Winterwind
INTERNATIONAL WIND ENERGY CONFERENCE

Inspection & repair: Why performing climatic chamber testing on wind turbine applications?

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OWI lab
Offshore Wind Infrastructure Application Lab

To reduce maintenance costs due to (extreme) low temperature

El Toqui Wind Farm - Chile

Why perform climatic chamber testing for wind energy applications?

Focus on potential cold-climate issues for wind turbine machinery

Introduction

In 2012, OWI-Lab opened its climatic testing facility in the port of Antwerp, home to one of Europe's largest climatic test chambers. OWI-Lab's goal is to meet wind energy companies' needs in terms of testing and validating their products in aggregated climatic conditions, such as extremely cold or hot temperatures and variable humidity. Some of the leading wind turbine component manufacturers indicated that they did not have access to publicly accessible and appropriate climatic test chambers. In response to that need, OWI-Lab invested in a large 10m x 8m x 7m test chamber capable of handling up to 150 tonnes.

Since inaugurating the chamber in 2012, OWI-Lab has served many well know companies in the sector and has become a full-service provider for the testing of large electrical and mechanical wind turbine equipment. Depending on the certification process and scope of the project, testing is typically witnessed either by the customer or by external parties to check the performance of equipment under conditions ranging from -60 °C to +60 °C, sometimes under load and sometimes not (For example: no-load start-up test of a gearbox or storage test of a transformer for).

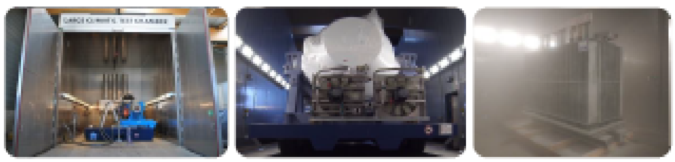


Figure 1: OWI-Lab large climatic test chamber, gearbox test and transformer test

The need for climatic testing in the wind power industry

As most renewable energy systems are located outdoors, sometimes in harsh conditions ranging from the extreme cold of Inner Mongolia, Scandinavia, Canada and North Dakota to the scorching hot deserts of the United States and Australia, critical attention must be paid to the suitability and robustness of equipment in such hostile environments. Mitigating the risk of potential failures caused by extreme temperatures (differential thermal expansion, brittle materials and potential cracks, highly viscous oils, etc.) early in the development phase can help to reduce maintenance costs in the long term. This has been the main driver for OWI-Lab in performing temperature testing in the climatic chamber on multiple turbine components and systems associated with wind energy projects.

- Electrical equipment
  - E.g. Transformers, switch gears
- Mechanical equipment
  - E.g. Gearboxes
- Hydraulic equipment
  - E.g. Pitch & Yaw systems
- Structural components
- Project development equipment
- Construction tools
- O&M tools

Content of this presentation based on recent white paper:

White paper OWI-Lab: Why performing climate chamber tests for wind energy applications?

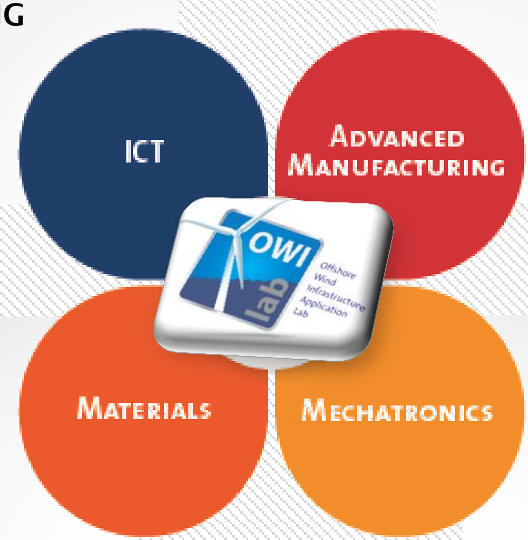
Quick Introduction

sirris
driving industry by technology

- Collective Belgian technology centre
- 2500 member companies
- Technology innovation for/with companies
- From collective projects to contract research
- High tech R&D and test infrastructure

SOFTWARE ENGINEERING
CLOUD COMPUTING
DATA INNOVATION

FACTORIES OF FUTURE
WORLD CLASS TECHNOLOGIES
ADDITIVE MANUFACTURING



METALS
COMPOSITES
PLASTICS & HYBRIDS
COATINGS
NANOMATERIALS

ECO-MECHATRONICS
SENSORIZED FUTURE
MODEL BASED DESIGN

-60°C → +60°C

Laboratory for environmental testing of heavy machinery

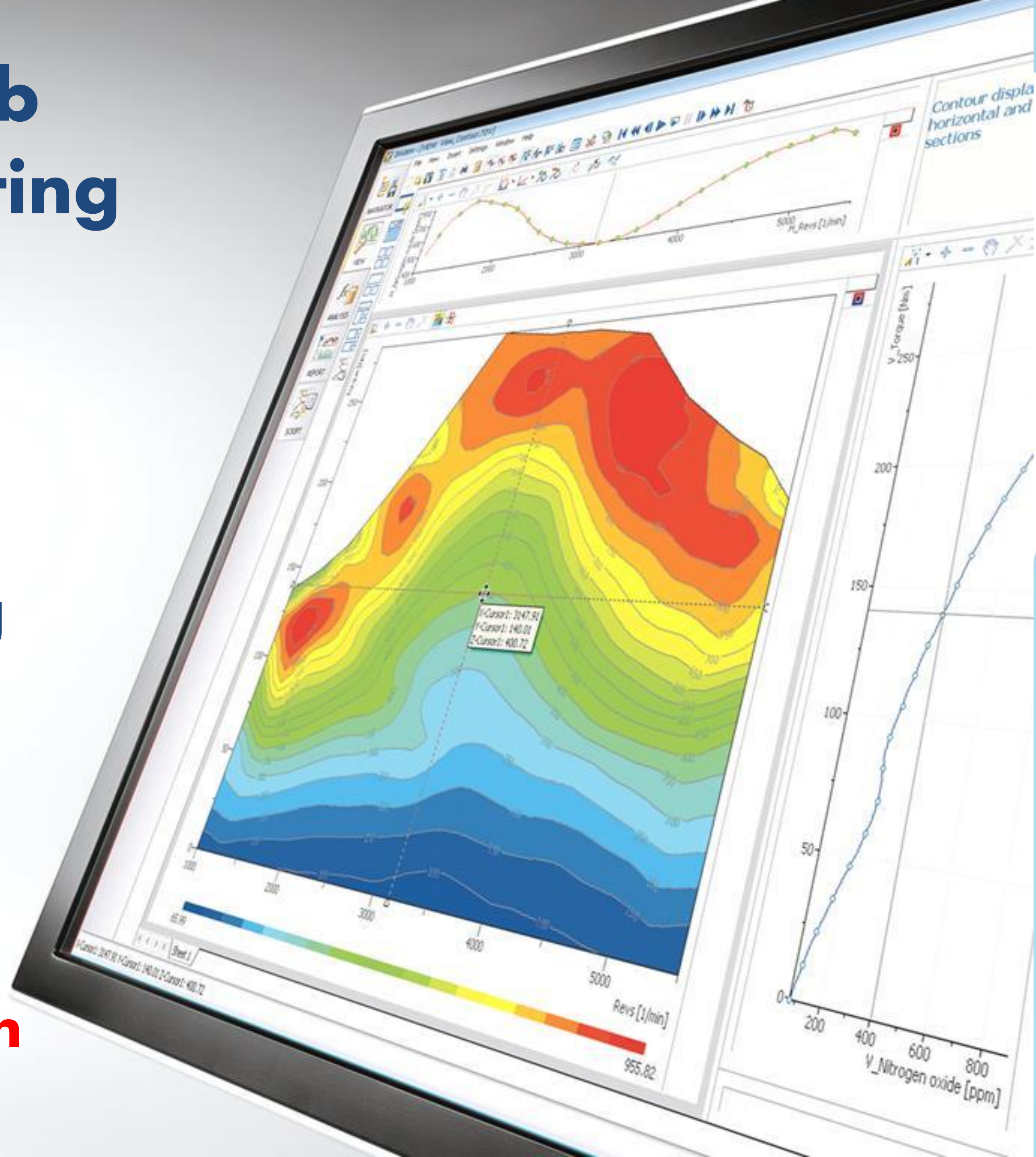
Focus on (extreme) cold temperature verification testing

Good design & good construction means reduced maintenance costs

Data from lab and field testing

Knowledge, insight and understanding

CAPEX reduction
OPEX reduction
Yield optimization
Risk reduction



Power plants in general are **not immune** for (extreme cold) weather events

The 2011 **'Southwest Cold Weather event'** and the **'Polar Vortex event'** last winter and have been a reminder that despite several years of mild winters, colder months can occur and have a big impact if not properly taken into account.

→ Valuable lessons learned for future and existing power plants

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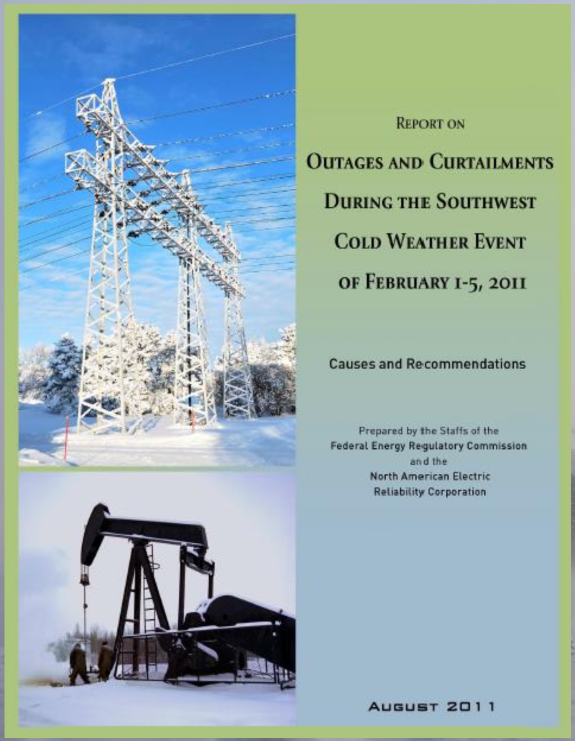
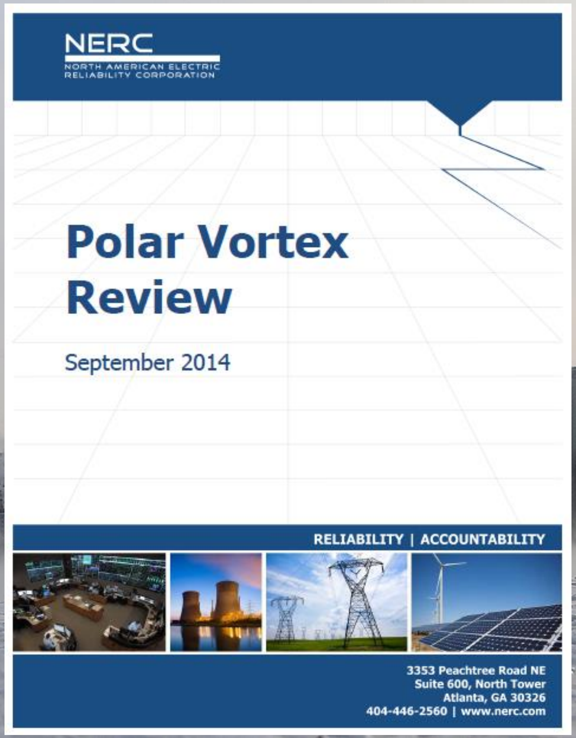
TEXAS RELIABILITY ENTITY
Ensuring electric reliability for Texans

