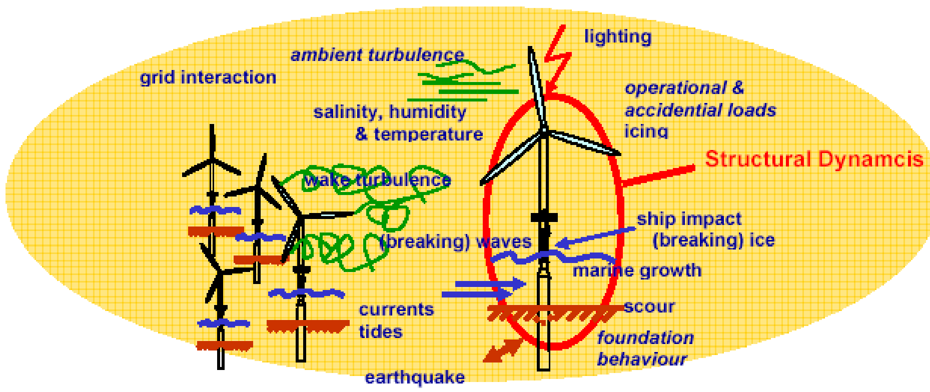
Offshore : Risk & Technology Consulting Inc.

Dr. Malcolm Sharples, Principal Author, Houston, Texas

Structure, Equipment and Systems for Offshore Wind Farms on the OCS

Part 2 of 2 Parts - Commentary



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December 2009

Front Page Acknowledgement–
Kuhn M. (2001), Dynamics and design optimisation of OWECS, Institute for Wind Energy, Delft Univ. of Technology

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Authors' Note, Disclaimer and Invitation:

This document has been written by engineers experienced in the offshore oil and gas industry and although much information, advice and comment has been given by those with years of experience in various aspects of the wind turbine industry many of the points made may be subject to a different interpretation, and the facts may differ from the information relied upon which is believed to be factual. This report has been written without prejudice to the interests of any parties mentioned or concerned and the Company and authors shall not in any circumstances be responsible or liable for any act, omission, default, or negligence whatsoever.

While we have used our best efforts to provide an impartial report, errors of fact or interpretation may have resulted: consequently, an invitation is issued to any readers to provide written comment for a limited period of time which will be reviewed for possible inclusion in an addendum to this report. Comments may be sent by email to msharples@offshore-risk.net.

1.0 OVERVIEW

It was reported in the International Energy Agency Wind Report 2008 that in the United States, wind energy capacity grew more than 50% in 2008 and accounted for 42% of the nation's new electrical generation for the year. Several projects are in the permitting process offshore United States and also in State waters.

The term "offshore" in the United States means on the Outer Continental Shelf (OCS), with exceptions of Texas and Florida, past the 3 mile limit. The term "offshore" in Europe for the wind energy industry and for the wind energy standards developed in Europe: "A wind turbine is considered "offshore" if its support structure is subjected to hydrodynamic loading". The applications standards and history termed "offshore" in the Europe inventory of wind farms should be examined in this context.

At the time of release of the Dept. of Energy document "20% Wind Energy by 2030 – Prepublication Version 2008" the Minerals Management Service of the Dept. of the Interior (MMS) had been identified to formulate existing regulations for submissions on Offshore Wind Farms.

> *"2.5.3 TECHNOLOGY NEEDS AND POTENTIAL IMPROVEMENTS. Conducting research that will lead to more rapid deployment of offshore turbines should be an upfront priority for industry. This research should address obstacles to today's projects, and could include the following tasks:*
>
> - *Develop certification methods and standards: MMS has been authorized to define the structural safety standards for offshore wind turbines on the OCS. Technical research, analysis, and testing are needed to build confidence that safety will be adequate and to prevent overcautiousness that will increase costs unnecessarily. Development of these standards will require a complete evaluation and harmonization of the existing offshore wind standards and the American Petroleum Institute (API) offshore oil and gas standards. MMS is currently determining the most relevant standards.*
>
> - *Develop design codes, tools, and methods: The design tools that the wind industry uses today have been developed and validated for land-based utility-scale turbines, and the maturity and reliability of the tools have led to significantly higher confidence in today's wind turbines. Offshore design tools are relatively immature by comparison. The development of accurate offshore computer codes to predict the dynamic forces and motions acting on turbines deployed at sea is essential for moving into deeper water. One major challenge is predicting loads and the resulting dynamic responses of the wind turbine support structure when it is subjected to combined wave and wind loading. These offshore design tools must be validated to ensure that they can deal with the combined dominance of simultaneous wind and wave load spectra, which is a unique problem for offshore wind installations. Floating*

system analysis must be able to account for additional turbine motions as well as the dynamic characterization of mooring lines.

- *Increase offshore turbine reliability: The current offshore service record is mixed, and as such, is a large contributor to high risk. A new balance between initial capital investment and long-term operating costs must be established for offshore systems, which will have a significant impact on COE. Offshore turbine designs must place a higher premium on reliability and anticipation of on-site repairs than their land-based counterparts. Emphasis should be placed on avoiding large maintenance events that require expensive and specialized equipment. This can be done by identifying the root causes of component failures, understanding the frequency and cost of each event, and appropriately implementing design improvements (Stiesdal and Madsen 2005). Design tools, quality control, testing, and inspection will need heightened emphasis. Blade designers must consider strategies to offset the impacts of marine moisture, corrosion, and extreme weather. In higher latitudes, designers must also account for ice flows and ice accretion on the blades. Research that improves land-based wind turbine reliability now will have a direct impact on the reliability of future offshore machines."*

Based on a study by Penn State University the following figure illustrates that the "normal" turbines manufactured for Europe application may not be considered appropriate for the extremes relevant to offshore the US East Coast or Gulf Coast: S-Class turbines are required in most locations. The wind speeds in this figure account for hurricane activities. In the North East of the United States the winter storms may have similar or greater values.

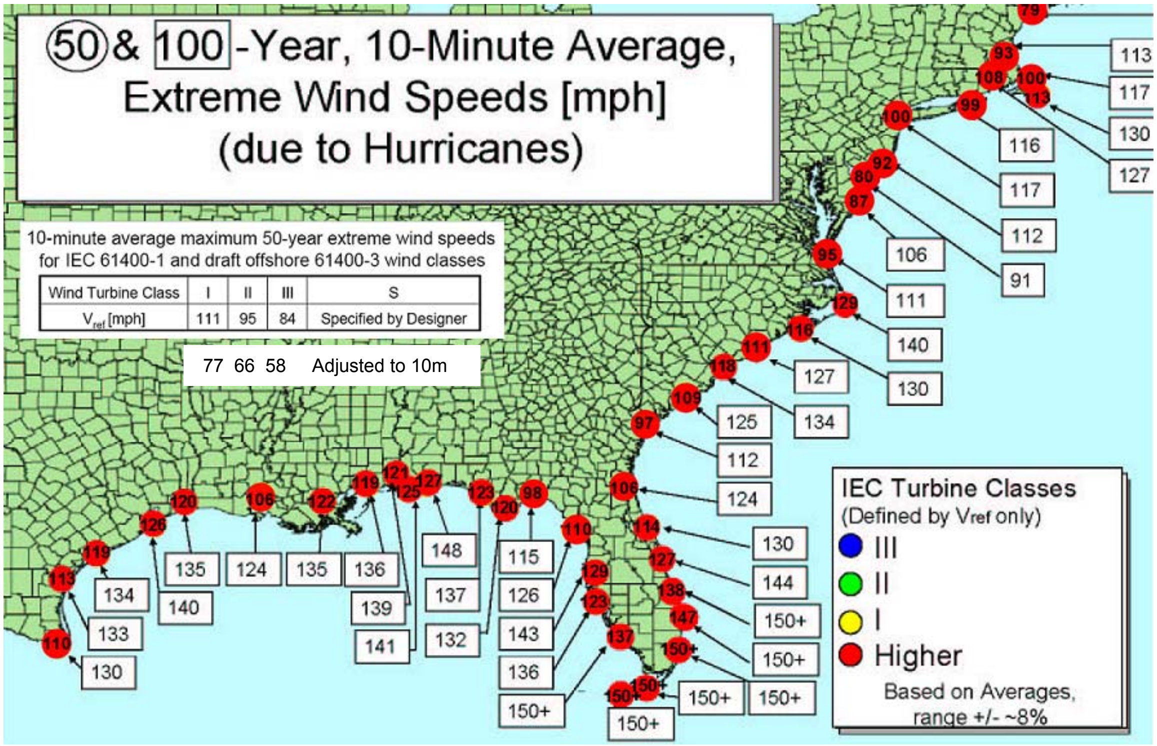

Figure 1: Based on ideas of Dr. Susan Stewart, Penn State: U.S Offshore Extreme Wind Analysis Based on Hurricane Return Probabilities, Poster, Penn State University.

Figure 1 indicates that for both 50 year and 100 year wind speeds the turbines will all have to be S-Class as the locations are for the most part above the specified Normal Class wind speeds when taking into account the hub height. Note: these wind speeds are not developed for site specific application and thus require further more-detailed scrutiny and only give a general indication.

The information in Figure 1 competes with the ASCE-7 reference giving land-based wind values of extremes, noting that ASCE values are based on 3-second gust rather than 10-min mean.

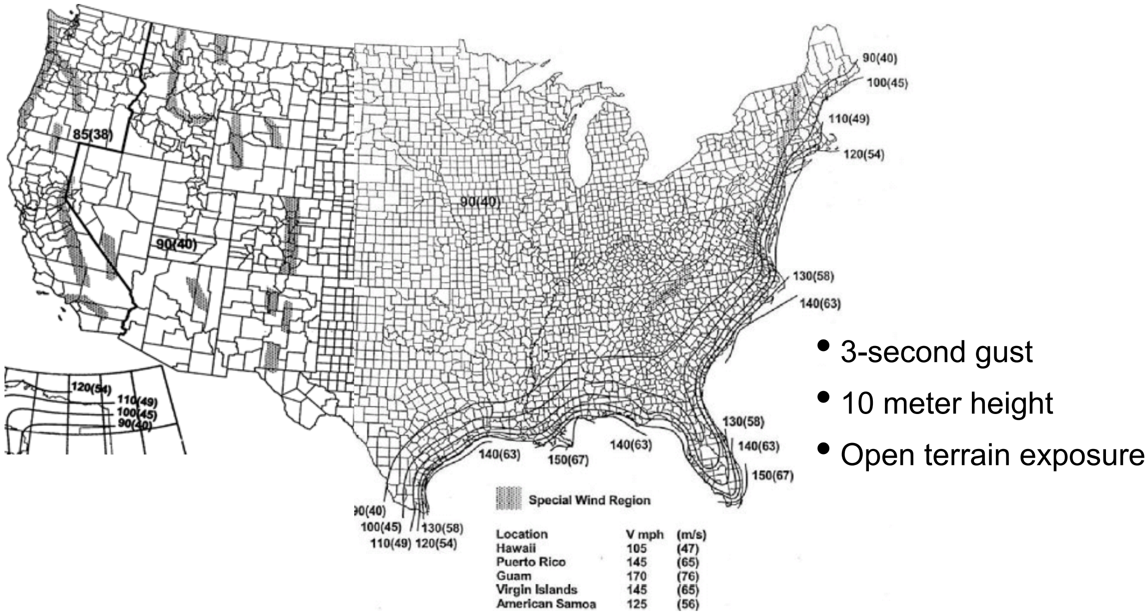

Figure 2: ASCE-7 Wind Speeds [Ref. 3.1.10].

As commented on later in the text the science/art of determining extreme wind speeds at site-specific locations requires much data and experts often arrive at significantly different values for the same phenomenon. This is an area requiring further study to have a consistent regulatory approach for acceptance.

The following may illustrate a very simplified "appreciation" of the issue with determining hurricane wind speeds. Data is collected for a historical 100 years of hurricanes: during the last 50 years better measurements have been made by flights measuring pressures in the storm instead of on land at the edge of storms. The 100 year dataset may produce a less accurate result than the 50 year dataset. Two different researchers might use different "circles of influence" to determine relevant hurricanes to determine the average value at the site in the appropriate return period: one researcher decides to use a 50-mile diameter and average the storms that are "captured" in that diameter and using statistics determine the worst extreme winds during that storm; the other researcher uses a 50-mile radius for the same determination. There may be no physical reason that the storms in the outside the 50-mile radius and within the 50-mile diameter may not have come directly across the subject site, but the two techniques may yield different results: perhaps 20% difference in value. While this is a simplistic explanation it serves to show the complexity of understanding how 2 different researchers come out with different values. The methodology used by the oil and gas community may be appropriate to be used for determining offshore wind farm metocean data. This subject, while important is beyond the scope of this study.

MMS and Alternative Energy Regulation

The Minerals Management Service, U.S. Department of the Interior (MMS), has developed a Renewable Energy and Alternate Use Program authorized by section 388 of the Energy Policy Act of 2005. MMS is authorized to grant property rights, collect payments for alternative energy and other uses of the OCS (in the form of lease rentals and operating fees), and establish a comprehensive “cradle-to-grave” regulatory program for authorizing alternative energy activity on the OCS. The published final regulations are in 30 CFR 285 Renewable Energy and Alternative Uses of Existing Facilities on the Outer Continental Shelf. The research in this Project is partly in response to the need for MMS to publish a guidance document to support the regulations and various plan submittals.

Section 285.600 requires the submission and MMS Approval of a Site Assessment Plan (SAP), Construction and Operations Plan (COP), or General Activities Plan (GAP) [Ref. 1.1].

The SAP describes the activities (e.g., installation of metrological buoys or towers including jack-up observation units) in the lessee plans to perform for the characterization of the commercial lease, or to test technology devices. The SAP must describe how the lessee will conduct the activities. It must include data from physical characterization surveys (e.g., geological or geophysical surveys or hazard surveys); baseline environmental surveys (e.g., biological or archeological surveys); and for facilities deemed by MMS to be complex or significant, the SAP must include a Facility Design Report, a Fabrication and Installation Report, and a Safety Management System [Ref. 1.1]. This item has some attention since a liftboat stationed on an offshore wind farm site

Figure 3.

providing service in what today would be termed the SAP with equipment which may not have been optimized (possibly airgap) and possibly with an inadequate Safety

Management System. A casualty and a fatality resulted. Information on the cause is still awaiting a U.S. Coast Guard Report.

The COP must describe the construction, operations, and conceptual decommissioning plans under the commercial lease, for all planned facilities. Paragraph 285.621 states that the COP must demonstrate that proposed activities "Use best available and safest technology" and "best management practices". The COP must contain information for each type of structure associated with the project and how the Certified Verification Agent (CVA) will be used to review and verify each stage of the project. The CVA is defined in Paragraph 285.112 as an individual or organization experienced in the design, fabrication, and installation of offshore marine facilities or structures, who will conduct specified third-party reviews, inspections and verifications. For all cables, including those on project easements, the COP must describe the location, design and installation methods, testing, maintenance, repair, safety devices, exterior corrosion protection, inspections, and decommissioning. Additional information requirements for the COP are detailed in paragraph 285.626 [Ref. 1.1].

