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Challenges of the offshore environment

Susanne Otto
DELTA Danish Electronics, Light & Acoustics www.delta.dk
Sdr. Boulevard 29, Bygn. 3, 3. sal, DK-5000 Odense C, Denmark
suo@delta.dk

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1. Summary

Offshore wind turbines face ever increasing challenges from the harsh environment of humidity, corrosion, vibration etc. at sea. The effect of the environment on the equipment employed at sea has caused many problems in terms of delay of projects, reduced reliability, down periods etc. Knowledge of the electrical, climatic and mechanical conditions to be conquered and their impact on the different subparts of the wind turbines is the key to design of wind turbines that meet the real world.

It is the aim of this paper to give input on how to implement the knowledge of the environment. It should be included in the early stage at specification level, through design guidelines and during development and qualification testing of the wind turbines. Thus, you are getting a cutting edge on reliability and time-to-market. Further, a case study demonstrates the effect of this on a real-life project.

DELTA has gained experience from a large number of projects for the off-shore and wind turbine industry. The presentation is based on the experience a couple of years after Horns-rev.

2. Introduction

Stepping into the sea and at the same time stepping up in size of the wind turbines have been a giant leap in the history of the wind turbines. Changes in technology and application emphasises the demand for clear and well defined requirement specifications. The specification serves as basis for the design and development process as well as the verification and documentation of quality and reliability.

The offshore environment is significantly different from that of the land based wind turbines. It is a very harsh environment characterised by high and low temperatures, high relative humidity, pollutants, vibrations, lighting etc. In addition to the effects of the surrounding environment are the environmental conditions generated by the wind turbine itself e.g. vibration generated by the wings, the gear and the generator, excessive temperature generated by the heat dissipated in the generator and control equipment, breathing of humid air by the enclosures and disturbances generated by the different subcomponents.

Further, demand for long life expectancies, high availability in combination with inaccessibility for repair leads to pronounced emphasis on reliability.

Thus structures, components and instruments for offshore application have to be carefully developed taking into consideration the challenges of the harsh environment in order to get reliable performance during their lifetime.

Presently, no globally common environmental requirements exist within the field of wind turbines. The individual wind farm owner has more or less well-defined environmental requirements as well as the individual manufacturers of equipment for wind turbines have their own design specifications including environmental parameters.

In the following a paradigm is suggested for design of environmental requirements and the application of these in the design and development process of the subparts.

3. From environment to requirements

Experience shows that there is a dependency of performance on environment and time. The performance at standard laboratory conditions is at a certain level as shown in the first diagram of figure 1. Applying environmental conditions as a parameter tend to reduce the performance as a function of the severity of the environmental conditions as shown in the second diagram. Applying time as a parameter reduces the performance as a function of lifetime due to fatigue, wear, degradation etc. as shown in the third diagram.

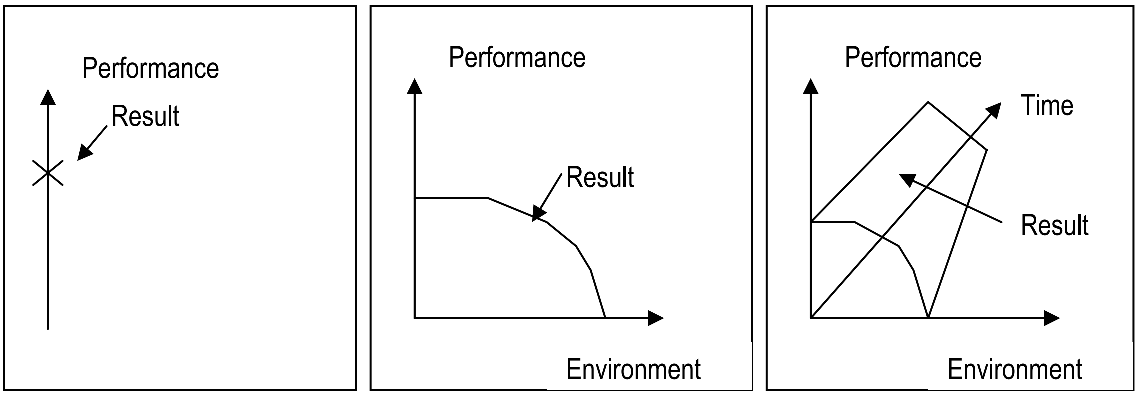

Figure 1. Performance as a function of environment and time.