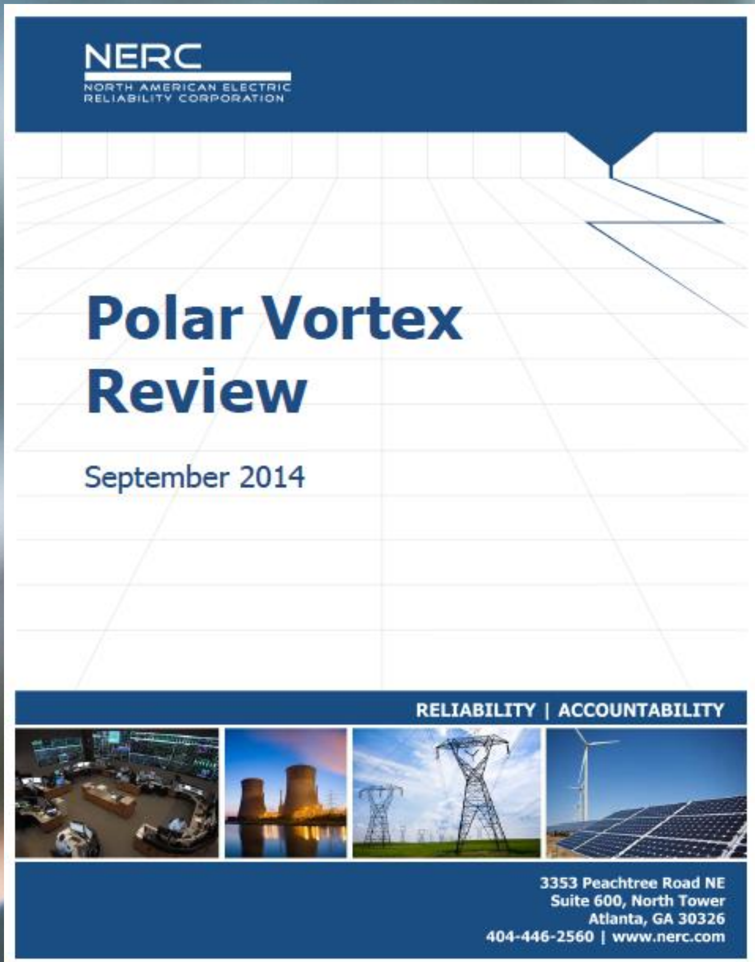




→ **Valuable lessons learned for future and existing power plants**

Understanding the risks and take them into account early in the design phase of a wind turbine or development of a wind farm can avoid most problems and increase resilience

Looking back 1 year – Wind energy as a critical electricity supply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Polar Vortex Review

September 2014

RELIABILITY | ACCOUNTABILITY

3353 Peachtree Road NE
Suite 600, North Tower
Atlanta, GA 30326
404-446-2560 | www.nerc.com

±19.500 MW lost capacity:

Overview of forced power outages during the polar vortex:

- 3 percent were associated with nuclear generation
- 26 percent of outages were associated with problems at coal plants
- 55 percent of outages were attributed to disruptions in natural gas supply or generation
- 16% others but renewable generation (wind and solar) are not part of the mandatory data submittal requirements

Looking back 1 year – Wind energy as a critical electricity supply

Looking back 1 year – Wind energy as a critical electricity supply


Wind energy saves consumers money during the polar vortex

Greg Hresko and Michael Goggin

American Wind Energy Association | www.awea.org

January 2015

Photo courtesy Flickr user Bill Dickinson using a Creative Commons license

AWEA AMERICAN WIND ENERGY ASSOCIATION

- Wind and solar power are often considered unreliable → **WRONG**
- **FACT:** Fossil-fueled plants had the most failures
- **FACT:** Under extreme weather conditions, conventional power plants regularly become more intermittent than (fluctuating) renewables
- **FACT:** Energy markets experienced major disruption during the 2014 polar vortex due to the unexpected shutdown of power plants and a run-up in natural gas prices caused by supply shortages
- **FACT:** 'Cheap' wind energy helped to moderate the disruption and keep electricity prices from skyrocketing further
- **ADVICE:** Make sure wind turbines and their components are capable of performing reliable in such conditions

2011 Southwest Cold Weather Event

Background - Unusually cold and windy weather during the first week of February 2011 resulted in:

- Increased Energy Demand (additional winter peak demand)
- Generation losses in different power plant assets due to frozen equipment, low temperature limits, fuel issues,…
- 225 units tripped, de-rated or failed to start.
- 1.3 million customers lost power

2011 Southwest Cold Weather Event

- Except for nuclear facilities, all power plant types including coal/lignite, simple cycle gas, combined cycle gas and wind resources experienced problems

- Mostly coal & gas power plants

- Frozen equipment & water lines ; cabinet heating elements failed ; Insulation removed, damaged, not adequate ; Heat traces failed or not adequate ; Blade Icing; Low temp. cutoff limitations; …
  → this is reason why we extensively test & validate !

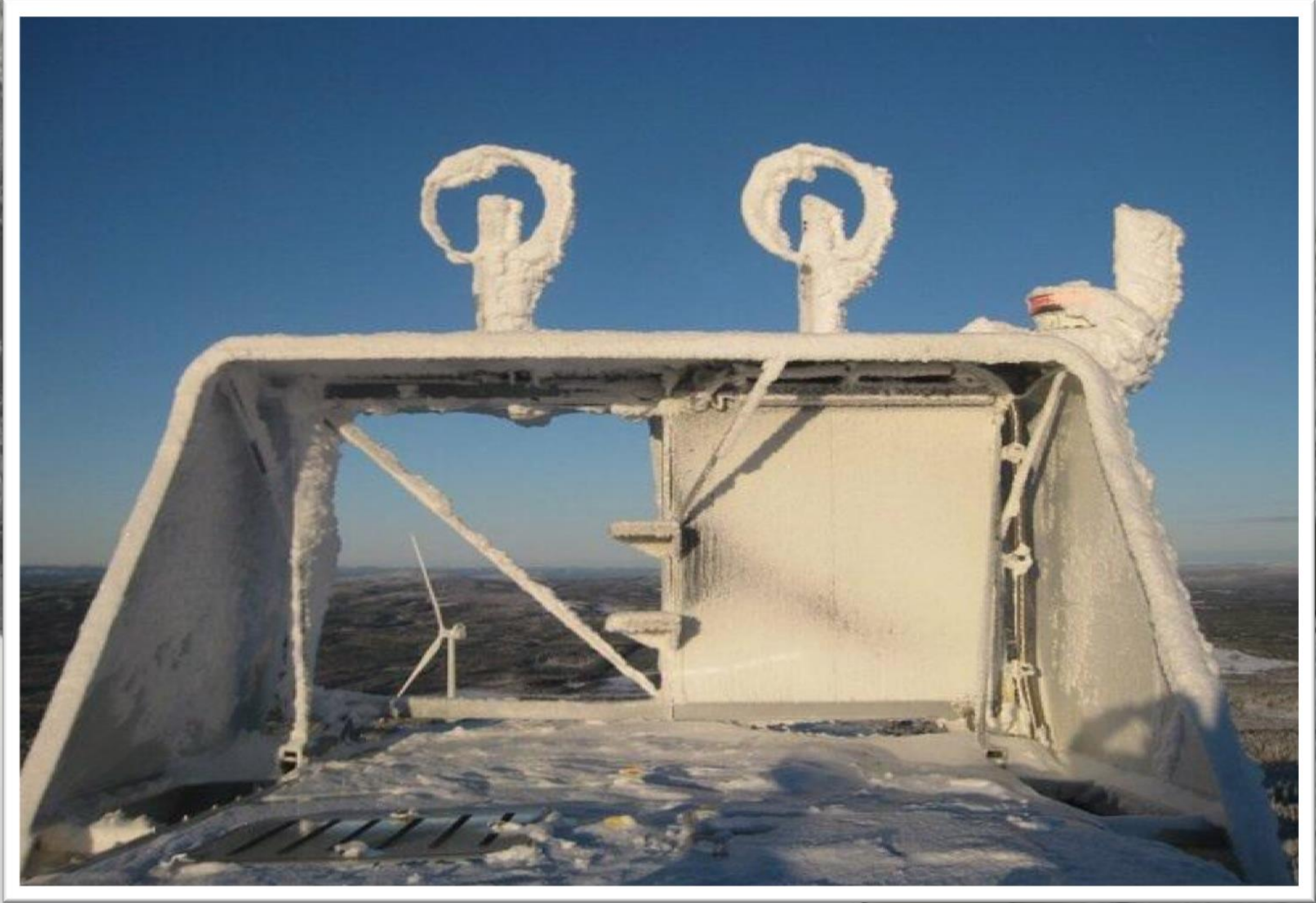
Conventional power plants and their problems during extreme cold if not properly taken into account

2011: Frozen valves: Insulation not re-installed for winter

Conventional power plants and their problems during extreme cold if not properly taken into account

2011: Frozen pipes: Frozen water in pipes cause damage

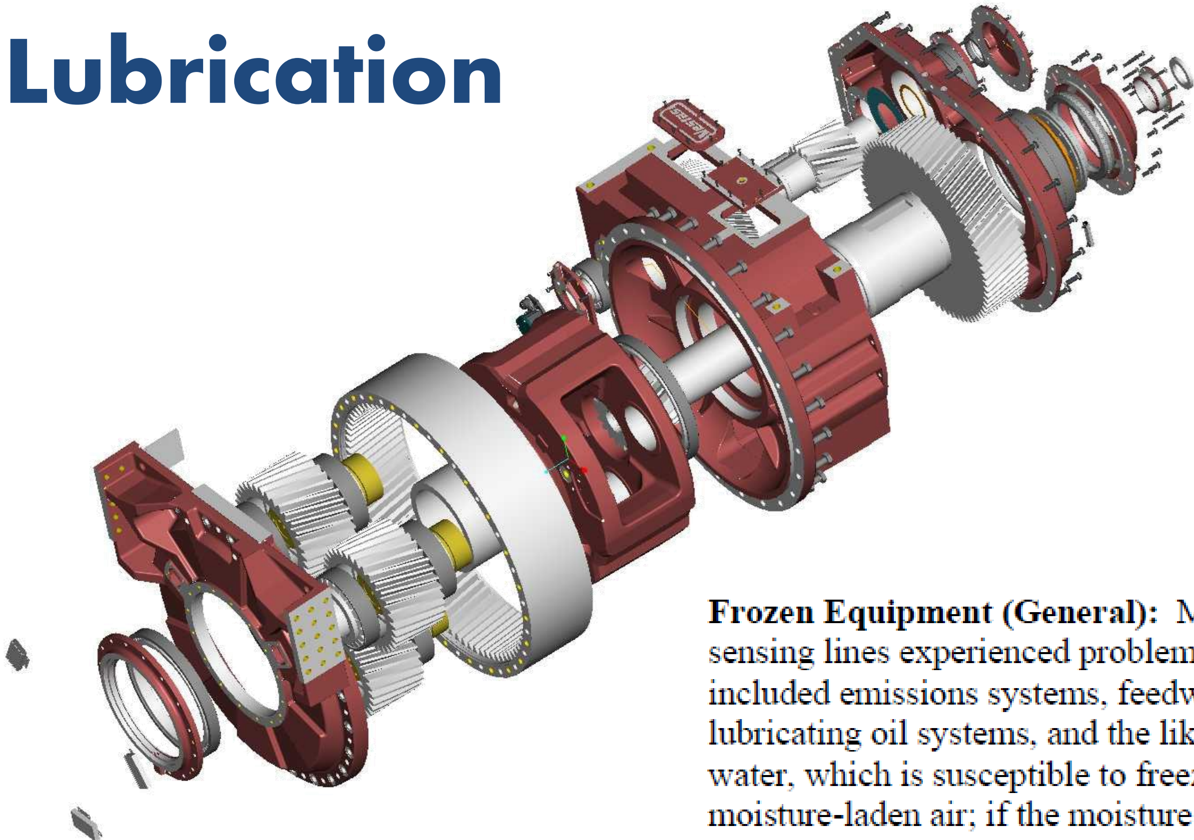
Wind power plants and their problems...



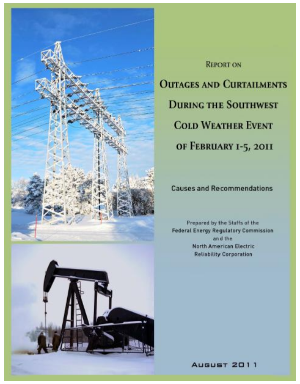
Challenges with turbines in cold climate

- **Yield - Production losses - Efficiency**
  - Icing effect on blades
  - Longer time for start-up – cold start-up time
  - Effect op parasitic power consumption
- **Reliability & Robustness**
  - Additional loads on certain components (blades, hydraulics, …)
  - Early failure of certain components due to temperature effects
  - Effect of cold climate on expected lifetime
- **Maintainability & Operational Safety**
  - Limited access (cold, snow, ice built-up and ice-throw, weather limits)
  - Special tools
  - Increased O&M-costs

Lubrication



Frozen Equipment (General): Many other critical systems besides sensing lines experienced problems from the low temperatures. These included emissions systems, feedwater systems, control air systems, lubricating oil systems, and the like. Emissions systems sometimes rely on water, which is susceptible to freezing. Control air systems contain moisture-laden air; if the moisture is not removed, freezing can occur. Changes in the viscosity and properties of lubricants that are not kept at specified temperatures can adversely affect the operation of equipment.