There have been several incidents with construction of near shore wind farms in Europe. One example is shown below with a crane collapse on installation of the North Hoyle project in 2003.

Figure 4. North Hoyle Crane Collapse

The GAP is a requirement for limited leases, ROW Grants and RUE Grants and must describe the proposed construction, activities, and conceptual decommissioning plans for all planned facilities, including testing of technology devices and onshore and support facilities to be constructed for the project, including any project easement for the assessment and development of the limited lease or grant. Its required content is similar to that for the SAP.

Paragraph 285.700 requires the submission of a Facility Design Report and a Fabrication and Installation Report before installing facilities described in an approved COP, SAP or GAP. The Facility Design Report must include a location plat, detailed facility drawings, a complete set of structural drawings, a summary of the environmental data used for design, a summary of the engineering design data, a complete set of design calculations, copies of project-specific studies (e.g. oceanographic and soil survey reports), a description of loads imposed on the facility, a geotechnical report and certification statement. API RP-2A-WSD is incorporated by reference in Paragraph 285.115 which addresses inspections and assessments [Ref. 1.1].

The MMS Record of Decision: Establishment of an OCS Alternative Energy and Alternate Use Program (December 2007) records the decision that the MMS reached to select the Preferred Alternative set forth in detail in the Final Programmatic EIS and establish the AEAU Program. The Record of Decision adopts initial Best Management Practices (BMPs) that were developed as mitigation measures in the Final Programmatic EIS. Among other requirements, the adopted BMPs include requirements for lessees and grantees to:

- conduct seafloor surveys in the early phases of a project to ensure that the renewable energy project is sited appropriately and to avoid or minimize potential impacts associated with seafloor instability, other hazards, and to avoid locating facilities near known sensitive seafloor habitats;
- take reasonable actions to minimize seabed disturbance during construction and installation of the facility and associated infrastructure, and during cable installation;
- employ appropriate shielding for underwater cables to control the intensity of electromagnetic fields;
- reduce the scouring action of ocean currents around foundations by taking all reasonable measures;
- comply with Federal Aviation Administration (FAA) and US Coast Guard (USCG) requirements for lighting while using lighting technology that minimizes impacts to avian species: (this may require deviations from existing regulations for lighting);
- avoid or minimize impacts to the commercial fishing industry by marking applicable structures with USCG approved measures to ensure safe vessel operation;
- avoid or minimize impacts to the commercial fishing industry by burying cables, where practical, to avoid conflict with fishing vessels and gear operation; and inspect the cable burial depth periodically during project operation;
- place proper lighting and signage on applicable energy structures to aid navigation per USCG circular NVIC 07-02 (USCG 2007);
- conduct magnetometer tows using 30-m (100-ft) line spacing in areas where there is a high potential for shipwrecks.

MMS also issues Notices to Lessees and Operators (NTLs) that supplement the regulations that govern operations on the OCS and provide clarification or interpretation of regulations and further guidance to lessees and operators in the conduct of safe and environmentally sound operations. There are two types of NTL's: those issued at the regional level pertinent just for the region and those issued nationally that are effective nationwide for all MMS regions. The NTLs can be found on the MMS web site at http://www.mms.gov. NTLs have been issued addressing several points of interest [Ref. 1.1]:

- incident and oil spill reporting
- shallow hazards survey and report requirements
- oil spill response plans
- warning signs for power cables
- procedures for the submission, inspection and selection of geophysical data and
- information collected under a permit as well as other topics
- synthetic mooring systems
- OCS inspection program
- OCS sediment resources
- military warning and water test areas
- decommissioning of facilities

1.1 Existing Standards and Guidance Overview

Some of the tasks involved in this Research Project involved review of the existing standards and certification documents in order to evaluate what might be applicable for use on the OCS, and to identify gaps. Upon review it became apparent that the standards to be used were not a straightforward reference to what had been done in Europe and elsewhere or in the offshore oil and gas industry. Several challenges became immediately apparent in the identification and review of candidate standards: there is a substantial number of organizations which are developing standards which has resulted in an enormous number of standards being developed, versions of which are ever changing, and all of which address certain aspects of the technology better that the others. In addition:

- Significant duplication exists between standards developed by different organizations;
- Standards are not always easily accessible in the latest editions and internal references to other standards. Assembling information to understand a specific standard may lead to a requirement to purchase many other standards and this can become prohibitively expensive;
- Many misapprehensions exist about the way standards should be worded for regulatory compliance (as opposed to general advice and guidelines);
- Some of the foreign organizations have regulatory regimes and documents developed that reflect performance based requirements rather than US traditional prescriptive requirements;
- Many misunderstandings as to the meaning of the certifications provided, lead to a false sense of security: failure is often of certified components leading to the question of the complete value of certification in its current form: although it is noted that the certification process may prevent more and larger failures;
- **Lack of transparency to the root cause of accidents/ incidents/ and maintenance issues have left the researchers puzzled as to what is incorporated into the technology going forward, and who has learned what**

lessons: this is a significant barrier to progress and confidence in the industry.

Reference has been made to the application of API standards and particularly API RP2A for fixed platforms. Current practice in the USA is to use Working Stress Design for fixed offshore platforms, although an LRFD version was written some years ago: the IEC Offshore Wind Turbine design code uses the LRFD approach. Fixed platform standards may migrate to an ISO based in the USA which has been developed over many years, but that is not the current practice. Fixed platforms tend to be wave dominant whereas wind turbines on-shore are often wind dominant. Depending on the location, the offshore wind farms may be wave dominant or wind dominant: the forces of breaking waves may dominate even in shallow water. Fixed platforms are not often subject to dynamic behavior to the extent of offshore turbine structures. The use of API RP2A in application to offshore wind farms is valuable, directly applicable to transformer substations, but limited with application to turbine structures although it is a useful reference for them.

None of the currently available standards could be directly applied to the US OCS as new complete offshore wind standards. IEC 61400 can and should be used as the basis for many of the requirements: they give an overview of the key issues to be taken into account but do not cover all technical details, nor in many sections do they demand compliance with specific requirements, reporting instead excellent advice on options for the designer to consider.

The load cases in IEC 61400-3 for offshore wind turbines reflect assumptions which need verification for the specific site and particular structure to result in long-term structural safety.

Germanischer Lloyd, a private company in the ship classification and European wind business, in particular, offers the most complete set of offshore guidelines in one single document of Certification requirements noting that under their methods national requirements which are equivalent may be adopted instead of the noted European standards [Ref. 1.35]. They are an important reference in offshore wind project development, address a complete package of information and are prescriptive in their nature. They should be consulted when technical details are needed on a specific topic regarding offshore wind standards.

Det Norske Veritas is another organization in the ship classification and European win business offering certification and they have some standards exclusively for wind turbines and some of their components, and have released a guideline on Offshore Transformer Substations the electrical requirements of which are still under review. Other of their standards can be applied/adapted where appropriate to offshore wind farms.

Other similar organizations including Bureau Veritas, Lloyds Register of Shipping as classification societies have done some significant work in this area; American Bureau of Shipping is planning to enter the market. The research has not found any significant standards pertaining to specifically offshore wind farms; however, existing marine standards may be able to be applied for those areas which the IEC Code does not cover.

Appendix A gives an outline of the main Standards and Certification guidance available.

The issue of the standards to which offshore wind farms on the OCS should be built is a thorny one. It is not simply "build it to the IEC Code". The IEC Code 61400-3 Offshore Wind Turbines reflects a great deal of work by individuals who have obviously spent considerable hours pulling together and agreeing a massive amount of information. References to component issues require further reference to IEC Code 61400-1 among others in the 61400 series. While the effort is to be applauded, it is still not sufficient for the purposes of offshore regulation and there is no single technical document to be referred to which covers all the technical content or certification requirements with the possible exception of GL's Certification of Offshore Wind Turbines [Ref. 1.35]. The IEC 61400 series is, however, very helpful in the guidance it offers. The series contains -1 on design of some of the components; -11 on Noise Measurement; -23 on Blade Structural Testing; -24 on Lightning Protection and -22 on Wind Turbine Certification, however the latter is based on a system which has developed in Europe is discussed later in this Report, and is unlikely to be able to be applied directly or completely in the USA.

To put the time-development of offshore standards in perspective: offshore jack-ups have been used worldwide and in the United States since the mid-1950s. It has not been until the last few years that there has been an industry guidance document on jack-ups [Ref. 2.5], and recently an ISO standard on jack-ups [Ref. 2.4]: neither is considered an "industry standard" as yet, and neither has been incorporated into US regulations. The cost of assembling and agreeing the content of that document over the years has been enormous: still the standard does not cover one class of jack-up, the mat-supported type (except so far as airgap is concerned). It is difficult enough to produce a standard, but when multiple country interests come into the picture it is even tougher.

Some of the issues that make applying the IEC Code difficult for application in the US OCS are outlined below:

- Steel codes cited are EU codes not ASTM codes or familiar marine class society codes;
- Welding standards are EU codes not AWS codes or offshore codes or marine classification codes;
- Wording is of an advisory nature e.g. – there is a list of test that may be done on blades, but not what "must" be done, nor the number of tests required;
- Advice is given in depth for some issues: a State-of-the-Art issues on lightning is a good example which offers the current situation and extensive advice: but does not compel its use;
- Many issues are not addressed e.g. fire protection; allowable stresses; resistance factors;
- The Certification document refers to a European accepted practice of accreditation of certification bodies that does not exist in the US and could not

easily be implemented; the type of advisory committee which agrees cross-recognition of certifiers' documents does not exist in the US.

- There is reference to providing food, water and supplies in case of being "caught" offshore, however, the issue of accommodation offshore requires compliance with regulatory issues such as firefighting, lifesaving and other standards – so implies a number of design issues which need thinking out in relation to US regulatory requirements.
- Some of the provisions are unlikely to be able to be certified because of 'legal issues' with interpretation.
- Some of the information may go out of date quickly as progress is made on the standards that are still in draft form.

Offshore oil and gas structures codes may not be directly applicable:

- Most of the offshore fixed structures are dominated by the forces of waves, and only a steady state wind is generally used to design offshore structures which have not included the dynamic components necessary for offshore wind turbine structures. Wind turbine structures are more dynamic i.e. they oscillate as the forces are applied to them and this affects the stresses and fatigue life;

- The design of turbine structures are subject to internal forces from start-up, emergency shut down, electrical faults that are not considered in offshore oil and gas structures;

- Offshore Mobile Drilling Units (MODUs) have guidance [Ref. 2.5] developed for taking account of dynamics developed in the foundations, but fixed structures generally consider equivalent static loads as primary design values. Jack-ups will be used for installation and maintenance so the information in those guidance documents will be useful for that aspect;

- Remote control used in the wind turbine structure is not typically part of the consideration of offshore oil and gas platforms. Ensuring control of the structure for positioning during the survival storm is not part of the design philosophy of offshore oil and gas structures (with the exception of manned intervention of mooring tensions in specific non-hurricane locations) whereas it appears it may be critical for offshore turbine structures;

- Requirements of power to position the turbine structure orientations to avoid structural failure are not part of the design philosophy of offshore oil and gas platforms;

- Fire protection, and safety management systems are very comparable and offshore oil and gas codes can be used (with some adaptations);

- Corrosion protection in principle is very similar, however there are differences in the economics of repair in that the turbine structure will need to be shut down for safety reasons during any repair time, and such precautions are not necessary on oil and gas platforms;

- Electrical standards may be able to be used for the structures. No electrical standards were found from the offshore oil and gas industry for electrical cables on the seabed.

- The extent of metocean (wind, wave, current including direction, periods, turbulence, etc) have to be far better known for a wind turbine structure than a typical oil and gas platform due to the fact that the structure itself responds far more dynamically (to vibration) than most offshore oil and gas structures. The amount of information developed in terms of wind in order to perform economic calculations as to wind produced that can turn the blades, is in much more detail than can legitimately be used for long term predictions of extremes particularly in the United States were the metocean data is mixed with extremes that are rare e.g. Hurricanes, Nor'easters etc. Many of the wind farms are in comparatively shallow water requiring the estimate of breaking waves for the determination of maximum loads: offshore oil and gas structure codes may need further work to consider such shallow water locations with suitable accuracy. Whether there is sufficient data to be sure of the likely future winds, waves, currents combination together with direction over 20 years following the design is open to some question: directionality is considered in offshore oil and gas codes but probably to a lesser extent than relied upon in the IEC Code;

- The accuracy of the forces from breaking waves in shallow water may require further scrutiny from any oil and gas structure guidance, since the concentration in recent years of the oil and gas industry has been in deeper waters;

- The structure itself is a key element in the economics of offshore wind farms, whereas for many oil and gas platforms the structure is a smaller % of the cost, compared to the drilling, completion, and production issues, and thus they can be designed more conservatively with less relevance to the economics;

- The engineers designing and building offshore wind turbines may not have the depth of experience that has been developed from offshore developments. Offshore structure standards have changed over the years with experiences that have recognized the consequences of under-design. This is particularly important since the activities and learning experiences close to shore occurred a long time ago and the population of platforms and mobile rigs tend to be further offshore nowadays and not so subject to some of the issues that are more complicated to estimate e.g. airgap for 100-year conditions (a minimum standards for oil and gas structures) is much more difficult to estimate in shallow water with breaking waves than offshore in deeper waters.

The issue of developing or adapting European guidance to US guidance becomes more complex because of the wide variety and extent of technical disciplines needed to develop a US equivalent and depth of knowledge in each for codified use coupled with the complexity of the different weather types in the various offshore areas encompassing the US OCS.

1.2 Country Requirements.

Historically in Europe, national standards determined the requirements for acceptance of wind farms. Increasingly as the IEC Code has developed reference is made in the literature to that code taking on board as many of the country requirements as possible, and rationalizing between the countries. The motivation is possibly to ensure that equipment can cross borders allowing equipment to be produced that is not of permitting country origin. Reference is given in the GL Certification document 2003 [Ref. 1.42] to country requirements.
While the IEC Code is becoming the unified standard there are differences in what Certification bodies such as Germanischer Lloyd require in their Rules. In general in the current issue, for example, the load cases which GL prescribes are different than IEC requires: some additional cases, and some omitted as apparently not being relevant after further study. Component requirements are described with more specificity in the certification guidance documents (GL and DNV).

The speed with which documents are being developed means that the current requirements of the codes and certification documents may be applied somewhat differently than in the literature which may not always reflect current practice which itself is acknowledged to be bespoke for each project. Additionally the reliance on European underlying codes in most instances makes application difficult on the US OCS.

Several European countries have appointed one authority to coordinate the permitting process. The IEC standards have been harmonized to the extent that one code covers the many countries installing offshore wind farms. The European approach is based on the method of analyzing limit states according to ISO 2394. Structural codes used mostly in offshore structures in the United States have been in working stress design, not in limit state design.

