SIEMENS Gamesa
RENEWABLE ENERGY

SIEMENS GAMESA case: cold start-up validation of a wind turbine gearbox by the use of a large climatic test chamber

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www.owi-lab.be | www.sirris.be

Winterwind
INTERNATIONAL WIND ENERGY CONFERENCE

Quick Introduction Sirris & OWI-Lab

sirris
driving industry by technology

- Set-up in 1949
- Belgian Technology center - 160 VTE
- Mission: to support companies by implementing technology innovations
- Multidisciplinary R&D and innovation projects
- ± 1.500 innovation projects per year with 1.100 different companies (80% SME)
- 22,5 mil€ revenue
- Core topics: Advanced manufacturing ; ICT & data innovation ; Materials engineering and Mechatronics

www.sirris.be

Set-up in 2010

sirris
driving industry by technology

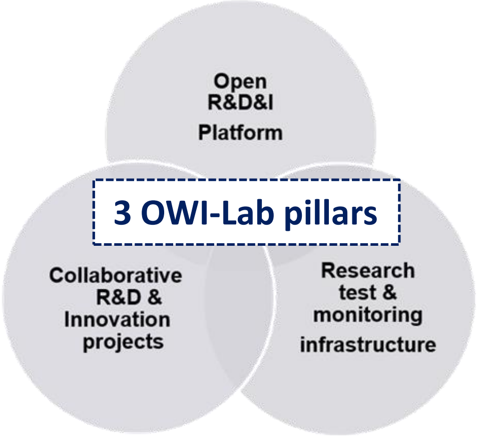
VUB VRIJE UNIVERSITEIT BRUSSEL

- RTO partnership focused on onshore and offshore wind energy topics with the aim to set-up and execute national and international RD&I projects
- Focus on challenges in harsh environments: offshore wind, cold climate wind energy
- Core topics: climatic testing facility & reliability in harsh environments ; SHM ; CMS ; O&M-optimization

www.owi-lab.be

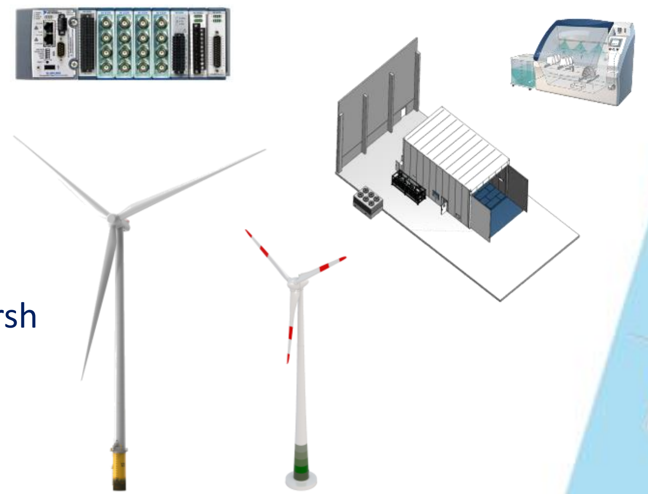
Business intelligence
Industry driven approach

www.offshoreenergycluster.be



R&D and Technology Expertise

Test & Demo
- Lab testing/demo
- In-field test/demo



OWI-Lab industry services for the wind energy sector

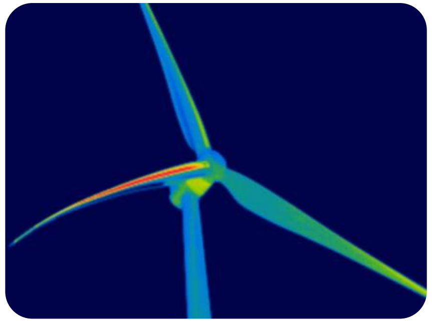
- **Climate chamber testing**

- **In-field test /measurement & monitoring projects**
  - Offshore and Onshore R&D measurements in general
    - Structural (vibrations, strain, EMA-OMA,…)
    - Machine parameters (thermal, electrical, mechanical)
    - Thermal camera measurements
    - Corrosion / environmental parameters

- **Virtual engineering department**
    - FEA model creation / model update / analysis

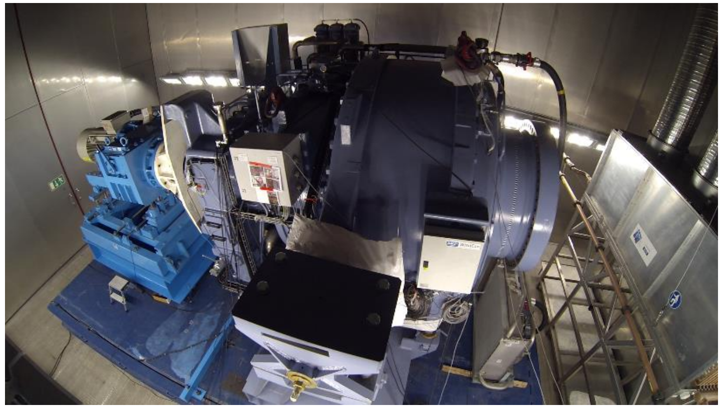
- **Materials engineering department**
    - Coupon material testing, destructive component testing and NDT
    - Failure analysis (RCA)
    - Coating testing
    - Corrosion testing

- **Innovation department**
    - RD&I projects (Local funded ; EU-funded)
    - Partnering & clustering
    - Innovation methodology / strategy / implementation




LARGE CLIMATIC TEST CHAMBER

Large climatic test chamber – example projects wind energy



Full size component testing of large and heavy machinery

Full size small & mid-range nacelle tests

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

Full functional electrical tests with or without wind turbine auxiliaries (forced cooling, pumps, heating, expansion tank,…)

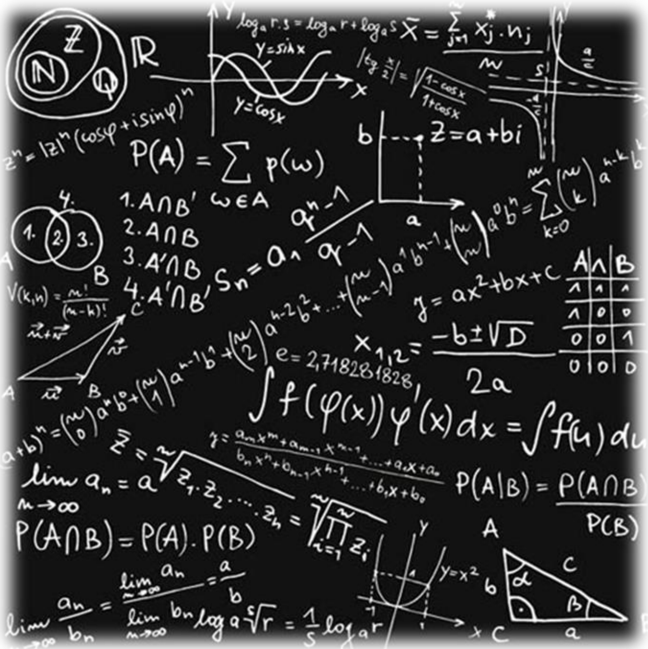
Smart solutions. Strong relationships.

