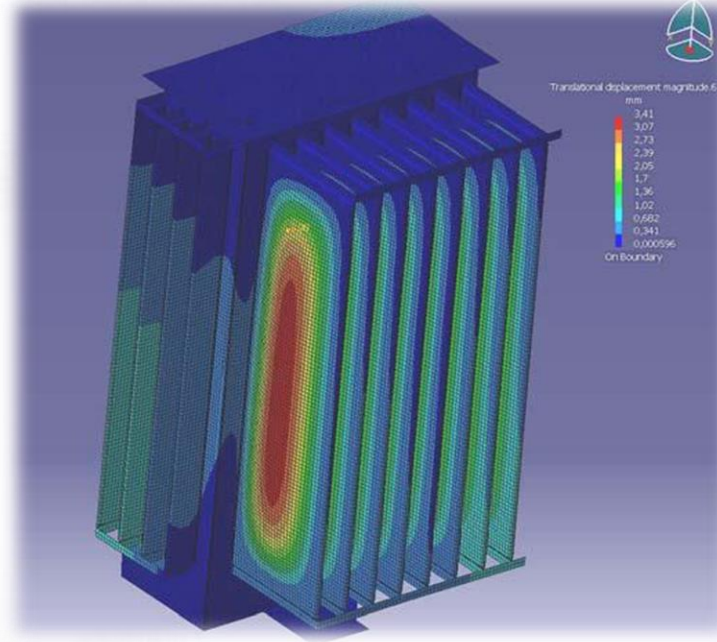
& OWI-Lab



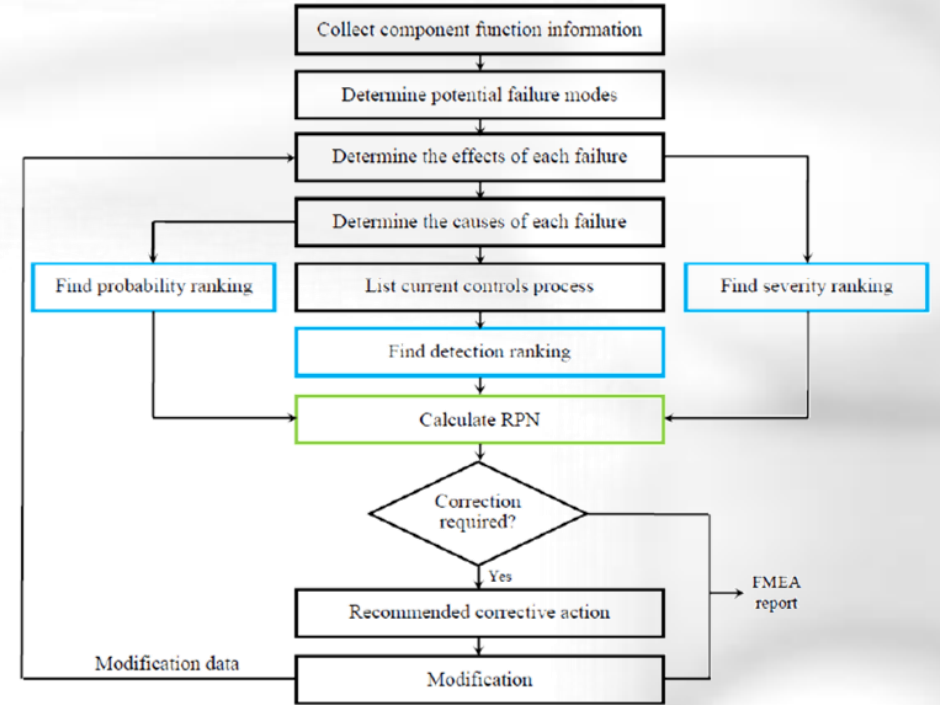
Purpose of prototype testing in the climate chamber



Design validation



Checking if simulation models are valid (model validation)