Countries in the EU have received a lot of advancement of technology in the wind power business from research funding and joint industry projects focused on cost-effective exploitation of the offshore wind energy resource, over many years. This has provided methods of analyzing wind farms, developing wind turbine loads, and provided funds for developing certification documentation methods for those participating. The country representatives are familiar with the codes and they are used for guidance of the approval process.

Germany has its own requirements, and the guidance set forth is useful. Their system appears to be based on appointing their own qualified inspectors or contract inspectors to make appropriate reviews, and has its similarities with the CVA process as applied by the MMS to offshore oil and gas platforms.

For country-based approvals the most prominent requirements involve:

- Country based codes
    - Design of Offshore Wind Turbines Bundesamt Fur Seeschifffahrt uhd Hydrographie (BSH), December 27, 2007;
    - Ground Investigations for Offshore Wind Farms, Bundesamt Fur Seeschifffahrt uhd Hydrographie (BSH), February 25, 2008;

    - Denmark: Executive Order on the Technical Certification Scheme for the Design, Manufacture, Installation, Maintenance, and Service of Wind Turbines (Ref: Danish Executive Order 651 of 26 June 2008 : www.wt-certification.dk/Common/Order%20%20651%20af%2026%20%20juni%202008%20eng.pdf).

- Class Society (Certification) codes
    - Germanischer Lloyd Guideline for the Certification of Offshore Wind Turbines 2005 which is very comprehensive covering all technical aspects not just the Turbine, and has developed in conjunction with the German insurance companies and Vertrauen durch Sicherheit (VdS). VdS Loss Prevention is a member of the General Association of German Insurers (GDV), with a tests laboratory and involved with certification in fire protection, security, as well as training and information.

    - DNV have certification documents on Design of Offshore Wind Turbine Structures, Design and Manufacture of Wind Turbine Blades Offshore and Onshore, and Offshore Transformer Substations and cite a number of their other standards for offshore within their documents.

The approval of the offshore wind farms by government appears to be set by the government and involves a mixture of their own Country requirements, the IEC Code guidance and both Type and Project Certifications by bodies which are accredited to a common European requirement.

The accreditation process involves a "multilateral agreement" for accreditations bodies which have developed requirements to confirm satisfactory processes for both quality and technical requirements of companies that apply for accreditation. DNV for example is accredited to do Type Certification and Project Certification by the Dutch Accreditation Council (RvA): www.rva.nl/home. The RvA are members of both the European Co-operation for Accreditation (EA), and a signatory to the International Accreditation Forum (IAF), which assures that accredited bodies are competent to carry out the work they undertake and ILAC (International Laboratory Accreditation Cooperation), an accreditation organization for laboratories. Both ANSI and the American Association for Laboratory Accreditation, where the National Renewable Energy Laboratory has its accreditation) are members of ILAC. Germanischer Lloyd has its accreditation through DAP (Deutsches Akkreditierungssystem Prűffwesen) according to DIN EN 45011.

Currently there is no such planned use of accredited bodies in the US for offshore wind certification on the OCS. The CVA qualification for offshore oil and gas has been less formal, but is believed to provide the same results: however, the complexity of materials, quality control and detailed competence in many disciplines required by the verifier of the structure of an offshore wind farm may require a much more robust system of ensuring competence of the CVA than has been necessary for the offshore oil and gas industry. The historical basis for CVA competence in the offshore oil and gas sector was a Professional Engineer qualification (P.E.) in the appropriate discipline: this has been dropped from the most recent regulations, but is incorporated into 30 CFR 285.706 for the offshore wind structures.

Another issue which is not the direct subject of this Report is the challenge of providing qualified, competent, and trained personnel to service this industry from domestic sources. It is an area worthy of attention. Europe has invested considerable funds both in terms of research and private company capital in the knowledge base to understand the issues and developed appropriate training courses. A most important factor in developing a safe working environment is dissemination of knowledge of the issues, and the historical record of incidents accidents and near misses. It is an important cornerstone of building a suitable industry.

1.2.1 Denmark

Danish Technical Approval of Offshore Wind Turbines used standard DS472 Recommendations for Technical Approval of Offshore Wind Turbines, Danish Energy Agency Approval Scheme for Wind Turbines 2001: a short description of the recommendations is given here:

- Wind turbines to be erected offshore Denmark have to fulfill the DS472 and other norms and regulations stated in the technical criteria:
    - For the analysis of wave loading, DS449 (Piled offshore structures);
    - For ice loading API RP 2N Recommended Practice for Planning, Designing, and Constructing Structures and Pipelines for Arctic Conditions is applied;
- Further Danish national construction norms (DS409, DS415) to be considered are named;
- Loads and load cases are based on DS472 and extended for offshore climate is stated. Recommendations on the combination of wind, wave, ice and current loading and the extraction of design loads from them are included;
- For foundations, reference is made to DS415 (Foundation) and DS 449 (Piled offshore structures);

In the late 1970s, the Risø National Laboratory was asked to draft a set of type approval norms for wind turbines installed with public investment grants. In practical terms this meant that wind turbines not approved under Risø's norms could not be installed. Today the 'approval market' has been liberalized and other test laboratories may obtain authorization to issue type approvals and perform the necessary tests in connection therewith.

Bodies authorized to provide services under the Danish scheme for certification and type approval for wind turbines:

Company acting as body	Type approval of wind turbines	Project approval of wind turbines	Type Testing			Type Characteristic Measurements		Quality system evaluation
			Power curve measurement	Load measurement	Blade tests	Acoustic noise measurements	Power quality tests	
DNV Wind Turbine Certification	X	X						
Germanischer Lloyd WindEnergie	X	X						
TÜV Nord Cert	X	X						X
Vestas		X						
Siemens		X						
Dewi-OCC Offshore and Certification Centre	X							
Ing.-Büro Frey			X	X				
TEM Risø			X	X			X	
BTC Sparkær					X			
Tripod			X	X				
Wind-consult			X			X		
WINDTEST Kaiser-Wilhelm-Koog			X	X		X	X	
Laboratorier godkendt af Miljøstyrelsen						X		
Bureau Veritas								X
Germanischer Lloyd Certification								X
Det Norske Veritas Aalborg								X

[Ref. Danish Energy Authority, Registered Bodies for the Danish Wind Turbine Certification Scheme].

It is of note that a variety of organizations are accepted for various certifications that are required.

The scheme for type approvals defines three approval classes: A, B and C.

- To obtain an **A-Type approval** there must exist a production certificate and an installation certificate. Loads and strength/service life must be documented for all load-carrying components. Outstanding items are not allowed. It is limited to 5 years duration.
- To obtain a **B-type approval,** production and installation certificates are required. The safety requirements are the same as for an A-type approval, but items judged to

have no essential influence on primary safety may be listed as outstanding items to be documented after the approval is issued. It is limited in duration as specified by the certifying body.

- **C-type approvals** are used for test and demonstration wind turbines in connection with the development of a new wind turbine type.

Because of the regulatory program, it was impossible to install or sell low-quality and potentially dangerous products. Thus the worst kinds of teething problems were eliminated, and this was very positive not only to wind turbine owners, but also to Danish wind turbine manufacturers.

The regulatory scheme in Denmark was probably the basis for the development of IEC 61400-22, Conformity Testing and Certification of Wind Turbines". IEC 61400-22 specifically states in paragraph 5.2 *"Operating bodies shall be accredited by a national or international accreditation body that has been internationally evaluated. This requirement is intended to facilitate recognition arrangements on an international level of certificates and test results and to increase public confidence in the competence and impartiality of the operating bodies."* It further goes on in paragraph 5.4 to establish a requirement for the establishment of an *"advisory committee"*. This committee is supposed to establish, among other things, by-laws on harmonization of requirements and mutual recognition of certificates. Part of the goal of the IEC Standards was to facilitate equipment crossing borders instead of having to be certified for each country.
.
Denmark has moved to the IEC document but with specific country supplements (part list only):

- *"Three categories of type approval (A, B, and C)*
- *Danish external conditions*
- *Aerodynamic acting braking system*
- *Blade reflection should be specified according to DS/ISO 2813*
- *CD Marking*
- *Foundation design Evaluation*
- *User manual in Danish*
- *Installation Manual in Danish."* [Ref.1.6]

"After July 1 2008 all turbines in Denmark have to be service by a certified or approved service company according to the specification set by the manufacture….

Owners must report to the Energinet.dk each time a regular service has been carried out and the time for the next. Spot checks will be carried out. " [Ref.1.7].

Note: there are no IEC standards available for the design assessment of the machinery components and the support structure. Certification Standards such as GL and DNV for wind turbines can be used for that purpose. A definition of the extent of subjects covered under Project Certification which may incorporate Type and Component certifications is required for every project.

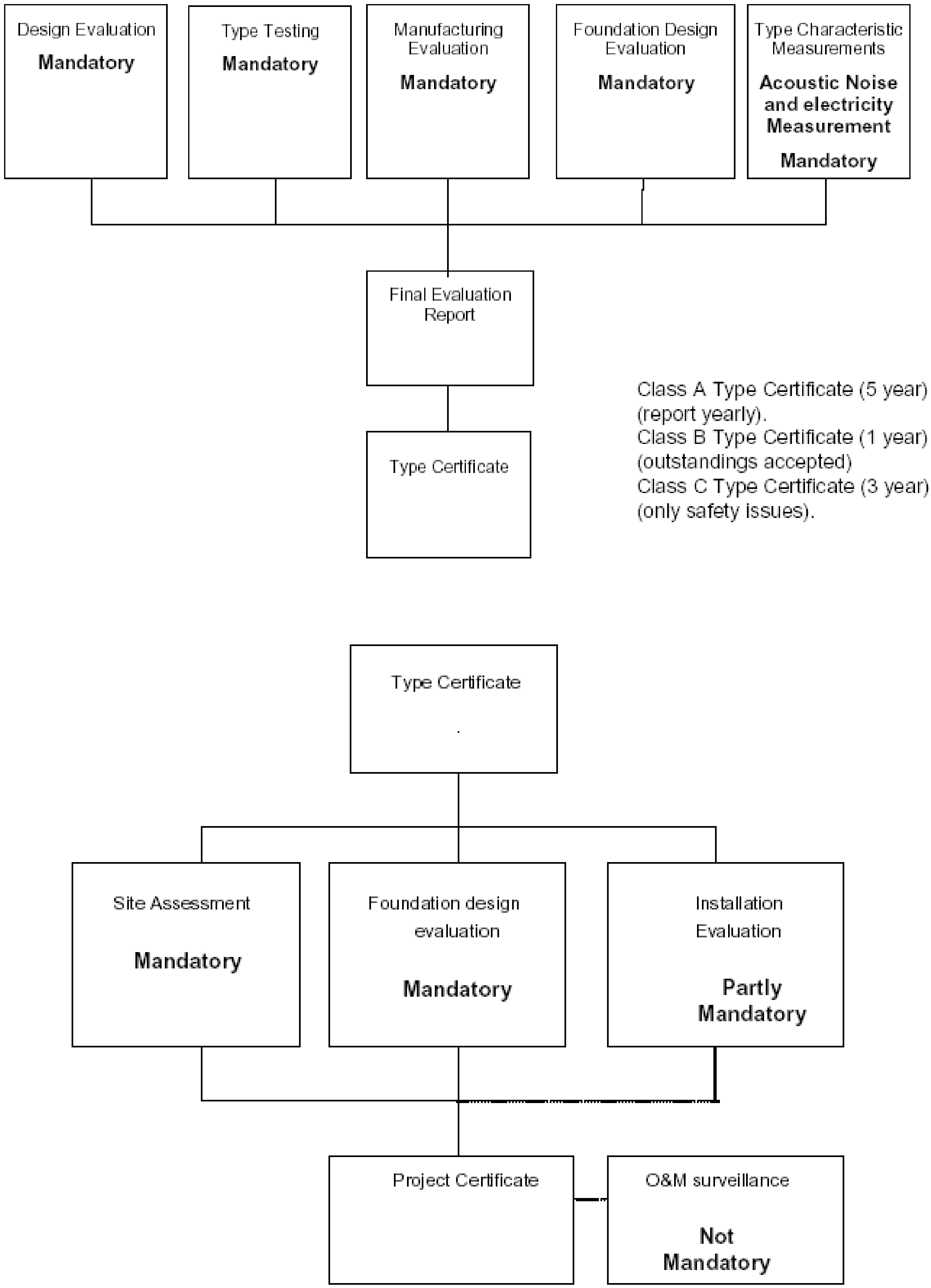

Figure 5: Danish Energy Agency approval scheme [Ref.1.8]

1.2.2 Germany

Germany has developed country standards and they are very specific in their requirements administered by Bundesamt Fur Seeschifffahrt uhd Hydrographie, The Federal Maritime and Hydrographic Agency (BSH). The standards that govern approval in Germany are:

- Design of Offshore Wind Turbines Bundesamt Fur Seeschifffahrt uhd Hydrographie (BSH), December 27, 2007 which includes specific requirements including color of paint being *"a low-reflectivity light grey, not withstanding regulations on aviation and shipping identification."* [Ref. 1.2].

- Ground Investigations for Offshore Wind Farms, Bundesamt Fur Seeschifffahrt uhd Hydrographie (BSH), February 25, 2008 which includes not only requirements for the turbine tower but also requirements for cable burial assessment [Ref. 1.3].

The BSH requirements include:

- Safety in the Construction phase;
- A state-of-the-art geotechnical study;
- Use state-of –the-art methods in the construction of wind turbine, prior to start up;
- Presentation of the safety concept;
- Installation of lights radar and the automatic identification system (AIS) on the turbines;
- Use of environmentally compatible materials and non-glare paint;
- Foundation design minimizing collision impact;
- Noise reduction during turbine construction and low-noise operation;
- Presentation of a bank guarantee covering the cost of decommissioning [Ref.1.9].

The approach of BSH is to not limit the loading conditions to those in the IEC Code but *"The extreme loads shall include all events that can lead to the greatest possible loads, given consideration for the probability of simultaneous occurrence (e.g. "50-year gust", "50-year wave", extreme angle of approach of the rotor, collision with ship (service ship), ice pressure, etc., "*

BSH refers to the IEC 61400-3 and other standards for loading conditions but in addition there is a requirement to perform a Quantitative Risk Analysis in the process of developing the design conditions. This, as documented, is a rigorous requirement developing ratings for Offshore Wind Turbine Collision, Environment and Safety. There is, however, no mention in the document of Societal/Reputation risk for Renewables or of Economic risk. Protection of the issues with shipping is dealt with in a way that is somewhat unusual indicating their agency is not primarily concerned with wind turbine economic risk:

"In connection with a risk analysis, it should be demonstrated that there will be no major environmental pollution incidents because a) either the entire collision energy can be absorbed by the ship and the offshore wind farm structure, or b) the offshore wind farm fails during the collision procedure without ripping open the ship's hull."

They note in terms of the structure design: *"in the event of collision with a ship, the hull of the ship shall be damaged as little as possible."*

Additionally instead of repeating the calculations independently the approach is that *"the certifier/registered inspector checks the plausibility of the loading assumptions and the results based on exemplary calculations. The comparison between parallel calculations and those in the presented load calculations forms a basis for the decision on whether to accept the loading assumptions and to issue the test report of the loading assumptions"*.