Report on
Outages and Curtailments
During the Southwest
Cold Weather Event
of February 1-5, 2011

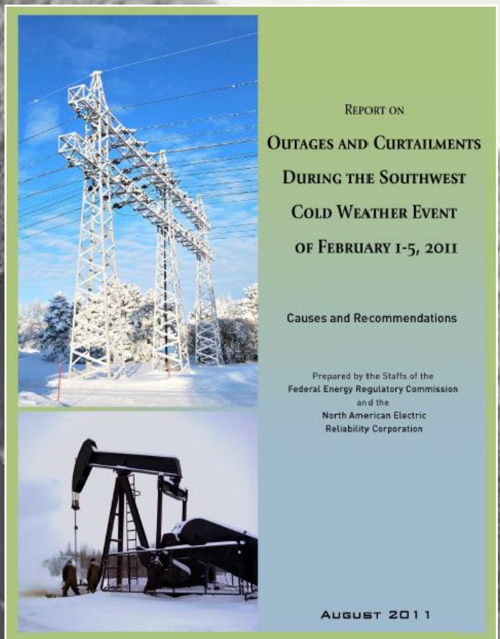
Causes and Recommendations

Prepared by the Staffs of the
Federal Energy Regulatory Commission
and the
North American Electric
Reliability Corporation

August 2011

- ✓ Two units at one plant were derated when the NOx water storage tank lines froze.
- ✓ At a City of Garland unit, 78 MW were lost from a draft fan failure, which was caused by frozen damper controls and a resulting low air flow trip.
- ✓ A wind facility lost six units when lubricating oil fell below the minimum operating temperature and automatically tripped the units.

Blades & Icing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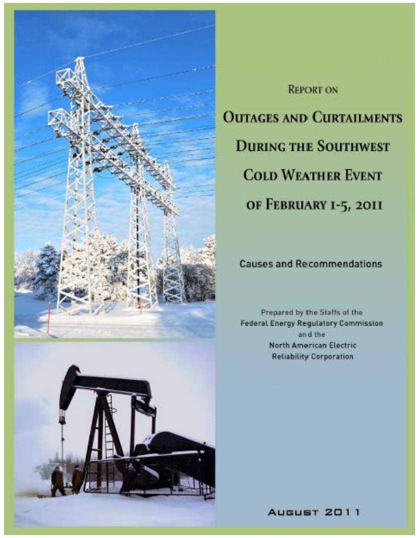
August 2011

Blade Icing: Blade icing caused problems for wind generators. Precipitation and condensation during cold weather can cause layers of ice to form on turbine blades, causing potential balancing, bearing, and other equipment problems (as well as safety problems resulting from "ice throws").

- ✓ Turkey Track Wind Energy lost 27 turbines and 40.5 MW of capacity during the event due to blade icing problems.

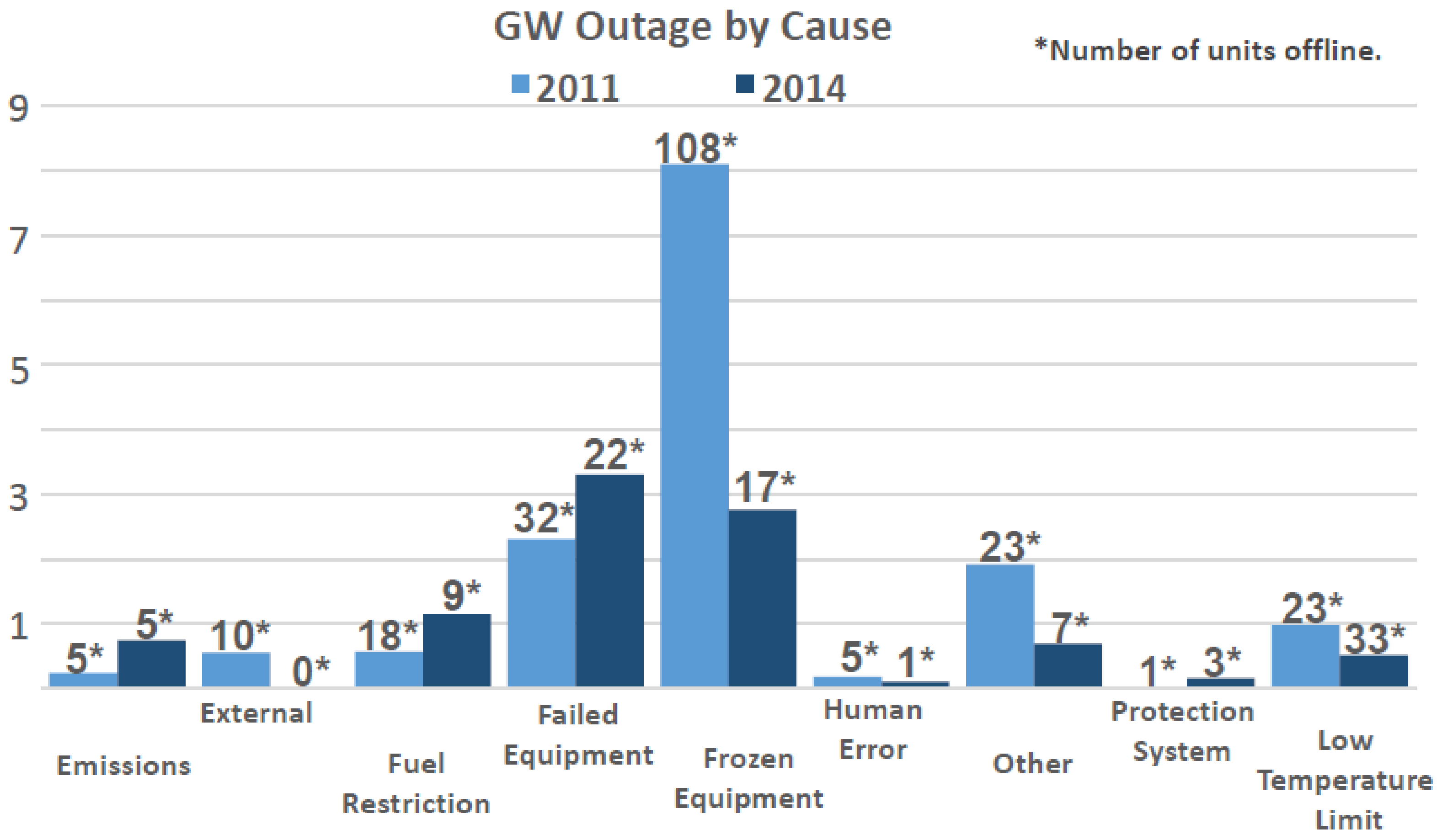


Low Temperature Limits: Wind turbines are typically designed to operate within a designated range of temperatures, and have an automatic shutdown feature to protect their components if the range is exceeded. Although manufacturers offer a "cold weather package"[210] that allows a turbine to continue operating in colder temperatures, it does not appear that the package is used in the Southwest.

- ✓ McAdoo Wind Energy suffered outages of 90 of its 100 turbines when the turbines, designed to shut down when the temperature drops below five degrees, performed as expected. Although McAdoo's turbines restarted automatically when the temperatures rose above the shutdown point, other units, such as Bull Creek Wind, did not come back online as temperatures rose.

Temperature limits

Generation outage by cause



Source: ERCOT Region Cold Weather Lessons Learned

TEXAS RELIABILITY ENTITY
Ensuring electric reliability for Texans

OWI lab

Also wind turbine have not been immune for the cold weather snaps

16% of the wind units failed in ERCOT (Electric Reliability Council of Texas)

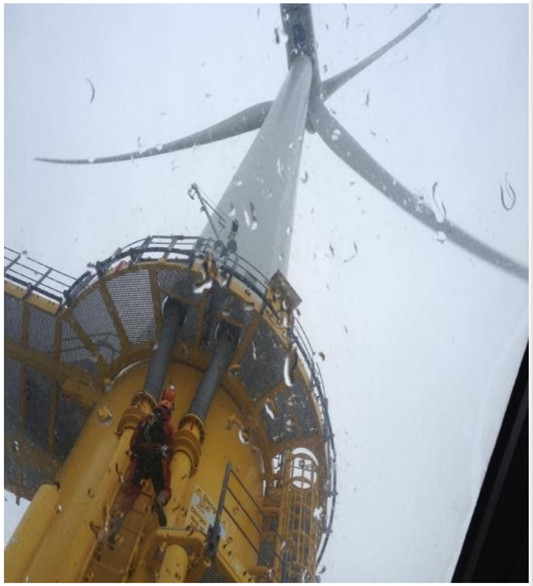
- 709MW due to icing
- 1,237MW due to exceeding turbine temperature limits or other reasons

Shift from standard wind turbines to ‘tailored wind turbines‘ according to their climate classification

