THE USE OF A LARGE CLIMATE CHAMBER FOR EXTREME TEMPERATURE TESTING & TURBINE COMPONENT VALIDATION

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1. Abstract

Wind energy in general is becoming a substantial part of the energy mix in many countries. Most of the operational wind turbines worldwide have been placed onshore, at sites which can be accessed quite easily for maintenance tasks. In many of these area’s the environmental loads are not that extreme. As the wind turbine industry is rapidly expanding, an increasing number of wind turbines are now being installed remotely were the wind resources are good and conflicting interests (like opposition by nearby residents – aka as the NIMBY ‘not in my back yard ‘syndrome) are few. Examples of remote located onshore wind turbines are those installed for example in the mountains, in the desert, at so called cold climate locations, or even in extreme environments like the arctic.

Because of the logistics at sea and possible weather restrictions, offshore wind turbines generally are more difficult to access than onshore turbines. They can also be classified as remotely located. .

In some of these remote areas, wind turbines need to work under extreme harsh conditions and additional uncertainties are involved in terms of operations and maintenance (O&M) compared to standard turbines. More environmental factors have to be taken into account for such assets: higher winds and gusts, wave impacts, corrosive environment, humidity,…

There is the apparent need to understand and mitigate the additional risks. High reliability for every component is key for these remotely located machines in order to avoid expensive maintenance tasks. Advanced reliability testing is paramount in this evolving industry and dedicated test facilities are set up to mitigate the involved risks for the new generation multi-MW wind turbines. In that way the industry can continue fulfilling the existing trend of cutting the cost of wind energy, also for remotely located wind turbines.

Keywords: Reliability, Operations & Maintenance (O&M) , Environmental testing, Extreme temperature testing, Climate chamber Cold climate

2. In general

Wind turbines and their individual components need to be designed and tested to make sure they can withstand operational and extreme environmental conditions. The IEC 61400-1 also suggests considering environmental factors, some of them are mentioned in figure 1.

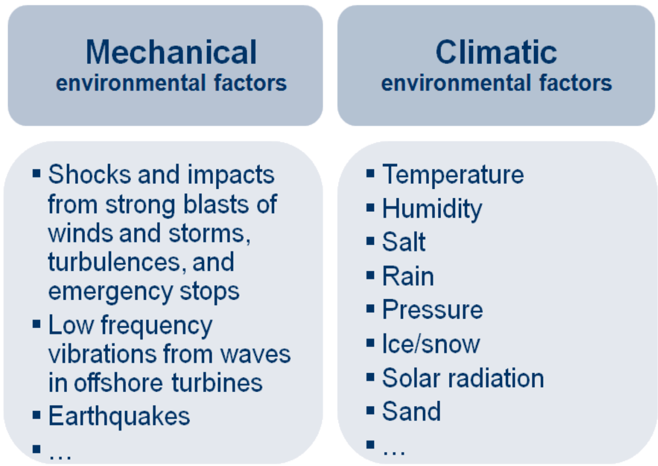

Figure 1: Example environmental loads according to IEC 61400-1

In order to reduce the O&M costs two approaches can be defined:

1. Improving component reliability

2. Reducing costs to perform maintenance

This paper focuses on the first approach and has a direct link with the activities of the OWI-Lab test facility which houses a large climate chamber for extreme temperature testing of wind turbine components. Onshore and offshore wind turbines are usually designed to operate in a temperature range between -10°C to +40°C.

In stand-still the turbine should keep its auxiliaries even working at -20°C ambient air temperature in order to start-up smoothly when wind speeds increase.

In some remote areas these specifications are not enough to ensure reliable operations. Locations like for example Inner Mongolia, Canada, the Scandinavian countries and Russia the ambient air temperatures can drop to -40°C to -45°C. In arctic regions even extreme temperatures of -55°C to -60°C occur during winter time. On the other hand, wind turbines located in hot regions (i.e. deserts in India, Africa, China,…) can suffer from extreme heat with temperatures up to +60°C maximum.