Referring to specific Technical Codes of Practice that are acceptable there are listed a number of specific codes which includes the IEC Codes and API RP2A, as well as the GL and DNV various Guidelines. Structural design codes listed are DIN standards. BSH specifically site standards on specific issues e.g.

- Fatigue Strength – DASt publication 439 "CEB-FIP Model Code 1990", Berlin 1994.
- Solid Structures - DNV-OS-C502 – Offshore Concrete Structures
- Grouted Connections – Structural Design of Grouted Connection in Offshore Steel Monopile Foundations (Global Windpower 2004), and GL Guideline 6-5.4.4 "Grouted Connections Finite Element Method".
- Finite Elements – GL Guideline Chapter 5 "Strength Analysis"

In regard to inspection: *"BSH is continuously involved in the inspection process…."* threatening *"construction and/or operating permits may be suspended if information and certificates are not presented in accordance with the regulations…"*

Plans and components are not only checked by BSH but also by the certifier/registered inspectors. It appears that there is a reliance on Type Certification which is specified in some detail as to the components of the Type Certification, and upon Project Certification, again specifying the components but leaving opportunity to have BSH review and approve the information directly, using observations and recommendations of their registered inspectors. *"Registered inspectors shall be accredited by the BSH on a case-by-case basis"*.

BSH has a list of specific tests required in order to produce Component/Type Certificates. For site-specific conditions the Type Certification is validated against a prescribed list of requirements of the site including design, production review, the quality management system of the manufacturer and prototype measurements. The task of the certifier/registered inspector is to check *"the completeness of the reports and evaluates the plausibility of the data"*.

The requirements for the regular inspection/certification are quite extensive and the frequency and depth of checking is left to the inspector/certifier but as an illustration:

> *"Concrete construction*
> - *Checking the concrete delivery notes*
> - *Checking the strength samples (sample cubes)*
> - *Checking the external inspection reports according to DIN 1045-3*
> - *Checking the reinforcement*
> - *Checking the concrete cover*
> - *Checking the dimensions of the structure*
> - *Checking the prefabricated components*
> - *Checking other quality records"*

1.2.3 The Netherlands

The Dutch national body for wind turbine certification is CIWI Holland, a foundation established jointly by ECN and KEMA in 1991. Within CIWI, ECN carried out the technical design assessment and the type testing, whereas KEMA was responsible for the assessment of the quality system employed by the manufacturer.

The whole procedure of certification is supervised by a so-called certification supervisory committee, consisting of representatives from the manufacturing industry, the users, the utilities and government.

In The Netherlands, wind turbine standardization is handled by the Committee NEC88. This is a sub-committee of the Dutch National Electrotechnical Committee NEC. Within this committee the development of a national wind turbine standard went on for several years, until 1990, when a full set of Technical Criteria for certification was developed by ECN. The NEC88 committee decided to adopt these criteria as preliminary draft national standard (NEN 6096/2), until international wind turbine standards would come available.

Dutch Standard NVN 11400-0 applies. The technical basis for approval is given by the technical standard NVN 11400-0, however, this has been harmonized with the IEC Code to a large extent. Certification bodies accredited by Raad voor de Accreditatie (RvA) are allowed to carry out the type approval. Safety inspections as well as technical type approval of the design and testing is required. The manufacturers are required to have ISO 9001 certification. NEN 6096/2 supplements the IEC requirements on personal safety and prototype testing of the wind turbine. Load assumptions follow the IEC Guideline.

1.4 IEC Code 61400-22 Certification.

Eric Hau [Ref. 3.4.2] in his book on Wind Turbines makes some interesting remarks about Certification:

"Wind manufacturers are primarily interested in the verification of load assumptions in order to be able to guarantee the stability and reliability of their products. The operator

is interested in obtaining independent information on whether the product is congruent with his concept of operational safety, performance and operating life. These various interests do by no means focus on the same points and must therefore be harmonized.

The most important European organisations dealing with the certification of wind turbines are:

- *Germanischer Lloyd (GL), Germany*
- *Det Norske Veritas, International*
- *Netherlands Energy Research Foundation (ECN), the Netherlands*
- *Risø National Laboratory, Denmark*

Apart from the certificates for they type approval and the power characteristics, other certifications are being offered for numerous other areas such as:

- *Quality of the power output,*
- *Electrical characteristics and grid compatibility*
- *Production*
- *Quality assurance*
- *Test methods, et al.*

At this point, some critical remarks with regard to the examination and certification of wind turbines are appropriate……In central areas, particularly relating to safety (public interest) and to performance (buyer's interest), independent and neutral certificates are indispensable.

On the other hand, certification has now developed into a "business". The certification companies are often profit-oriented commercial companies which offer their services in a competitive market and, therefore, attempt to extend their products to all types of areas in which it is more doubtful whether a "certificate" for, e.g. "production" or "transport" has any objective use. The situation has not been improved by the circumstance that the organizations have for some year been advertising so-called "accreditation certificates" which, in turn, are issued by private commercial organizations.

As ever, the decisive criterion for the quality of a product is the technical competence and financial capacity of its manufacturer. It is the manufacturer exclusively who has a position to lose in the market and who bears responsibility for his warranty. If something goes wrong, it is the manufacturer and his customer who are the financial losers, and never the certification companies. However high-sounding a certificate is it will never replace confidence in the manufacturer and his product."

It should be noted, however, that while the warranty is an important part of developing confidence, at the expiry of the warranty, the owner becomes responsible and should be very knowledgeable about the design basis, assumptions made particularly those for structural integrity.

It is of note that in Europe the national research laboratories are involved in a certification process to some extent which is unlikely to be the case in the US for items like blade tests e.g. Netherlands Energy Research Foundation (ECN), Risø National Laboratory, Denmark. In the US items like blade tests are likely to be carried out by the National Renewable Energy Lab (NREL), but certified by DNV, GL, LR, ABS or the appointed CVA.

1.4.1 Introduction

The stated purpose of those crafting the 61400-22 document is given:

> *"The purpose of the rules and procedures is to provide a common basis for certification of wind turbines and wind turbine projects, including a basis for acceptance of operating bodies (i.e. certification bodies, inspection bodies and testing laboratories) and mutual recognition of certificates."*

One reason may be that it facilitates working across country lines and country regulatory regimes. Another may be to give a common meaning to certification services being offered and so that the consumer understands the basis of the certification.

Certification is not the type of subject that consumers curl up in front of a fire with a good book and read: this lack of meticulous study leads to a lot of confusion in the Certification world about what a particular Certificate means. Operators often realize they have to have a piece of paper with the logo of the Certification body on it, and there is often confusion as to whether the Certificate in fact endorses the owner's intent. As a simple example, the author has been presented with a Certificate for a safety critical valve, which was presented as approval for design review, material checks, supervised fabrication, testing and classification society approval: the Certificate itself stated that the class Surveyor had merely witnessed a test being carried out on the valve: and that was the total sum of the attestation on the Certificate – none of the other points had been covered!

We offer the following as a simplified example to help explain:

> A "Certificate" in our context is a representation that an independent party has done something and the documentation, the certificate, is "evidence" of this.

Certification is the process used to carry out the actions that lead to a Certificate.
…so you need to know what the Certificate is stating that was done and something about the process that led to the organization issuing the Certificate in order to ensure a full understanding of the value of the Certificate.

Example:
The XYZ organization decides to set up as a Certification Bureau. They will plan on certifying red products that are manufactured and painted red. They will issue Certificates that say the product is red. Those buying the thusly certified product may presume because the organization is called the "XYZ Certification Bureau" that more is implied by their Certificate than it is painted red or made of red material, even though all the documentation states the facts.

The XYZ organization then further decides to issue Type Certificates to manufacturers of red products so they can show their clients that the product they are acquiring is indeed red, (and not reddish brown). The XYZ organization goes to the manufacturer's location, goes through their quality system to ensure that the formulation of the material or the surface coating comes out red, and that the quality control organization of the manufacturer never lets a product leave the factory unless it is red. The Certifier selected by the XYZ organization attends at the factory, watches one product be built, and it turns out red. The Certifier tests the redness of the color and issues the Type Certificate, saying he'll be back in 6 months or 1 year to see if they are still churning out the appropriate redness with their products. The vendor selling a product to a consumer may then state that the product is certified by the XYZ Certification Bureau. This may become misleading if the consumer is not aware of what the certification means. Simplistic though this is it sets the scene for the process to be discussed below: which is more complex.

1.4.2 Certification Industry Practice on Land or in Europe Offshore

The extent to which Certification has been carried out in the land wind farm industry is not part of this study and from initial enquiry could not easily be ascertained. From the various documents that have come to our attention some of them, at least, and been Certification schemes derived for the project itself in agreement with Regulators, Owners, Insurers and Financiers as to what was required for the specific project, and when it was required e.g. Type Certification whether the "optional modules" were included and whether deviations were allowed for compulsory modules.

Certification may have been useful in preventing more and larger issues, but there have been many serial issues in wind turbines that suggest a need for suitable scrutiny of what has been agreed in the certification process. In many instances the risks of manufacturing issues have been retained by the manufacturer in the warranties offered to sell the product: in some cases up to 5 or more years. While the manufacturer is most at risk, the regulator has a responsibility to ensure that the lifetime safety risk of the facility is considered. The owner has to cope with the situation after the warranty expires and so should also have an interest in ensuring a robust mechanism to last the full lifetime of the product.

1.4.3 Type Certification

Type Certification as it is practiced generally has the possibility of including several steps:

1. Type Certification of the design – the person wishing to obtain Type Certification, normally a manufacturer will submit drawings, datasheets, calculations and test results, to verify compliance with **stated standards**. Note the **standard** is the underlying basis for the approval. Unless you know what the standard says, you cannot know what the product approval means. The usual standard for wind farms

is the IEC Code, however, one must keep in mind that the IEC standard is written often in an advisory mode rather than a "must do" a specific thing in a specific way e.g. lightning protection. Fire protection is not mentioned in the IEC Code. Many US Standards are written more prescriptively. For example the IEC Code determines what the loading is on a wind turbine structure but does not determine what the resistance must be in terms of defining the resistance factors. Thus Type Certification to the IEC Code requires some scrutiny of the details of how the Certification body interpreted the IEC Code paragraphs in order to be sure of the extent of the approval. If the Certification body is approving to the Manufacturer's standard it requires you know what that Manufacturer's standard says in order to understand the extent of the approval.

2. Type Certification may stop at only the design review or it may go onto Prototype Testing for conformance with the standard, and Manufacturing Surveillance to ensure the product can be produced in a consistent way over a period of time.

3. Once the product goes into production a Certification Test may be carried out to ensure the product performs much like the Prototype Test (provided the documentation says so).

4. Production surveillance will be conducted on a periodic basis usually annually and the extent of surveillance may or may not be noted. The diligence with which this is to be performed also requires scrutiny to ensure the surveillance reflects the understanding of the stakeholders.

5. It is important that the Certification body provide a suitably qualified inspector/surveyor with in-depth experience of the product being produced. This may turn out to be a major task depending on the locations of global manufacture of the components and the limited number of experienced inspectors/surveyors.

Type Certification only applies to the specific product/model covered in the design review and no variations allowed (within reason, which itself is open to a judgment call). A change in the product invalidates the Type Certification. If a change is made and inadvertently not disclosed to the Certifier the change may have had an impact on acceptability that may not be recognized until the annual or periodic survey or possibly until after failure.

There is much reliance put on the manufacturer of a product being ISO Certified when a manufacturer is getting a Type Certification. While the ISO Certificate may be a useful benchmark, it merely confirms the manufacturer is "doing what he says he's doing": and the requirements stated in the documentation may not be sufficient to ensure the appropriate reliability of the offshore wind farm structure.

While it has not been possible to ascertain whether the manufacturer of the piles was ISO certified, the piles for Greater Gabbard presented some significant problems on arrival in

UK from China and a significant number of personnel (65 was reported) were brought in by the manufacturer in order to satisfy the warranty claims with re-working the welding.

Considering Type Certification of blades, a number of questions come up after failure such as:

- How close in quality was the prototype blade to the production blade i.e. did the production blades have the same quality?

- Was only 1 test done on the first production blade and did the process for manufacture change as the production line manufactured more blades?

When prototype tests are carried out, some Certifiers require the tests be carried out in a specified way by a specified laboratory. Germanischer Lloyd, for example, requires many of the laboratory tests for Type Certification be at a facility approved by them. It is not yet clear what laboratories will be acceptable for tests carried out for use on the US OCS. Several of the blade test facilities are privately owned.

The purpose of Type Certification (Approval) when Type Certified to the IEC Standards under 61400-22 is somewhat more comprehensive than can be specified by classification societies: however the consumer needs assurance that it the Type Certification is in fact to this standard and not just Type Certified to an alternate set of requirements:

"The purpose of type certification is to confirm that the wind turbine type is designed, documented and manufactured in conformity with design assumptions, specific standards and other technical requirements. Demonstration that it is possible to install, operate and maintain the turbines in accordance with the design documentation is required. Type certification applies to a series of wind turbines of common design and manufacture. It consists of the mandatory modules:

design basis evaluation;
- *wind turbine design evaluation;*
- *type testing;*
- *manufacturing evaluation; and*
- *final evaluation;*

and the **optional** *modules:*
- *foundation design evaluation;*
- *foundation manufacturing evaluation; and*
- *type characteristic measurements.*

A Type Certificate is issued for a wind turbine designed and evaluated for conformance with the technical requirements of this specification and IEC 61400-1, IEC 61400-2 or IEC 614003, on the basis of the completeness and correctness of a Final Evaluation Report.

A Type Certificate documents conformity for all the mandatory modules and may additionally document conformity for optional modules."

The caution above is that if there were "options" as to the assumptions in and deviations from the IEC Code then it is necessary to know what options were taken e.g. the blade could be type certified considering IEC 61400-24 on Lightning Protection, and the option that the manufacturer might have taken was not to have lightning protection; or e.g. the assumption about the amount of yaw that can be accepted in the load cases is a function of whether one assumes power is present to make the yaw system function in the extreme storm: the IEC advice is for a 6 hr battery life in case of power failure but unless a specific enquiry is made the assumption made by the designer as to whether the power failure at site would last longer than 6 hrs the ability to resist extreme weather at $\pm 180^{O}$ yaw is simply not known and not slated for noting in the Type Certificate.

Whether the product is suitable for your site is irrelevant to the Type Certification process i.e. a manufacturer could receive Type Certification for a Blade that would shatter in arctic temperatures but was appropriate for temperate climates……leading to the issue of Project Certification.

Type Certification for offshore wind turbines is better defined by the GL and DNV standards, as to what they recommend, however by agreement these requirements may have been changed for a particular contract or agreement.

1.4.4 Project Certification

Type Certified products which are components of the project process are only one of the aspects of Project Certification. It is not necessary to have a Type Certified product to obtain project certification but it helps and speeds the process if the product has already been type approved.