FMEA Process – Pillay and Wang 2003

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

'Cold climate' wind turbines



'Offshore' wind turbines



'Hot climate' wind turbines



'standard' wind turbines



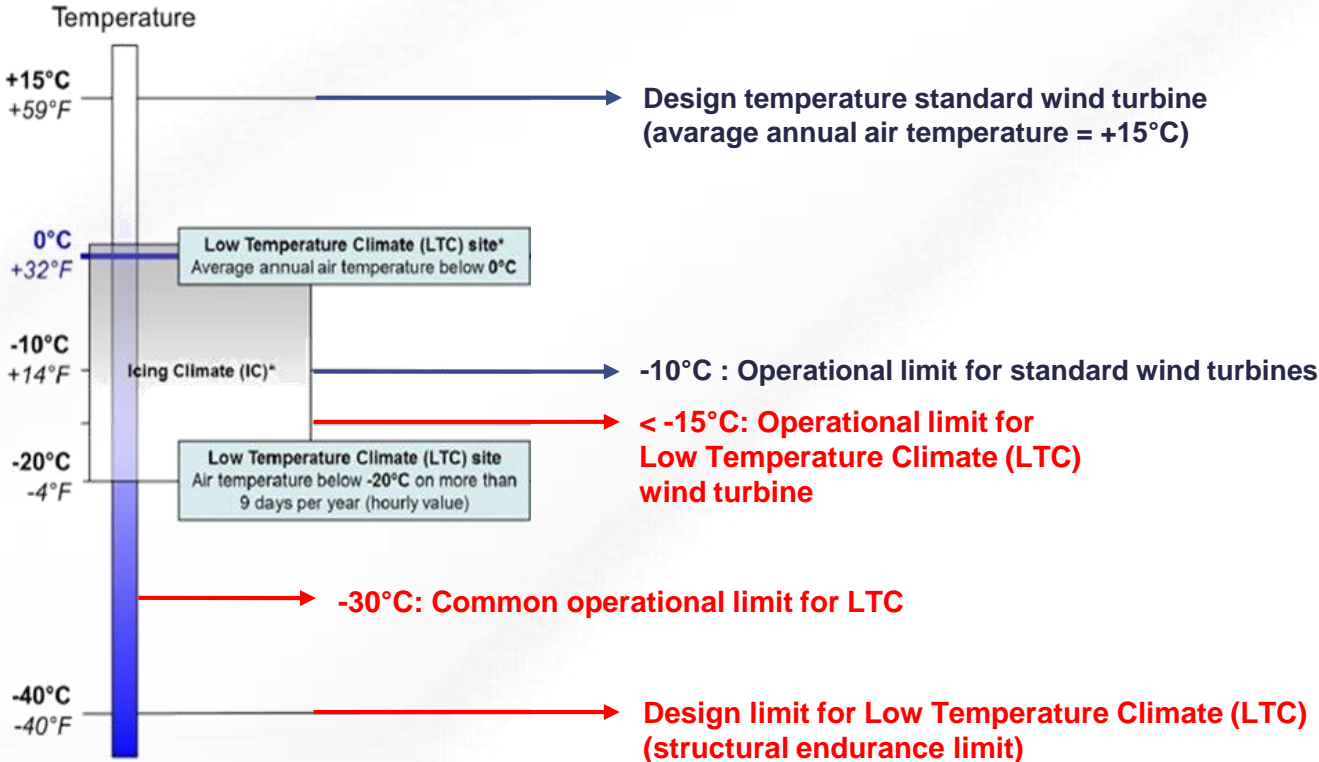
DNV·GL



Designed for

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

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



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

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



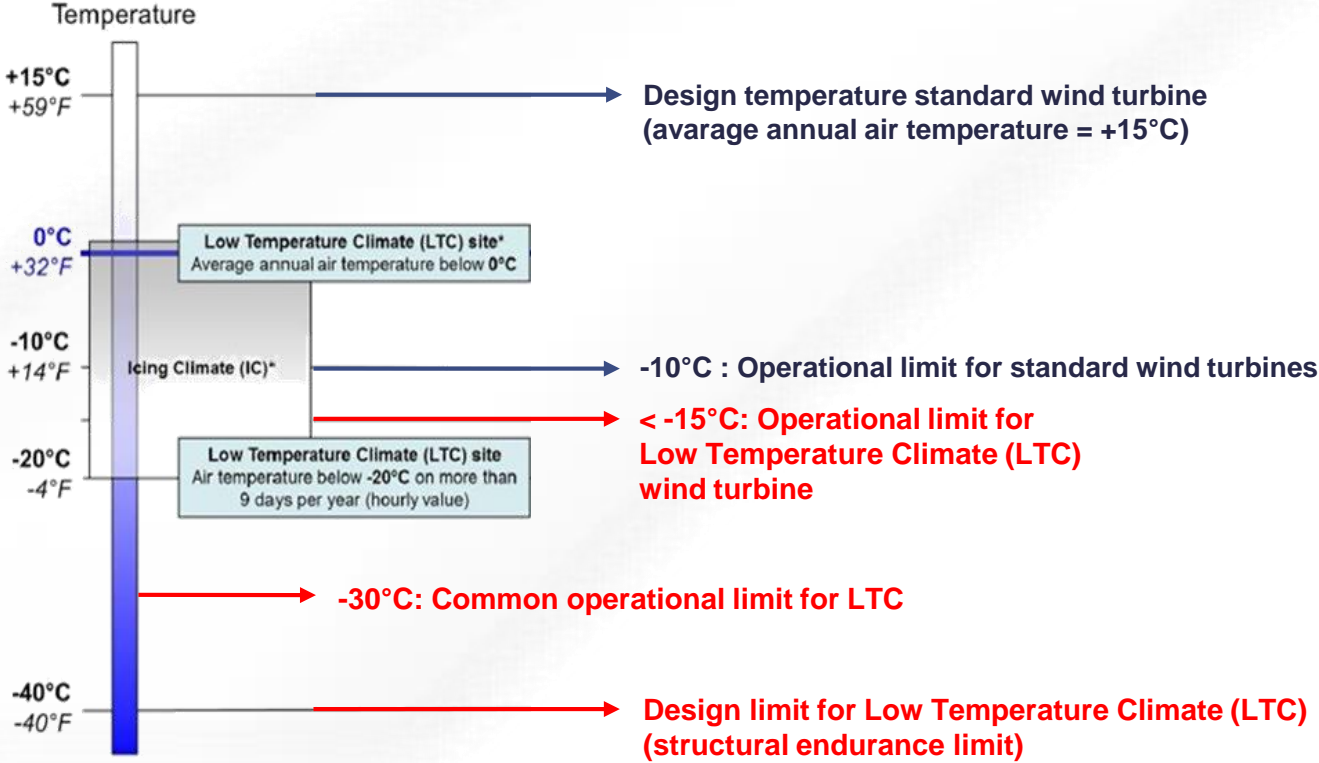
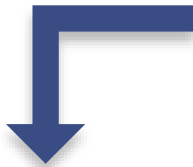
'Hot climate' wind turbines