Focusing on offshore wind energy the temperature variations are not that extreme, not taking into account the planned arctic offshore wind farms. Nevertheless, the validation of offshore wind turbine components in their operating temperature ranges remains important to ensure that they are reliable and unplanned repairs are avoided. These inhospitable areas form a huge challenge for the machine itself and clearly there is the risk of affecting the turbine availability and profitability.

Maintenance at remote locations can be cumbersome and very expensive, and weigh on profitability. For example, seaborne maintenance teams need special safety gear, handling equipment and machinery compared to standard onshore maintenance crews which makes repair works more expensive (figure 2).

Another financial risk is the possibility of losing a great deal of energy generation and income as repair works may have to be postponed because of weather (i.e. temperatures, winds, precipitation) and related restricted access. Because of these reasons the industry needs robust and validated components capable of surviving in extreme conditions in order to be cost-effective.

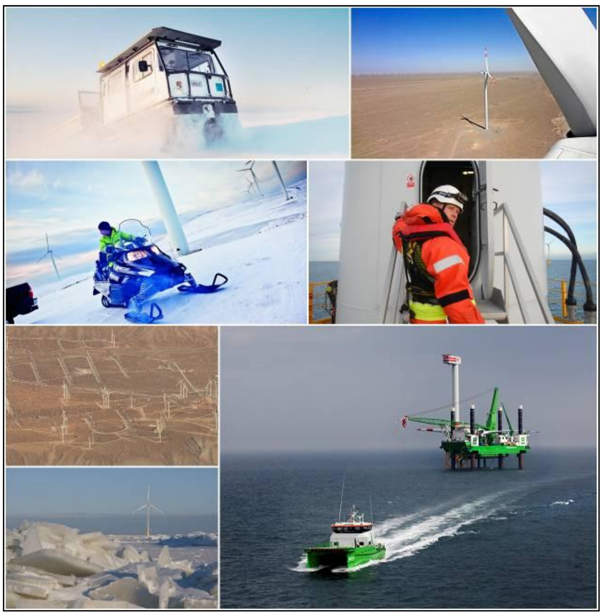

Figure 2: Maintenance machinery and gear in remote locations (STV, Voith, ReCharge, OWI-Lab, DEME-GeoSea)

3. Improving product robustness and reliability through testing

Robustness and reliability are the result of a successful design and development process. Robustness means: "the ability of a system to perform a required function, under given environmental and operating conditions and remain effective'. On the other hand 'reliability' has the same definition but for a stated period of time. Because wind turbines should have a lifetime of 20 to 25 years the concepts of 'robustness' and 'reliability' are important to take in consideration during product development. Testing can be a method to achieve robustness and reliability, meet customers demand to have optimal turbine operations for 20-25 years, and shorten the time-to-market of the product.

Ideally, testing is done throughout the product development cycle as shown in Figure 3. This allows model validation, product specification verification, and confirms robustness and reliability in specific environmental conditions.

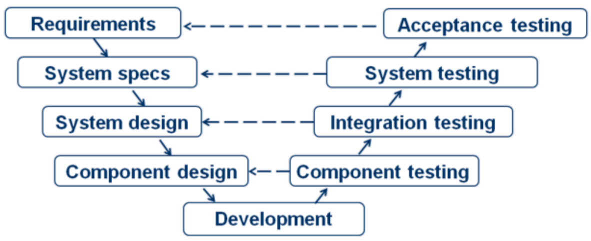

Figure 3: Product development cycle

When a new concept, component or system (like for example a wind turbine) is being tested a number of failures and flaws will occur and be corrected. We usually call them the infant mortality failures. After this initial stage one will usually experience a constant (and hopefully low) failure rate until the components reach their calculated lifetime (for example 20 years). After this stage an increasing failure rate will occur. The phases are shown in the bathtub model in figure 4.

