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.

Figure 2: Cold climate wind farm in Sweden

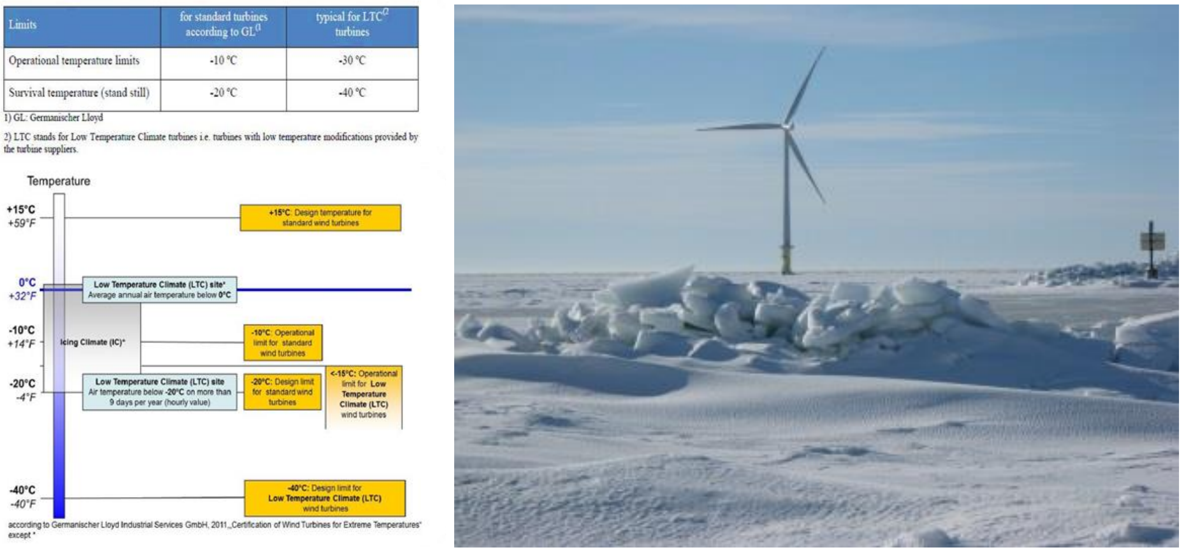
While the vast majority of wind turbines are located in moderate climates, a rising number of wind turbine assets are being installed in challenging and remote locations, such as offshore, in subarctic locations, in the mountains or in deserts. Since these locations often have good, stable winds and are sparsely populated, they are ideal locations for installing large numbers of wind turbines. For such applications, it is necessary to develop appropriate and dedicated specifications for turbines and components.

The current international standards (IEC, GL) for wind turbine design do not fully take into account all the challenges encountered in cold-climate (CC) use. For standard wind turbines the operational temperature limit is -10 °C, and the survival temperature (standstill) is -20 °C.

Cold weather packages have been developed and marketed to extend the operational and standstill temperature range of wind turbines in cold climates and subarctic locations at limits of -30 °C in operation and -40 °C in standstill. However, cold weather packages also lead to additional ‘parasitic’ power consumption needed for the heating of turbine components. To maximise overall performance and profitability, these solutions need to be optimised in terms of levelized cost of electricity and risk reduction.

Even for regions with moderate climatic conditions, temperatures may unexpectedly exceed the wind turbine operational and survival limits during a cold snap, as happened, for example, in February 2011 when the ERCOT (The Electric Reliability Council of Texas - Texas grid operator) reported that 16% of its wind turbine assets had failed. 709 MW was caused by icing and 1,237 MW by turbine limits being exceeded, resulting in production stops and therefore production losses. So even for standard wind turbines, thoroughly understanding and optimising the turbine for cold conditions may pay off.