→ Cold weather packages: extended limits & heating

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

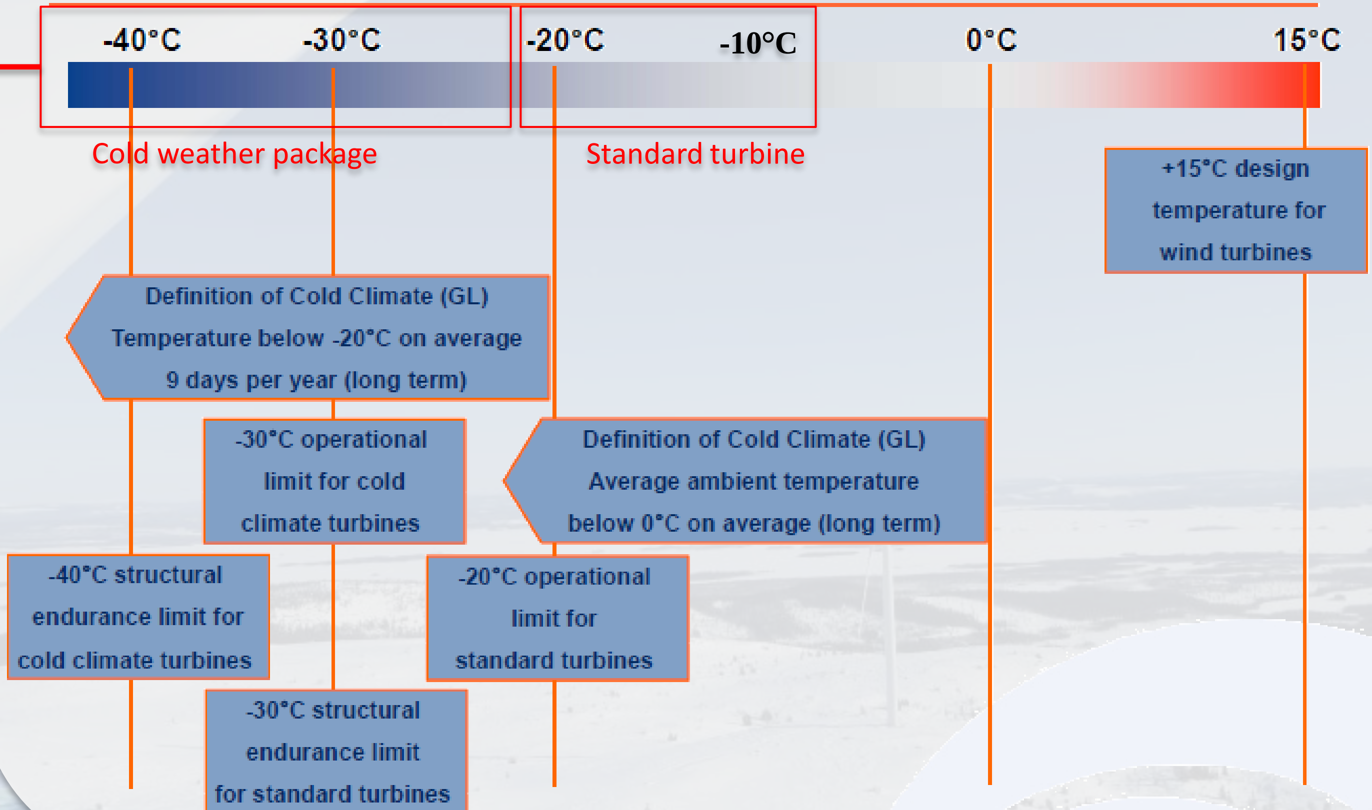
HCV wind turbines

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

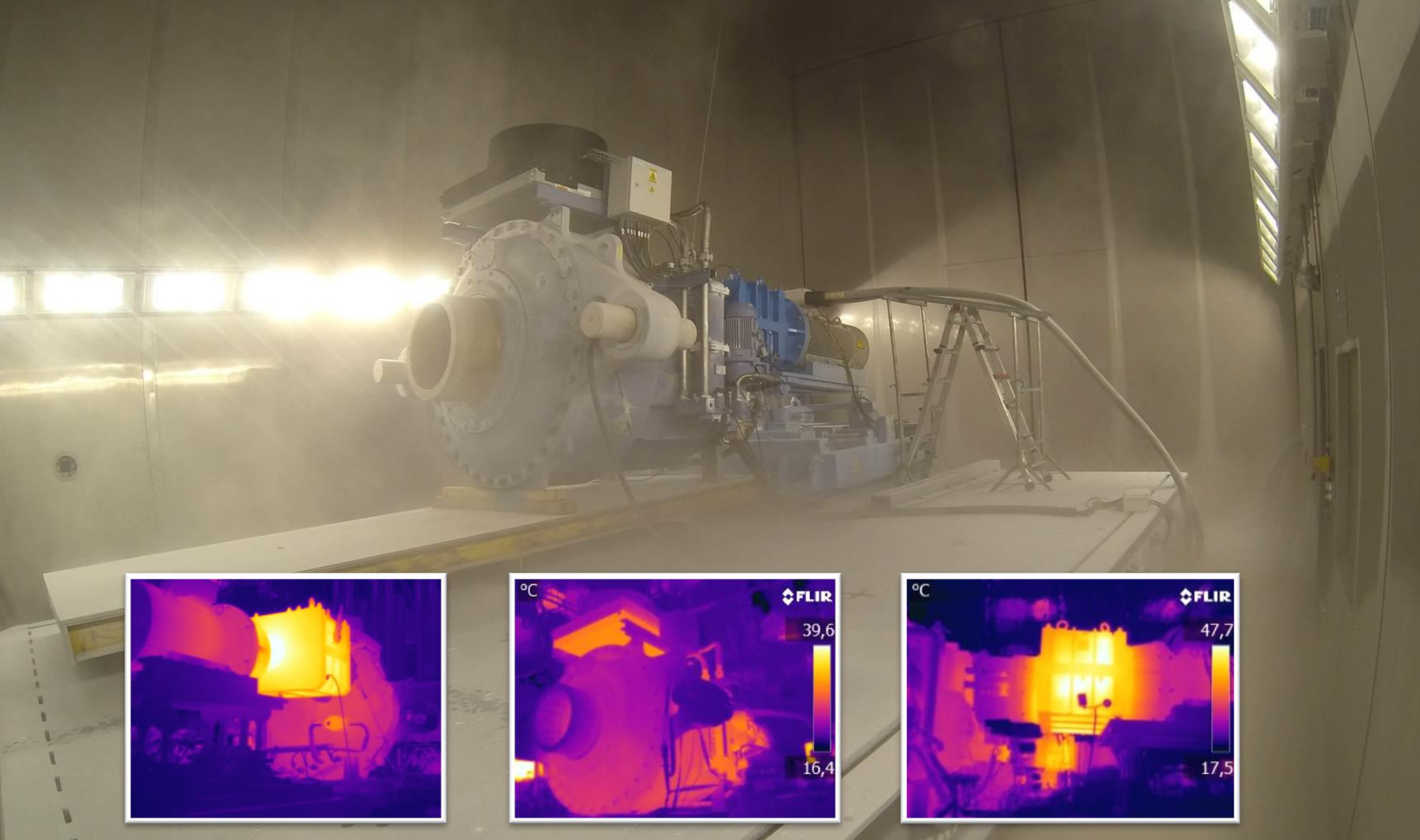
Limits	for standard turbines according to GL[1]
Operational temperature limits	-10 °C
Survival temperature (stand still)	-20 °C

1) GL: Germanischer Lloyd

Existing definitions and standards



"Extend temperature ranges, using 200 kW to 300 kW parasitic power per turbine at conditions below –20C for heating components such as the nacelle space, yaw drive and pitch motors, and the gearbox, slip ring, controller and control cabinet, and battery"



"Cold weather package testing" of wind turbine components to ensure reliability and mitigate risk

2011 Southwest Cold Weather Event

Lessons learned:

According to NERC, "it does not appear that cold weather packages were used in the Southwest" during the 2011 event. It recommends that all entities investigate the purchase of these packages in preparation for extreme cold events.

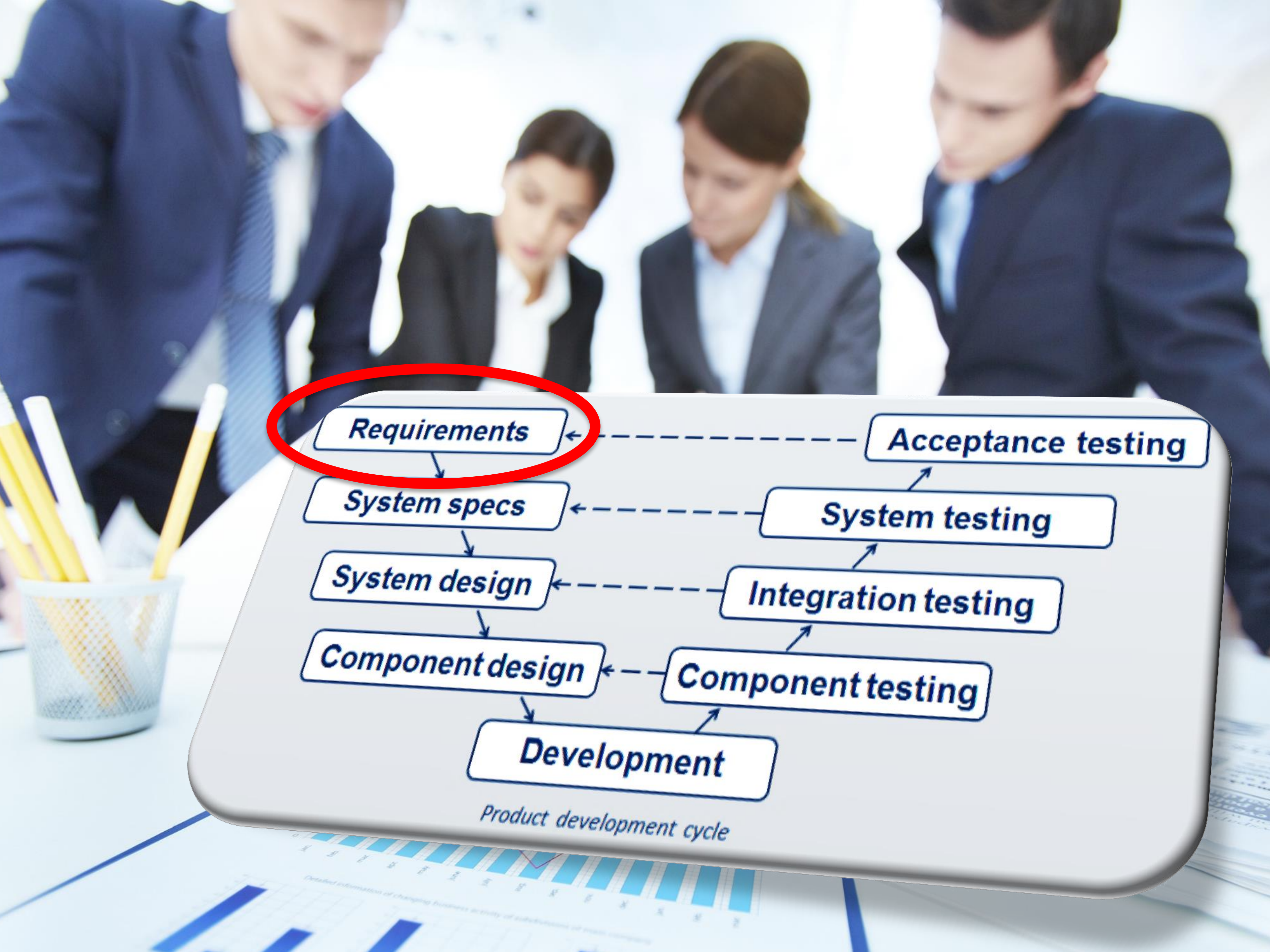
Also wind turbine have not been immune for the cold weather snaps

Polar vortex – 6/01/2014

- 1000MW cutout's due to extreme cold
- "models reaching their minimum operating temperatures according to the federal energy regulatory commission"

How to increase resilience and mitigate the Risk?

1) Design classification and realistic cold climate requirements for wind turbine


Requirements
System specs
System design
Component design
Development
Component testing
Integration testing
System testing
Acceptance testing
Product development cycle

How to increase resilience and mitigate the Risk?

2) **Testing and validation** in controlled laboratory conditions under realistic climatic conditions **to find weak links** in components and assemblies, **early in the design phase**

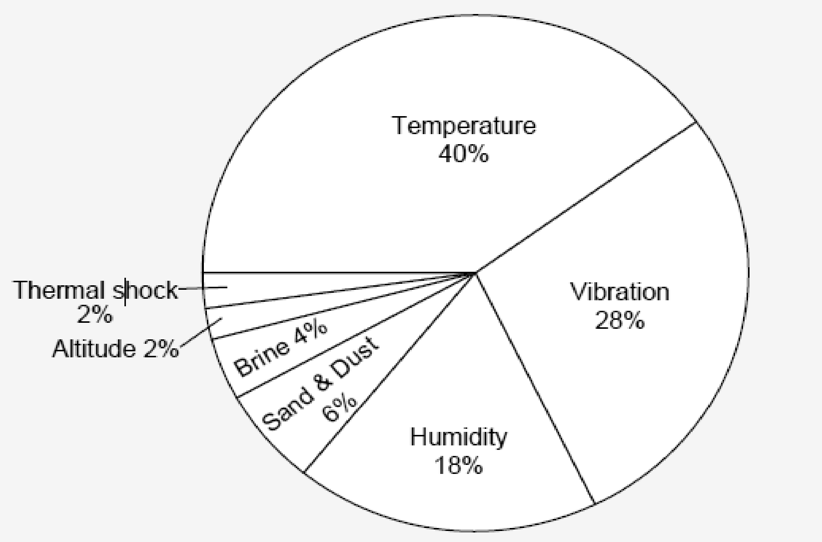

BMW Group
Umweltwindkanal


GEnx 747
STR
4013527-901 G01
S/N 003
WEIGHT 2127 LBS.
FOR GROUND
TEST ONLY


U.S. AIR FORCE
6013
436th AW
512th AW
LOCKHEED MARTIN

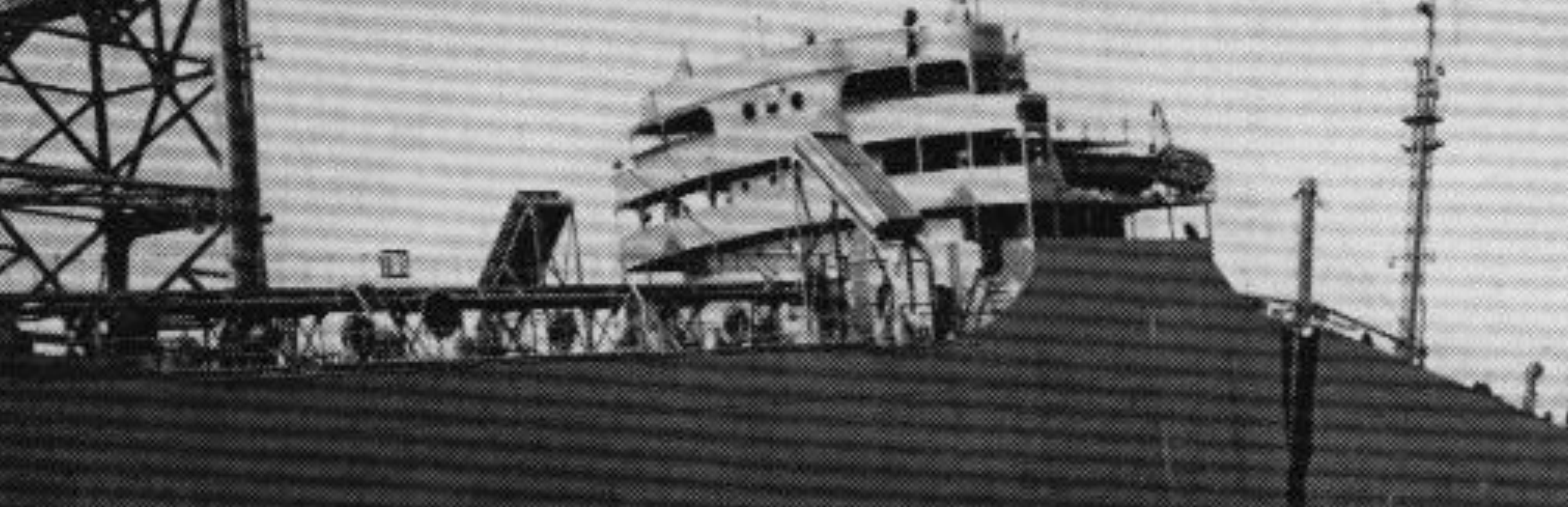
Relationship between environmental factors and failure:

Products fail due to environmental conditions. Few reports have been made on the relationship between failure and these environmental factors, but Hughes Aircraft Co. (USA) has done so.