Figure 2 below describes the flow from description of the environment to the verification test requirements and design guidelines.

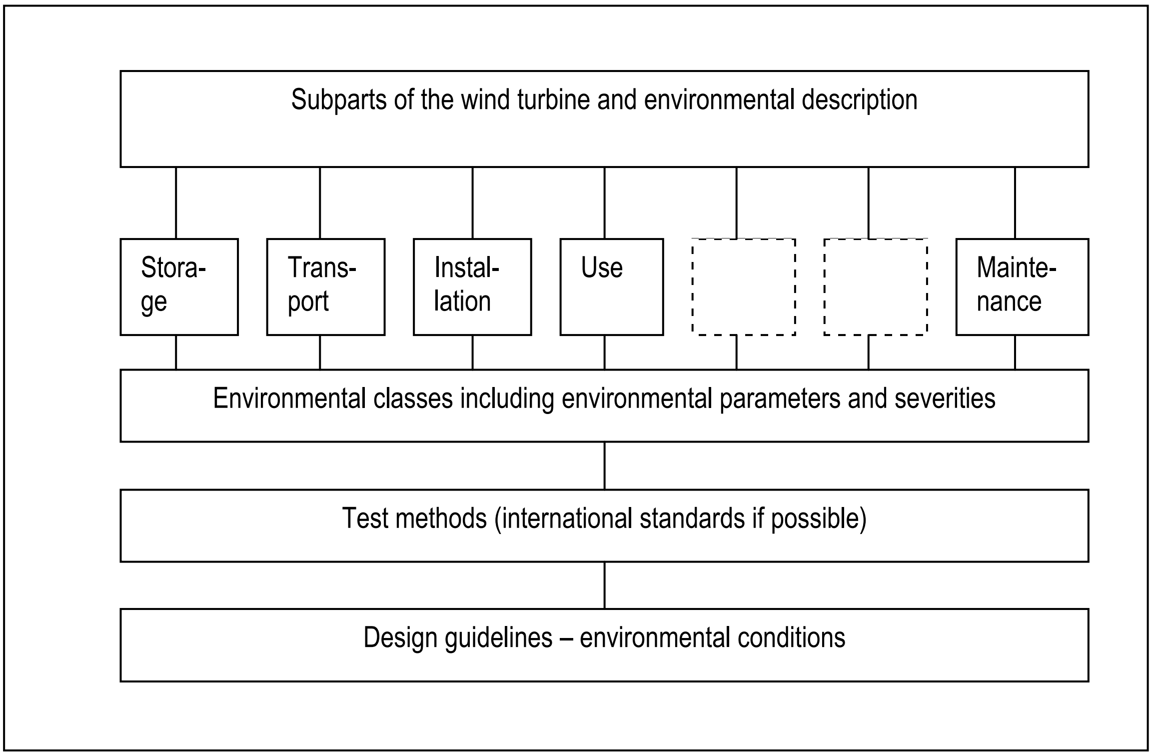

Figure 2. Paradigm for the design of environmental requirements.

Step 1: Description of environmental conditions

The starting point is listing of all subparts i.e. structural parts, components and instruments. For all of these subparts a verbal description of all relevant environment conditions is given. The verbal description should include information about the surrounding environment including electromagnetic emission from neighbouring equipment, means of protection i.e. enclosure, surfaces, heating, special EMC immunity protective means, vibration dampers, packaging and external conditions other than environmental.

During the life of a component different modes of conditions i.e. storage, transport, installation, use, maintenance etc. are encountered each of these modes impose different stresses on the subpart. All these modes of conditions should be taken into account when considering the environmental conditions.