For cold climates, of course, the stakes are high. Last year’s ‘polar vortex’ cold wave in the US and Canada showed that long periods of low temperatures (down to -40 °C in some cases) can occur and must be taken into account for certain cold-climate locations. In the case of last year’s polar vortex, 1,000 MW of wind power outages due to extremely low temperatures were reported.



Limits	for standard turbines according to GL[1]	typical for LTC[2] turbines
Operational temperature limits	-10 °C	-30 °C
Survival temperature (stand still)	-20 °C	-40 °C

1) GL: Germanischer Lloyd

2) LTC stands for Low Temperature Climate turbines i.e. turbines with low temperature modifications provided by the turbine suppliers.

Figure 3: Operational and survival limits in cold climates (as per GL) and picture of 'Pori Offshore 1' an offshore cold climate turbine

It makes sense for equipment to be capable of operating in extremely cold temperatures, as production yield is greater in winter due to high average wind speeds and greater air density. With regard to the latter positive effect of cold-climate production sites, E.ON's *Wind Turbine Technology and Operations Factbook* mentions, for example, that 11% more power is produced at -10 °C than at +20 °C with similar wind speeds. Firstly, production losses caused by shutting down wind turbines for longer periods in (extreme) cold weather situations should be avoided. Secondly, the repowering time following such events needs to be as short as possible in order to minimise production losses. Thirdly, the 'parasitic power' used for heating during cold temperature survival needs to be optimised in order to ensure an efficient cold-climate wind turbine.

In some cold-climate wind turbines, the components – such as the nacelle drivetrain, yaw and pitch system, rotor, slip ring, batteries, etc. – are heated using 200 kW to 300 kW of parasitic power at conditions below -20 °C for survival. Currently, state-of-the-art wind turbines tend to perform better. For example, components can survive lower temperatures without additional heating. OWI-Lab states that there is still potential to perform better by using new materials and oils to, for example, extend the low-temperature operational and survival limit. Lowering parasitic power consumption and shortening cold-start times by using new control strategies to increase the efficiency and reenergising time of the turbine are the way forward here.

Another issue that needs to be addressed is downtime losses due to maintenance and repair. These are more expensive for cold-climate wind turbines than for regular onshore variants. Just as we see higher maintenance costs in the offshore market, the same applies to the cold-climate market as access time is limited and repair costs in winter are more expensive. In addition, special tools are needed to access wind turbines in winter. Therefore, OEMs and component suppliers tend to perform climatic chamber tests in order to check and validate if their products are capable of operating in and surviving extreme temperature events. They strive to deliver robust and reliable products in order to eliminate expensive repair work in winter. Climatic chamber testing tends to be valuable for proving performance under aggregated climatic conditions and shortening the product's time-to-market, especially since field tests are expensive and very time-consuming.

To help you understand why climatic chamber testing could be beneficial in the product development cycle for wind turbines and components, we provide below an overview of some of the equipment tested in the laboratory and some of the issues that need to be examined during the design phase with regard to cold-climate wind turbines.

Mechanical and hydraulic components: gearboxes, pitch and yaw systems, hoists

Wind turbines are equipped with several large and small mechanical and hydraulic components, such as gearboxes, bearings, and yaw and pitch systems that can suffer from long exposure to cold weather. When the temperature drops, the viscosity of lubricants and hydraulic fluids increases, causing the oil to stiffen and making it unable to lubricate the gearbox and bearings sufficiently.

One critical component in the wind turbine is the gearbox. Special attention must be paid to this component in cold climates as damage to the gears can occur in seconds after the start of operation if the oil is too thick to freely circulate. Highly viscous oil also puts extra pressure on the oil pumping equipment and reduces the efficiency of the drivetrain. Plastics and steels are also affected by low temperatures. They become brittle, which could lead to cracks and leakage. For these reasons, most manufacturers provide cold-climate version (CCV) gearboxes with special lubricants, steel alloys, (additional) enhanced heating systems, etc. to reduce the risks caused by low-temperature operation. Seals, cushions and other rubber parts also need to be checked as they tend to lose flexibility at low temperatures. This may not necessarily result in part failure but can cause a general decline in performance.