When a specific site is chosen, the technical staff which carried out the Type Certification or the equivalent would then verify that the product, as already approved, is suitable for the intended use. This can be done with a simple review of the Type Certification original documentation and not require submittal of further information from the manufacturer, or if the location is significantly different than intended in the Design Basis, further examination is required. This requires that all assumptions of the Type Certification are disclosed.

A thorny point may come up if the product is Type Certified by one Certifier and another Certifier has been appointed to carry out the Project Certification. The trust between Certifiers is not always harmonious in the marine/shipping business and getting documentation of the original Type Certification to another Certifier is sometimes not an easy thing unless this is set up formally (which appears to be the intent of 61400-22 which sets up a country accreditation body and proposes a Joint Advisory Committee: there is no such body set up in the United States).

In order to evaluate whether the Type Certified product is suitable for the site the wind, wave, weather, current, temperature and other metocean conditions, and soil conditions must be known, evaluated, and compared to those defined in the design documentation for the specific wind turbine type and foundations. Additionally instead of just relying upon a review of the tests that were done to get Type Certification, the Project Certification requires surveillance of the manufacturing process. Surveillance means going to the manufacturer's site and reviewing the documentation and manufacturing as you would for Type Certification but related specifically to the products intended to go to the specific project site. The extent of surveillance is stipulated as being agreed upon for a project. Clearly it would be prohibitively expensive to have an independent body attend at manufacture of each sub-component, but if the sub-component is safety critical, there must be found a methodology to assure appropriate quality and conformance to specification. Project Certification as described by the IEC 61400-22 also encompasses the following activities:

- support structure manufacturing surveillance;
- transportation and installation surveillance;
- commissioning surveillance;
- operation and maintenance surveillance.

The extent of surveillance is not noted except by agreement although GL offers two frequencies of surveillance. The amount of attendance may vary depending on the "trust" between the manufacturer and the certifier: but it is also important to do surveillance of the manufacturer's subcontractor to ensure their standards are being met. How the "trust" is measured and by whom is not clear in the documentation. Since surveillance is a large cost item, competing certifiers may use reduced surveillance as a bidding strategy.

Project Certification rather implies that the Certifier has checked out that system is suitable, had been manufactured, transported, installed, commissioned and is being operated appropriately for the conditions at site. It is taking on a lot of "responsibility" that it is not yet clear that the customary Certifiers i.e. Classification Societies will be willing to take on in the USA to the extent that the IEC specifies in the US. The normal route for a similar service is known in the marine industry as Classification, whereby the Class Society develops its own requirements and confirming that it meets **what they interpret as their standards** which may include deviations from their standard. This offers some legal protection since the standards are self-interpreted.

Other Certifications:

Two other Certifications are available in the IEC Code:

- Component Certification

  The component certification *"is to confirm that a major component of a specific type is designed, documented and manufactured in conformity with design assumptions, specific standards and other technical requirements."*

- Prototype Certification

  The prototype certification is *"to enable testing of a new wind turbine type in order to obtain type certification in accordance with this specification", "issued for a wind turbine that is not yet ready for series manufacture, at a specific site and for a limited period of maximum 3 years"* primarily to ensure safe operations.

While there are some "bumps in the road", effectively the advocated position in 61400-22 is that type and project certification is accepted as testifying to "fit-for-purpose". This has not been the customary position in marine ships: which has always relied upon a classification process as being more robust rather than relying on type approval to make up mandatory systems in the classification process. Nonetheless, if applied robustly the system that has grown up in the wind farm business of Type Certification and Project Certification can be configured appropriately to provide a suitable overall approval scheme for regulatory purposes.

The certification documentation seems to be worded in a way which may be problematic. Certifying a system for 20 years may be an issue when the history of component failures is much shorter than that. Certifying the readability of manuals by technicians would not be a task easy to carry out in the USA because of the potential for "interpretation" of what is readable in the US and potential legal issues for the certifier.

One issue is that IEC Code may not be sufficiently prescriptive for application in the USA. The stamp "type certification" to IEC alone would be insufficient without a further level of specificity. In order to cope with this situation GL and DNV have developed their Certification Guidelines. The GL Guidelines appear to spell out precisely what it to be done to gain certification in one clear document down to the amount of surveillance which has often been a point of issue in the marine business. DNV Guidance relies upon some specific documents for the offshore wind industry and also their suite of offshore and marine standards.

Variations from the IEC Code will undoubtedly be required since the code references European Directives, European Standards for welding, safety of structure, foundations etc. Without deviations approved by a standards body it is unlikely that the IEC Code alone will be sufficient. Deciding the equivalencies of the underlying standards is a sizeable task. This will drive the certification process toward Certifiers' own codes e.g.:

- Germanischer Lloyd Guideline for the Certification of Condition Monitoring Systems for Wind Turbines 2005.
- DNV Offshore Standards Design of Offshore Wind Turbine Structures, Design of Wind Turbines Blades, Gearboxes, and Offshore Substations.

…..and others that will appear over time. These too are fraught with issues over references to European standards and also over approved laboratories to carry out some of the testing required.

1.4.5 Acceptance of Operating Bodies

The question may be asked who selects and certifies the Certifiers?

In ships, Class Societies are virtually a requirement for doing business, and they are a mandated requirement by the International Maritime Organization when trading internationally. These Certifiers are accredited through the International Association of Classification Societies, which in turn relies upon the ISO process to assess the Class Societies. In the US fixed platform world the class societies often perform the CVA function when structures require certification, which is only specific classes of structure i.e. those for deepwater, and floating structures.

The IEC notion of this is that for each country, there will be a body that accredits the Certifiers and checks the competence of the body to do certain technical work. No accreditation body has been appointed in the United States for this function in wind turbines (although laboratory accreditation appears to be used in the USA).

> *"Accreditation: procedure by which an authoritative body gives formal recognition that a body is impartial and technically competent to carry out specific tasks such as certification, tests, specific types of tests etc."*

> *"Operating bodies shall be accredited by a national or international accreditation body that has been internationally evaluated."*

Accreditation from the IEC Code appears to have a number of features:

> *"Operating bodies shall be capable and competent to operate their elements of the wind turbine certification – "*

So the first question is who can be an operating body?…first it needs to be someone who knows about wind turbine certification – i.e. knows about blades and how to tell a good one from a bad one, design, fabrication, installation etc., rotors, foundations –whatever is being certified. A National Laboratory that carried out the tests? A classification society? A Certifier such as SGS? or as carried out traditionally by MMS a registered Professional Engineer with the right discipline that can demonstrate knowledge of the subject being Certified or Verified (30 CFR 285.706).

IEC notes that a recognition arrangement should be made such that one Certifier will recognize another one's work, which we believe is not an easily workable arrangement in the US (noted in 5.3).

> *"Operating bodies shall seek to obtain, preferably multilateral, recognition arrangements for the acceptance of each others work, e.g. test results or quality system certificates."*

There is a legal position that makes this difficult in the United States, and a technical position because precisely what the other operating body checked may be uncertain.

There have been many difficulties in making such a system work in the marine business, so it may be unlikely this is workable in the US with offshore wind farms business.

> *"Certification Bodies operating type and project certification according to this specification shall seek to establish and participate in a joint Advisory Committee. The committee should establish by-laws and provide advice to the operating bodies on"*

Another notion in the same vein is the idea of a joint "Advisory Committee", which does not exist in the United States and is unlikely to find a home in any of the Government agencies (noted in 5.4).

While this accreditation scheme appears to work in Europe, it seems unlikely that such an arrangement will happen in the USA. While this may be a theoretically good goal, recognition of certification organizations in the ship classification business has been problematic: relying upon other certifiers has legal issues in the USA; precisely what was checked and how thoroughly is often an issue; and in a competitive marketplace accepting a competitor's certificate, the basis of which is probably not disclosed for confidentiality reasons just doesn't seem workable for the organization taking on the responsibility to rely upon another's work.

Without the acceptance body, there is no definition of the requirements to be a Certifier and the qualifications of the individual personnel who do the surveillance. There is no requirement in the check of technical procedures in the ISO certification process for a company. If the technical check on a wind farm in a company's technical requirements was that they checked it was painted green, and all of those they certified were painted green – that would be sufficient. "We say what we do and we do what we say" is the ISO Company certification process.

It seems likely, in our view, that the current method of acceptance of the certifier by the MMS CVA process is likely to prevail and a process similar to that used in Germany results. It may be that the project certifier and the CVA are the same entity, although less conflict of interest may result from the CVA and project certifier being different entities.

1.4.6 Extension of the Certificates.

Certificates are extended based on reports, audits (a.k.a. surveys or surveillance), and certain documentation as laid out in the IEC Code 61400-22 Part 6.5. This reflects the same type of system that is prominent in maintaining a Classification certificate for a ship. The issue in the future as to how much one can rely upon condition monitoring methods to continue approval, and how much direct eyes on surveys may be required to continue extending the Certificates, is still an open question.

1.4.7 Observations on the Certification Requirements of the IEC Code

One issue with the IEC Code is that it does not completely define the requirements for aspects of the certification concerning materials, structures, machinery and electrical components and these are only covered in brief form. For this IEC 61400-3 states:

> *"When determining the structural integrity of elements of a wind turbine, national or international design codes for the relevant material may be employed. Special care shall be taken when partial safety factors from national or international design codes are used together with partial safety factors from this standard. It shall be ensured that the resulting safety level is not less than the intended safety level in this standard".*

There is no selected nationally accepted code for offshore wind farms and thus the application of this requirement cannot be directly applied from the IEC Code. The intended safety level is implied based on the return period selected for design checks and the load factor but not specifically stated as a reliability factor.

A number of the Technical Requirements of Certification appear to be difficult to carry out and the actions required do not themselves appear to be well specified though the spirit of the intent is strong in the document IEC 61400-22 as written. Several areas are pointed out on the issues of Certification to highlight the definition problems with the Code for a Certifier.

1.4.7.1 Load Cases (IEC 61400-22 8.3.3)

*"the Certification body shall evaluate the loads and load cases for compliance.....**by independent analysis**."*

This appears to be a costly option and focuses on calculation error rather than errors of assumptions which are often the causes of failures. While there is a need for the Certifier to be qualified to run the independent analyses the concentration on that aspect may be something that needs to be examined. German requirements refer to the "plausibility check" to assure that the numbers are judged experientially.

1.4.7.2 Control and Protection System (IEC 61400-22 8.3.2)

"The Certification Body shall evaluate the documentation of a control and protection system, comprising:

- *description of wind turbine modes of operation;*
- *design and functionality of all elements;*
- *fail-safe design of the protection system;*
- *system logic and hardware implementation;*
- *authentication of reliability of all safety critical sensors;*
- *braking system(s) analysis;*
- *condition monitoring if applicable; and*

- *a test plan for the verification of the control and protection system functions".*

Since much of the control and protection system is run by computer it requires Certification of the software system as well as the logic.

It seems that with offshore wind farms they will be large and fairly complex projects; there will be a number of systems and subsystems that have to be controlled, others that have to be monitored. The suppliers may potentially be significant in their number so each of the interfaces may have to be developed with good coordination. Some of this may be avoided if it were decided that the manufacturer's owned system was part of the package. It may be that the manufacturers verify the software since the warranty provisions that have to date been offered make not doing so a higher risk for the manufacturer: however the regulator may be prudent not to rely on the risk profile of others to determine acceptability.

In order to Certify the systems it would be necessary to review the systems, the simulations and review the network analysis, and assure that the owner/operator responsible for the software kept a log of the changes and had a system to ensure it was known what version of the software was operating at any time, and that indeed it had been tested thoroughly and the operators trained thoroughly including potential glitches. It should be clear at commissioning that there is document of the software version which is installed. A formal testing process needs to be in place at commissioning and it is necessary to define what tests should be run based on any changes to commissioned software. A change control process is important since the structural capability of the towers depends on the software working.

Code security: it should be defined who has authority to read the software and change it is another issue as well as the necessity to create notifications in case of change to the software.

The basis of ensuring the system has had a check would involve carrying out a Failure Mode and Effect Analysis on the hardware and software, among other things checking for single points of failure on the software and the hardware associated with control and monitoring. Interviews with those providing the software would be part of the process as would the operator training definitions and requirements.

Appendix E of 61400-22 does give guidance which is useful in the process of Certification on this subject.

1.4.7.3 Acoustic Noise Measurements (IEC 61400-22 8.8.3)

The acoustic noise measurements are spelled out well in the IEC Code so it would be straightforward to certify according to the IEC requirements 61400-11 for this activity.

1.4.7.4 Tower, Nacelle and Spinner

These details are not specifically covered in the IEC Guidelines except that load conditions apply to the components so one must look to DNV for Tower and GL for Tower, Nacelle and Spinner or alternative certifier requirements.

1.4.7.5 Personnel Safety (IEC 61400-22 8.3.14)

The IEC code contains a section on Personnel safety and suggests several inclusions:

- safety instructions;
- climbing facilities;
- access ways and passages;
- standing places, platforms and floors;
- hand rails and fixing points;
- lighting;
- electrical and earthing system;
- fire resistance;
- emergency stop buttons;
- provision of alternative escape routes;
- provision for emergency stay in an for offshore wind turbine for one week; and
- offshore specific safety equipment for an offshore wind turbine

There is insufficient guidance to reflect the specifics of how to consider these and to what standard.

GL state that EN 50308 Wind Turbines –Labor Safety as the document they use to Certify this aspect of Offshore Wind Farms and is quite prescriptive in many of the requirements: it is an excellent code and directly applicable to the offshore wind turbine industry. (Note: For further discussion a sections 3.5 and 4 of this Report and the Safety Management System Template directly addresses Personnel Safety).

1.4.7.6 Inspection of Personnel Safety (IEC 61400-22 (D.6))

The intent of the checks to be carried out are applaudable, however, the specifics need to be laid out for implementation e.g. *"the existing of suitable lighting shall be checked"* and *"the function of the emergency light shall be checked".* The Code, however, does not specify any details of what is suitable and whether indeed an emergency light is required though it appears to imply it.

What is clear from the above is that there was a tremendous amount of energy and effort that went into this code, but it requires a level of more detail for application with clarity of what is intended as mandatory in order that the result will be the quality of the certification process that is intended.

1.4.8 Attendance of Certifier

Since the amount of attendance of the Certifier in Surveillance activities is crucial to the approval role and to the roll of the CVA, this section quotes significantly from the various documents to add clarity to the issue and a detailed understanding.

The amount of attendance of the certifier/surveyor/inspector depends on a negotiated position i.e. *"The Certification Body will tailor the Scope of Work for Inspection Service (9.8.2)".* Since cost is often the issue with the amount of inspection this effectively determines that the least cost Certification with the least scope is likely to be high on the list for acceptance as the low bidder: and that may itself be an issue.

Several statements are troublesome in trying to turn them into action: *"the extent of inspections and audits to be carried out for a Project Certification shall be determined for each project".* The obvious question is "by who?" the manufacturer has his own quality control process and may just be interested in the Certificate; the constructor likewise is mainly interested in documentation and schedule; the owner likewise wants the system to work but has a focus on price and may be relying unduly on the warranty provisions to provide a "good feeling" of long-term reliability.