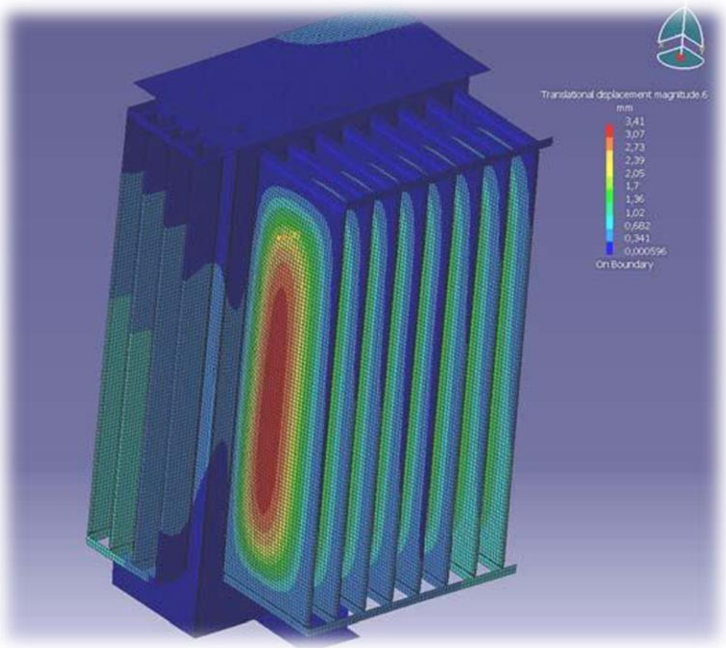
R&D tests on the behavior of fluids, oil and hydraulics in a full functional set-up

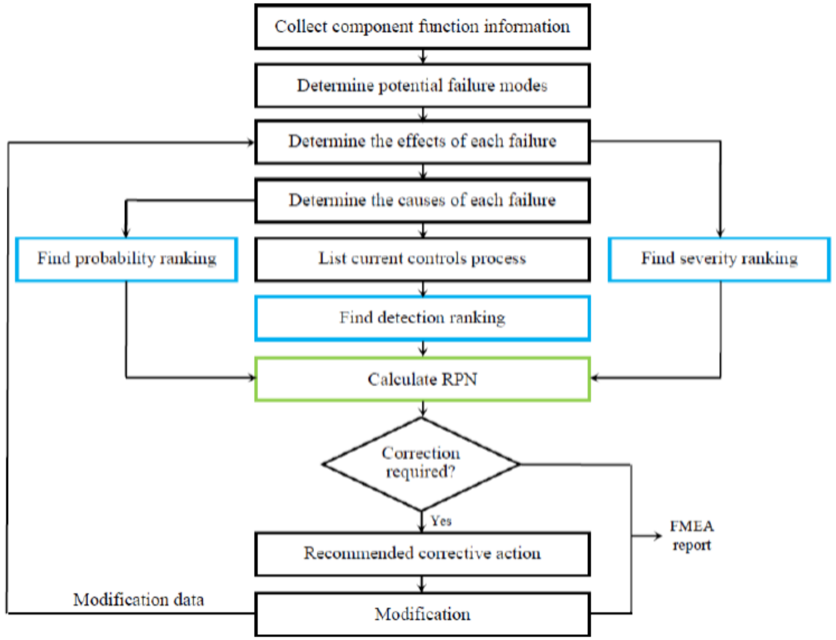
Smart solutions. Strong relationships.

Climatic test lab = Environmental testing of large / heavy electro-mechanical machinery
→ Functional testing under electrical, mechanical, hydraulic load during cold / hot / tropical / Humid environment

Large climatic test chamber – Why ?







FMEA Process – Pillay and Wang 2003

Design validation

Checking if simulation models are valid (model validation)