When the oil is highly viscous, internal friction reduces the power transmission capacity of the gearbox and thus negatively impacts efficiency. Consequently, the cold-start time needs to be as short as possible while ensuring that the safe gearbox oil temperature is reached quickly enough to begin full-load operation. In most cases a cold-start time (also known as time-to-grid time) needs to be taken into account in order to reach a minimum component and oil temperature before full-load production can be applied. In many cases the turbine will first idle (with or without reinforced heaters) and then produce at partial load before working at full load.

As OWI-Lab stated in its presentation at EWEA, newly designed wind turbine gearboxes have cold-climate modifications to handle the risks encountered during cold-start scenarios, and gearbox systems including pumps, filter, valves, tubes and cooling systems are tested in large climatic chambers. (For details, see Extreme cold start-up validation of a wind turbine gearbox by the use of a large climatic test chamber.) In order to encourage research in this area, OWI-Lab purchased a 2 MW research gearbox. In combination with its cold-start test bench for gearbox system testing, OWI-Lab is well equipped to accept the challenge and support and perform testing and design validation, and to build up deeper knowledge together with the wind industry to further optimise cold-climate wind turbines.

CASE STORY – wind turbine gearbox and cold start

A cold-start event is actually a rather unusual load case, but the impact can be high if it occurs and the machinery is not fitted appropriately. Lessons Learned from Winter Storm Issues, published by NERC (North American Electric Reliability Corporation), addresses the need for a full-system approach instead of only performing sub-component and component tests for cold temperatures. In the NERC case study, 15,000 MWh of lost energy production was related to cold and stormy weather as a chain of events resulted in the failure of the majority of turbines in a 200 MW wind farm.

Surprisingly, the turbines where shut down due to high gearbox oil temperatures. Snow and ice had accumulated on the nacelle-mounted radiators, and, due to shut down for repair, stationary oil in the radiator became viscous. When the turbines were returned to service, the bypass valve (which operated due to high differential pressure across the cooling system) caused hot oil to return the gearbox, resulting in a high gearbox oil temperature fault. Apart from highlighting the level of robustness required during extreme cold, this case study shows that it is also important to validate a proper cold-start sequence. It also makes sense to perform a frost/ defrosting tests for example on the cooling equipment when covered with ice and snow and check the effect on other equipment (like for example the gearbox). Physical design verification becomes important here, as simulating the effects described above is very complex and time-consuming. Moreover, when models are used, they need to be verified via physical tests.

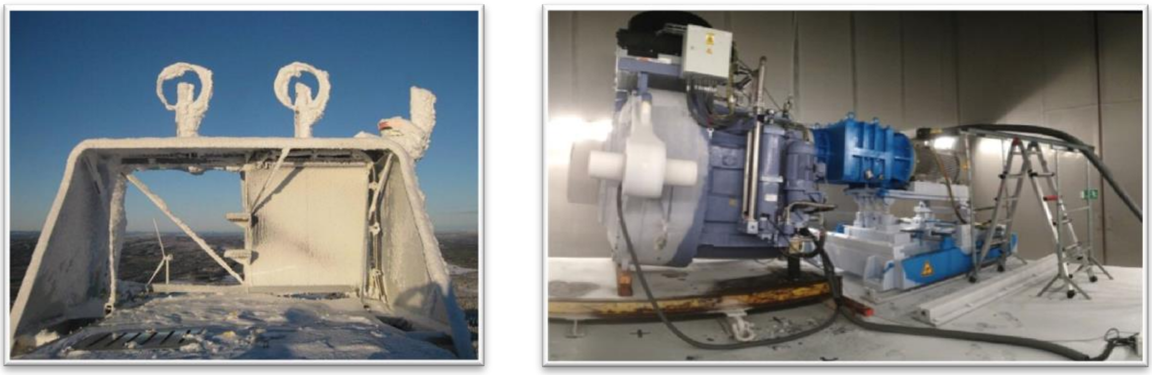


Figure 4: Nacelle cooling affected by snow and ice. Gearbox test bench in OWI-Lab climatic test chamber.