The following is an example of a verbal description:

The control panel is placed in the nacelle in 900 MW wind turbines to be placed at sea in Northern Europe and USA. The control panel is mounted via profiles in the bottom to the floor of the nacelle near the generator. The nacelle itself is water and dust tight. However, the nacelle cover may be opened during maintenance. The control panel is mounted in the nacelle during transportation. Means of transportation are land mobile vehicles and ships. The influence of the storage environment is considered insignificant.

The verbal description provides all involved with the fundamental understanding of the origin of the requirements and the consequences of changes in the application.

Step 2: Definition of environmental classes

A limited number of environmental classes of application are designed covering the main applications and locations of subparts. Each of the classes is characterised by similar climatic, mechanical or electrical conditions and severities of these. The grouping into environmental classes significantly limits the number of locations to be described as opposed to giving a description for each position of each piece of equipment.

The following four environmental classes might be suggested for wind turbines:

- Tower
- Nacelle
- Hub
- Open air at sea

The definition of environmental classes provides overview over requirements and ease of specification of requirements for new products as soon as the classification has been established in detail with environmental parameters and severities.

Step 3: Environmental parameters and severities

Environmental parameters e.g. high and low temperature, humidity, water, dust, salt mist, other pollutants, vibration, bump, shock, lighting, immunity and emission limits have to be considered for each environmental class.

The actual environmental parameters to be included as well as the severities of these are based on field measurements. Only propriety and limited data exist at present. Further measurements of environmental data in a variety of locations on different wind turbines placed differently geographically are required.

However, findings from other studies of related fields as well as experience with design of environmental specifications for similar applications like offshore oil rigs, maritime equipment etc. can be utilised as well.

In the following examples of available data are given:

Data regarding corrosion environments can be found in ref. [8]. The data show that "Seaside" is classified as the most severe corrosion class – namely GX Severe, where "only specially designed and packaged equipment would be expected to survive", see figure 3 below. Each of the corrosion classes are defined by TOW (time of wetness) classes i.e. $\tau 1$ – $\tau 6$ and pollutant classes i.e. P1 – P5.

(TOW) Time of Wetness is the time where most of the corrosion observed takes place and thus an important factor classifying corrosivity. It is defined in the following way: Time per year during which the temperature is above 0˚C and the relative humidity is above 80%

The GX has TOW ranging frim 30% to more than 60% of the year. It should be noted that this environment is the open air environment around the wind turbines