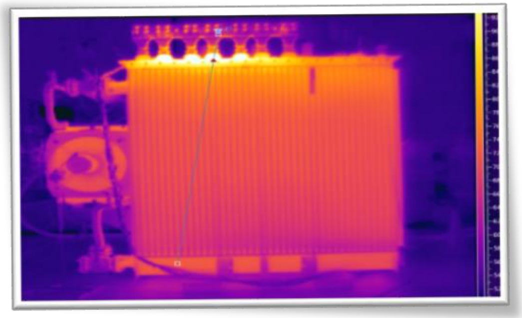
Risk mitigation

Certification

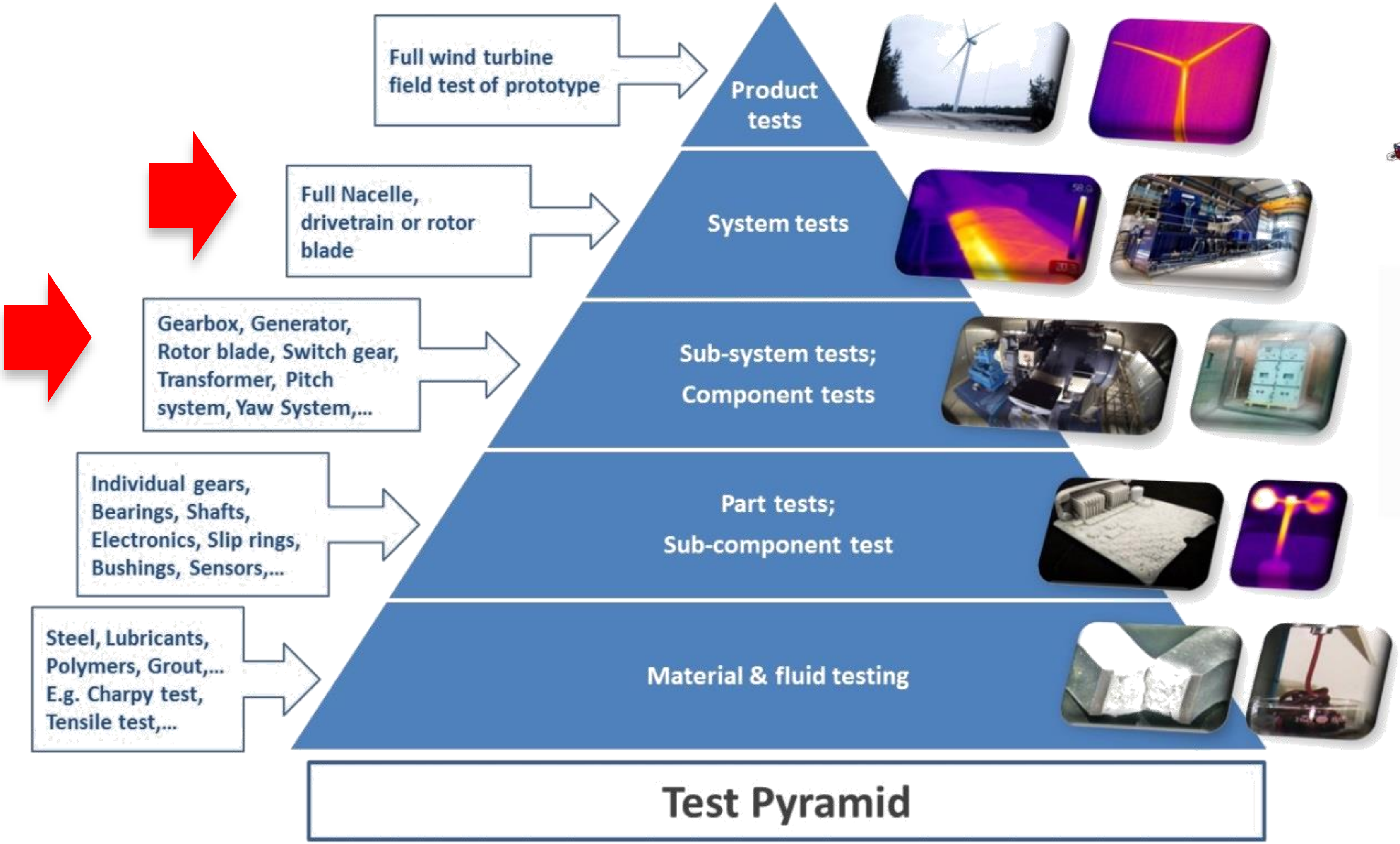
Deliver reliable machinery + shorten the time-to-market

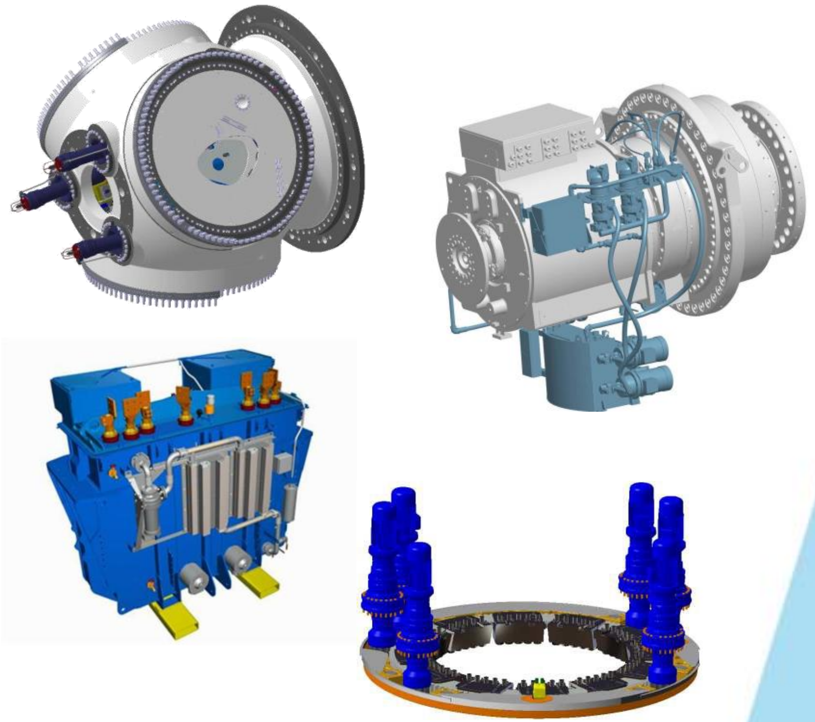
Large climatic test chamber – specifications