A wind turbine's pitch and yaw system can also be affected by cold temperatures, which means special attention must be paid to the behaviour of viscous hydraulic oils and the seals in order to prevent leakage. Due to their proximity to the outside environment, these systems are more vulnerable to extreme cold than the other electromechanical components in a wind turbine.

Wind turbine heating systems cannot operate during power outages (grid-falls). Restarting a unit after a power outage at cold temperatures is one of the most critical events for any wind turbine subsystem, with the ensuing risks of component failure, expensive repairs and prolonged periods of unavailability.

In electrical pitch systems, batteries are a weak point as they can be affected by cold weather and the windings of the pitch motor can suffer from thermal shock. When starting up in cold conditions, damage can occur due to the sudden increase in heat and the resulting differential thermal expansion in the cold machine, ultimately leading to failure or a decrease in lifetime.

In order to cope with such challenges in the design phase, GL published a specific technical note on cold-climate tests for pitch systems as part of the Certification of Wind Turbines for Extreme Temperatures. This document states that all parts of the pitch system (including the accumulator, pitch drive/cylinder, valves, controller, pipes and cables, and pitch gearboxes) must be tested in a climatic chamber to ensure operability under extreme conditions.

With regard to operational safety, special attention must be paid to the safety brake system, among other things. Mechanical hoists used for service cages located in the turbine tower also need to be modified for safe cold weather operation, as the cold causes cables to become brittle. In most cases no heating is installed in the tower section, making this component vulnerable to cold temperatures in wintertime. Special attention needs to be paid to this equipment to ensure nacelle accessibility under all conditions for maintenance and to ensure that work can be reliably performed via the service cage.

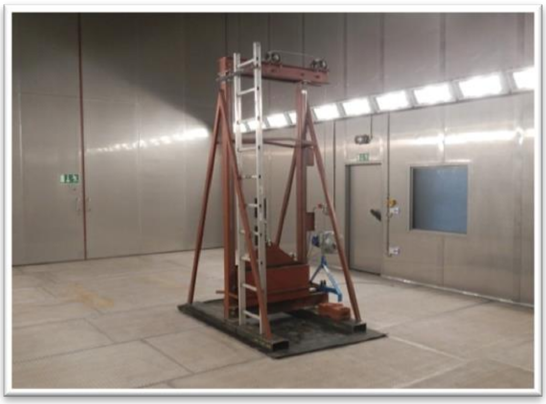


Figure 5: Service cage hoist test set-up in climatic test chamber

Electrical components: liquid-filled and cast-resin transformers, switchgear and generators

Not only can mechanical components be affected by temperature, electrical parts located in a wind turbine, such as transformers, generators, convertors, cables, switchgear and other electrical grid infrastructure, can also be affected if not properly taken into account. The distribution transformer, for example, is an essential component in the wind turbine layout. If this component fails or does not work properly, it can cause prolonged downtime and associated losses. These components often have long delivery times due to batch production. It can cost €25,000 to €40,000 to replace a 1MW to 2.5 MW transformer, but the downtime cost of the turbine due to long delivery times can be much higher. Delivery times of three months are not unusual, causing ±€100,000 in downtime costs in the same power range. This case study makes it clear that the failure of such an electrical component can lead to high O&M costs. It is therefore essential that such equipment is suitable for all operational conditions, including extreme temperature events.

Figure 6: Cold-climate wind farm – grid infrastructure and transformer testing at OWI-Lab

For example, after a few days of no wind in a cold environment, the transformer can be cooled down to -30 °C or even -40 °C depending on its location in the wind turbine. Due to the higher viscosity of the cooling liquids at such low temperatures, the natural convection cooling of the internal windings may be limited.