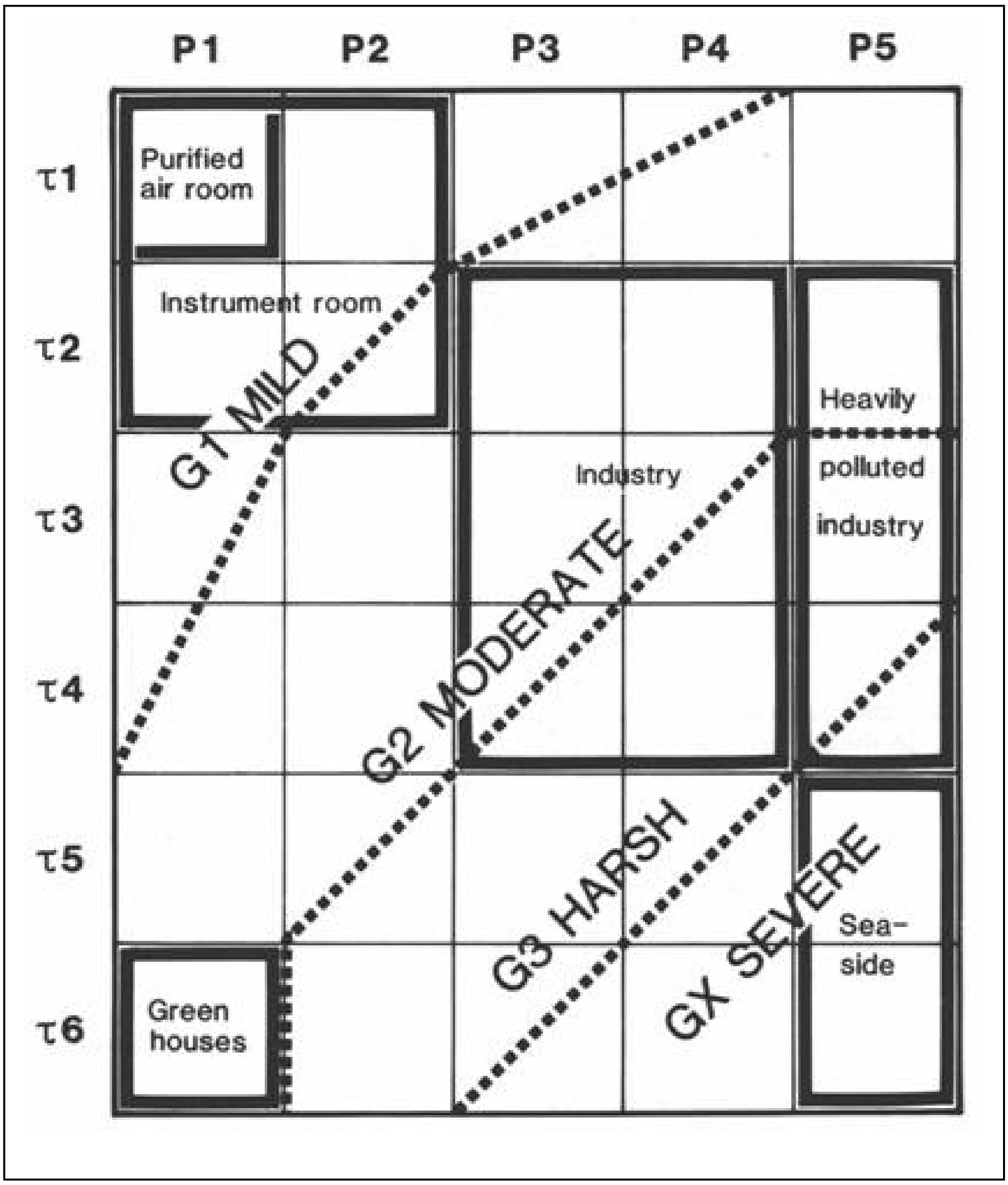

Figure 3. Examples of how different types of environment fit into corrosivity classification system ref. [8],

However, the surrounding environment heavily influences the environment of the equipment inside structural parts of the wind turbine. From ref. [1] we have field measurements of temperature and humidity measured simultaneous in open air, in a shelter and inside equipment in a shelter as described in ref. [1]. The measurements demonstrate the increase of the relative humidity inside equipment in a shelter as a function of open air variations of temperature and relative humidity. In less than a month the relative humidity inside the equipment exceeds 80% which at temperatures above 0˚C is defined as "wetness" i.e. a condition where corrosion takes place.

Some data and experience regarding severities of environmental parameters exist. However, further measurements of environmental data in a variety of locations on different wind turbines placed differently geographically are required to quantify the environmental parameters.

Step 4: Design of tests

The environmental data obtained is transformed into test methods. The transformation depend on the test philosophy i.e. whether it is development tests, qualification tests, life tests or production tests.

A development test is aimed at finding potential weaknesses during the development process in a time-effective manner. The test conditions are selected depending on the failure mechanisms expected. HALT (Highly Accelerated Life Test) described further in ref. [6] has obvious advantages. The idea is simple: Apply stress to a product in excess of its design specification to generate failures, find the root cause of each failure and eliminate them by design improvements. When this is done during the original design of the product, it will result in a more reliable product.

Qualification tests are aimed at verifying compliance with the originally specified requirements. The objective of qualification testing methods is to be well defined, reproducible and according to internationally accepted standards. Environmental data are transformed into test severities by selecting short term worst case conditions field data as test severities for tests like temperature.