LOCKHEED MARTIN


Fraunhofer
IWES



Also for **extreme environmental conditions**

Such conditions don’t occur often, but if they do they can have a big impact when not been taken into consideration

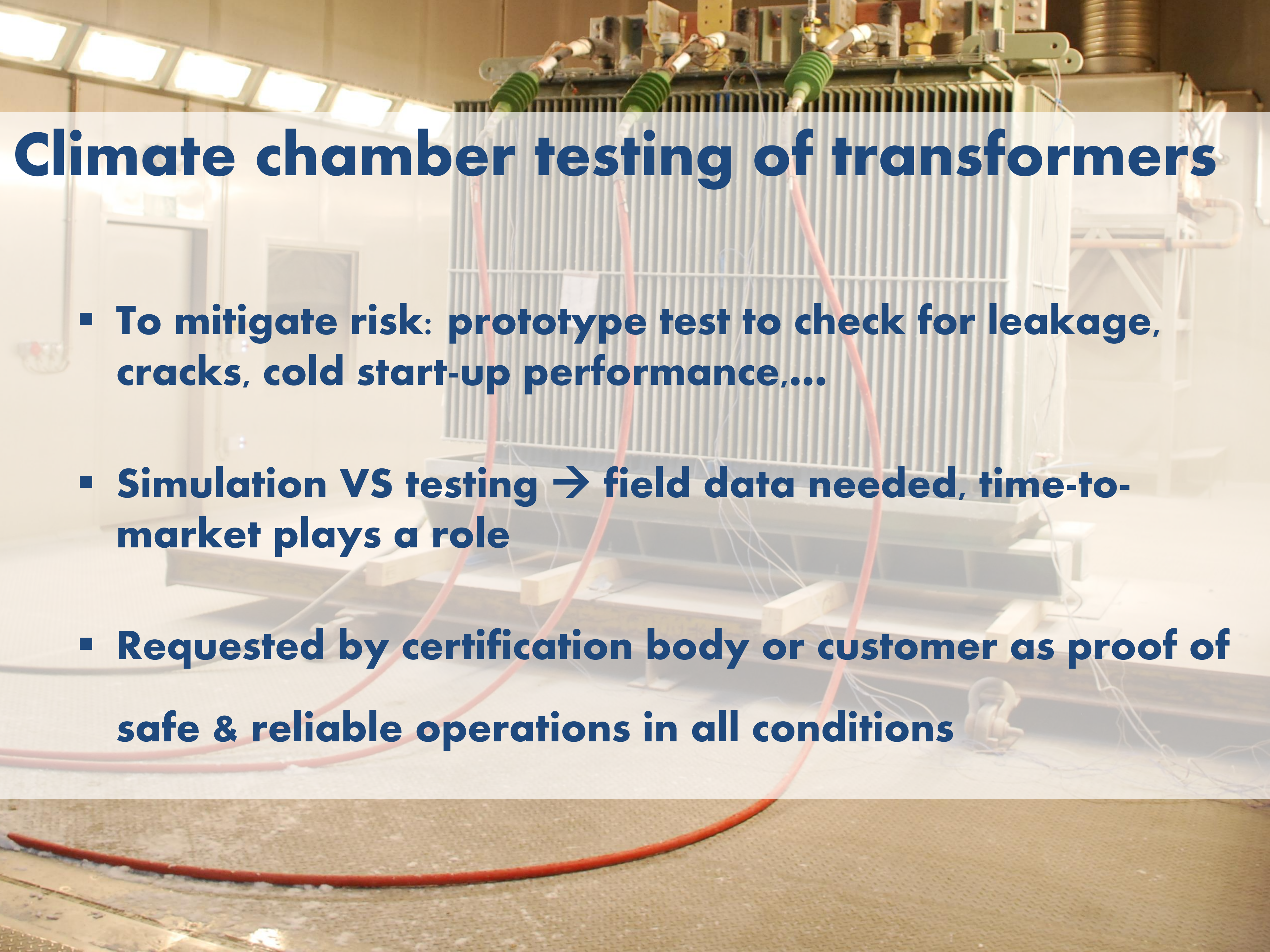
Brittle fracture: Liberty ships 1943

- Cold North Sea water

1943: #20

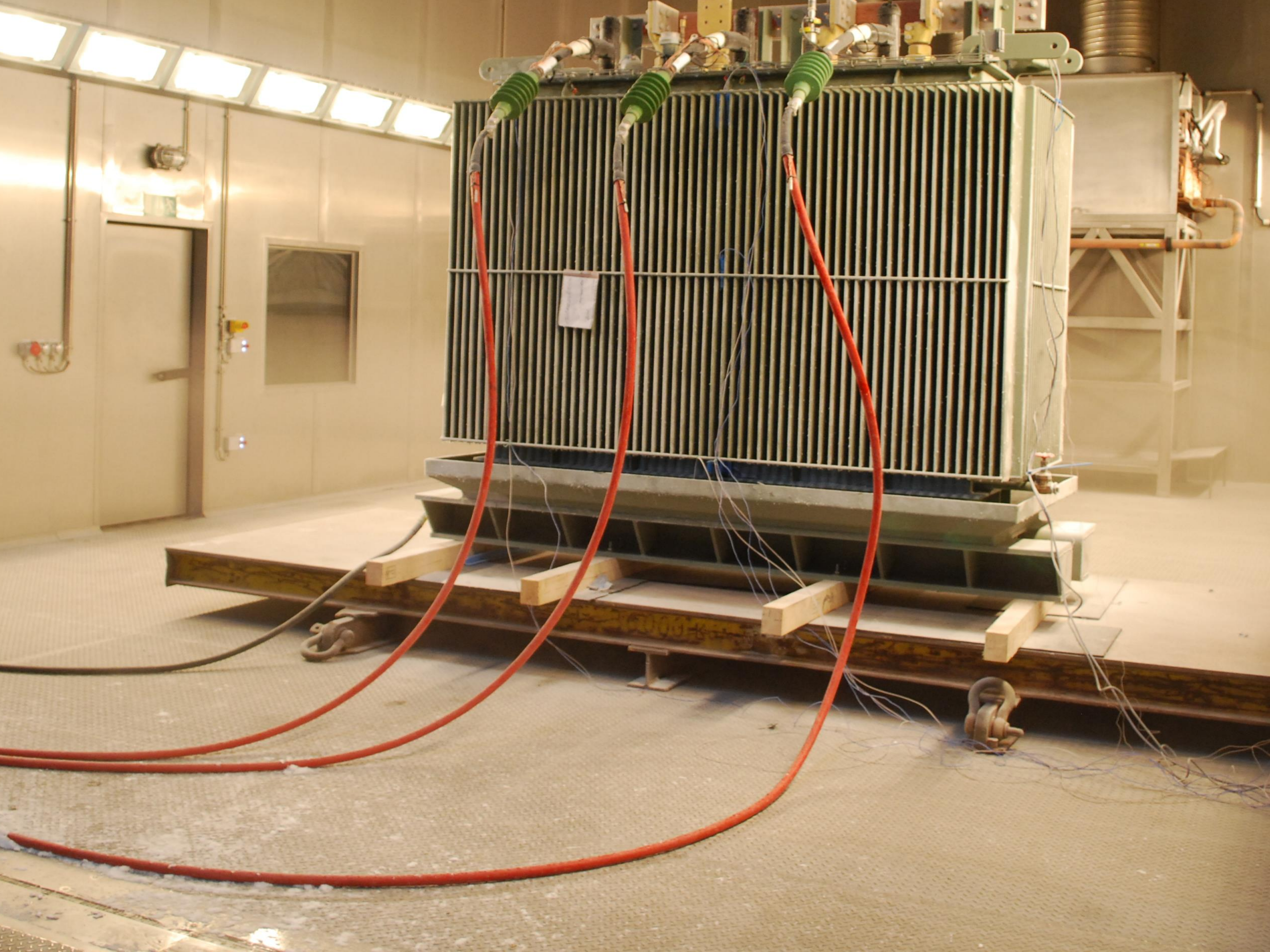
1944: #120

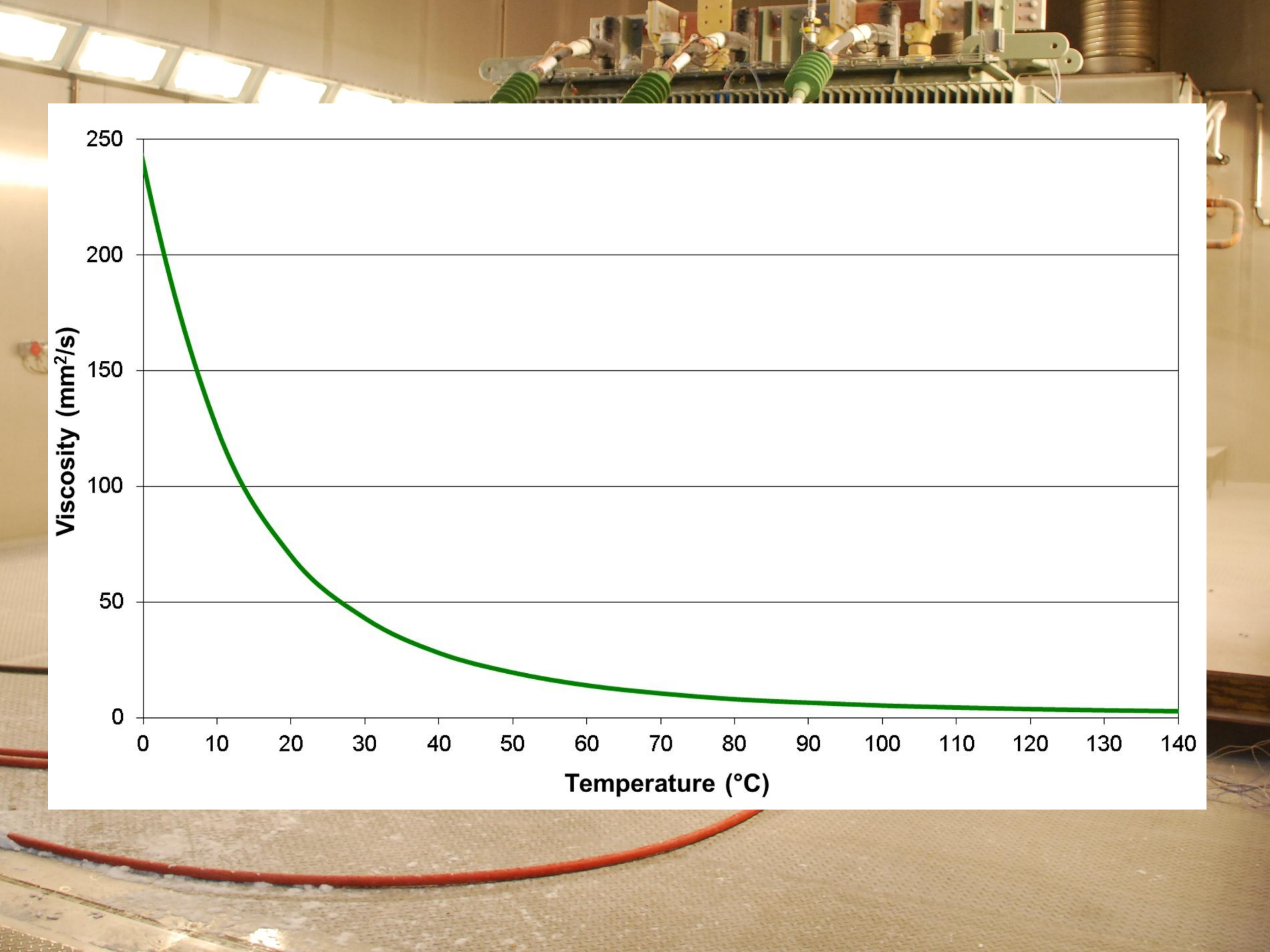

2



Climate chamber testing of transformers

- To mitigate risk: prototype test to check for leakage, cracks, cold start-up performance,…
- Simulation VS testing → field data needed, time-to-market plays a role
- Requested by certification body or customer as proof of safe & reliable operations in all conditions