'standard' wind turbines



DNV·GL



Designed for

'Survival' temperature limit: -20°C to +50°C
 'Operational' temperature limit: -10°C to +40°C



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



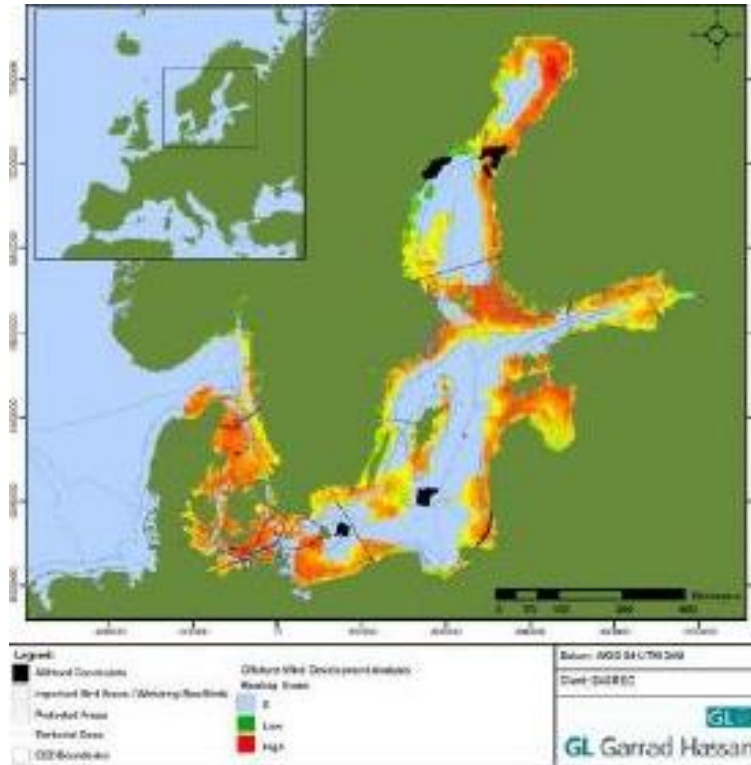
Designing to withstand Arctic conditions

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)