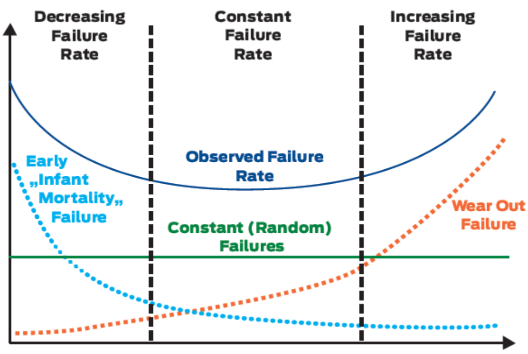

Figure 4: Bathtub model

Robustness and reliability testing are both a strategy to tackle flaws and failures upfront before the turbines are installed in order to reduce expensive maintenance costs. Both testing methodologies have the same goals but in practice there is a difference. Robustness testing is about finding the weak spots in a sub-component, component, or system in order to reduce the failures in the first phase. A relevant load (for example one of the environmental loads factors in Figure 1) is increased above the client specification limit or operational limit until the component fails. After evaluating the failure and determining whether it is relevant, a re-engineering task takes place for optimization and further testing continues. It is all about finding the weak spots in the design.

When the objective is to simulate the occurrence of failures over a certain life time (let's say 20 or 25 years) in a short period of time, reliability testing comes in the picture. The idea is to accelerate realistic loads in the sub-component, component or system in order to simulate the third phase in the bath tub curve, the wear out phase. For some wind turbine components like foundations structures and rotor blades this is already a relevant methodology to cope with fatigue failures. For drivetrain components the robustness tests are more relevant at this moment.

Advanced testing is becoming a crucial phase in the product design cycle of wind turbine manufacturers and their component suppliers in order to meet customer requirements. This might look like an additional and superfluous development cost factor, but because of the liabilities towards maintenance costs and income loss, it proves to be a very good investment in reality.

4. Testing & test infrastructure

Wind turbines consist of different mechanical, hydraulic and electrical components. Obviously different system and integration tests need to be developed and performed for all these components in their specific working conditions:

- Wind turbine field testing
- Nacelle and drivetrain testing
- Drivetrain component testing
- Sub component testing
  (i.e. bearings, individual gears)
- Blade testing
- Tower & foundation testing

Independent of turbine component type, one can distinguish different types of tests to meet design properties, reliability, robustness and durability: Design verification and model validation tests, Prototype development and optimization tests, End of line and quality tests, Certification tests, Accelerated lifetime and reliability tests (HALT, HASS, CALT).

In general the described tests are translated in three types of test rig concepts or procedures: End-of-line test rig, development test rig and endurance test rig. In order to timely detect and correct the infant mortality failures, end-of-line tests are implemented. At such test infrastructure a manufactured unit is tested for a short time in order to guarantee functionality. Next to that development test stands for testing prototypes and model validation come in place. In contrast to the robustness testing were a unit is tested until failure occurs, development tests (like design verification, and certification tests) usually takes place without 'breaking' the unit. The third kind of test stand, the endurance test rig, is used for testing a unit for service life validation and is related to the concept 'reliability' testing.

Figure 5: Risø National Laboratory blade test ; FAG bearing test rig ; ZF Wind Power Antwerpen NV gearbox test rig ; 7.5MW drivetrain test rig – Renk test systems

The availability of specialized test stands to perform advanced testing in controlled environments is crucial. They can indeed help to speed up the time-to-market, contribute to improved reliability and reduce testing costs as laboratory testing is cheap in comparison to field testing in remote locations. The advantage of controlling the mechanical and climatic loads in the laboratory is to apply new test methodologies like for example accelerated lifetime and reliability testing. Also reproducing certain events and failures modes are less complex and time consuming in the laboratory in comparison to field testing. In the ideal case both laboratory and field testing occurs.