Other parameters like e.g. vibration are further accelerated in order to reduce test time. Acceleration factors relating shorter exposure time to higher exposure levels are used. The formulas most frequently used are based on cumulative fatigue. The formula for acceleration of random vibration is as given below. A random vibration signal will expose all the structure resonances simultaneously within the vibration test frequency range. The interaction of the different resonances on each other will consequently occur, resulting in a response as from a practical environment

Random vibration at power spectral density level W_2 for the time T_2 will produce the same damage as vibration at level W_1 for the time T_1, provided that:

$$\frac{T_2}{T_1} = \left(\frac{W_1}{W_2}\right)^4 \quad \text{ref. [7]}$$

Life testing is aimed at predicting useful service life of equipment. Life cycles can be defined according to ref. [3]. The method enables the design of test conditions for endurance test with some acceleration of time versus real use. This acceleration can be accomplished by reproducing only the part of the use conditions imposing a considerable stress on the item and omitting the conditions of low stress. However, detailed knowledge of the use conditions is required.

Functional requirements are an integrated part of all the above mentioned test philosophies.

4. Case study – design of accelerated salt mist test

The case study demonstrates how an accelerated test based on the HALT philosophy has been designed based on knowledge of the environmental parameters in the wind turbine and relevant failure mechanisms when test from other applications i.e. the maritime proved to be insufficient.

A developer of subparts for wind turbines anticipated corrosion problems related to salt mist of a new product. Previous products had been qualification tested against a test specification namely EN/IEC 60068-2-52, test Kb widely used for maritime equipment placed on board ships at locations where it is exposed salt mist. This test is one of the most severe of the internationally standardised salt mist tests. No significant corrosion had been observed during the previous tests. However, field failures related to corrosion had been experienced regardless of the positive results of the testing.

Figure 4 below shows the conditions of the test.

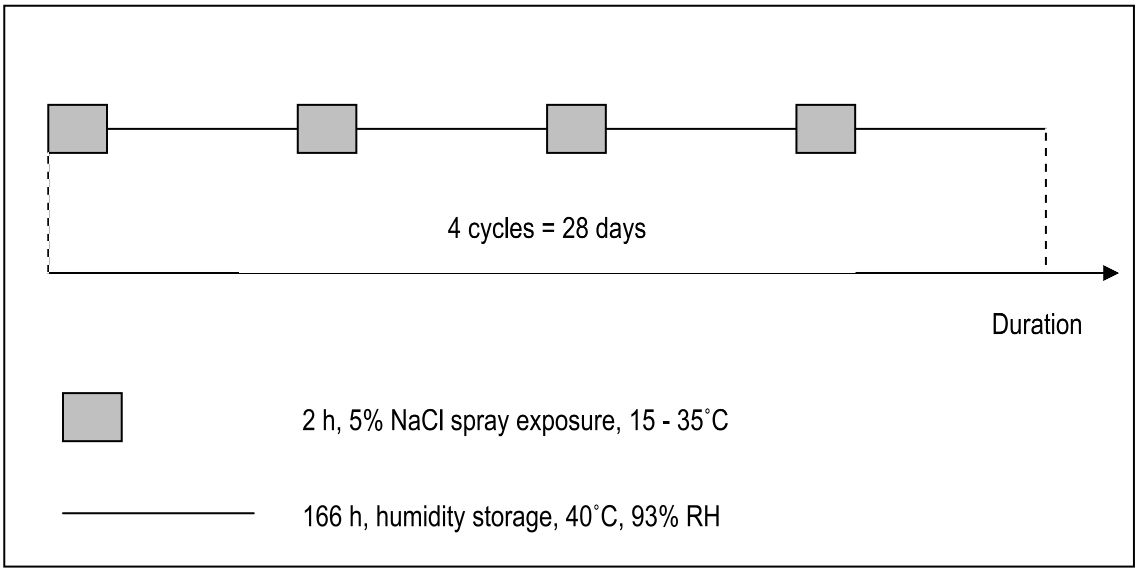

Figure 4. EN/IEC 60068-2-52, test Kb: Salt mist, cyclic, 28 days.

Thus, it was attempted to develop a new test method which in a short duration would produce the same failure mechanisms as experienced in the field. The use environment was investigated in order to determine significant environmental parameters related to corrosion. These parameters were identified to be salt mist, humidity, change of temperature and high temperature. A test consisting of cycles as shown in figure 4 was designed. The test was performed on the new product together with another product, which had also been exposed to the field. Thus there were field observations to be correlated with.

