Extreme cold start-up validation of wind turbine components by the use of a large climatic test chamber

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Understanding the topic: Why climate chamber testing?
Wind turbines are installed worldwide. Therefore, wind turbines operating in different environmental conditions...
Some wind turbines are subjected to extreme environmental loads

Offshore wind turbines
- Corrosive environment
- Humidity & Rain
- Strong gusts & heavy wind loads
- Wave impacts; low freq. vibrations
- Vibrations due to wind loads

CCV wind turbines
- (Extreme) cold temperatures: -40°C; -45°C
- Ice-rain & icing
- Heavy wind loads
- Snow
- Vibrations due to wind loads

HCV wind turbines
- (Extreme) hot temperatures: +45°C; 50°C;
- Sand & dust
- Vibrations due to wind loads
- Solar radiation
Some examples worldwide

Belgian North Sea
Stormy weather during Alstom Haliade installation - 2013

USA: Polar vortex causes cancellations of turbine maintenance tasks - 2014

China: Turbine failure caused by typhoon - 2006

Icing on blades ice-throw scandinavia

16m high monster wave impacts on offshore substation near the Alpha Ventus wind farm – 2006

Different environmental conditions need to be taken into account during the product development cycle, installations phase and operational phase
What about extreme temperatures?

Canada (Saskatoon)
January 2014: -49°C

Chicago
January 2014: -30°C

North China
February 2014: -46°C

Sweden
16/01/2014: -30°C

Australia
15/01/14: +46°C
Engineers need to take these environmental loads into account in order to deliver a **reliable** wind turbine in all conditions.
Reliability means: ‘the ability of a system to perform a required function, under given environmental and operating conditions and for a stated period of time’.
The environmental loads need to be taken into account both in the DESIGN-PHASE, both also in the VALIDATION PHASE, by testing throughout the product development cycle.

This allows model validation, design verification, and confirms the reliability in specific environmental conditions.
## Which requirements?

<table>
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<th>Requirements</th>
<th>for standard turbines according to GL(^1)</th>
<th>typical for LTC(^2) turbines</th>
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<tr>
<td>Operational temperature limits</td>
<td>-10 °C</td>
<td>-30 °C</td>
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<tr>
<td>Survival temperature (stand still)</td>
<td>-20 °C</td>
<td>-40 °C</td>
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1) GL: Germanischer Lloyd  
2) LTC stands for Low Temperature Climate turbines i.e. turbines with low temperature modifications provided by the turbine suppliers.

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**Temperature Diagram:**
- **+15°C (+59°F)**: Design temperature for standard wind turbines
- **0°C (+32°F)**: Average annual air temperature below 0°C
- **-10°C (+14°F)**: Normal climate (NC)
- **-20°C (-4°F)**: Low Temperature Climate (LTC) site with an average temperature below -20°C for more than 9 days per year
- **-40°C (-40°F)**: Design limit for Low Temperature Climate (LTC) wind turbines

![Diagram of temperature requirements](image-url)

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*according to Germanischer Lloyd Industrial Services GmbH, 2011, „Certification of Wind Turbines for Extreme Temperatures“ except.*
Improving Products by Testing

Environmental testing

Mechanical environmental testing

Environmental factors handled:
- shock, vibration, collision,
- acceleration, loud noise, strong blasts of wind

Combined environmental testing

Environmental factors handled:
- a combination of both kinds of factors

Climatic environmental testing

Environmental factors handled:
- gas, salt, rain, wind, pressure,
- humidity, temperature,
- solar radiation

- Vibration testing transformer
- Load & climate testing blade materials
- Cold start-up testing gearbox
The loads that wind turbines encounter during their 20-year lifetime:

- Road vibrations
- Sand
- High & low pressures
- Dust
- Freezing & icing
- Heavy wind loads
- High temperatures
- Rail shocks
- Dry & humidity
- Handling shocks
- Shocks due to installation
- Wave induced vibrations
- Wind gusts
- Electromagnetic interference
- Rain & Hail
- Solar radiation
- Lightning
- Salt fog
- High wave impacts during storms
- Thermal shock
- Snow
- Drivetrain induced vibrations
- Low temperatures
- Biological fouling
- Blade induced vibrations
Case story: wind turbine transformers
The transformer is affected by temperatures due to its locations inside or outside the wind turbine.