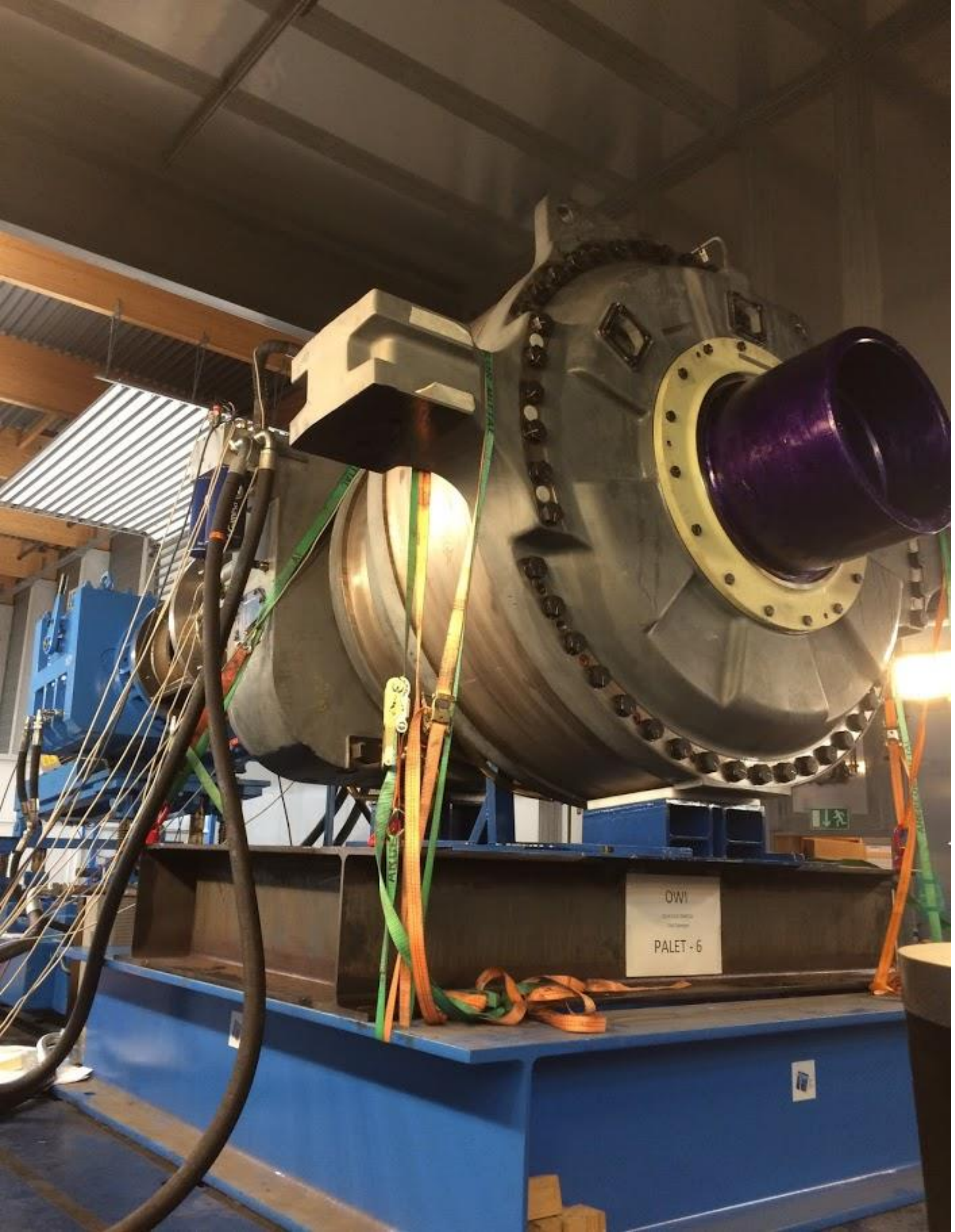
- One of the largest climatic test chambers in the Europe, dedicated for wind turbine components in harsh and extreme climates
- 10,5m x 7m x 8m inner dimensions
- Up to 300 ton possible
- **-60°C to +60°C temp testing**
- 8%RH to 95%RH humidity simulation
- No-load gearbox / generator test bench (cold start testing)
- IR solar light simulation
- Ice testing set-up
- Flexible set of electrical power up to 8MVA
- Located in the port of Antwerp



Focus = (functional) system & sub-system testing







SIEMENS GAMESA case: Cold start-up validation of a wind turbine gearbox

- Siemens Gamesa Renewable Energy (SGRE): one of the leaders in manufacturing multi-MW wind turbines (onshore & offshore)
- SGRE Gearbox Division: design and manufacturing of WTG gearboxes
- Worldwide market

SIEMENS Gamesa
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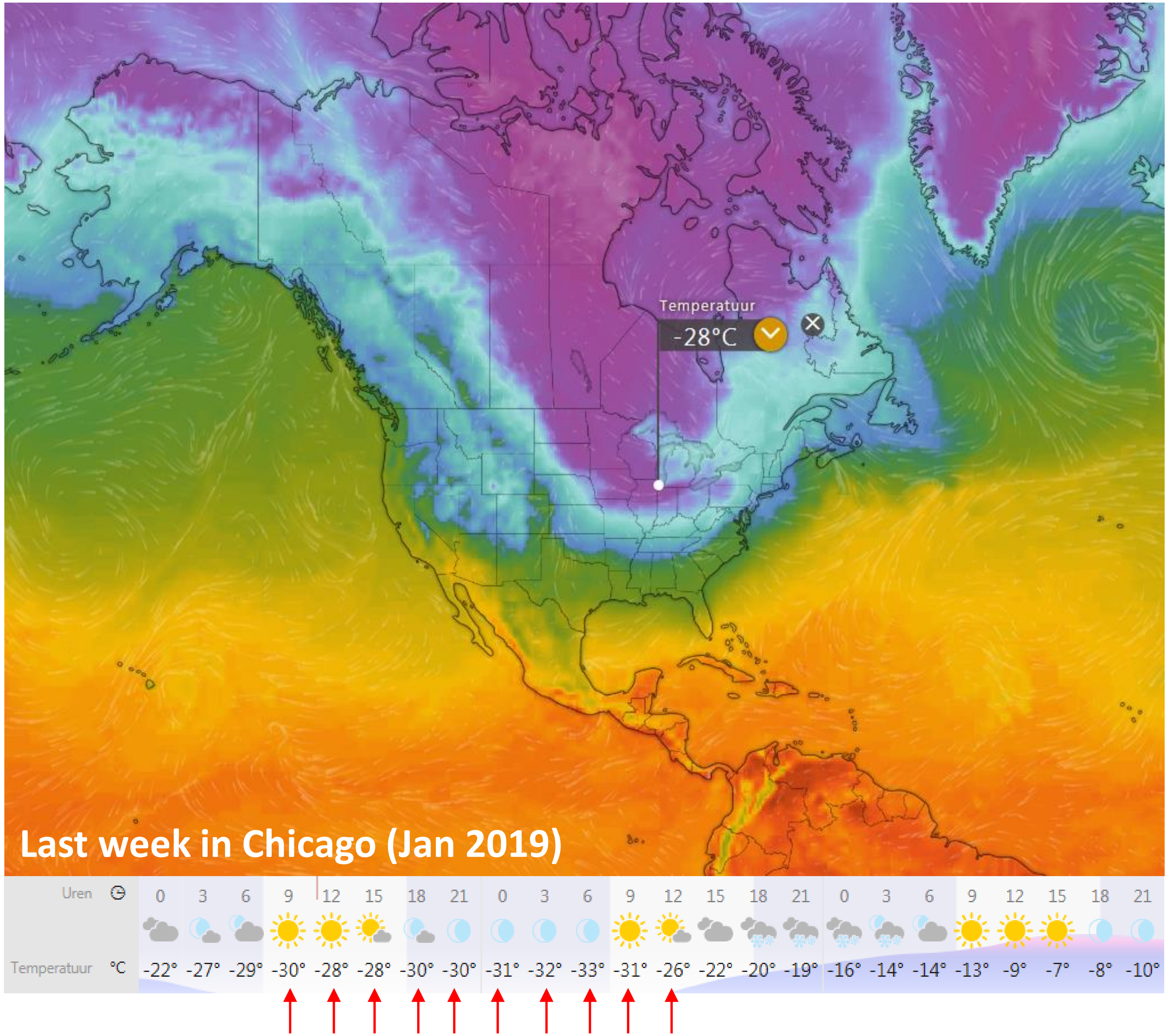
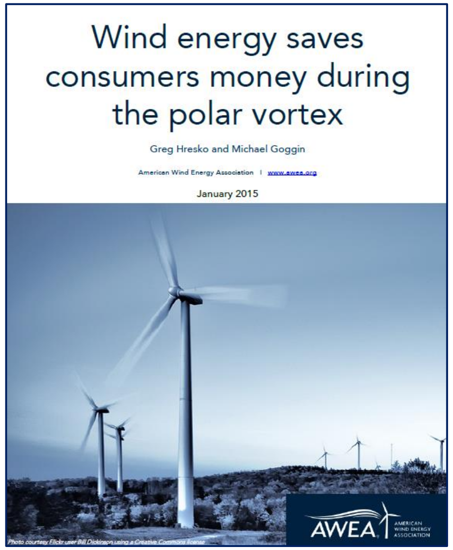
SGRE cold climate test: why needed?