Figure 5 below shows the custom designed test.

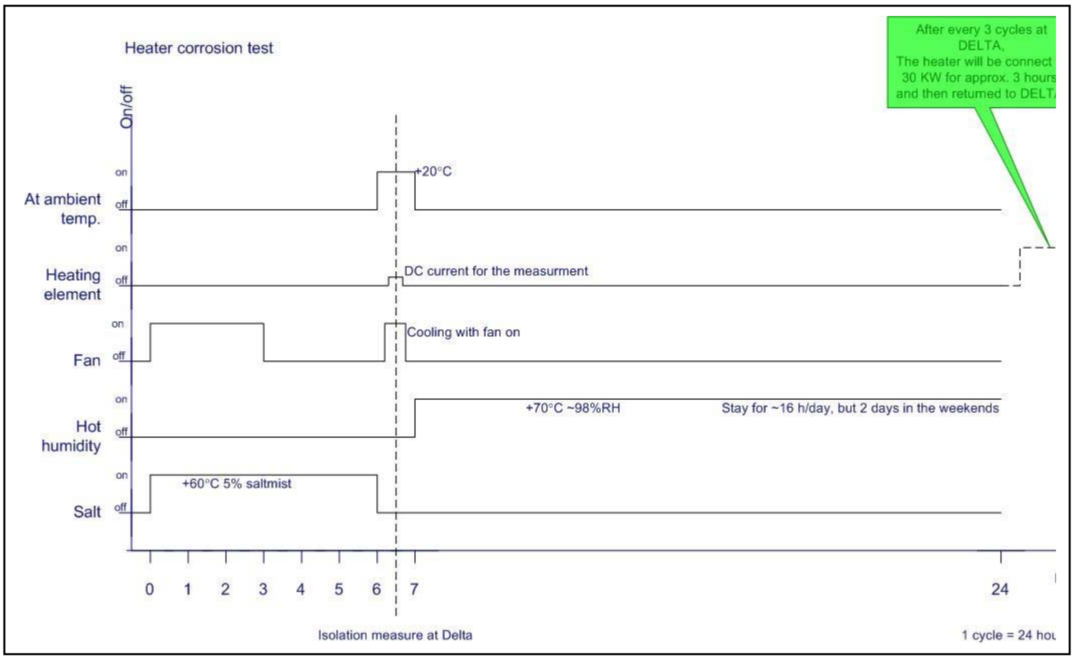

Figure 5. The custom designed test.

The results of the testing look promising with corrosion patterns similar to what can been seen in the field. However, further investigations have to be carried out.

5. Design guidelines

Design guidelines can be derived from the severities of the environmental parameters and test requirements. Examples are:

- High temperature limits together with component data serve as input for thermal management.
- Humidity requirements serve as input regarding coating or by other means protecting electronic circuitry.
- Corrosion requirements serve as input for selection of materials and strategy whether to seal, ventilate or heat against humidity.
- Vibration requirements i.e. frequency range and acceleration level gives guidance regarding the required rigidity of structures, fastening of component, mounting methods etc.

Conclusions

The offshore environment is significantly different from that of the land based wind turbines. Thus, structures, components and instruments for offshore application have to be carefully developed taking into consideration the challenges of the harsh environment in order to get reliable performance during their lifetime. Knowledge of the electrical, climatic and mechanical conditions to be conquered and their impact on the different subparts of the wind turbines is the key to design of wind turbines that meet the real world.

Environmental specification serves as basis for the design and development process as well as the verification and documentation of quality and reliability.

Presently, no globally common environmental requirements exist within the field of wind turbines. The individual wind farm owner has more or less well-defined environmental requirements as well as the individual manufacturers of equipment for wind turbines have their own design specifications including environmental parameters.

A paradigm for design of environmental requirements and the application of these in the design and development process of the subparts is suggested.

Further measurements of environmental data in a variety of locations on different wind turbines placed differently geographically are required in order to specify severities of actual environmental conditions.

Transformation of field data and test experience into the design of an accelerated salt mist test was demonstrated in the case study. Further investigations have to be performed to prove more general usability of the method.

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