- Inside nacelle
- Inside tower section
- Next to turbine tower
- Offshore platform

Thermal stress $\rightarrow$ Mechanical stress

Design verification needed to ensure reliable & safe operations in all conditions.
Why cold start-up testing of a liquid filled transformer?  
1) Check natural cooling performance of liquid:

- After some days of no wind, the transformer can be cooled down to -30°C or even -40°C depending on the location of the turbine, and the location of the transformer in the wind turbine.

- Due to the higher viscosity at low temperature of the used cooling liquids, the natural convection cooling of the internal windings may be limited in such way that the initial losses generated inside the transformers’ windings cannot be evacuated fast enough.

- A design verification test was needed to proof that there is sufficient internal cooling during cold start-up events as simulating such an event is difficult and complex.
Why cold start-up testing of a liquid filled transformer?

1) Check natural cooling performance of liquid:

- A successful full-load cold start-up test was carried out by CG Power Systems to verify the performance of the transformer at -30°C conditions.

- The losses generated by the windings of the transformer were evacuated fast enough to ensure a reliable and safe operation during cold start events at -30°C.
Reliability means: 'the ability of a system to perform a required function, under given environmental and operating conditions and for a stated period of time.'

Test set-up for full load test at -30°C of a 5,5 MVA liquid filled offshore wind turbine transformer in OWI-Lab’s large climate chamber.
-30°C Full load cold test on a 5,5MVA transformer to verify start-up performance and natural convection at high viscosity
Why cold start-up testing of a liquid filled transformer?
2) Leakage & cracks in extreme conditions

- At low temperatures materials become brittle (metal thin plated cooling fins, seals, cables, bushings, ...).
- During a cold start-up test, temperature rise can cause thermal stress and mechanical stress.
- Pressure built-up inside the transformer due to temperature rise in combination with brittle materials can cause problems.
- A successful storage test was carried out at even -40°C to check for leakages and cracks to verify this. No problems occurred.
Cast resin transformers
Why cold start-up testing of a cast resin transformer?

1) Check for cracks at low temperature operations:

- After some days of no wind, the transformer can be cooled down to -30°C or even -40°C depending on the location of the turbine, and the location of the transformer inside the wind turbine.

- Thermal stress $\rightarrow$ mechanical stress due to brittle materials.

- Aluminium is often used as the conductor as its expansion coefficient is closer to that of epoxy resin than copper. However the expansion of aluminium is still different to that of epoxy and as such thermal cracks can appear in the insulation. These cracks represent the weak point within the insulation structure.
Why cold start-up testing of a cast resin transformer?

1) Check for cracks at low temperature operations:

- A design verification test is needed to proof reliable and safe operations.

- Thermal shock test according to IEC-60076-11 is a standard test
  - C1 climatic class
  - C2 climatic class

- The classes are defined in relation to the minimum ambient temperature to which the transformer can be exposed in order to approach the temperature variations sustained during load variations and overloads.

- IEC 60076-11-C2 test procedure: the transformers is cooled down to -25 °C and subsequently shock-heated with twice the nominal current. This procedure must not result in the formation of cracks.
Why cold start-up testing of a cast resin transformer?

1) Check for cracks at low temperature operations:

- Class C1 = operation at ambient temperatures down to – 5°C; transport and storage at ambient temperature down to – 25°C; installation inside.

- Class C2 = operation, transport and storage at ambient temperatures down to – 25°C; installation outside.

- Some epoxy materials which encapsulates the windings withstand low temperatures better than others (Epoxy glass fiber is better suited than particle filled epoxy in low temperatures).