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

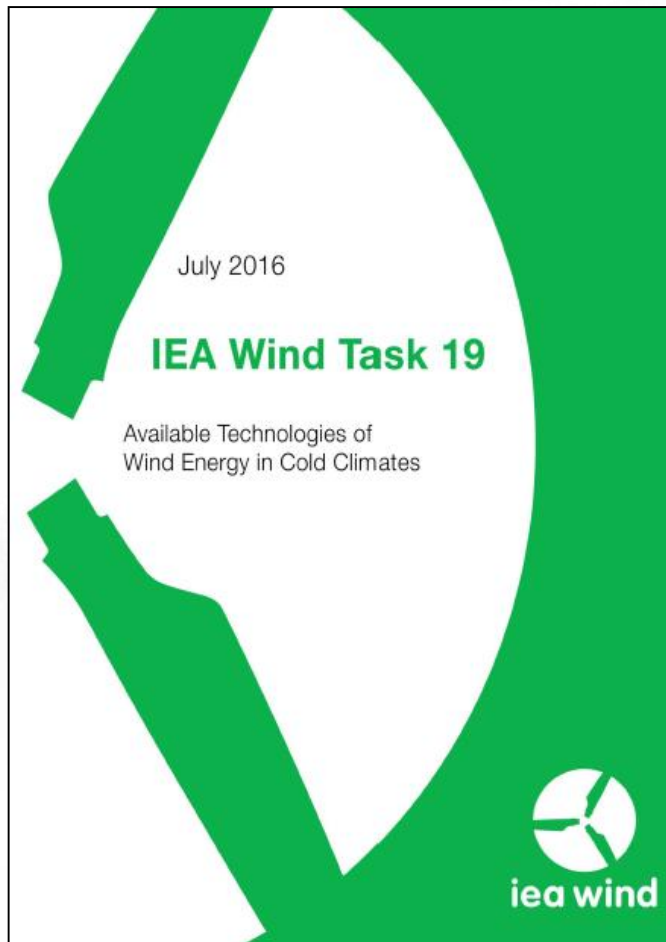
29/02/2016

Source:

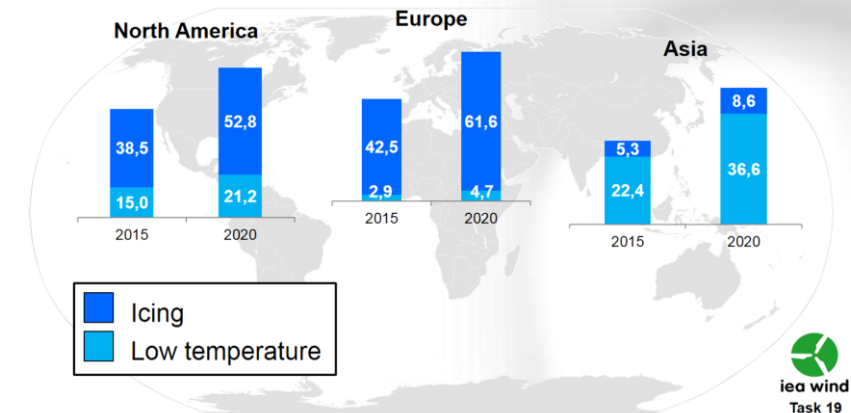
**WIND
POWER**
MONTHLY

Largest "non standard" sectors for wind energy today !

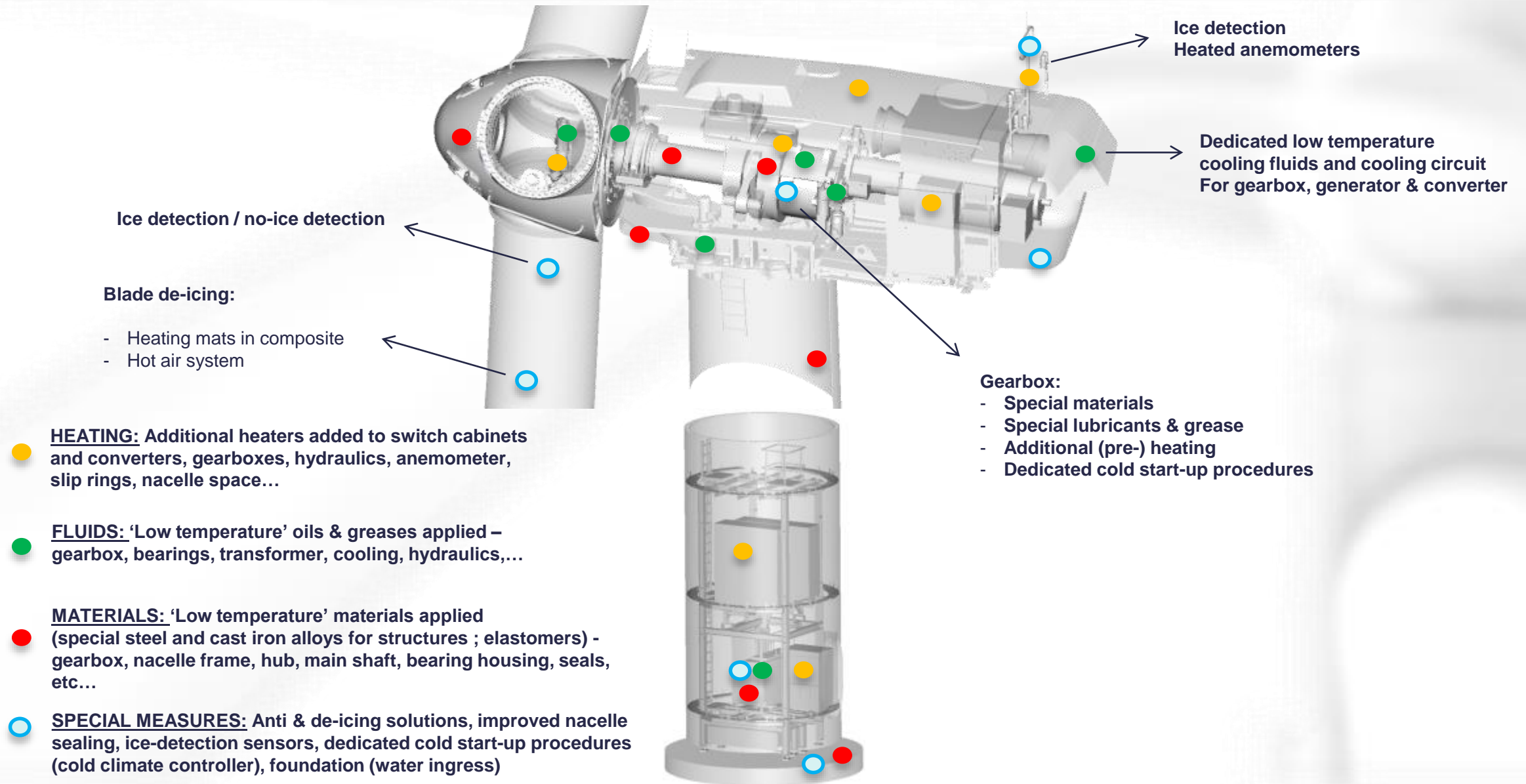
Dedicated solutions and low temperature adaptations are developed to cope with the challenges of cold climates wind farms