Wind energy saves consumers money during the polar vortex

Greg Hresko and Michael Goggin

American Wind Energy Association | www.awea.org

January 2015

AWEA

Climate Changed

When Does the Windy City Lose Wind Power? During a Polar Vortex

By Chris Martin

30 januari 2019 22:57 *Updated on 31 januari 2019 13:00*

Bloomberg

- Turbines often idled during deep freezes to prevent damage
- Reduction in wind output boosts fuel burns as prices climb

The wind farms erected across the central U.S. over the past decade were supposed to provide cheap power during the blustery winter months. But they were never designed for cold like this.

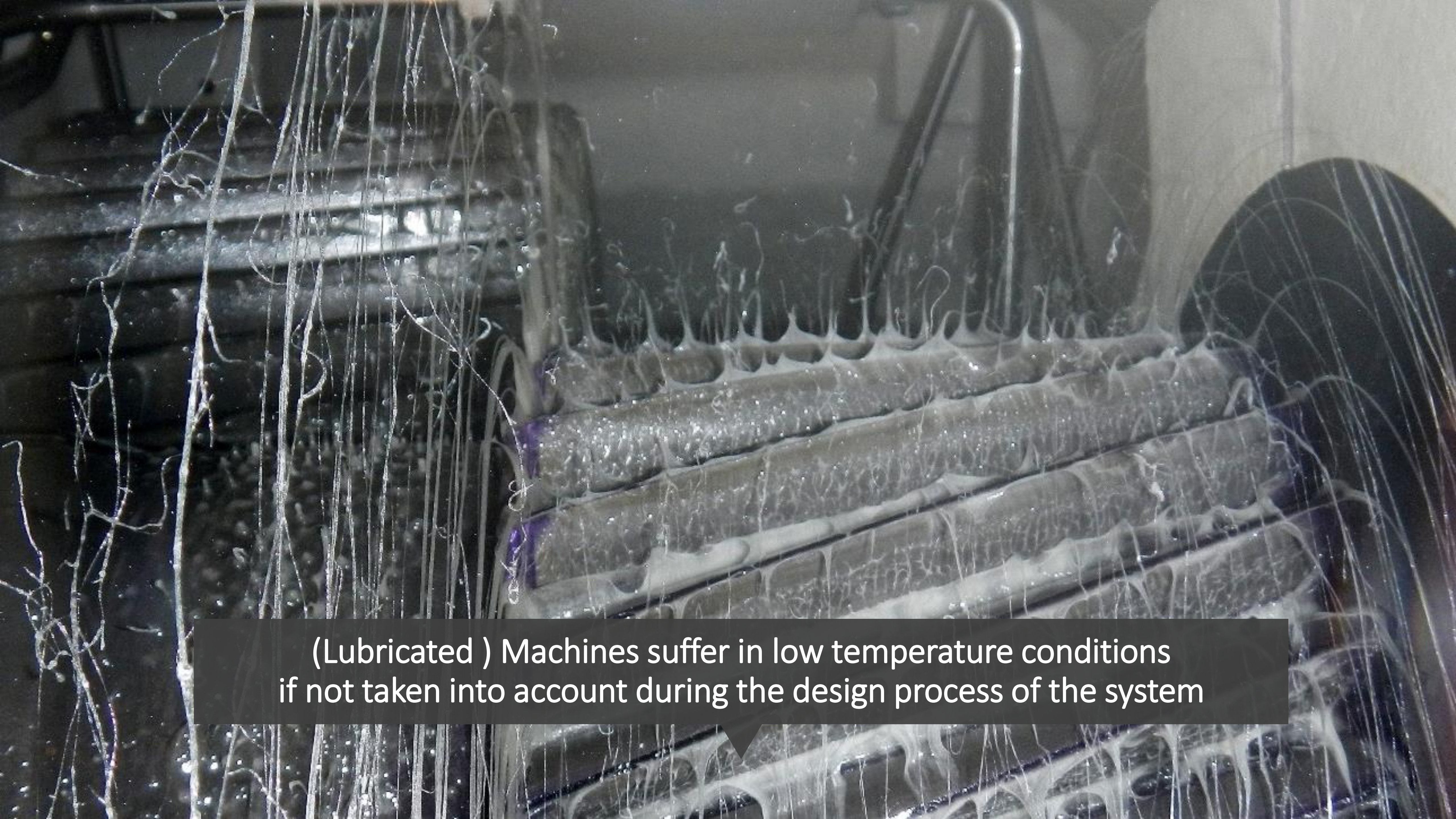
As a life-threatening freeze brought temperatures that may reach all-time record lows in the Chicago area Thursday morning, heating demand surged and power suppliers were forced to start up older coal and natural gas facilities that only operate on an as-needed basis. One of the reasons why is that wind-power generation has plummeted.

