



Low temperature compliance testing of wind turbine applications



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 **Winterwind** FEB 6-8
INTERNATIONAL WIND ENERGY CONFERENCE 2017

-60°C → +60°C

%RH

Solar IR

Icing

Laboratory for environmental testing of heavy machinery

Quick 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

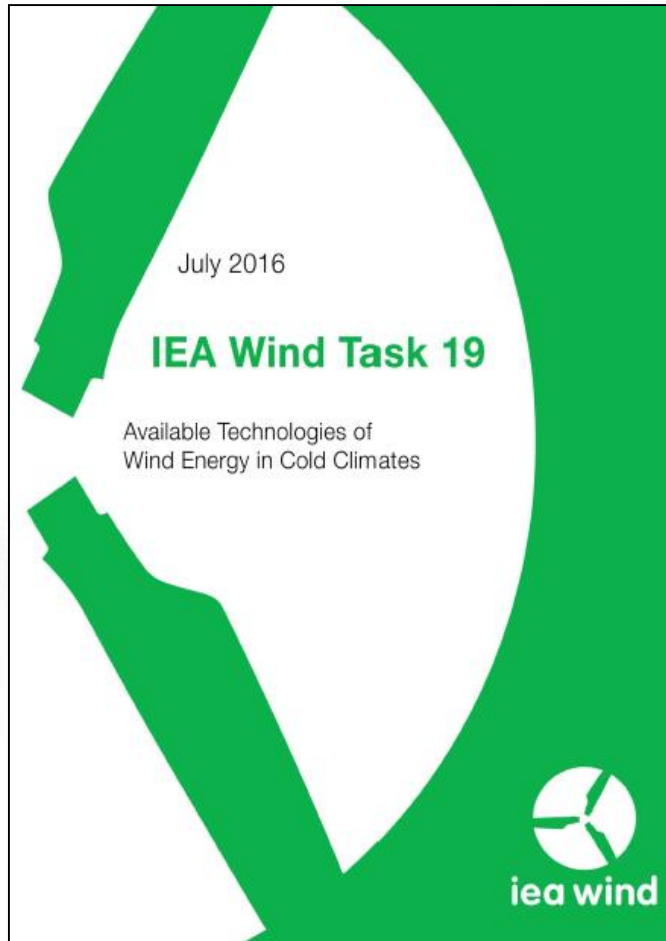
▪ OWI-Lab - RD&I center for wind energy in Belgium

- 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 EERA JP Cold climate
- Member of IEA Wind Task19 Wind Energy in Cold Climates

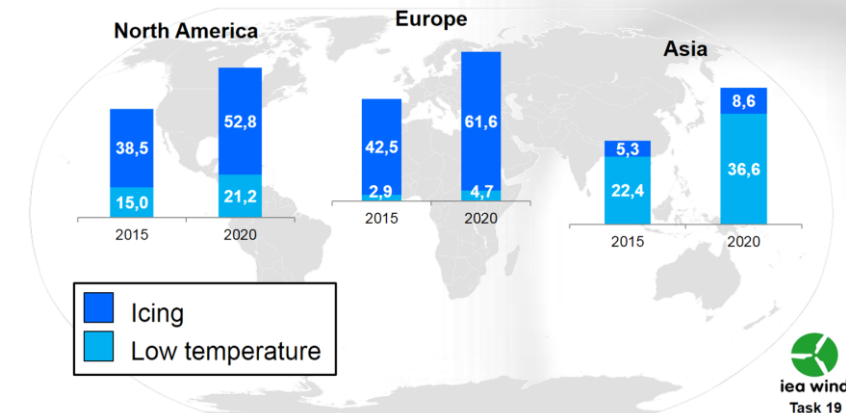


Rationale: Largest "non standard" sectors for wind energy today !