In liquid-filled transformers, heat generated by the internal losses generated inside the transformer windings may not be evacuated fast enough in cold-start scenarios. Efforts should also be made to examine the possibility of tank leakage and cracks due to brittle material in combination with pressure increase in a combination of thermal and mechanical stresses on the system. Climatic chamber testing is indispensable in terms of improving insight into these phenomena, mitigating risks and underpinning this with real results and facts for customers. Climatic testing can help to reduce time-to-market and complement modelling. Simulation has the disadvantage of being time-consuming and requiring real-life data (in some cases not available) for the studies. CG Power Systems is using OWI-Lab's climatic test chamber to verify full-load cold-start at -30 °C.

Not only do liquid-filled transformer designs need to mitigate the risk of cold temperature, but cast-resin transformers are also at risk, since the resin of the transformer becomes brittle under such special conditions. Applying electrical load to the windings can cause cracks in the resin material due to the rapid increase in heat. OWI-Lab also performs extreme thermal shock tests on cast-resin transformers at -20 °C (cold climate) to -60 °C (extreme cold climate) for certain cold-climate markets to validate optimal safe performance in the event of start-up under conditions of extreme cold.

Switchgear and generators are also tested by some manufacturers. The operation of the drive mechanisms and switchgear leakage levels must be checked under extreme cold temperature conditions. As with the electrical pitch system, low temperatures can also damage generators and motors as the systems can suffer from thermal shock after a long period of cold. In the case of generators, special attention must be paid to the generator slip ring, as its lifetime can be affected by the parameter temperature.

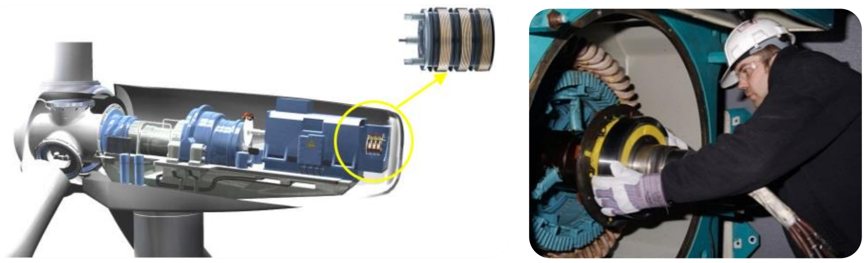


Figure 7: Location of generator slip ring in nacelle and example of slip ring replacement

A slip ring is a rotary coupling used to transfer electric current from a stationary unit to a rotating unit. Slip rings are commonly found in electric generators and other systems in the wind turbine. Vibrations, leaking oil and extreme temperatures affect the resistance of the slip ring circuit. Therefore such conditions must be taken into consideration in order to ensure a long lifetime and minimal maintenance costs. Some manufacturers perform climatic tests on this component as part of the product development cycle.

Structural components

The mechanical properties of the structural elements in wind turbines – e.g. steel, composite materials, grout and concrete – are all subject to change as the temperature changes. At low temperatures, materials tend to become brittle (reduced ability to deform without damage) and less tough (capacity to absorb energy upon impact, as expressed by the Charpy value). Differential thermal expansion must also be addressed in the design and validation stage of structural wind turbine components. For composite materials used in the rotor blades, unequal shrinkage of the fibre/matrix components leads to residual stress. Micro-cracking can occur if the stress is sufficient and if this phenomenon is not taken into account. This potential failure applies not only to rotor blades, where both stiffness and impermeability are reduced, but also to cast-resin transformers, where, for example, micro-cracks can appear in the resin due to low temperatures, as seen above.