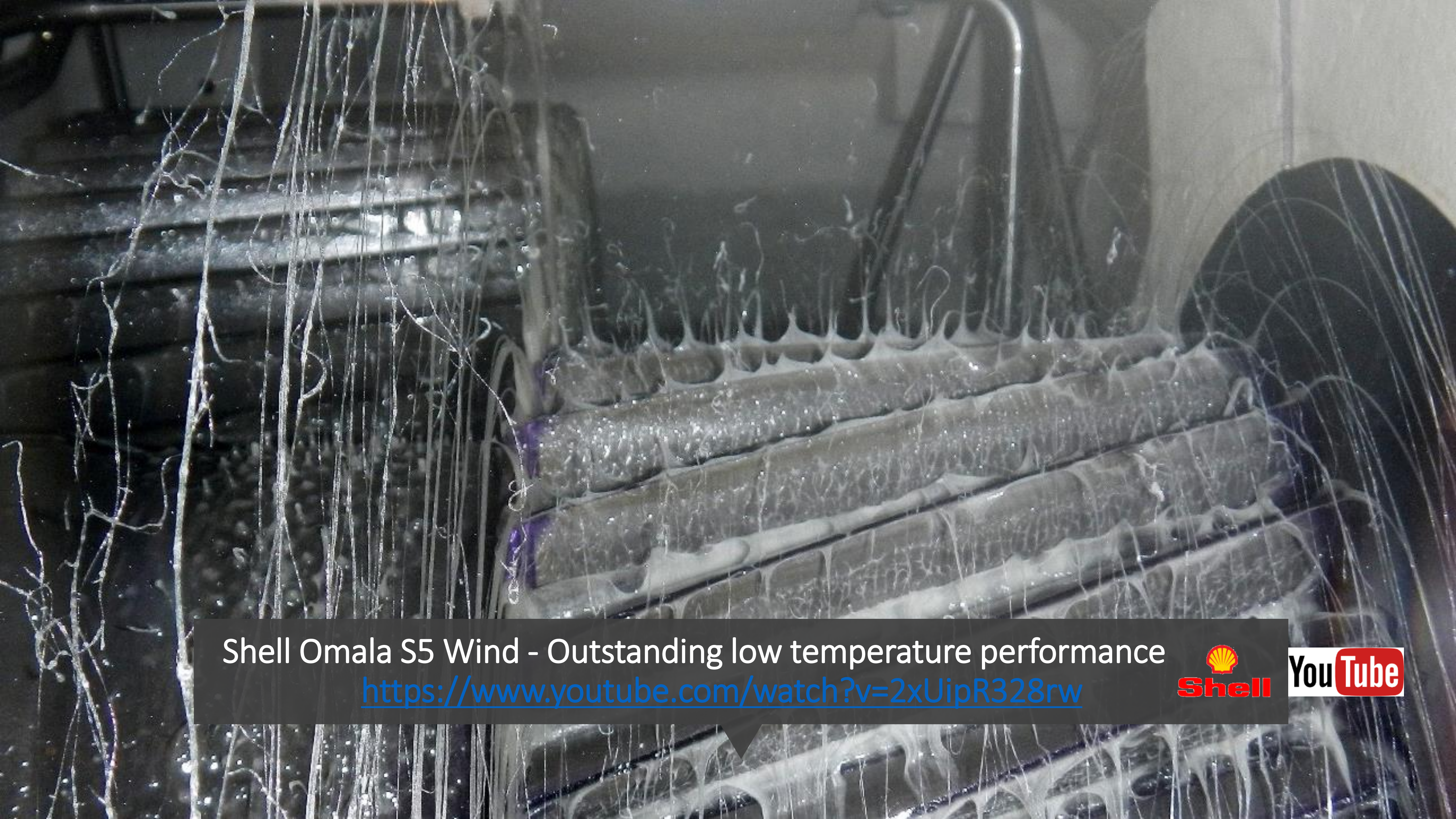
Wind generation on Wednesday afternoon was less than half its annual average in the Southwest Power Pool, the grid operator from North Dakota to Oklahoma.

"It's just too cold for a lot of wind farms," Adam Jordan, director of power analytics at Genscape Inc., said in an interview. "They can get damaged in weather like this."

With a deep freeze like this one, wind-farm operators may have to hit the brakes as ice builds up on blades and to prevent lubricated bearings from seizing up and stiffened fiberglass blades from cracking. The National Weather Service warned that records may topple from the upper Midwest through the Ohio Valley by Thursday, and the Chicago area may see wind chills as low as minus-50 degrees Fahrenheit (minus-46 Celsius).

https://www.bloomberg.com/news/articles/2019-01-30/when-does-the-windy-city-lose-wind-power-during-a-polar-vortex

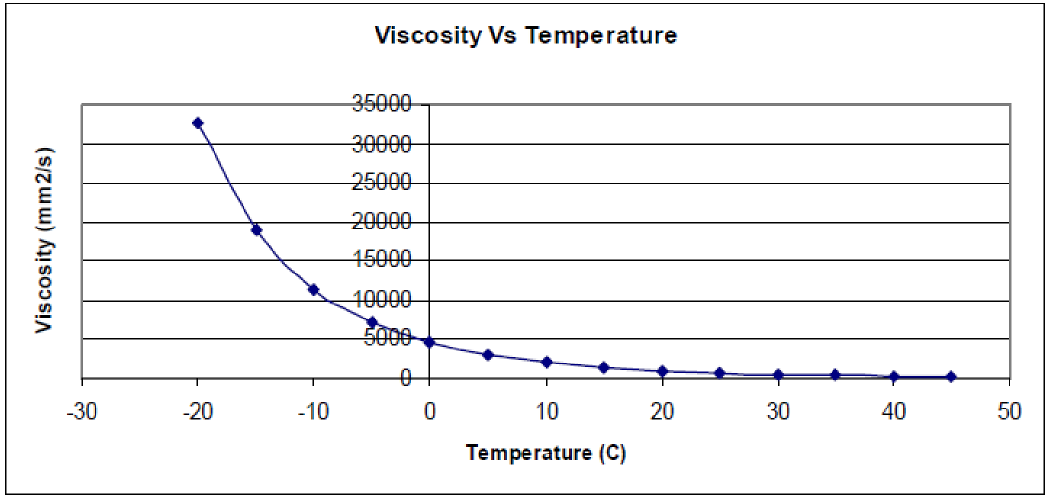

(Lubricated) Machines suffer in low temperature conditions
if not taken into account during the design process of the system

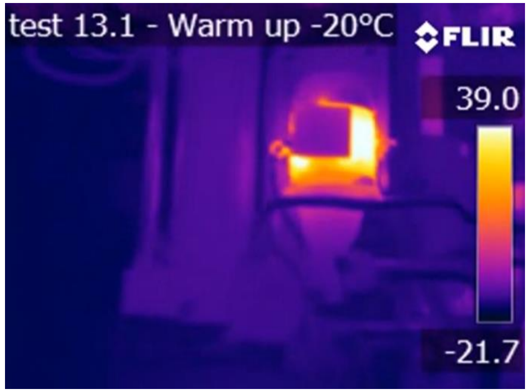


Shell Omala S5 Wind - Outstanding low temperature performance
https://www.youtube.com/watch?v=2xUipR328rw

Cold climate test in general: why needed?