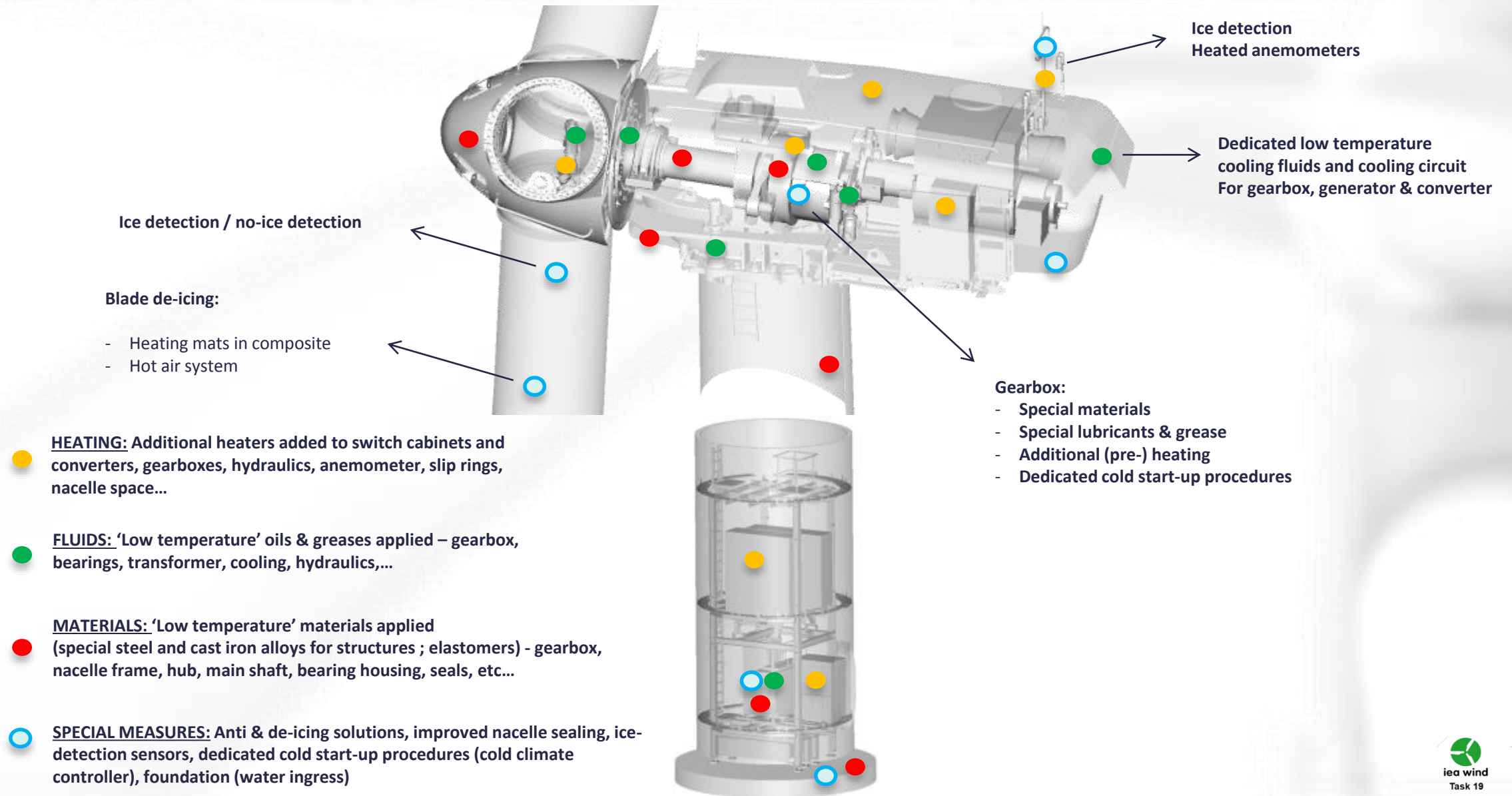
Dedicated solutions and low temperature adaptations are developed to cope with the challenges of cold climates wind farms