Different companies and knowledge centers are currently investing in dedicated test stands as an alternative for field testing in order to better understand the failure modes in wind turbines and support the wind energy industry. The challenge to cope with the ongoing trend towards bigger multi-MW turbines which means larger weights and dimensions, higher power and torques, more cooling capacity, etc…

5. Extreme temperature testing

Heavy machinery applications are often exposed to climatic and mechanical stresses. They must work smoothly despite these environmental loads. Climatic environmental testing, in particular (Extreme) Temperature testing is one of the essential development tests for wind turbine components. Extreme temperatures provide design challenges because components subjected to wide temperature fluctuations can result in premature failure of the components. Possible impacts of (extreme) temperatures are related to:

- Differential thermal expansion of (sub)-components and materials
- Lubricants can become more or less viscous which effects the oil flow in bearings and raceways
- Metals can become brittle at low temperatures
- Cooling systems can experience overheating problems during extreme heat
- Cold start problems and their negative effect on energy yield (long start-up time; production loss)

Usually on- and offshore turbines are designed to operate in a temperature range of -10°C to +40°C but in some cold climate applications low temperatures can reach -40°C to even -60°C in arctic regions. Many wind turbine problems can be caused by cold temperatures. All materials: steels , plastics, rubber seals, and even wiring used in sub systems need to be designed or adapted to withstand cold climates.

For gearboxes for example, special cold climate oil and grease, heating elements, appropriate alloys and special sealing materials are used in order to meet cold climate requirements. Also the gearboxes are tested for cold start tests. A proper and fast cold start-up procedure, has a big influence on the reliability and productivity of these turbines. During start-up of a wind turbine after idling in cold conditions, the rotating elements in a gearbox can be at risk because of insufficient lubrication and/or differential thermal expansion of its components.

Bearings and their lubrication have proven to be particularly sensitive to temperature fluctuation in (extreme) cold temperatures.

Figure 6: Cold start test ZF Wind Power Gearbox

Not only mechanical machines need to be tested for temperatures in order to meet customer requirements. Also some electrical equipment like transformers which are housed in the turbine nacelle or tower need temperature tests. In liquid filled transformers, the gas cushion influences the liquid level and the internal pressure of the transformer. Internal pressure and liquid level must stay within a certain range in order to guarantee optimal performance. In onshore and offshore applications, liquid immersed transformers equipped with a gas cushion can have temporary pressure peaks. This phenomenon should be controlled in order to prevent unnecessary switching off the transform and harm the turbines availability.

Also, in a worst case scenario, the interaction of the gas cushion and the oil level have a negative effect on the elasticity of the tank which can ultimately cause cracks and leaks when mechanical stress reaches an unacceptable level. For optimal operation and model validation cold start conditions are tested as part of the development process in order to mitigate the risks and ensure optimal an efficient operations.

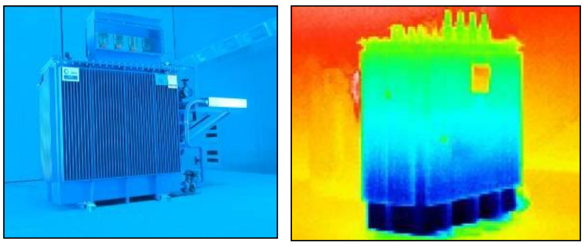

Figure 7: CG Power transformer in climate chamber and cold start test

These cases illustrate the requirement for testing gearboxes and transformers in cold temperatures, and the need of large climatic test chambers which can handle heavy machinery as these turbine components tend to become heavier and larger.

On the other hand tests are needed to make sure turbine components don't get overheated due to extreme heat while operating in hot weather applications. For application in hot climates, adapted thermal management measures like extra cooling power might be needed and tested.

6. Large climate chamber OWI-Lab

The wind power industry indicates that there is a lack of multifunctional and appropriate climate chambers in comparison to other sectors and applications that have the same stringent reliability needs like the automotive industry. Many wind turbine components are indeed much larger and heavier than cars and therefore cannot be tested in the same climate chambers. To respond to this need, OWI-Lab has built a dedicated test facility in the Port of Antwerp. This large 560m³ climatic chamber allows for wind turbine component testing in a wide range of temperatures. Mechanical, hydraulic and electrical turbine components of up to 150 tonnes, like for example gearboxes or transformers, can be tested in a temperature range from -60°C to +60°C.