Viscosity (mm²/s)
250
200
150
100
50
0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
Temperature (°C)

Climate chamber testing of transformers
Focus cold climate – Liquid Filled transformers

- Storage test at -40°C: check for leakages/cracks on seals, thin plated cooling fins, bushings, cables,…

- Cold start-up test at -30°C:

  - Check leakage/ cracks due to brittle material in combination with pressure increase (thermal & mechanical stress)

  - Check natural cooling performance of transformer liquid during cold start-up

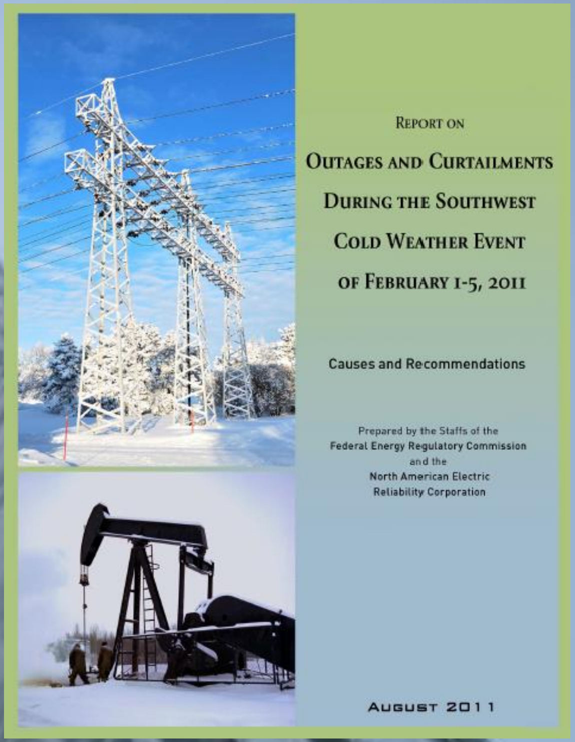
Paper EWEA: Cold start of a 5.5MVA offshore transformer

EWEA 2014 BARCELONA
EUROPE'S PREMIER WIND ENERGY EVENT

Approach -30°C Full load cold test on a 5,5MVA transformer

Approach -30°C Full load cold test on a 5,5MVA transformer

- **“Design for cold climate”**
- **Make sure cold start-up is not a potential issue**
- **Higher Capex, but lower Opex**



Some of the vulnerabilities identified and addressed the week before included re-routing piping or moving vulnerable equipment, correcting transformer oil levels at wind farms, and adding freeze-resistant chemicals. At least five generators kept units running, started units earlier or took other measures to keep from having a cold start. After so many static sensor and other lines froze the week before, some units left water lines draining, or took other measures to keep water flowing.

Reference: http://www.owi-lab.be/content/cg-power-systems

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Lesson Learned
Transformer Oil Level Issues During Cold Weather

Cold weather event – link with inspection & repair

- Problem: 2 substation transformers tripped offline due to low oil levels during extreme low temperatures
- Result: Half of wind farm down (100MW)
- Side effect: Issue could not be resolved for 6 days due to weather restrictions & icy roads
- Root cause: low oil level error due to not proper maintenance of contractor when filling oil after a repair – oil level was near alarm set point
- Link to case story


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lab
JSP

> Climatic test C3*

Climate classes defined by IEC 60076-11

Climate +++

-50°C

C1	Lowest ambient temperatures: > Operation -5°C > Storage / Transport -25°C
C2	Lowest ambient temperatures: > Operation -25°C > Storage / Transport -25°C
C3	Lowest ambient temperatures: > Operation -50°C > Storage / Transport -50°C

Thermal shock test proceeded under C2 Climatic test conditions but conducted at -50°C:

- Temperature lowered to –50°C in 8 hours.
- Holding at – 50°C for 12 hours.
- Thermal shock test at – 50°C.
- Dielectric tests and partial discharge measurements.
- Visual inspection

* C2 Thermal shock test carried out at -50°C

- Class C1: -5° C & -25° C)
- Class C2: -25° C & -30° C or -40° C
- Class C3*: operation at -40° C, -50° C or -60° C

Schneider Electric

-60°C

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DNV KEMA

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Lesson Learned
Wind Farm Winter Storm Issues

Primary Interest Groups
Balancing Authorities (BA)
Generator Operators (GOP)
Generator Owners (GO)

Problem Statement
During an extreme cold weather event, a wind farm with 100 wind turbines and a total capacity of over 200 Mw experienced the loss of 75 percent of its generation for over 100 hours due to turbine faults. The lost generation could have helped to prevent a Balancing Authority (BA) and Reliability Coordinator (RC) from having to implement rotating load sheds.

Details
A wind farm experienced rigid winter conditions of temperatures below freezing, ice, as well as snow for over four days. At times the sustained winds were over 20 mph with gusts much higher which created wind chills in the single digits. These weather conditions had been predicted a week earlier by weather services in long range forecasts.

Before the event, the wind facility implemented its Standard Operating Procedure (SOP), "Icing Conditions Action Plan," that established guidelines and steps to be taken during icing conditions. This procedure, among other things, emphasized safety of the crew and turbine equipment both during a winter event and as ice begins to shed from the turbines and turbine blades. Also, in preparation for the upcoming storm, a major upgrade to the Supervisory Control and Data Acquisition (SCADA) server was delayed and the additional manpower for the upgrade was used for restoration efforts. It should be pointed out that the wind facility had established minimum and maximum operating temperatures and during the event the ambient temperature sensors on the turbines reported that the ambient temperature stayed within those parameters.

When the winter storm first began, lightning knocked out many turbine anemometers and related equipment. Because wind turbines require at least one functioning anemometer, the wind turbines could not run. They set for a period because crews were unable to physically get to the faulted turbines during the weather event due to snow and ice covered roads. As repairs from the lightning strikes were completed and turbines were going through their restart procedure, the temperature had been falling and snow and ice had been accumulating on the nacelle-mounted radiators* of each of the wind turbines. Due to not running in a while, oil was not circulating and being stationary in the radiator passages, the oil temperature quickly plummeted and its viscosity increased. Radiator cooling fans had been left on and this added to the rapid cooling of the oil. When the turbines were returned to service from the lightning repairs and the gearboxes heated up, the bypass valves (operating due to high pressure differentials across the radiators) diverted the oil, which was hot now due to cooling the generator parts, directly to the gearbox and the turbines with cold radiators faulted on high gearbox oil temperature. As a result, a majority of the turbines faulted. There were no operator-initiated shutdowns.

Corrective Actions
Besides clearing snow and ice off of the radiators, the wind farm facility personnel consulted with the turbine manufacturer about various methods to heat up the cold oil. Generator tests were performed to warm the valves

RELIABILITY | ACCOUNTABILITY

Cold start-up failure gearbox – winter storm issues

- 75% down for 100 hours (100 wind turbine - 200MW)
- Cascade of events resulting in high gearbox oil temperature
- [Link to case story]

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Lesson Learned
Wind Farm Winter Storm Issues

- Heating could also prevent another insidious cause of turbine failure: When a turbine is not running, oil that is stationary in radiator passages can quickly cool, and its viscosity can increase.

- Even if wind turbines are not being used, an important lesson worth learning is that the turbines should be cycled online to provide flow of cooling oil, NERC says. All cooling equipment for radiators on wind turbines should also be disabled for cold weather events.

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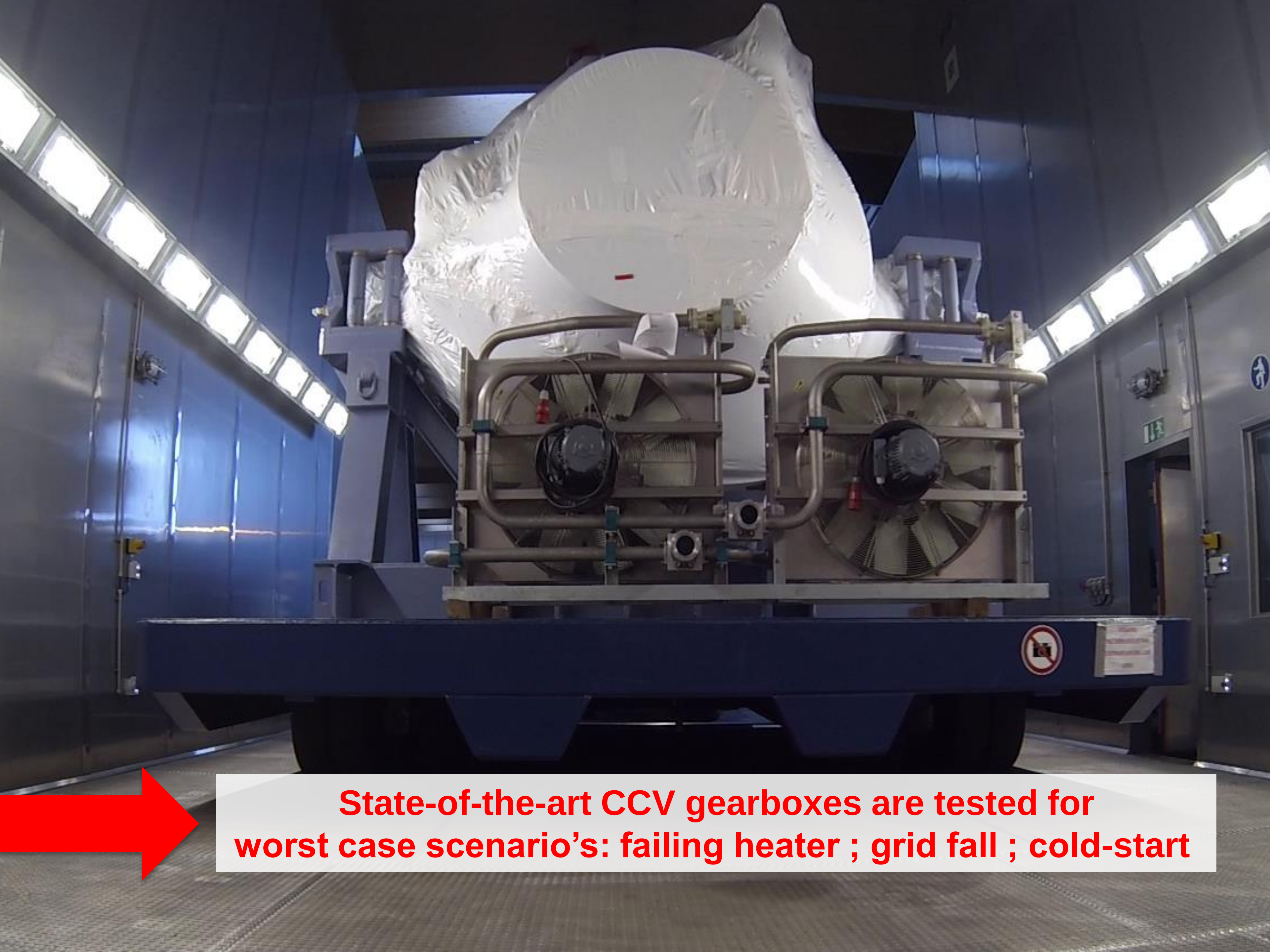
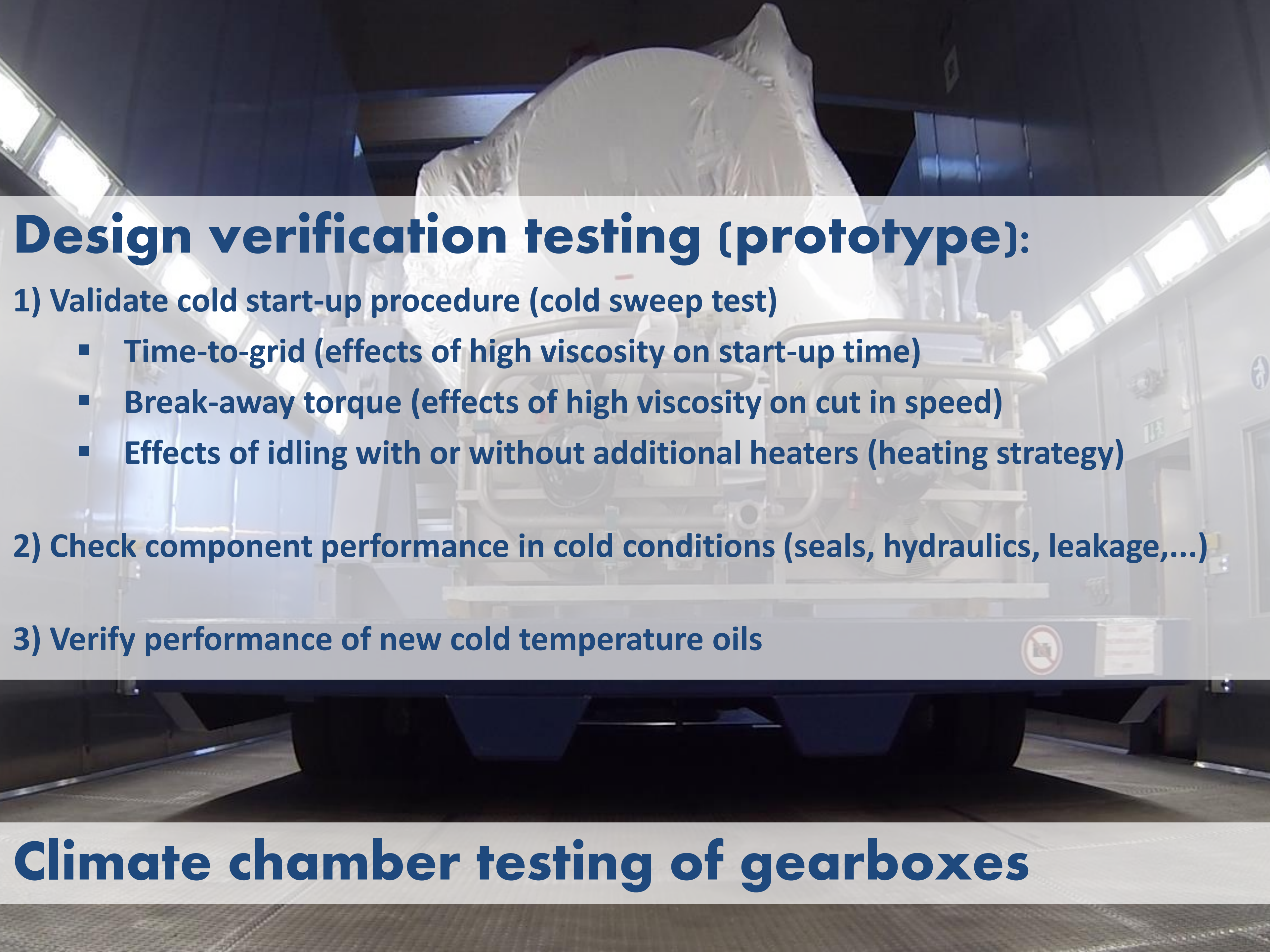
Lesson Learned
Wind Farm Winter Storm Issues