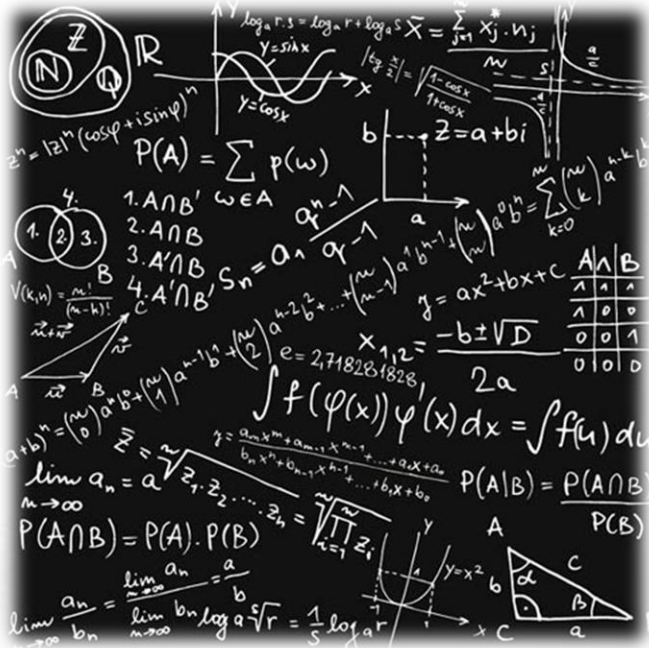
- [Overview study of the 'Available technology' made by IEA Wind Task 19](#)
- Study made public recently – July 2016 (see website)
- The study summarizes existing technologies and solutions from weather modelling, to ice detectors,... and turbine manufacturers that deal with wind energy in cold & icing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



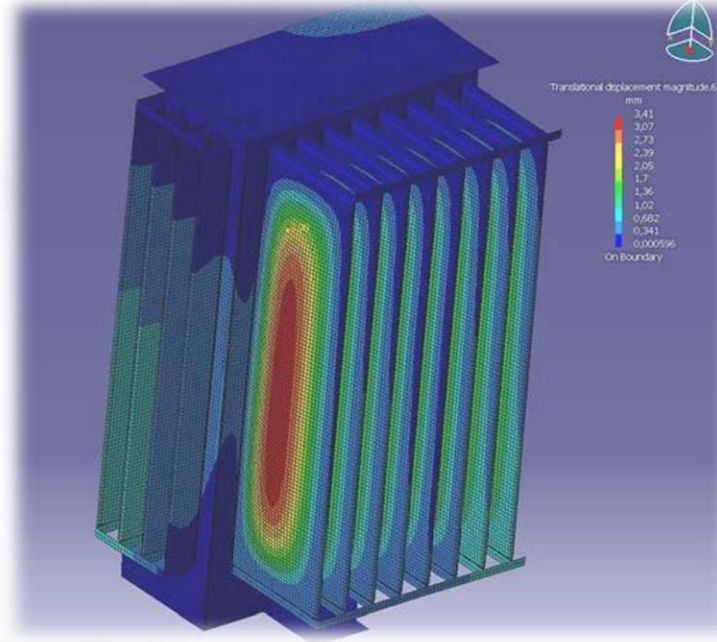
Overview of most popular measures in “cold climate package”