Typical testing activities in the facility include design verification testing, component validation and prototype testing. Also 'storage tests', were client temperature range specifications tend to be wider than operational limits, of large and heavy components can be performed in the large climate chamber. Dedicated R&D tests are supported by providing all the required auxiliaries like for example: a flexible set of power supplies of up to 2MVA for electrical testing, and a 315kW motor drive and intermediate gearbox for rotary parts like gearbox cold start testing.

Figure 8: OWI-Lab's large climatic test chamber

OWI-lab's large climate chamber is available to test a broad range of current and future wind turbine components: Mechanical components (gearboxes, yaw & pitch systems,...), Electrical components (transformers, switch gears,...), Electro-mechanical equipment (generators, hybrid gearboxes,...), Power electronics (convertors, ...), Hydraulic components (hydraulic gearboxes, oil filters,...), Cooling and heating systems.

Figure 9: Potential development tests at OWI-Lab's climate chamber

Facts and figures of the large climate chamber:

- Maximum test dimensions 10m x 7m x 8m (LxWxH)
- Temperature range for testing: -60°C to +60°C
- Located nearby a breakbulk quay in the port of Antwerp to handle large and heavy objects (up to 150 ton); capacity test chamber
- Floor: 30 ton/m²
- Large cooling and heating power
- 315 kW drive and intermediate gearbox (1:5) to drive mechanical components (i.e. Gearbox cold start tests)
- High power to feed any electrical components for system testing can be foreseen by mobile generators up almost any required power range (including multi MVA)

7. Conclusions

The application of wind energy in remote areas is rapidly expanding . Often these wind turbine generators need to work under extreme conditions. Usually onshore and offshore wind turbines are designed to operate in a temperature range from -10°C to +40°C, but in some locations temperature can even drop lower and customer requirements are higher. These inhospitable locations form a huge challenge for the machine itself but also for the maintenance and repair teams. In some cases repair works have to be postponed because of harsh weather conditions and/or extreme temperatures and thereby affects the turbine availability and its business case. Reliability is key for wind turbines at remote locations and therefore extreme environmental scenarios have to be tested. Advanced testing becomes more and more important to reduce the time-to-market of turbine components, ensure reliability to clients and to obtain certification. Different test beds are currently being built in order to support the wind industry to reach its goals of improving reliability and decreasing the levelized cost of onshore and offshore wind energy. (Extreme) temperature testing is needed for the validation of certain drivetrain components like gearboxes and transformers in remote locations. OWI-lab invested in a large public climatic test chamber in order to support manufacturers in the testing process.

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References

IEC 61400-22 Ed.1: Wind turbines – Part 22: Conformity testing and certification.

IEC 60068-2-1 environmental testing – Part 2: tests – Tests A: cold.

Bram Cloet, Stefan Tysebaert, Raymond Van Schevensteen – CG Power Systems Belgium. Corrosion and low temperature tests on liquid-filled transformers for offshore applications.

GL Technical Note 067 “Certification of Wind Turbines for extreme Temperatures (here: Cold Climate)”, Rev. 4

GL Technical Note: Load assumptions at extreme temperatures.

GL Technical Note: Certification of Wind Turbines for Hot Climate Application.

Mike Woebbeking – GL, winterwind 2011 presentation: GL technical not for cold climate – an overview

CEEES: The different type of tests and their impact on product reliability.

Simon Ferguson - GL presentation, 2010: Wind energy development in Harsh environments.

ISO 81400-4: “Wind turbines – Design and specification of gearboxes”, 2005

Shane Palmer, Thomas E. Nemila – Clipper Wind Power: Performance validation of a wind turbine gearbox in extreme cold temperature operation

Harry Roossien, The importance and future of reliability in a complex and turbulent environment.

Qiying Zhang - Guodian United Power China, Winterwind 2011 presentation: China low-temperature wind turbine design and its application

Jahnel-Kestermann: Cold climate test run in climate chamber with a 1.5MW wind turbine gearbox

Voith: WinDrive cool climate test down to -40°C