- C2 class only covers -25°C lowest temperature; wind turbines operate in locations where temperatures even drop lower than -40°C. OWI-Lab, together with DNV KEMA has a collaboration to conduct such tests at extreme low temperature (-30°C→-60°C)
- Power electronics
- Variable wind patterns

Transformer windings subjected to a rapid increase of heat

In low temperature operations/cold start-up sequence: brittle windings (= additional risk)

Cracks $\rightarrow$ partial discharge in concentrated area which cannot be dissipated
Case story: wind turbine service cage
Why cold temperature testing of a service hoist?

→ Design verification with regard to operational safety and reliability

- The Sky Man hoists use a state of the art hoist principle, based on a polymer compound pressure ring.

- At low temperatures materials become brittle, the effects of this behavior should be evaluated to:
  - Ensure reliable operations in all conditions for maintenance tasks
  - Operational safety

- Successful system tests were carried out at different temperatures down to -40°C with different loads on a unique test bench.
Sky-Man test bench to simulate service hoist operations in climatic test chamber (system testing)

Service hoist drive unit

Test approach
Case story: CCV wind turbine gearbox
Why cold start-up testing a wind turbine gearbox?

→ Design verification gearbox and its auxiliaries

1) Validate cold start-up procedure (cold sweep test)
   ▪ time-to-grid time (effects of high viscosity on start-up time)
   ▪ break-away torque (effects of high viscosity on cut in speed)
   ▪ Effects of idling with or without additional heaters

2) Check component performance in cold conditions (seals, hydraulics,...)

3) Verify performance of new cold temperature oils.
Why cold start-up testing a wind turbine gearbox?

→ Design verification gearbox and its auxiliaries

4) Performance and reliability of auxiliaries mounted on the gearbox
   - Gearbox cannot work without the needed auxiliaries (lubrication systems, cooling system, ...).
   - Such systems are not always in scope of the supply, but all systems need to work in all conditions.
   - System test is needed to validate design.
   - For example: oil pumps need to be able to work with high viscosity lubricants in cold start-up scenario.
Successful -40°C climate chamber tests have been performed on a 2.X MW gearbox.
Approach: a new cold start-up test bench was designed to cope with cold sweep tests (max. break-away torque: 10kNm)
Test results 2. XMW gearbox:

- Cold ambient temperature was kept steady during the extreme cold sweep test.
- Time-to-grid measured between -40°C to +5°C oil temperature.
  (at 5°C oil temperature, load can be applied on drivetrain to produce energy)
- Different machine parameters were monitored to verify the design.
  (temperature oil sumps, temperatures auxiliaries, oil pressures, ...)

![Graph showing test results](image-url)
Research questions:

- Work on optimization solutions to reduce the time-to-grid time in order to increase the turbine’s availability.
- Test effects of new generation lubricants and greases for cold climate wind turbines.
- Effects of high viscosity on oil pumps / high starting currents on pump windings. The sudden increase of winding temperature when they are brittle could cause thermal stress; (accelerated degradation, partial discharge).
- Thermal fatigue on seals, hydraulic tubes, cables and prevention of leakages.
Possible partnerships / collaborations:

- OWI-Lab purchased a R&D gearbox to facilitate research on CCV wind turbines
- Demonstration opportunity to reduce time-to-grid
- Demonstration opportunity for new CCV lubricants
- Align CCV turbine field data with laboratory testing
- ...
Verification tests continue at OWI-Lab
80 ton gearbox tests finished yesterday
Other turbine components:

- Low temperatures can be a risk for electrical equipment such as generators, yaw drive motors.

- When power is applied to these machines after they have been standing in the cold for a long period, the windings can suffer from a thermal shock and become damaged. Also thermal fatigue needs to be taken into account (effects of multiple cold start events).

- Also generator slip-rings are affected by extreme cold temperatures.

- Condensation in electronic cabinets caused by thermal fluctuations and during downtime need to be taken into account.

- Power cables become brittle when exposed to extreme cold, the combination of this effect with turbine vibrations need to be taken into account.

- Not much field data and the effects of cold temperatures are available to feed research.
Thank you for your attention!

Any questions?

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