Main topic: low temperature effect on the lubrication → + side effects if this



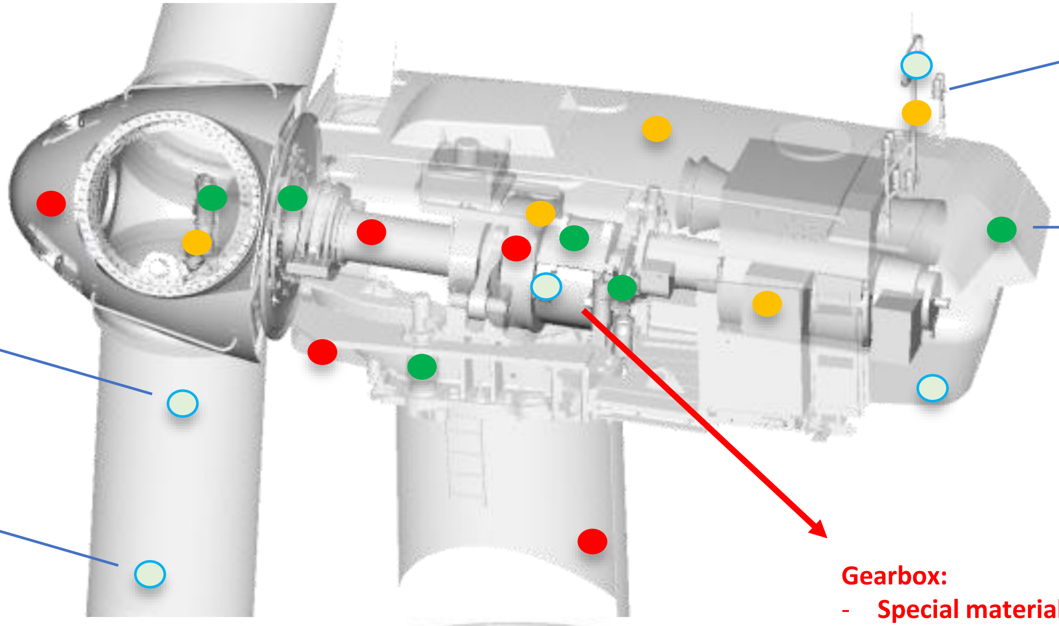


- High viscosity contributes to high churning losses, high pressure drop, and insufficient flow in the lubrication components of the wind turbine gearbox
  (gears & bearing need sufficient lubrication to prevent wear)
- Low viscosity causes low film thickness, which increases wear
- Oil type: finding a balance → low temp/high temp limits
  - Preferred oil viscosity is dependent on the environmental temperature range of the application
    → cold climate = other GBX-oils
- Cold start-up = risk → pre-heating needed before starting
- In general: survivability of the machine in low temperature (pumps, sensors, filters,lubrication,…) during idling conditions

SGRE cold climate test: why needed?

- **Potential failure modes of a gearbox at extreme cold temperatures**
- **Lubricants become viscous and stiff**
  - ➔ exceptional load on pumping equipment and auxiliaries
  - ➔ non-optimal oil flow in bearings
- **Rotating elements at risk**
  - ➔ insufficient lubrication (non-optimal oil flow)
  - ➔ differential thermal expansion of sub components
- **Long cold start-up runs**
  - ➔ negative effect on energy yield
- **Low temperatures effect materials (plastics, metals, rubbers)**
  - ➔ brittle fracture of elements (sealings, cables, gears,…)
- **Heaters for oil pre-heating**
  - ➔ surface temperature of heaters low enough
    - not to burn oil

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

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

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

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

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

Wind turbine applications → 'the misery law' due to large Δ T

Table 1: Cold weather properties of base oils		
Base Oil	**Viscosity Index**	**Pour Point** (temperature below which the oil does not flow by itself)
Mineral Oil	80 - 100	Poor low temperature behavior
PAO	150 - 250	Good low temperature behavior -40 to -50 C
Esters	140 - 175	Excellent low temperature behavior -50 C or below
PAG	150 - 270	Good low temperature behavior -40 to -50 C
Silicone Oils	190 - 500	Excellent low-temperature behavior -50 C or below
PFPE	50 - 350	Some types can go as low as -70 C

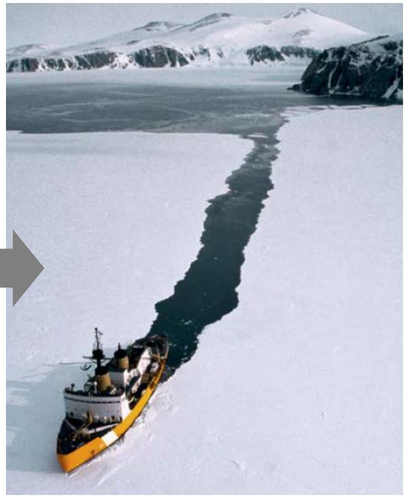
As with lubricating oils, the choice of thickeners can impact cold weather performance (Table 2). Typical grease thickeners are lithium soap, aluminum soap, calcium soap, barium soap, and PTFE (polytetraflouroetheylene also known as silicon).

Commonly, grease that shows good low-temperature stability will often perform poorly in high-temperature applications— requiring grease change out in warmer weather. Moreover in maritime applications (offshore wind), some additives have a negative environmental impact !

Table 2: Cold weather properties of greases

Lower Service Levels (Celsius)

Oil Type	Li	Al	Na	Ca	Ba	Pu	PTFE
Mineral	-10 to -35	-10 to -30	-20 to -30	-10 to -30	-10 to -20	-10 to -35	Not Common
PAO	-25 to -50	-25 to -50	Not Common	-35 to -50	-35 to -50	-20 to -40	-20 to -50
Ester	-40 to -70	Not Common	Not Common	-20 to -40	Not Common	-10 to -50	Not Common
PAG	-30 to -50	Not Common	Not Common	Not Common	Not Common	Not Common	-20 to -30
PFPE	Not Common	Not Common	-25 to -40	Not Common	Not Common	Not Common	-20 to -70
Silicone	-40 to -50	Not Common	-30 to -60	Not Common	Not Common	Not Common	-40 to -70



SGRE cold climate test: why needed?

Design verification testing (of prototypes)

- Validate cold start-up procedure (cold sweep test)
  - Time-to-grid (effects of high viscosity of oil on start-up time)
  - Break-away torque (effects of high viscosity of oil on cut in speed)
  - Effects of idling with or without additional heaters (heating strategy)

- Check auxiliaries components performance in cold conditions (pumps, cooling circuits, filters, sensors, seals, etc)

  → survivability testing in full functional set-up

- Verify performance of new cold temperature oils

Limits	typical for LTC[2] turbines
Operational temperature limits	-30 °C
Survival temperature (stand still)	-40 °C

DNV·GL

RECOMMENDED PRACTICE

DNVGL-RP-0363 Edition April 2016

Extreme temperature conditions for wind turbines

DNV GL AS

DNVGL-RP-0363 Extreme temperature conditions for wind Turbines (April 2016)

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.