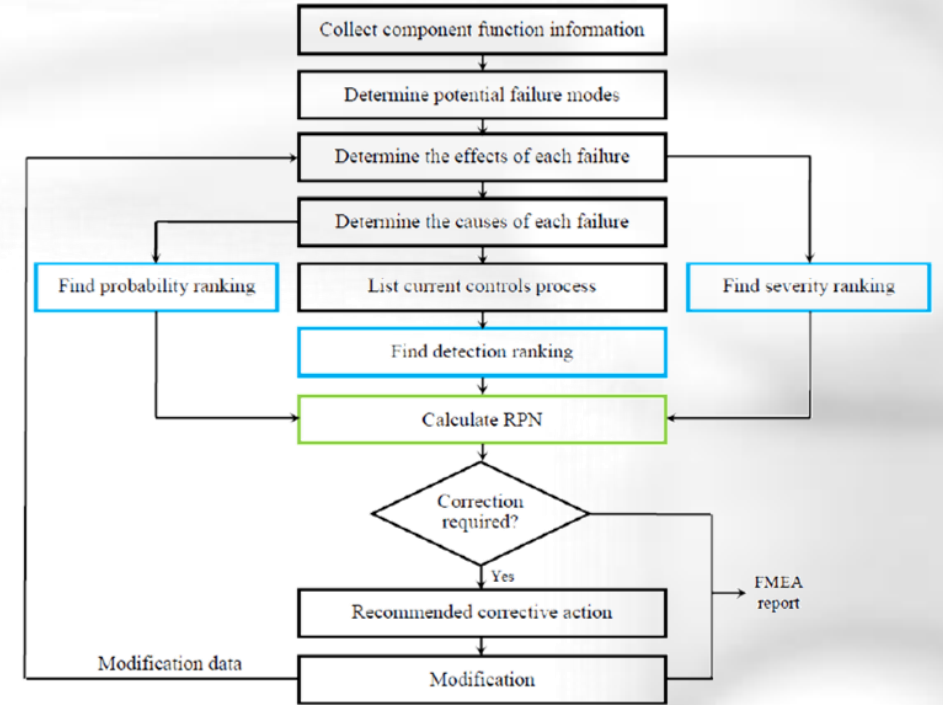
Purpose of prototype testing in the climate chamber



Design validation



Checking if simulation models are valid (model validation)



FMEA Process – Pillay and Wang 2003

Risk mitigation

Certification

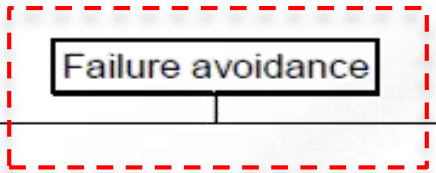
Deliver reliable machinery + shorten the time-to-market

Driver 1 and reasoning for 'testing' within the wind power business

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



Higher reliability and better maintenance
 ↓
 Lower downtime
 ↓
 Lower OPEX and higher AEP
 ↓
 Lower COE



1

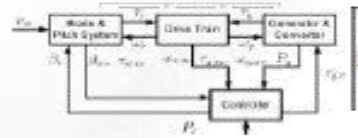
Operational means



Maintenance



Control algorithm



CMS



Replacement



2

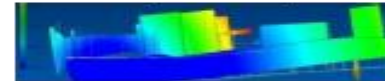
Development process



Quality



Design



Testing

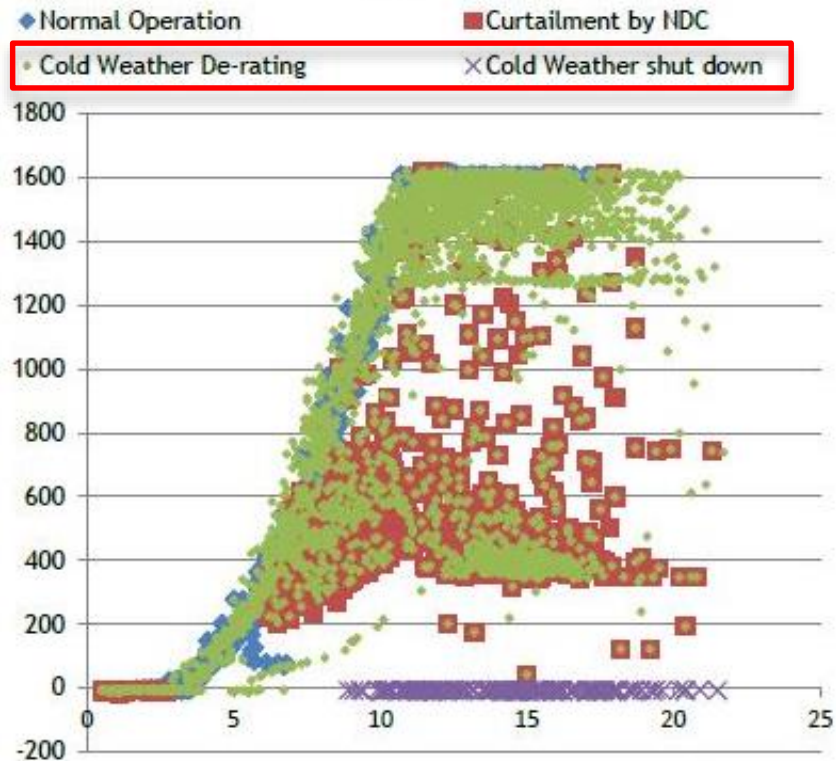


Essential part in the product development cycle

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

Insights in field performance in low temperatures → driver 2 = increase production during good cold wind conditions (maximum energy yield)