"The following items will also typically influence the detailed scope for the Inspection Service: - the manufacturer's experience with respect to delivery of the specific items for incorporation in support structures" etc. (9.9.2). It is not clear how these very subjective judgments can be applied to determine the extent of inspection conducted. For example: one of the manufacturers has had a lot of experience with blades being broken in shipment (and even with a nacelle catching fire in the port of Houston as was one case), with transport of blades by trucks etc. does this require that blades and nacelles by this manufacturer have more or less surveillance than one with no issues (being as those issues of experience may well have improved the delivery of on-going projects)?

The sections below on Germanischer Lloyd and Det Norske Veritas Certifications describe surveillance policies and should be noted in conjunction with this Section.

1.4.8.1 IEC Code 61400-22 on Surveillance

The IEC Code defines Surveillance: (3.23)

> *"continuing monitoring and verification of the status of procedures, products and services, and analysis of records in relation to referenced documents to ensure specified requirements are met".*

Maintenance of the Type Certificate (6.5.1)

> *"the Certification Body shall perform periodic surveillance with the purpose to check that the wind turbines produced correspond to the type-certified turbines and meet the required surveillance according to ISO/IEC Guide 65. The period shall in general not exceed 2 1/2 years, if the serial production has started. Such surveillance shall*

be on a recently installed wind turbine or in the workshop. The scope of the surveillance has to be significantly lower than for the inspections as they were performed as a part of the type certificate. If the applicant does not operate a quality system that is certified according to ISO 9001, the Certification Body shall verify at least once a year that manufactured wind turbines continue to be in conformance with the certified design. This verification shall follow the elements of 8.5.1 and 8.5.2".

Surveillance Requirements (9.8.2)

"The extent of inspection and audits to be carried out for Project Certification will be evaluated for each single project and Wind Turbine type.

"The Certification Body will tailor a Scope of Work for Inspection Service. This scope will include use of international standards together with input from the design evaluation. Such input from the design evaluation may be:

- *critical items/processes identified during the design evaluation;*
- *test programs/procedures for serial production;*
- *approved design documentation such as drawings and specifications; and*
- *details from prototype testing.*

"The following items will typically influence the detailed scope for the Inspection Service:

- *the manufacturer's experience with respect to delivery of the specific item to wind turbines;*
- *the Certification Body's experience with the manufacturer;*
- *time schedule and number of items for the specific delivery;*
- *number of production plants;*
- *type of manufacturing process, e.g. hand lay-up or vacuum injection of laminates, manual or automatic welding, etc.;*
- *type of quality control e.g. NDT or visual inspection, statistical methods or testing each item, etc.;*
- *appropriateness of the manufacturer's quality system in relation to the specific manufacturing process and control activities;*
- *extent of inspection by purchaser, e.g. manufacturer's inspection on case of sub-supplies;*
- *availability of certified documents specifying the quality requirements;*
- *manufacturing codes and standards applied, e.g. national or international;*
- *availability of relevant quality control documents such as requirements for final manufacturing documentation, test programmes, acceptance test procedures, NM' procedures, weld procedures, corrosion protection, handling, curing, heat treatment, mechanical testing requirements, etc.;*
- *access to the manufacturing facility's sub-suppliers and manufacturing documents; and*
- *procedures for handling of deviations to requirements, e.g. waiver procedures."*

How the "inspection service" is shaped by these factors is not clear: except to say they are most probably negotiated for each project. Depending on the stakeholders, their representatives, and any motivation scheme in place on the project: the results could vary considerably.

Commissioning Surveillance Requirements (9.13.2)

"The Certification Body shall evaluate whether the commissioning of the wind turbine(s) is in conformance with the instructions supplied by the manufacturer in accordance with relevant parts of the IEC 61400 series. Other tests to be performed during commissioning in addition to tests in accordance with the general instructions may be agreed with the manufacturer.
This evaluation requires examination of commissioning records. In addition, the Certification Body shall witness the commissioning of at least one wind turbine and additionally at least one wind turbine per every 50 turbines in the project,

The Certification Body shall as a minimum verify that:

- *the commissioning instructions supplied by the manufacturer are adequate;*
- *the instructions supplied by the manufacturer are followed during commissioning; and*
- *the final commissioning reports are complete.*

Verification and surveillance activities shall be concluded with reports that describe the activities carried out".

1.4.8.2 Germanischer Lloyd Certification

GL has a definition of Type Certification to suit their procedures.

The Type Certification assessment of a design can be carried out on 3 different levels per Germanischer Lloyd Certification Guide.

- Type A Certification is appropriate valid for 5 years (reporting annually)

- Type B Certification is appropriate valid for 1 year (non-safety outstandings permitted)

- Type C Certification is appropriate valid for up to 2 years (prototype: only safety issues)

For Type A & B a full check of the design is carried out prior to certification. For Type C a plausibility check is carried out on the basis of design documentation. GL point out those local requirements may dictate that the tower is checked fully prior to deployment.

GL note: *"When carrying out Project Certification it is common practice to rely on a turbine type (machinery including nacelle, rotor blades, safety and electrical system), which has already been type certified according to a wind turbine class……Other external conditions are to be chosen conservative, which allows that the type certified offshore wind turbine type will cover the external conditions of specific offshore sites during project certification. Alternatively a site specific certification of the machinery can be performed instead of Type Certification."* Since many of the wind turbines installed offshore USA may have to be S-type it will require specific review since these are not the "normally" used turbine types sold.

GL follows much the same path shown in Figure 5 for the Danish Energy Agency.

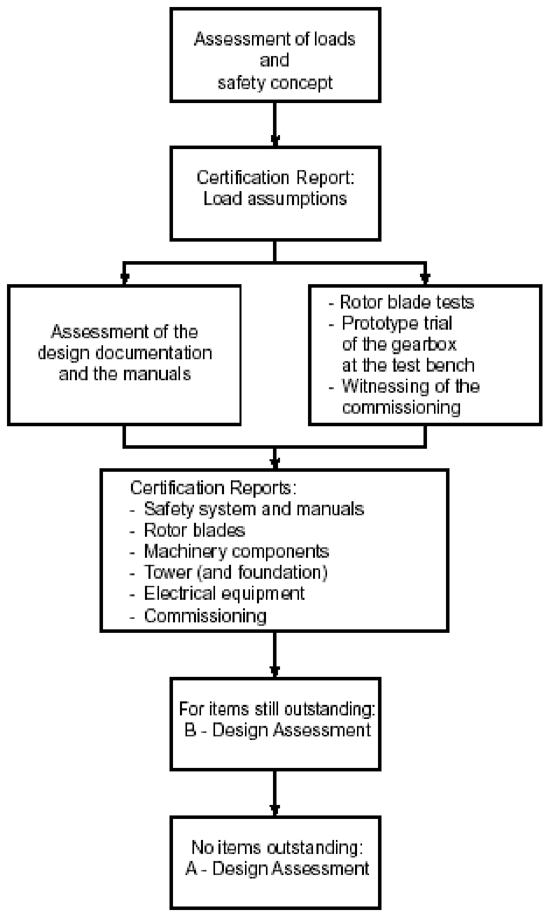

Figure 6: Procedure for Type A and Type B Design Assessment.

Prototype tests are carried out on the turbine including tests on the gearbox which is the focus after the number and extent of the issues.

The Project Certification process follows the same path as illustrated in Figure 6.
The GL notes specifically Commissioning surveillance which is represented by the box "installation" in the Figure 6.

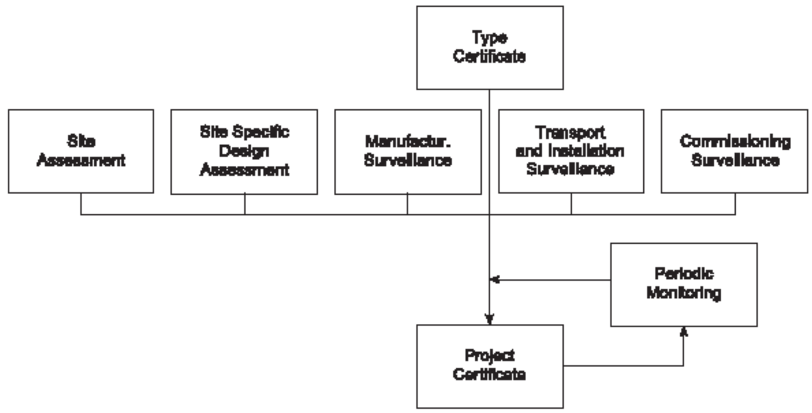

Figure 7: GL Project Certification

Within the GL system there are 2 different levels of Project Certification:

- **A** *"Surveillance is to be undertaken covering 100% of the offshore wind turbines of the offshore wind farm are to be monitored. Surveillance shall cover the support structure and essential parts of machinery, blades and electrical system".*

- **B** *"Surveillance is to be undertaken covering 25% of the offshore wind turbines on a random sample basis, which means that a minimum of 25% of the offshore turbines are to be monitored . Surveillance shall cover the support structure and essential parts of machinery, blades and electrical system. In case the surveillance should reveal major failures, deviations from the certified design or deviations in the quality management the number of turbines to be monitored is to be doubled."*

According to GL there is no need to adopt the GL-Guidelines to the US, because in all the GL guidelines it is stated that local / national regulations may be applied instead of those mentioned. This is done in Denmark, in India and other countries and would work for the US.

Surveillance of manufacturing (GL 1.2.3.4)

Since the details supplied by GL are quite definitive it is worthy of noting the activities carried out by them in surveillance of manufacturing.

"Before surveillance of manufacturing begins, certain quality management (QM) requirements shall be met by the manufacturers. As a rule, the QM system shall be

certified according to ISO 9001, otherwise the QM measures will be assessed by GL Wind. This will involve meeting the minimum requirements according to Section 3.2.3.

The extent of the surveillance of manufacturing and the amount of samples to be surveyed depends on the standard of the quality management measures, and shall be agreed with GL Wind. In general, the following actions and approvals will be carried out by GL Wind:

- *inspection and testing of materials and components (see Section 3.4)*
- *scrutiny of QM records such as test certificates, tracers, reports*
- *surveillance of manufacturing, including storage conditions and handling, by random sampling inspection of the corrosion protection*
- *dimensions and tolerances*
- *general appearance*
- *damages"*

Surveillance of transport and installation (GL 1.2.3.5)

"Before work begins, transport and installation manuals shall be submitted (see Section 9.1), which take account of the special circumstances of the site, if necessary. These will be checked for compatibility with the assessed design and with the transport and installation conditions (climate, job scheduling, etc.) prevailing at the site.

The extent of GL Wind's surveillance activities and the amount of samples to be surveyed depends on the quality management measures of the companies involved in transport and installation. As a rule, GL Wind will carry out the following activities:

- *approval of transport and installation procedures*
- *identification and allocation of all components of the offshore wind turbine in question*
- *checking of the components for damage during transport*
- *inspection of the job schedules (e.g. for welding, installation, grouting, bolting up)*
- *inspection of prefabricated subassemblies, and of components to be installed, for adequate quality of manufacture, insofar as this has not been done at the manufacturers' works*
- *surveillance of important steps in the installation on a random-sampling basis (e.g. pile driving, grouting)*
- *inspection of grouted and bolted connections, surveillance of non-destructive tests (e.g. welded joints)*
- *inspection of the corrosion protection (see Section 3.5)*
- *inspection of scour protection system (see Section 6.7)*
- *inspection of the electrical installation (run of cables, equipment earths and earthing system) (see Chapter 8)*
- *inspection of sea fastening and marine operations (see Chapter 12)"*

These surveillance activities are very close to what is currently used for the CVA process by MMS.

Surveillance of commissioning (GL 1.2.3.6)

"Surveillance of commissioning is to be performed for all offshore wind turbines of the offshore wind farm and shall finally confirm that the offshore wind turbine is ready to operate and that the offshore wind turbine fulfils all standards and requirements to be applied.

Before commissioning, the commissioning manual (see Section 9.2) and all tests planned shall be submitted for assessment. Before commissioning, the manufacturer shall provide proof that the offshore wind turbine has been erected properly and, as far as necessary, tested to ensure that operation is safe. In the absence of such proof, appropriate tests shall be carried out when putting the offshore wind turbine into operation. The commissioning is to be performed under surveillance of GL Wind.

This surveillance covers witnessing by the surveyor of approximately 10 percent of offshore wind turbines during the actual commissioning. The other turbines shall be inspected after commissioning and the relevant records shall be scrutinized. Within the course of commissioning, all functions of the offshore wind turbine deriving from its operating and safety function modes shall be tested. This includes the following tests and activities (see also Section 9.2):

- *functioning of the emergency push button*
- *triggering of the brakes by every operating condition possible in operation*
- *functioning of the yaw system*
- *behaviour at loss of load*
- *behaviour at overspeed*
- *functioning of automatic operation*
- *checking the logic of the control system's indicators*

In addition to the tests the following items shall be examined during commissioning surveillance by visual inspection of the entire offshore wind turbine (see also Section 9.2):

- *general appearance*
- *corrosion protection*
- *damages*
- *conformity of the main components with the certified design and traceability / numeration of the same".*

Manufacturing Surveillance for FRP (GL 3.4.6)

"Manufacturing surveillance of FRP components comprises quality control of the raw material, surveillance during production, and checking the quality of completed components.

A distinction is made in manufacturing surveillance between internal and external surveillance. External surveillance in the sense of this Guideline means regular random-

sampling checks of the internal surveillance and of the component quality by GL Wind or a body recognized by GL Wind."

To ensure that the product has continuity of quality:

"*GL Wind reserves the right to make unannounced inspections of the works. The manufacturer shall allow the representative of GL Wind access to all spaces serving the purposes of manufacture, storage, and testing and shall permit him to examine the available production and testing documentation.*"

Periodic Monitoring (GL 1.2.3.7)

"To maintain the validity of the certificate, maintenance of the offshore wind turbine shall be carried out in accordance with the approved maintenance manual (see Section 9.4), and the condition of the offshore wind turbine shall be monitored periodically by GL Wind in accordance with Chapter 11 "Periodic Monitoring". Maintenance shall be carried out and documented by authorized persons. Periodic Monitoring intervals are to be defined in the inspection plan and to be agreed with GL Wind. These intervals may be varied depending on the condition of the offshore wind turbine.

Major damages and repairs shall be reported to GL Wind. To maintain validity of the certificate, any alterations have to be approved by GL Wind. The extent to which this work is to be surveilled shall be agreed with GL Wind.

The maintenance records will be perused by GL Wind. Periodic Monitoring by GL Wind comprises the following assemblies (see also Chapter 11):

- *foundation and scour protection (if appropriate only perusal of relevant inspection records)*
- *substructure*
- *tower*
- *nacelle*
- *all parts of the drive train*
- *rotor blades*
- *hydraulic/pneumatic system*
- *safety and control systems*
- *electrical installation"*

1.4.8.3 DNV Certification

DNV appears from the documentation to follow the IEC Code in terms of type certification.