State-of-the-art CCV gearboxes are tested for
worst case scenario's: failing heater ; grid fall ; cold-start



Design verification testing (prototype):

1) Validate cold start-up procedure (cold sweep test)
   - Time-to-grid (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 (heating strategy)

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

3) Verify performance of new cold temperature oils

Climate chamber testing of gearboxes

Lubrication – and effects on other components

Frozen oil system

Many Chinese turbine companies are struggling in cold areas. For example, every winter CSR-wind has a lot of broken electrical pumps, which are used to pump lubricant oil in the gearbox. When temperature drop below -10℃, oil turns into mush, which increases the resistance to the electrical motor when it suddenly starts running after a turbine restart during cold weather. Heat accumulates if the motor was stuck, and then it burns. Many replacements of such motors are needed for CSR wind every winter because of these accidents. There are different solutions for such problems; heat the frozen equipment, modify control strategy that allows turbines to restart only when nacelle temperature reaches a certain level or use improved lubricant.

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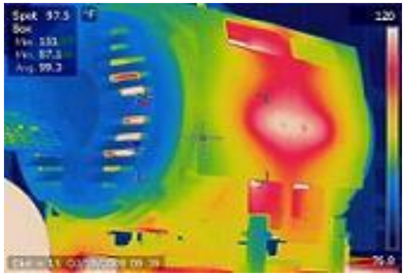
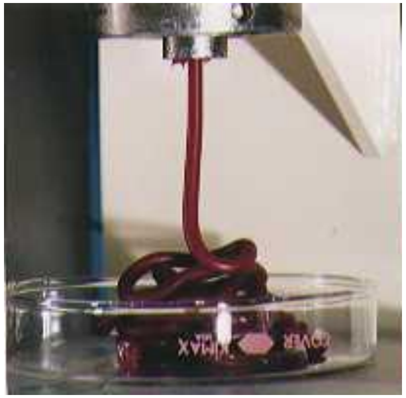
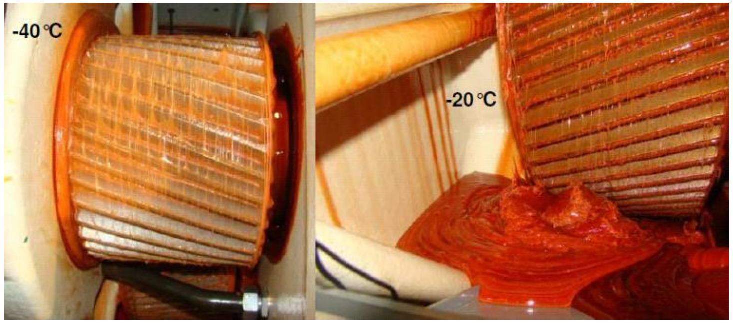
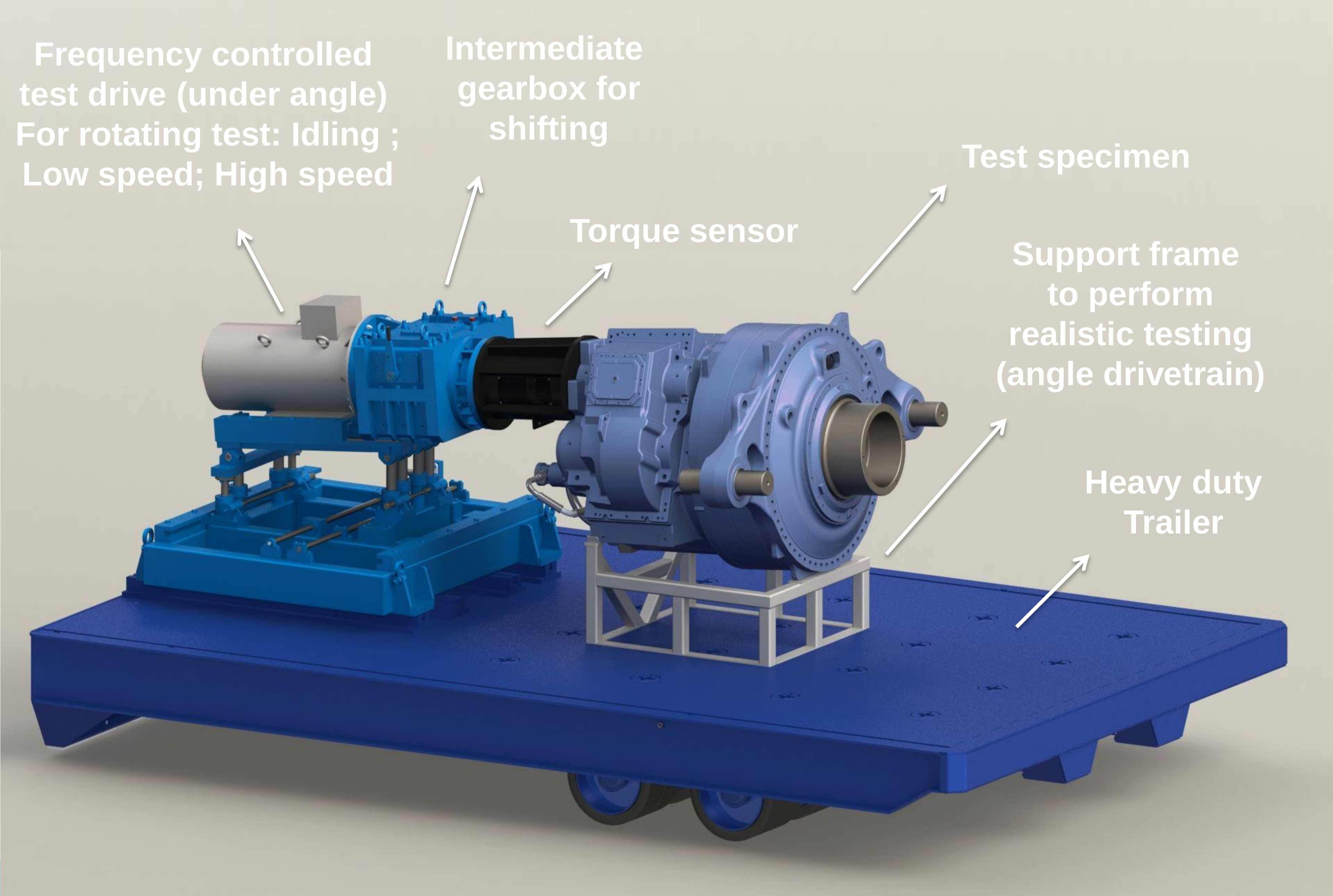
China Wind Industry : Challenges & Opportunities 2014