Another example of potential damage and failure which has to be taken into account due to differential thermal expansion in cold climates can be found in the foundation. This is known as thermal cracking. Grout spalling between the tower flange and grout connection is one example of this. Again, this affects the permeability in the same way as it does with the composite rotor blade. In the worst case, water infiltration can cause freeze-jacking of the grout, and endanger the structural integrity of the wind turbine. In addition, water infiltration will lead to a higher risk of corrosion. One way to take this risk into account in the operational phase is by installing a structural health monitoring (SHM) kit in order to monitor the structural health parameters of the grout and tower, such as vibration levels in different directions, loads, temperatures, corrosion rates, etc. Also, ice on the blades can be detected by SHM systems since aerodynamic and mass imbalances can be detected by using accurate operational modal analysis (OMA) techniques.

With regard to laboratory testing, climatic test chambers can be used to perform thermal ageing and thermal cycling tests to check the behaviour of new grouted materials and foundation designs. The effect of humidity and freeze/thaw cycles can also be tested in real life.

Figure 8: Foundation damage caused by extreme temperatures (as per GL)

Project development, construction and O&M tools

Figure 9: Example of construction and O&M tools for cold climate wind energy projects

It is not only the wind turbines themselves that suffer from extremes. Looking at the whole value chain of wind energy projects, from ‘environmental impact study’ to ‘project development’ and on to construction, operation and maintenance, all equipment can undergo cold temperatures when the scope includes cold-climate sites. Early last year, a mobile bird radar system was tested at OWI-Lab and approved for service at -20 °C. On the other hand, performance was also tested for hot areas with high humidity. The trailer-mounted bird-radar system is used for bird migration research and risk assessment for bird impacts during the environmental impact assessment phase of a wind farm project. Other off-highway machinery – used either in the construction phase (dump trucks, wheeled excavators, cranes, etc.) or in the maintenance phase (snowcats, dozers, tracked service vehicles, etc.) of a wind farm – is tested in the laboratory to ensure reliable operation under all conditions.

Figure 10: Bird radar system, arctic dump truck and wheeled excavator being tested at OWI-Lab’s climatic test facility

OWI-Lab's large climatic test chamber

Figure 11: OWI-Lab's climatic test facility

OWI-Lab's test facility is located at one of the break-bulk terminals in the port of Antwerp. Housing a 10m x 8m x 7m (LxHxW) climatic chamber and the ability to handle machinery of up to more than 150 tonnes in size on the quay directly from ship, train or lorry is a real asset when serving international customers. The laboratory also houses a test bench for the cold-start testing of rotating wind turbine machinery, as well as an energy supply for functional testing of electrical equipment (50Hz, 60Hz, different powers, voltages and currents). Temperature testing ranging from -60 °C to +60 °C is possible, as is humidity and IR radiation testing. Also, the testing can be monitored remotely by the use of an IP camera, thermal camera (FLIR) and dedicated data acquisition tools and analysis software (NI). The large testing space makes it possible to test multiple systems simultaneously under the same test conditions. Simultaneous testing can be useful for benchmarking the results of changes, modifications and different versions of machinery under the same climatic conditions.

Figure 12: Simultaneous transformer testing and multi-MW gearbox testing at OWI-Lab

Conclusion

In certain locations, extreme temperatures need to be taken into account in wind turbine design. Conditions like extreme cold are rare, but if they occur they can lead to significant production losses if not properly taken into account in the design of wind turbine components. In addition to addressing such issues for components, it is also necessary to ensure that equipment associated with maintenance access in the turbine, maintenance vehicles and development machinery can perform perfectly under all climatic conditions. One approach for guaranteeing reliable operation under extreme conditions is to perform climatic chamber testing as a way to validate designs and simulations.

To find out more about testing turbine components in order to reduce maintenance costs caused by extremely low temperatures, you may like to attend our presentation at the Windpower Monthly conference on Optimising Wind Farms In Cold Climates (26-27 November in Helsinki). Alternatively, please feel free to contact Pieter Jan Jordaens for more information.

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