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

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)



XANT

**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.



SIEMENS

**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,...

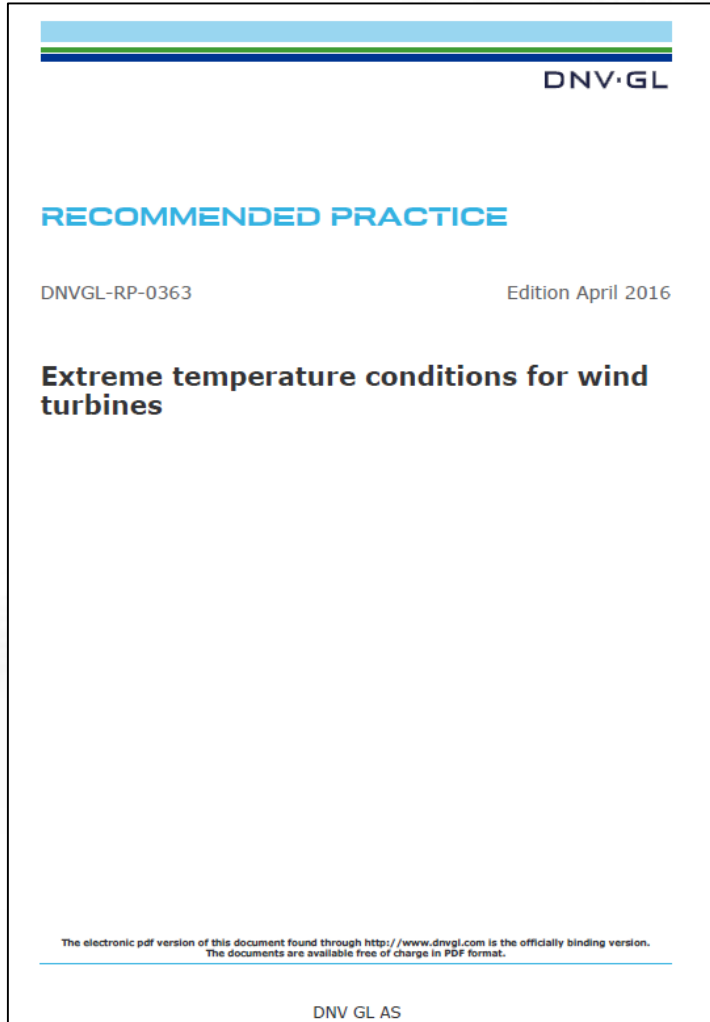


R&D tests on the behavior
of fluids, oils and hydraulics
in a full functional set-up



Icing tests in the climate chamber

Recommended practice & Lab Testing experiences



DNV·GL

RECOMMENDED PRACTICE

DNVGL-RP-0363 Edition April 2016

Extreme temperature conditions for wind turbines

The electronic pdf version of this document found through <https://www.dnvgl.com> is the officially binding version. The documents are available free of charge in PDF format.

DNV GL AS

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8.2.2 Start up procedure of wind turbine after long stand still during grid failure

A complete start up procedure concerning heating up or cooling down to operational temperature range should be given for the complete wind turbine after grid failure. The procedure should contain the measures for heating/cooling without grid power where necessary (e.g. for heating up the generator or main power transformer before switching on). The electrical installations (transformer, generator, converter and control cabinets etc.) are to be included in the procedure.

4.4 Braking systems

It is to be shown that the braking systems (including their possibly existing energy storage) remain functional in the temperature range between $\theta_{min,operation}$ and $\theta_{max,operation}$.