- [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

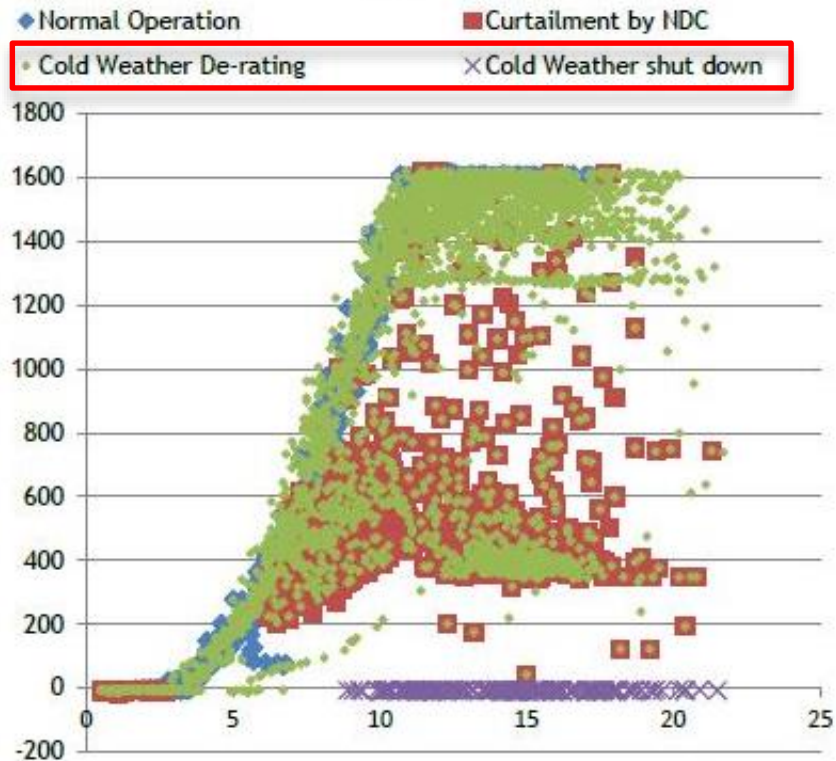


Overview of most popular measures in “cold climate package”



Insights in field performance in low temperatures

10 minute interval sample turbine output
(Jan 2016)



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 $T < -15^{\circ}\text{C}$ and $> -30^{\circ}\text{C}$ 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:



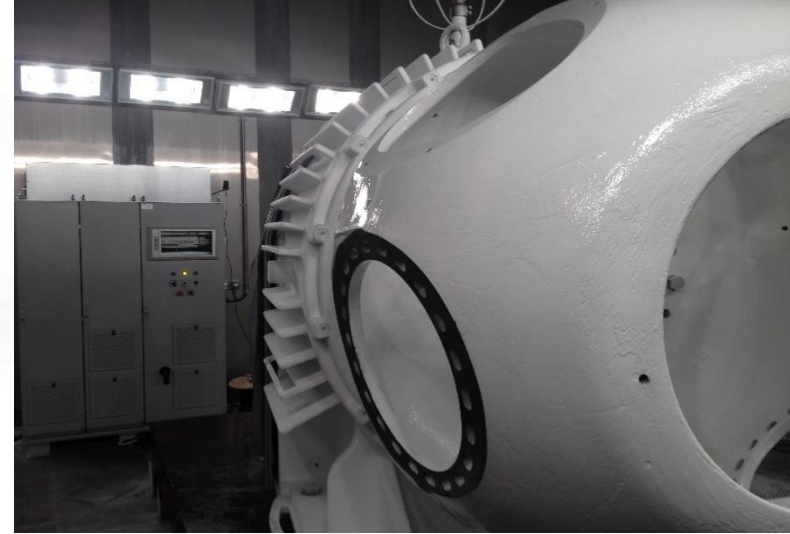
SIEMENS

Lessons learned when testing wind turbine machinery

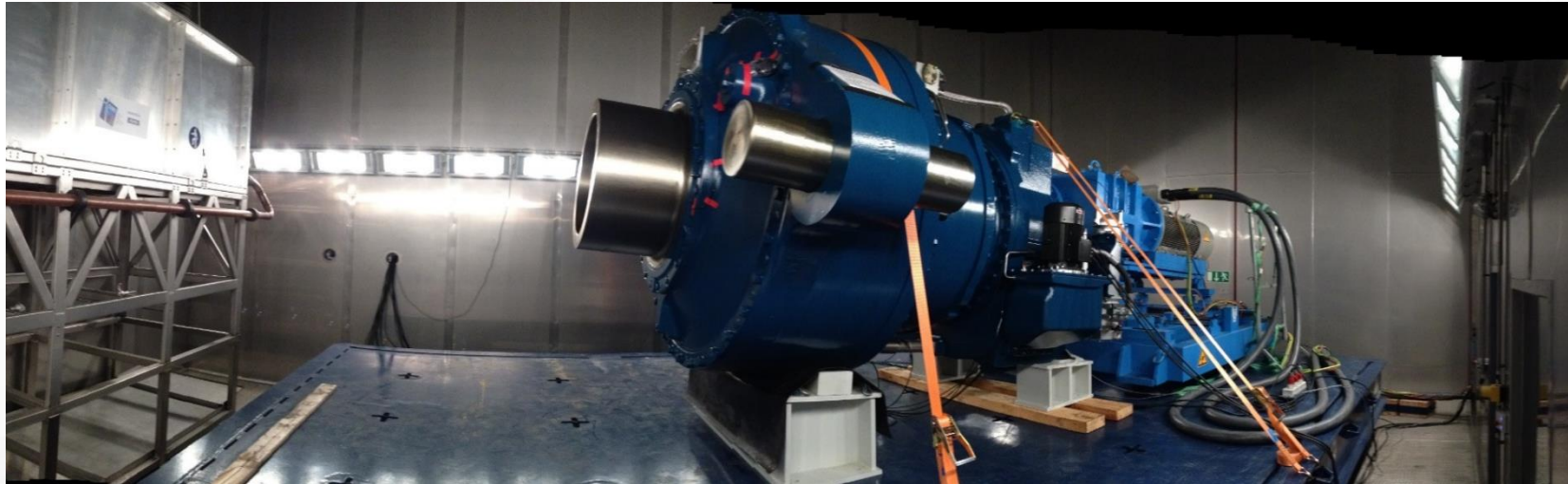
1.



3.



2.



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.)

POJD 059

Cold start of a 5.5MVA offshore transformer

From OWE's Paper (see references), also available at: <http://www.ow-lab.be>

(1) OG Power Systems Belgium; (2) OWI-lab (Brite)

Abstract

The state of the art 5.5MVA wind turbine generator transformers (WTGT) have to operate in wind farms which are often located in remote locations with harsh conditions and very low temperatures. After some days of no wind the transformer can be cooled down to -30°C or even -40°C, these conditions need to be tested to ensure the reliability of OG Power System Belgium's WTGT's and the possibility to start in cold conditions. Several tests were conducted in OWI-lab's large climatic test chamber. OWI-Lab's test facility is the first public test centre in Europe that deals with extreme climatic tests of heavy machinery applications up to more than 150 ton.