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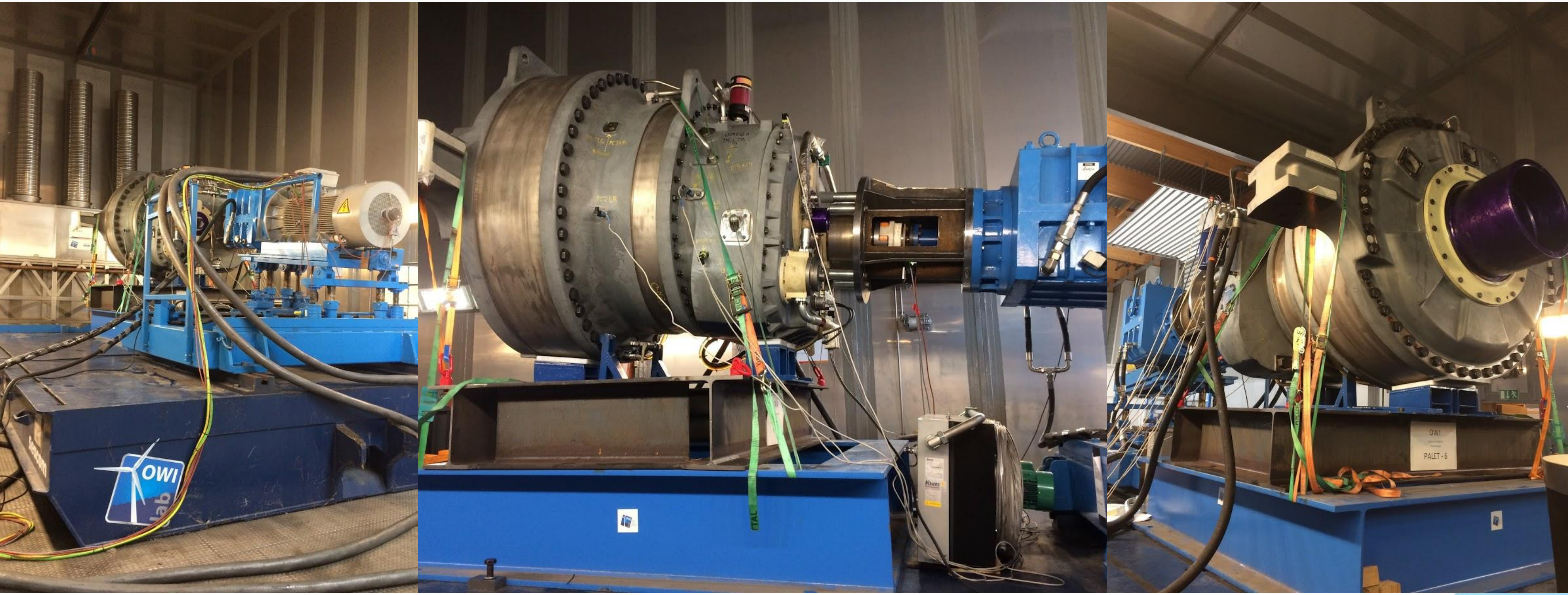
→ SGRE end goals of testing: having a reliable & robust machine that is able to meet with the customers expectations worldwide – even in the most extreme conditions that can occur

→ Servitization trend: reliability = key

SGRE cold climate test set-up



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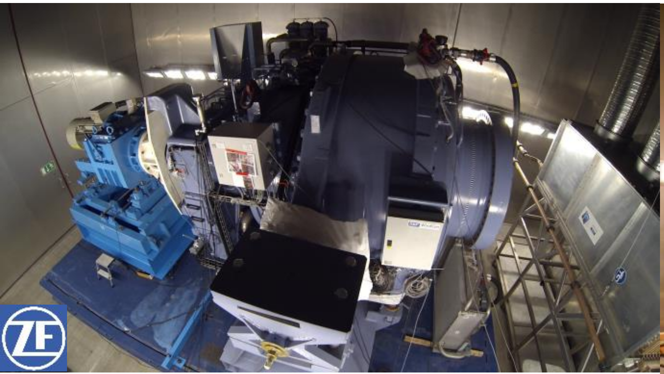
2.5 MW wind turbine gearbox

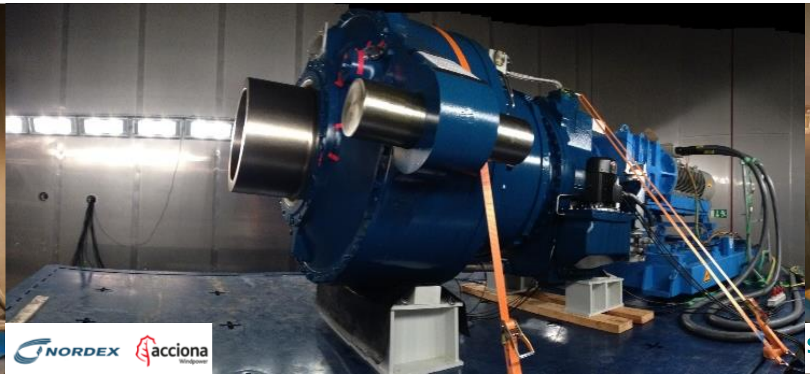
OWI-Lab conclusions of gearbox testing past 5 years

- **All gearbox suppliers and OEM's are well aware of the risks of low temperatures / cold climates**
  - Dedicated mitigation measures taken for these scenario's (cold climate packages)
  - All of them test & validate their components for extreme environments

- **Generic lessons learned:**
  - Validation testing in climate chamber pays off → infant failures are early detected & adapted before in-field validation (can be expensive)
  - In general mainly errors with: oil pumps, seals (leakage), cavitation, small components & sensors
  - Average time-to-grid time for gearboxes: ±5h (with wind) ; early days: x2 or x3

- **Future R&D topics:**
  - Cold start-up durability test: accelerated cycles for 20 year lifetime to evaluate the durability of the full systems after X-amount of cold-start cycles (>100 cycles) → wear of gears, bearings, winding wear of pumps?
  - Investigation of any correlation between stand-still marks and cold climate regions | Develop test in climate chamber for bearings
  - Virtual testing of cold start-up





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