The main description in DNV-OS-J101 refers to Project Certification, which is consists of 5 phases:

Table M1 Phases of project certification and associated activities							
Phase No.	*Description of certification phase*	*Activities*					
		Site conditions	*Wind turbine design and manufacture*	*Support structure and foundation design and manufacture*	*Installation of wind turbines, support structures and foundations*	*Planning and evaluation of operations and maintenance*	*Evaluation of measurement and monitoring program*
I	Verification of design basis	X	X	X		X	
II	Verification of design		X	X	X	X	X
III	Manufacturing		X	X			
IV	Installation				X		
V	Commissioning		X				
VI	In service		X	X		X	

The 6th phase is the in-service inspection to keep the project certificate valid.

As in the case of GL, and DNV the project certification scope is decided between the parties prior to commencement of the work. DNV standard states the work can be certified to other than DNV standards e.g. IEC depending on the client wishes.

DNV-OS- J 101 Wind Turbine Structures

DNV relies upon auditing of the manufacturer's quality control system, and ensuring manufacturing is done in accordance with an accepted system.

No specific amount of time is given at the factory nor information as detailed of what is to be done as presented in the GL Guidelines.

More description is present in the 2004 version of this document. In the 2008 edition the details of requirements for manufacturing surveys has been removed.

DNV-0S- J102 Wind Turbine Blades

DNV notes the following:
"The third step consists of inspection of manufacturing of individual blades according to the design drawings and work instructions verified in the second step. The procedural manuals verified in the first step are used as guidance for this inspection.

Type certification is limited to a specific design, and ***may not involve the complete verification of material qualification*** *and other generic procedures. Only those elements of the material qualification and generic procedures deemed critical for the design will be verified.*

Guidance note:
Both the designer and manufacturer must decide on how to communicate the design and manufacturing process to the certifying body. In cases where the design or manufacture is based on prior certification, the prior-certification sought must be clearly stated and referenced. All generic and specific documentation shall also be clearly identified."

1.4.8.4 Practical Matters

In review of the load cases required by IEC 61400-3 many of the assumptions in the load cases are not as clear as they might be, coupled with the fact that many items are open to some interpretation in the code documents. In 2001 EWTC attempted to address this issue in relation to IEC 61400-1 by trying to identify variations in interpretation by in parallel carrying out three “certification cases”. The result is a set of Guidelines to be used together with the IEC standards and other Certification “Regulations” used by the Certifying Bodies.

Several points are of note: *“there is a well-defined need for improvement on the certification procedures”* and *“however it is not realistic to assume that the Certification Bodies will formulate, update, and apply these Guidelines on a voluntary basis without external “enforcing” or supporting mechanisms”.* The document covers a number of points in each of the following subjects important to structural survival [Ref. 1.36]:

- Control & Protection Systems covering protection system logic, fault analysis through FMEAs, software relevance and version, overspeed sensing, etc.;
- Load Cases & Loads
- Structural Components;
- Type testing.

1.4.8.5 The Need for Oversight

A news article sets the scene for discussing the need for oversight:

July 2, 2007 by Hisashi Hattori in Asahi Shimbun

“*Power-generating wind turbines will soon have to comply with tough new technical standards to ensure they can withstand typhoons, lightning strikes and other extreme weather conditions.*

Wind-power generation is a major pillar in the government's push to use alternative energy sources to fight global warming. In recent years, however, storms have caused extensive damage to many wind turbines.

International standards drawn up in Europe are not sufficient to protect wind turbines from Japan's weather patterns, according to officials of the Nuclear and Industrial Safety Agency, an arm of the Ministry of Economy, Trade and Industry.

Officials have resolved to introduce new standards of durability for the giant structures by fiscal 2008. Currently, wind turbines need only satisfy a stipulation in the Electric Utilities Industry Law that they be "structurally safe" against strong winds.

However, there is nothing to regulate how they should be designed to cope with thunder and lightning.

In 2006, about 75 percent of the wind turbines in Japan were foreign made, although local manufacturers are now rapidly entering the market.

In fiscal 2005, there were 100 cases of malfunctions and accidents reported in a survey of 900 wind turbines by the New Energy and Industrial Technology Development Organization (NEDO).

The survey found that 38 cases were caused by natural phenomena, in particular strong winds and lightning strikes.

Twenty-five were due to faults in construction or manufacturing, and four were the result of poor management. In 33 cases, the causes were unknown.

Wind turbines stand about 100 meters, making them vulnerable to lightning strikes.

Wind-power generators facing the sea of Japan in the northwestern Tohoku and Hokuriku regions are hit by lightning strikes each winter.

As a result, they experience at least four times as much damage as similar structures elsewhere.

In addition, 13 percent of the reported damage was caused by powerful winds in years when many typhoons hit Japan. Wind turbines apparently are especially vulnerable to sudden gusts of wind.

Mitsubishi Heavy Industries Ltd. and other domestic manufacturers of wind-power generators have already adopted designs in their new models that cater to Japan's weather conditions.

NEDO officials will study weather patterns, strong winds and thunder in particular, on a nationwide basis so as to compile a report by the end of this fiscal year."
[Ref. http://www.windaction.org/news/10484].

Many parts of United States are subject to hurricanes (Gulf Coast and Eastern Seaboard), and severe winter storms (Northeast Coast). The conditions where wind farms have been sited offshore in Europe do not have to cope with such severe conditions. On land, the record in Japan, Philippines, and Taiwan certainly indicates there are issues which are not yet resolved: though so far as the literature reflects the design loads were exceeded in all the incidents that occurred to date in severe weather. There is much that is not known about the root cause of incidents as the root causes are almost never available. For those casualties where publications reflect the issue – it leads to a need to understand the extreme design loads put forward in the IEC publication.

Miyako region – All 7 turbines failed in typhoon Maemi(2003) (Gust 74.1 m/s)

Figure 8.

- Turbine failure rate in Japan is 3 times that of Denmark
- Gust winds experienced about 7 times larger than IEC guidelines.
- Source: Suguro (MHI) [Ref. 3.1.37], [Ref. 3.7.54].

Design load cases call for alignment of the wind turbine to various yaw limits leading to an important assumption which is not customary on most structures: that the structural survival of the tower may depend on electrical power, control systems being operational, as well as load cases particular to the location being considered.

An interesting report failures from Typhoon Miyako is reported on the issue of the yaw control:

"The wind turbine failures in Mikyako have been well investigated by several groups. They detected that the direction was different between tower falling and rotor about Karimata No. 3 and Nanamata No. 1. And the electric stems were broken and power failed former than wind turbines broken. When typhoon passed through, the wind direction changes from North to Southwest for 3 hours. From these evidences, these turbines would lose yaw control, then subjected to the side attack of strong gust and broke. This experience shows the importance of wind turbine protection against power failure." [Ref. 3.7.54].

There is a huge amount of information wind farm incidents, much of which is about the incident, but not about the root causes.

A short review of the news press on wind farms leads you to the conclusion that wind farms are not without their issues:

"A farmer has described the shocking moment a 16-foot wind turbine blade smashed through the roof of his home as his family slept inside. "It was like a bomb hitting the roof of the house. It shattered the tiles and the blade disintegrated itself," David Campbell told the Belfast Telegraph. The turbine was one of a batch of 11 defective machines installed on farms in Northern Ireland with the help of European funding provided by the Department of Agriculture. All 11 of the Chinese-built turbines, sourced from the same supplier, have broken down but the farmers have been left thousands of pounds out of pocket and they complain that no-one is doing anything to help…… He said his turbine "took off of its own accord" one stormy night in January 2007: "It got up momentum with the wind blowing. It went for four hours until about 4am and the three blades came off. One of the blades went through the roof of the house — it cut through it like a chainsaw. Source: Belfast Telegraph 19 June 2008."

According to the Copenhagen Post (25.02.2008), *"The climate minister, Connie Hedegaard, is calling for an investigation to determine the cause of two violent wind turbine collapses in Denmark in the past week. Both of the windmills were produced by Vestas, and Hedegaard's request to the Energy Board comes after other breakdowns both here and abroad have been reported in the past two months."*

On 8 November 2007 another Vestas turbine collapsed, causing the site to be shut down. Shetland News reported on 13 November that *"A 200 foot high Vestas V47 turbine was bent in half during storms at Scottish Power's 26 megawatt wind farm, at Beinn an Tuirc, in Argyll and Bute, last week. This site and two others owned by Scottish Power, in the Borders and Ayrshire, had their turbines shut down as a precaution until the cause of the problem is investigated fully by engineers".*

The Campbeltown Courier reported that in *"what has been described as 'a catastrophic failure' of the turbine, the tower section has folded in the middle smashing the blades and nacelle into the hillside. It is thought by those in the industry that this is the first time a turbine tower has ever collapsed in the UK and Vestas Celtic, which manufactures towers at its nearby Kintyre factory and Scottish Power owners of the farm have launched an inquiry to find out what went wrong with the Vestas V47 turbine".*

Scroby Sands offshore windfarm report, prepared by E.ON UK and published by the DTI (now the Department for Business, Enterprise & Regulatory Reform), the Vestas V80 turbines come in for particular criticism…… *The site is off the coast of Norfolk, and the 30 V80 2MW turbines were manufactured and installed by Vestas during 2004. Despite a capital grant of £10M from the UK taxpayer, the site produced significantly less energy than budget, and there were multiple failures of gearbox bearings. The report states that*

27 generator side intermediate speed shaft bearings and 12 high speed shaft bearings have had to be replaced, together with four generators. "The turbines have suffered from poor availability for the first three years. This has been due to several causes, but mainly due to inadequate testing of the prototype to this design. .....The wind farm has also suffered a cable fault due to installation deficiencies and a lightning strike which destroyed a blade".

"Tuesday, 31 January 2006, 11:06 GMT
"Wind turbines are again producing power at the giant Nissan car plant on Wearside, a month after one of the six machines burst into flames.
"Eight fire crews attended the Sunderland car plant after fire broke out on one of the 167ft (51m) Danish-built turbines on 23 December".

"Operator Elsam is hoping to have all 80 turbines at its Horns Rev offshore wind farm [off the west coast of Denmark] up and running by the autumn following several months of repairs dealing with defective transformers and generators. For some time there have been technical problems with the V80 2MW-rated turbines at the site, causing them to run at below design output, which made operation of the site impossible to sustain. Twenty turbines are currently down for repairs; the remaining sixty will be assessed and repaired during the remainder of the summer".

"The Horns Rev offshore wind farm development was shut down on 4 November when a test wind turbine of the type being used in the project suffered damage owing to the failure of a safety system. The unit in question was a Vestas V80-2.0 MW offshore unit located at Tjæreborg, Denmark. All damage was confined to the turbine blades. But it was the second turbine failure due to overspeed in just a few days, the other occurring on a Nordex site in Norway. Both were caused by human interference in control systems, and have serious implications for how testing and service procedures are currently carried out, and how they should be".
"In relatively low speed wind (10 m/s), a failure occurred in the control system causing the turbine to over-speed. The safety system that has to stop the turbine in such a situation failed. However, the turbine's secondary emergency system cut in and stopped the rotor.
"Despite Vestas' confidence about recurrences, the Nordex event, a remarkably similar accident - similar, that is, in cause, not outcome - had happened only a few days before, but to a turbine sited at the Arctic Wind site near Havöygavlen, Norway.
It occurred on October 29 and the mechanical damage was far more extensive. It also was an overspeed accident, in 15 m/s wind, with the rotor getting up to 44 rpm (tip speed 663 km/h [over 400 mph]) before catastrophic failure occurred and the entire nacelle with its rotor was ripped from the tower".
Modern Power Systems © 2005 Published by Wilmington Publishing Ltd.

Noble Environmental Power Confirms Altona NY Turbine Collapse

March 6, 2009: Nacelle catches fire

Investigation by GE crews into Wind Turbine 59, which also didn't shut down but didn't collapse, revealed a wiring anomaly that allowed the blades to keep spinning. Data from the Wind Turbine 42 indicates the same wiring anomaly.

Figure 9.

The rather unique characteristic of wind turbines is that features other than external loading conditions can cause structural collapse. In the instance above a wiring anomaly apparently may have been a cause of the collapse. Lack of power leading to lack of being able to control yaw may lead to structural issues. The following information from Horns Rev 2 has left the turbine structures without power for a period of time:

> *"Faulty terminal strips in the cables from Horns Rev 2 have shut down the massive wind farm.*
>
> *After just two months of operation technical problems have forced the blades of the world's largest offshore wind farm to stop turning.*
>
> *But it isn't Dong Energy's Horns Rev 2 itself that is the problem. Rather, there are problems with the terminal strip on the 56-kilometer-long power land cable that sends the turbines' energy on to the grid along the West Coast.*
>
> *The wind farm has not been producing energy since last weekend and Dong Energy, which owns the wind farm, is losing approximately 1.1 million*

> *kroner each day the turbines stand still.*
>
> *Kim Kongstad, maintenance manager at Energinet.dk, which is responsible for the cable, said the turbines would probably not be back in operation until the end of the month.*
>
> *'We hope to have all terminal strips repaired by 29 November, after which the cable can be reconnected so the turbines can start turning again and provide power to the grid,' Kongstad said that the terminal strips have been a problem since before Horns Rev 2 opened this past summer, where 24 were repaired prior to setting the turbines in operation.*
>
> *Dong's information states that the farm's 91 turbines produce an average of 2.2 million kWh each day – energy sold on to electricity customers both in Denmark and abroad.* [Ref. Copenhagen Post Nov 20, 2009]

There was an interesting article in Clean Energy magazine (nacleanenergy.com) September/October 2009 written by SGS. Some of the remarks are instructive and give sufficient insight to ask further questions.

"When a utility company buys a turbine, particularly one that has been around for 20 years or more, they believe they are getting a proven design. What a many may not take into account is that some of these critical components might be produced from a relatively new sub-contractor or a new manufacturing facility."
"It should be of little surprise that the industry is now reeling in a series of major blade repair and service issues. There are stories of rotor blades breaking off and sailing through the air only to end up in some cornfield, and of manufacturing defects causing wind turbines to sit idle while new blades are being shipped out and replaced. All too often these costs end up being 10 to 100 times the cost of a well-implemented blade inspection program."……
"Just last year, the following blade-related issues hit the headlines:

- *One US manufacturer spent $25 million to strengthen 1,251 blades;*
- *Another spent 15 million to strengthen 780 blades; while yet another had to*
- *Replace more than 1,200 blades worldwide."*

"Keep in mind, these cost overruns also contribute to negative perceptions of wind energy as being unreliable, difficult to maintain, and still not a proven technology."

The background to some of this is in the following articles:

"March 3, 2008

The Indian company said blade cracks were discovered on some of its turbines in the U.S. Pune, India-based wind turbine maker Suzlon Energy said today that cracks were discovered on the blades of some of its S88 turbines in the U.S.

The company said it would spend $25 million on a retrofit program to fix the problems.