Due to the higher viscosity, at low temperatures, of the used cooling liquids, the natural convection cooling of the internal windings may be limited. According to the properties of the cooling liquid that is used inside the WTGT it remains liquid above -42°C (pour point), but due to the high viscosity the natural convection may be limited and it may be possible that the internal losses generated inside the transformers windings cannot be evacuated fast enough. To verify this a full load cold start test was conducted at -30°C. During the cold start test the internal pressure and several temperatures were measured. Also a storage test was done at -40°C to prove that no leaks or other visual issues occurred on the tank and gaskets.

The need for cold start testing

- Cooling performance at low temperatures
- Higher viscosity limits natural convection
- Possible cooling issues during cold start

- Lower operating temperatures required
- Operating conditions as low as -40°C
- More wind turbines installed colder climates, US, Canada, China
- Influence on operating pressure
- Bigger temperature range and fluctuating load thus bigger pressure changes
- Risk for fatigue failure of metal tank

Storage test -40°C

Introduction and test object

First a storage test was done at -40°C on a synthetic ester filled Bio-OLIMB transformer. Secondly a cold start test was done on this Bio-OLIMB transformer to verify that the transformer is well suited to cope with a full load start after the transformer was cooled down to -30°C. These tests were conducted at the brand new climatic chamber of the Sintis OWI-lab located in the port of Antwerp [1].

The tests are performed on a synthetic ester filled off-shore WTGT Bio-OLIMB transformer with the following properties:

- Rated power: 5500kW
- High voltage: 33kV
- Low voltage: 690V
- Short circuit impedance: 12%
- Total losses: 50kW
- Total mass: Approx. 1 ton
- Cooling Liquid: Synthetic ester (integrally filled) pour point: -42°C

Cold start test at -30°C

We can see that the top oil starts to rise after about 15 minutes. This indicates that natural convection starts quite quickly with evacuation of the losses from the transformers windings. We have noticed that on top of the cooling this temperature starts only with rising after about 25 minutes and then rises more quickly than the top oil.

In the temperature rise however we do not see strange temperature excursions like in [2] where a cold start test at -30°C is described on transformer filled with a natural ester with pour point above -30°C. Here sudden changes in temperature rise are seen after about 1-2 hours, this is due to the fact that the natural ester was not liquid at start. This behaviour is not seen in our case which indicates that the synthetic ester in our test was still liquid enough to evacuate the losses fast enough.

Conclusions

From this poster we learned that there is a need for transformer testing at low temperatures. Thanks to OWI-Lab's large climatic test chamber a successful cold start test has been done on a 5.5MVA off-shore WTGT. This test proved that the synthetic ester filled WTGT Bio-OLIMB transformer is able to cope with a sudden full load cold start at an ambient temperature of -30°C. No abnormal behaviour was detected during this test. Even an ambient temperature of -40°C, to test the storage conditions, did not bring up any issues.

Future works

- Measurement of temperature inside windings with fiber optic sensors.
- Increasing temperature step during cold start by also raising ambient temperature to the worst case condition.
- Cold starts at temperatures down to -60°C.
- Testing other types of cooling systems like sFAP.
- Perform HALT tests with pressure cycles to simulate mechanical fatigue by the pressure variations.

References

[1] OWI-lab, "OWI application list" (online), Available: <http://www.ow-lab.be> [Accessed 14 2 2014].

[2] K. Rapp, G. Gauger and J. Lukasz, "Behavior of Ester Dielectric Fluids Near the Pour Point" in IEEE Conference on Electrical Insulation and Dielectric Phenomena, Austin, TX, 1999.

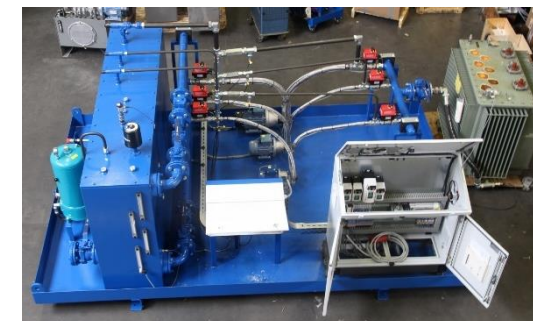
EWEA 2014, Barcelona, Spain: Europe's Premier Wind Energy Event