A test of the pitch system for extreme low temperature conditions may be required (see [7.4.3]) and the respective requirements in the following should be taken into account:

The test shall ensure and show that the pitch system is capable to run all blades into feathered position in an appropriate time under assumption of appropriate loading. This test is required whenever a braking system is designed as pitch system.



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

(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 minor 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 gauges.

The need for cold start testing

- Cooling performance at low temperatures
- High 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 cooler 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-5.5MVA transformer. Secondly a cold start test was done on this Bio-5.5MVA 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 climate chamber of the Brite OWI-lab located in the port of Antwerp [1].

The tests are performed on a synthetic ester filled off-shore WTGT Bio-5.5MVA transformer with the following properties:

Rated power:	5500kW
High voltage:	33kV
Low voltage:	690V
Short circuit impedance:	12%
Total losses:	50kW
Total mass:	Approx. 11ton
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-5.5MVA 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 xFAP.
- Perform HALT tests with pressure cycles to simulate mechanical fatigue by the pressure variations.

References

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

[2] K. Rapp, G. Gauger and J. Lukason, "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

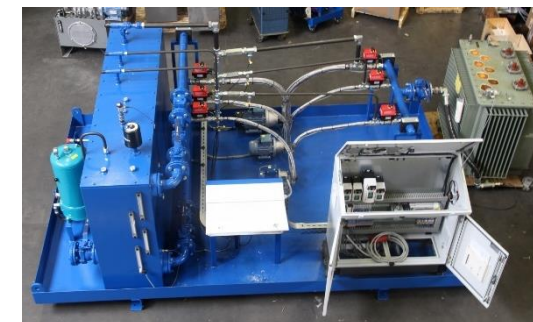
- **Lessons learned during climate chamber tests:**

- 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



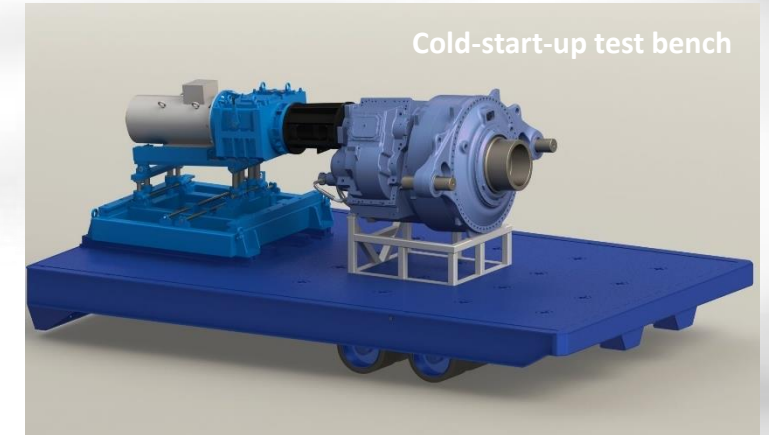
- **Continuous optimization and R&D effort:**

- 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 (North - USA)



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):**

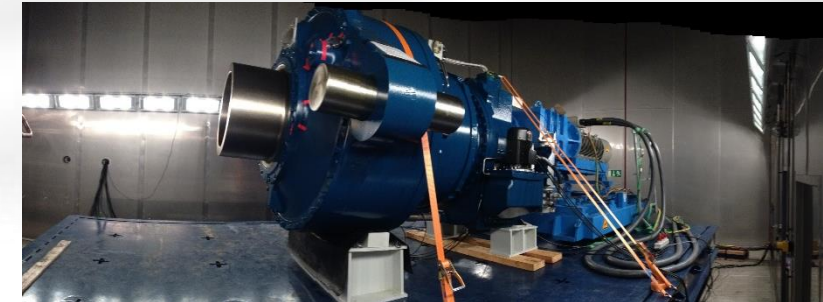
Lubrication oil is heated up in separate oil tank and the gearbox oil sump from -40°C to $+10^{\circ}\text{C}$. Friction losses from gearbox are then used to heat-up the oil quicker, next rotor speed is increased in a pre-determined procedure until partial load and full load can be applied.

- **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



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