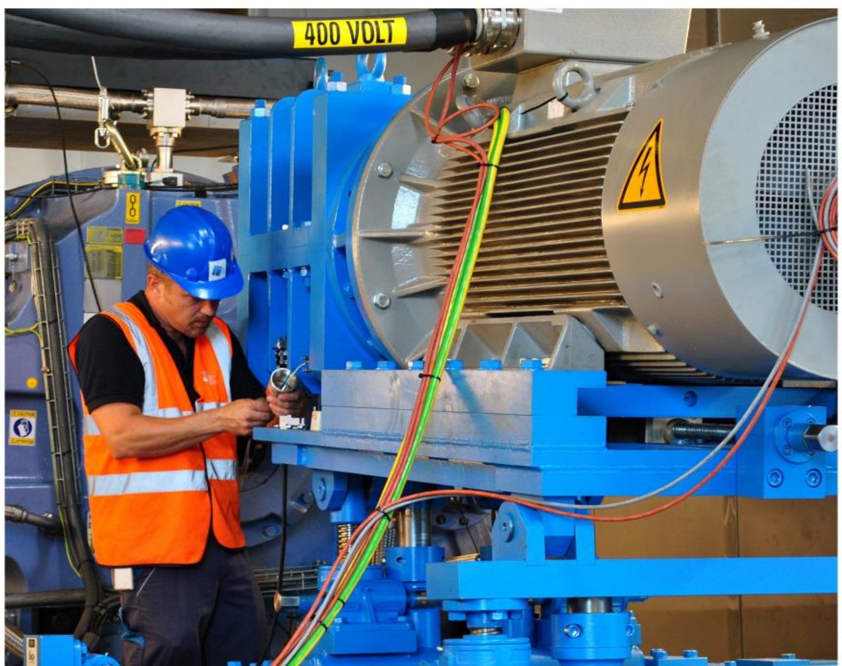


Cold start-up test bench – 10 kNm torque

Research gearbox CCV – 2.x MW climate


ZUIDNATIE


LARGE CLIMATIC TEST CHAMBER


400 VOLT


Hydraulics testing: for example pitch

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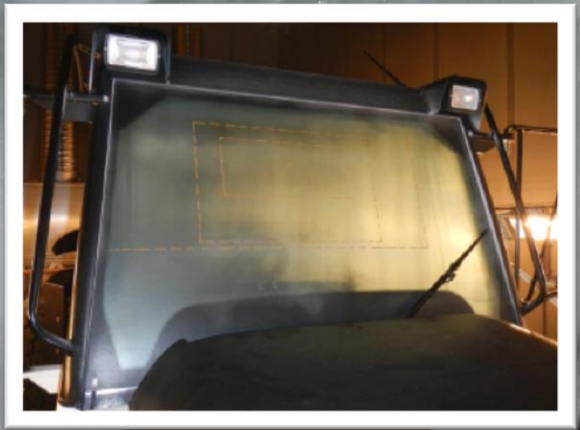
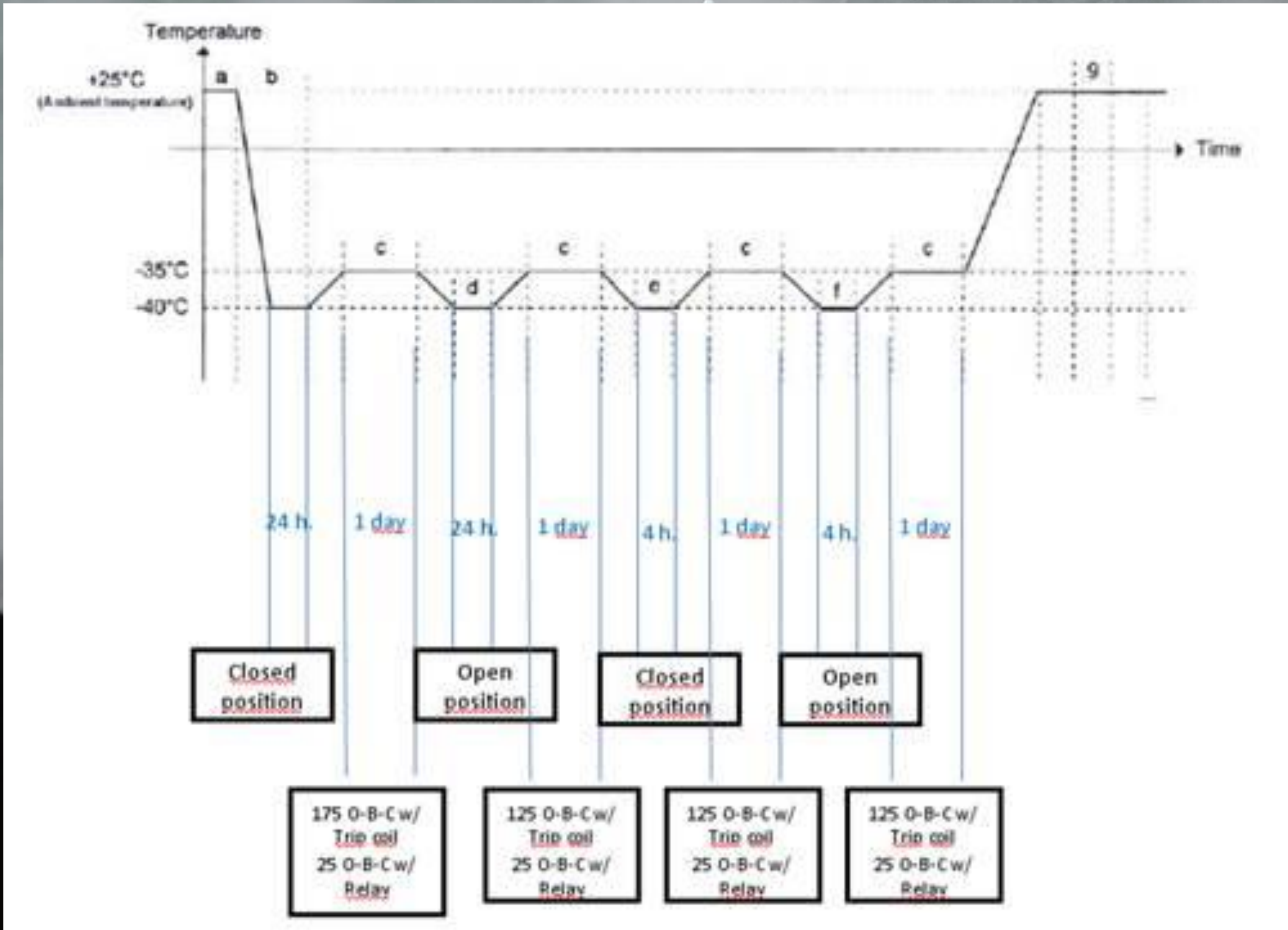


Structural components - blades/ de-icing



Structural components - blades/ de-icing

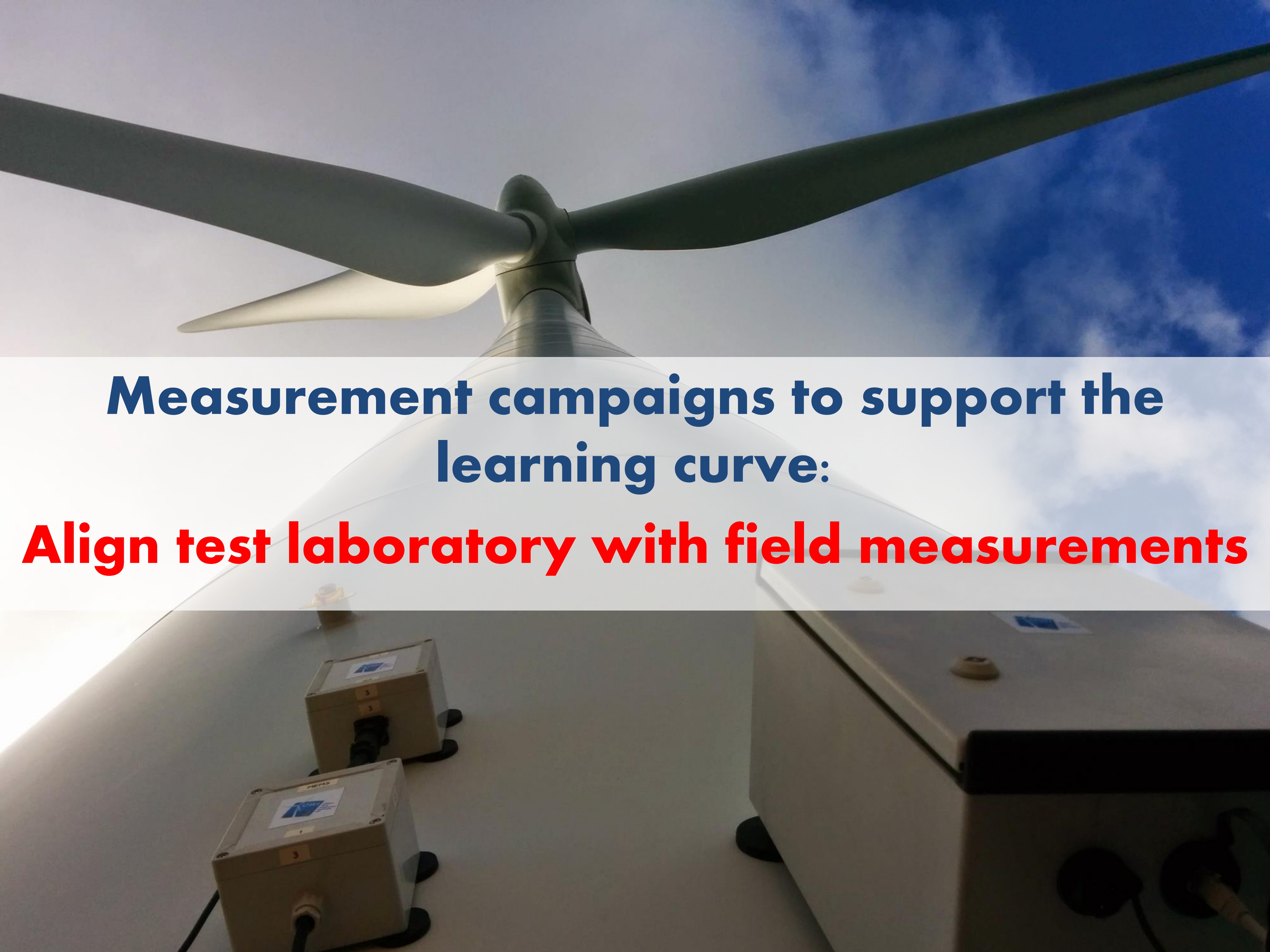
Project development equipment

Construction equipment

O&M equipment

How to increase resilience and mitigate the Risk?

3) **Testing and validation** in real life field conditions for **design verification testing** and **optimization**



Measurement campaigns to support the learning curve:

Align test laboratory with field measurements

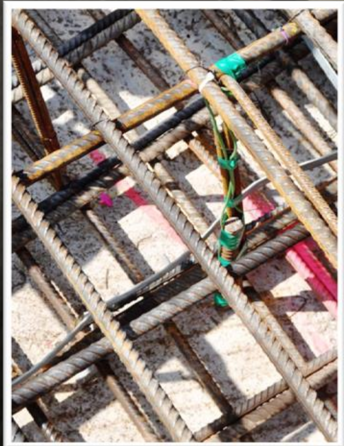
How to increase resilience and mitigate the Risk?

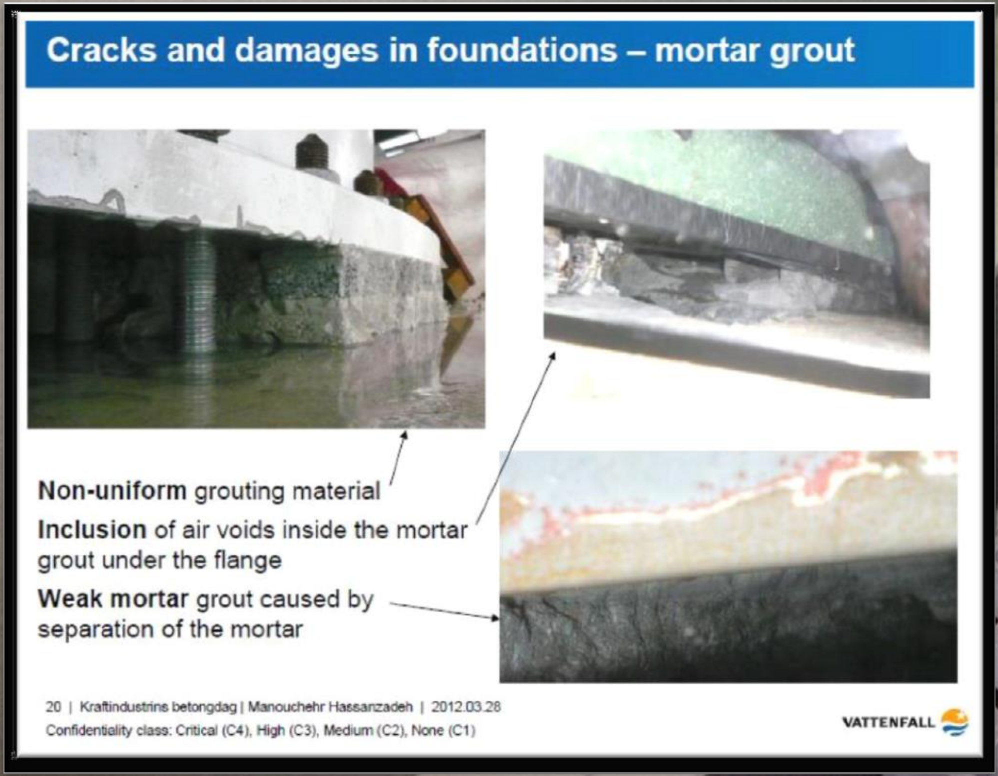
4) **Health monitoring** during the **operational phase** on critical components with high risk

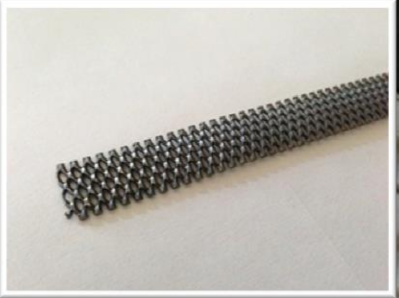
Vrije Universiteit Brussel

OWI lab Offshore Wind Infrastructure Application Lab

COM&SENS







ZENSOR intelligent monitoring

Potential collaborative topics OWI-Lab

- **Cold start-up procedure optimization**
  - Failure: Robustness & reliability of drivetrain
    - FMEA
    - Control optimization / additional monitoring
  - Efficiency gain
    - Increased yield
    - Reduction of parasitic power consumption
  - Insights in economic value (Failure + Efficiency)
  - Testing procedures for cold start-up
  - Modelling of thermal management

Potential collaborative topics OWI-Lab

- **Sensors & controls for cold climate**
  - Critical alarms provoked by extreme weather events
    - Anemometer freezing
    - Other sensors
  - Link with smart control strategy
    - Intelligent heating
    - Additional monitoring

Potential collaborative topics OWI-Lab

- **Impact of imbalance due to ice build-up on dynamics and fatigue**
  - SHM + Residual lifetime
    - Drivetrain effects
    - Structural effects
  - Integration of advanced monitoring in control

Thank you for your attention!

www.owi-lab.be/
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Group: Offshore Wind Infrastructure Application Lab (OWI-Lab)

OWI lab
Offshore Wind Infrastructure Application Lab

sirris
driving industry by technology

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