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



Liquid filled wind turbine transformers

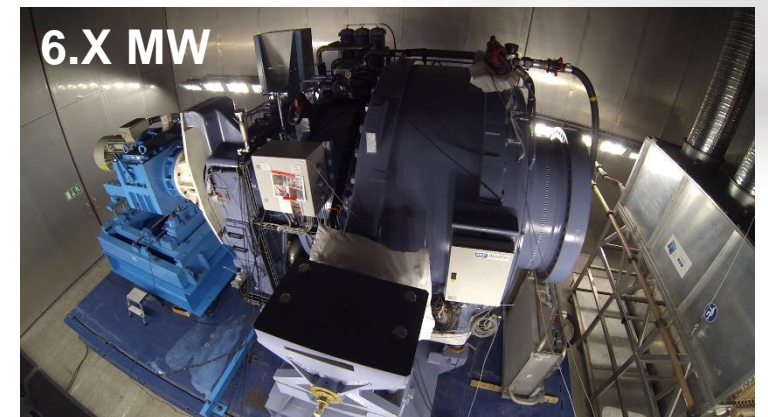
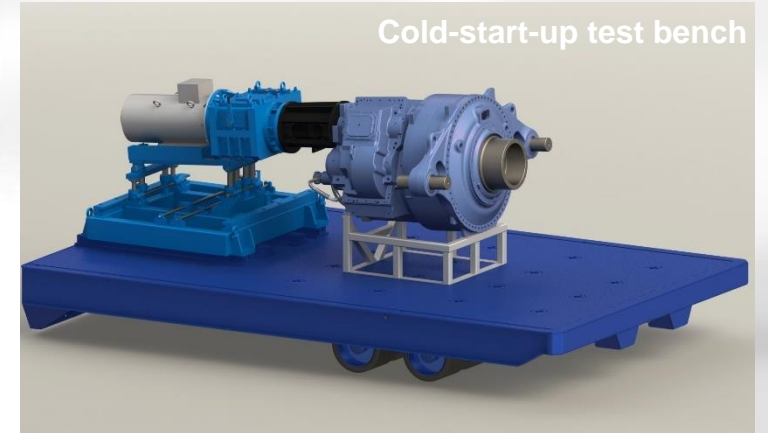
- **Lessons learned during climate chamber tests:**
 - Design of the transformer tank flexibility should take low temperature cool down and start-up into account (under- and overpressure)
 - Usage of correct type of pressure control in tank (hermetically sealed, gas cushion, breather, expansion tank)
 - 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



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):**

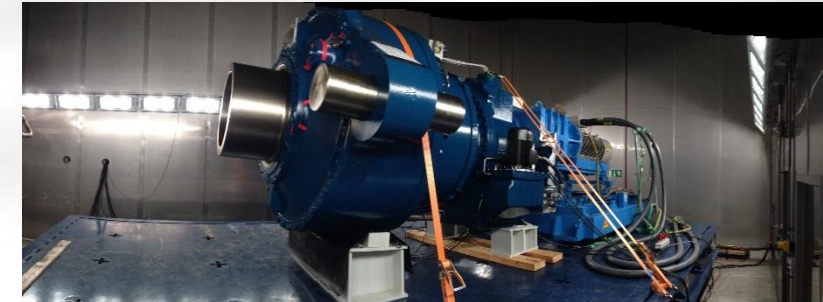
Lubrication oil is heated up in separate oil tank and the gearbox oil sump from -40°C to $+10^{\circ}\text{C}$. Friction losses from gearbox are then used to heat-up the oil quicker, next rotor speed is increased in a pre-determined procedure until partial load and full load can be applied.

- **Lessons learned during climate chamber tests:**

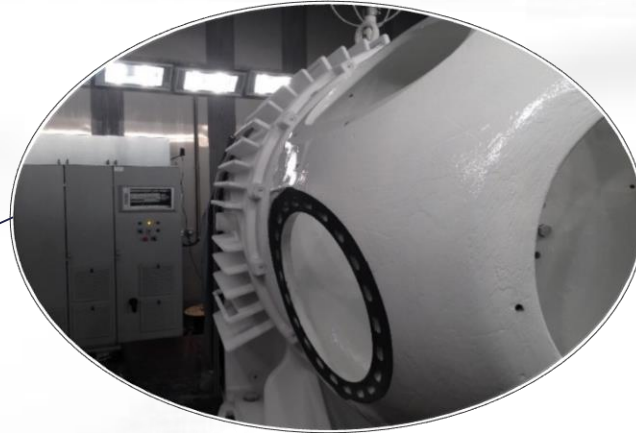
- Generic lessons linked to the associated risks – example oil pumps, cavitation, seals,...
- Climate chamber test = Standard test in validation trajectory (Cf. Automotive or off-highway vehicle tests)
- Average cold-start-up time for gearbox: 5h – with wind

- **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

pieterjan.jordaens@owi-lab.be

be.linkedin.com/in/pieterjanjordaens/en



@OWI_lab



**Knowledge sharing – LinkedIn Group:
Offshore Wind Infrastructure
Application Lab (OWI-Lab)**



www.owi-lab.be