"We have a close working relationship with our customers, and this program is a proactive measure to safeguard the interest of all our stakeholders," said Andre Horbach, CEO of Suzlon.

"The retrofit program is designed to minimize impact for our customers and Suzlon."

The company said the retrofit involves the structural strengthening of 1,251 blades, or 417 sets of blades, on 2.1 megawatt turbines."

Suzlon said 930 of the problem blades are already installed while the remaining blades are in transit or inventory. "

Wind turbine blades: Big and getting bigger
Article from: Composites Technology, Contributed by: Chris Red, Contributing Writer
Article Date: 6/1/2008: This article reported that a total of 43,777 composite blades were produced in 2007.

While the recalling of blades due to cracking (only 13% of the total of Suzlon's had actual issues), these may not have been due to defects alone. One must ask the question: "with that number cracked, is there an issue with design standards?" A key issue here goes to the recommendations for research by "identifying the root causes of component failures, understanding the frequency and cost of each event, and appropriately implementing design improvements". While carrying out this research it became painfully obvious that of those databases that exist: the contents are hidden from access, even for researchers. Those incidents that have occurred and noted publically, there are rarely follow-up to root causes: thus preventing the industry from benefiting from those experiences.

Similar remarks apply to the multitude of gear box issues that have dogged many of the wind farms, particularly those offshore: lack of transparency as to the root cause. The European projects have done a very good job of documenting that there were failures. Two comprehensive studies mentioned: the POWER research project carried out by a consortium of countries and reported at the Offshore Center Denmark website, and the research reports carried out by the UK DTI and BERR e.g.

- Monitoring and Evaluation of Blyth Offshore Wind Farm, DTI Publication, AMEC, 2001 (7 documents).
- Annual Reports filed on the Capital Grants Scheme, Dept of Business Enterprise & Regulatory Reform (BERR).

POWER reports the issues primarily with construction and commissioning whereas BERR reports both those and issues that arise in Unplanned Work giving insight into operational issues on an ongoing basis. The reports of the issues arising and how they were dealt with come to the surface but the root causes have not been successfully tracked down. There is said to be in many contracts the requirement to disclose information on incidents and accidents to the Certification body, and to the manufacturer. Clearly the manufacturer has a vested interest in getting down to a root cause and fixing the problem: and because of the warranties that have been in place to date we can assume that action is being taken by the manufacturer. Whether there has been any action by those issuing Certificates does not appear to be well reported in the literature. Insurance companies that collect data have taken some action, but they have not been forthcoming in the data which, of course, gives them a proprietary advantage over other insurers. VdS a testing group in Germany, working with Germanischer Lloyd have produced a number of interesting documents with recommendations as to the standards to meet, and providing sufficient background to understand the issues. Some of their standards are quoted extensively within this report on subjects that are part of the study e.g. on fire protection.

The best standards that have been produced related to offshore wind issues are European. Codes sited in these are European: steel's sited are European, qualifications of welders are European, and electrical requirements are European. These are also written with offshore European metocean conditions in mind and there are some significant differences in the US dealing with winter storms offshore Maine, hurricanes up the east coast and in other potential US locations. The idea of adopting an International Standard has its appeal when moving into locations which have no standards in place related to the work done, however, the IEC Code suite while simply excellent in laying out all the information and guidance what the issues are, may not be detailed enough and prescriptive enough for them to be successful as the cornerstone of codes suited to the U.S. offshore at this moment in the initial stages of development. The solution to this is to build on the enormous and hard work that quite obviously has been put into the IEC Code, by those who have participated in its development, and write a U.S. Annex to that Code. For those areas that are sufficiently described in the Code it would also be useful if the GL document on Certification was also appended with a U.S. annex, since much of the information in that document has been produced with years of research and understanding but it is limited in that it too refers to European, GL standards and approved testing facilities and VdS documents all parts of which may need deviations to be appropriate for the U.S. An initiative is underway led by the AWEA entitled "Road Mapping US Standards and Permitting Requirements with International Standards" which may take several years to conclude.

1.6 MMS CVA Function

1.6.1 MMS Platform Verification Program for Oil and Gas Platforms:

It should be noted that Type Certification without manufacturing surveillance has normally not been part of the MMS CVA process. Project Certification based on Type Certification with manufacturing surveillance has likewise not been part of the MMS CVA process. It is therefore prudent to request an owner to indicate the proposed amount of surveillance as part of the submission requirements for approval.

MMS developed the CVA portion of the Verification Program in the late 1970s in response to deeper water platforms being put into the OCS. By the time the CVA program was developed, shallow water platforms deemed to be <400 ft or with a natural period greater than 3 seconds, had been developed successfully for many years. With the advent of the deeper water platforms and floating platform solutions it was deemed appropriate to have a Certified Verification Agent to augment the MMS engineering staff that was responsible for technical assurance for regulatory purposes.

The CVA program as stipulated for offshore wind farms applies to all offshore wind farms without depth limitation. MMS will have to focus on how to optimize the regulatory function while ensuring cost effective ways of carrying it out, in terms of defining the activities of the CVA. As background the required activities are summarized. They are found in 33 §CFR 250.914 - 918.

1.6.1.1 Qualifications of the CVA for oil and gas Industry

(Abbreviated to discussion items):

Qualifications of the CVA:

- Previous experience in third-party verification or experience in the design, fabrication, installation, or major modification of offshore oil and gas platforms;
- Technical capabilities of the individual or the primary staff;
- In-house availability of, or access to, appropriate technology…. programs, hardware, and testing materials and equipment; and understanding of the level of work to be performed by the CVA.
- Individuals or organizations acting as CVAs must not function in any capacity that would create a conflict of interest, or the appearance of a conflict of interest.

In the original form in the 1980s there was a list of individuals/companies who had been pre-qualified by the MMS for each activity i.e. design, fabrication, or installation based on these qualifications. The requirement was later changed to have the leaseholder nominate the CVA.

There is no specific requirement for the CVA to be a P.E. in the current requirements. It is however, implied that the documentation should be in the lease holder's possession and the documents available in the United States for MMS audit purposes. The language should be in English and the units in English units not metric.

1.6.1.2 Activities carried out by CVA for oil and gas Industry

A. Design Verification Plan

1) Documentation of the design including location plat, site specific geotechnical report, contract design drawings and met-ocean data;
2) Abstract of computer programs used for analysis; and a
3) Summary of major design considerations and approach needed for verification.
4) Conduct an independent assessment of all proposed:
    - Planning criteria;
    - Operational requirements;
    - Environmental loading data;

- Load determinations;
- Stress analyses;
- Material designations;
- Soil and foundation conditions;
- Safety factors; and
- Other pertinent parameters of the proposed design.

B. Fabrication Verification Plan

1) Approved for fabrication drawings and material specifications,
2) Material traceability procedures, and
3) A summary description of structural/fabrication specifications, tolerances, quality assurance, material quality controls/placement methods and methods/extent of NDE testing.
4) Make periodic onsite inspections while fabrication is in progress and verify:
    - Quality control by lessee and builder;
    - Fabrication site facilities;
    - Material quality and identification methods;
    - Fabrication procedures specified in the approved plan, and adherence to such procedures;
    - Welder and welding procedure qualification and identification;
    - Structural tolerances specified and adherence to those tolerances;
    - The nondestructive examination requirements, and evaluation results of the specified examinations;
    - Destructive testing requirements and results;
    - Repair procedures;
    - Installation of corrosion-protection systems and splash-zone protection;
    - Erection procedures to ensure that overstressing of structural members does not occur;
    - Alignment procedures;
    - Dimensional check of the overall structure, including any turrets, turret-and-hull interfaces, any mooring line and chain and riser tensioning line segments; and
    - Status of quality-control records at various stages of fabrication.

C. Installation Verification Plan

1) Summary description of planned marine operations,
2) Contingencies considerations,
3) Alternative course of action, and
4) An identification of areas to be inspected, specifying acceptance and rejection criteria.
5) Verify, as appropriate..........
    - Loadout and initial flotation operations;
    - Towing operations to the specified location, and review the towing records;
    - Launching and uprighting operations;

- Submergence operations;
- Pile or anchor installations;
- Installation of mooring and tethering systems;
- Final deck and component installations; and
- Installation at the approved location according to the approved design and the installation plan.

(6) Witness (for a fixed or floating platform)
- The loadout of decks, piles, or structures from each fabrication site;
- The actual installation of the platform or major modification and the related installation activities.

(7) Witness (for a floating platform)
- The loadout of the platform;
- The installation of drilling, production, and pipeline risers, and riser tensioning systems (at least for the initial installation of these elements);
- The installation of turrets and turret-and-hull interfaces;
- The installation of foundation pilings and templates, and anchoring systems; and
- The installation of the mooring and tethering systems.

(8) Conduct an onsite survey.......
- Survey the platform after transportation to the approved location.

(9) Spot-check as necessary to determine compliance with the applicable documents listed in §250.901(a); the alternative codes, rules and standards approved under 250.901(b); the requirements listed in §250.903 and §250.906 through 250.908 of this subpart and the approved plans.

- Equipment;
- Procedures
- Recordkeeping.

1.6.2 CVA Activities for Offshore Wind Farms

Qualifications for the CVA for Offshore Wind Farms are given in 30 CFR 285.706. Two key components are:

- *Individuals or organizations acting as CVAs must not function in any capacity that will create a conflict of interest, or the appearance of a conflict of interest.*
- *The verification must be conducted by or under the direct supervision of registered professional engineers.*

Duties of the CVA are included in 30 CFR 285.707:

- *The CVA must certify in the Facility Design Report to MMS that the facility is designed to withstand the environmental and functional load conditions appropriate for the intended service life at the proposed location.*
- *The CVA must conduct an independent assessment of all proposed …Load Determinations;*

The primary duties for fabrication and installation review include in 30 CFR 285.707 the requirement to check

- *"Quality control by lessee (or grant holder) and builder;*
- *Fabrication site facilities;*
- *Material quality and identification methods;*
- *Fabrication procedures specified in the Fabrication and Installation Report, and adherence to such procedures;*
- *Welder and welding procedure qualification and identification;*
- *Structural tolerances specified and adherence to those tolerances;*
- *The nondestructive examination requirements, and evaluation results of the specified examinations;*
- *Destructive testing requirements and results;*
- *Repair procedures;*
- *Installation of corrosion-protection systems and splash-zone protection;*
- *Erection procedures to ensure that overstressing of structural members does not occur;*
- *Alignment procedures;*
- *Dimensional check of the overall structure, including any turrets, turret-and-hull*
- *interfaces, any mooring line and chain and riser tensioning line segments; and*
- *Status of quality-control records at various stages of fabrication"….etc.*

It is not clear if this should be carried out on the component parts such as blades, nacelles etc all of which may come from component stock and thus not being manufactured specifically for the designated location. The various parts may come from multiple sources making the specific equipment certification process expensive compared to the type certification process.

The IEC indicates that blade testing is of key importance to assuring that blades do not break off and cause injuries etc., yet there is no specifics in the CFRs about tests to be done or indeed if any are required. This like many other items in the CFR is provided with no specifics about how to certify and indeed in CFR 285.708 it is left to the CVA (or project engineer) to *"use good engineering judgment and practice in conducting and independent assessment of the fabrication and installation facilities"*.

The CVA functions 30 CFR 285.710 include: verify, survey, witness, survey or check the following items during facility installation:

- *"Loadout and initial flotation activities;*
- *Towing operations to the specified location, and review the towing records;*

- *Launching and up righting activities;*
- *Submergence activities;*
- *Pile or anchor installations;*
- *Installation of mooring and tethering systems;*
- *Final deck and component installations; and*
- *Installation at the approved location according to the Facility Design Report and the Fabrication and Installation Report"* etc.

1.6.3 CVA Going Forward

One method of carrying out the verification program without any major changes in the Certification methods currently used by the Wind Turbine industry would be to adopt the Type Certification and Project Certification method of basic checks on the equipment.

The Project Certifier could perform the CVA functions, provided there is an acceptance of the project certifier by the regulator, although the conflict of interest issue would be clearer if they were separate entities. The CVA has historically had to qualify as a registered Professional Engineer for this purpose: this is not currently a requirement of oil and gas structures but is required for offshore wind farms according to 30 CFR 285.706. The audits performed by the regulator may have to consider whether approval can be granted as a CVA if the engineering work is done outside the United States.

The CVA responsibilities will have to extend beyond what is currently done in the oil and gas business because the wind turbine towers to remain structurally sound have to be assured of power, a robust control system, and mechanical devices working: this is not the case in fixed platforms with no mechanical or electrical requirements to structurally survive.

As a specific example of the desirability to have a knowledgeable independent party observe the erection process:

The bolted connections of wind turbines are notably exposed to fatigue loading during turbine operation. Thus accurate design and dimensioning is an important requirement for the operation and the safety of a turbine……

The ring flanges of the towers are normally not machined for parallelism of the flange interfaces after having been welded to the tower shells. The distortions arising due to the welding procedure can lead to decisive geometrical irregularities (imperfections) of the flanges connection.

Other deviations from the reference geometry of the ring flange can occur due to transport and on-site erection (see Fig. 2).

Fig. 2: Imperfect ring flange connections before pre-stressing

The influence of geometric imperfections on the load carrying behaviour of the pre-stressed ring flange connections is a given fact, which is not to be neglected.
Ref: Load carrying behaviour of imperfect ring flange connections of wind turbine towers by Fabio Pollicino, Germanischer Lloyd Technical Paper.

The CVA process is closely aligned with the German BSH system and their documentation is recommended for this purpose. The CVA is equivalent to the BSH qualified inspector. With this CVA methodology the CVA's task is to check the Type and Project Certification documents, examine the assumptions and the deviations from the stated complete component certification as outlined in the GL certification document, and present the results in a report confirming verification or identifying the shortcomings.

Certification should rely upon IEC with GL and DNV Certification documents to carry out the more precise requirements. The CVA should also be present at the FMEA of the wind field structures and risk analyses which are used to confirm the load cases.

CVA then becomes someone who reviews and makes sure the Certificates do what is intended by the Certification documents. The CVA doesn't have to be at each fabrication as long as it is certified. If there is no Certification then the CVA has to take over and perform those activities. The CVA has to occasionally show up on site but not perhaps even as much as for oil and gas structures if the trusted Project Certifier is also present.

The CVA would not be expected to duplicate the work that the Certifier does. What the CVA does is to look for the technical issues that are not certified that need Technical Review. The CVA should perhaps be there to ensure covered items such as: the bolts are being tightened properly and that a robust procedure is in place to ensure they are torqued to the right value since the tower depends on it. Perhaps the CVA should be present for the lifting of the Nacelle and blades to witness that there are no defects to the extent that surveillance can detect. The CVA may need to be there for the first few foundations being driven/placed.

1.7 Social Risk and Responsibility

In the Gulf of Mexico offshore platforms were originally sited with a lesser magnitude (25-year return period storms) but over the years the 100-year storm has prevailed in this region for fixed offshore platforms. Norway retains the 100-year storm criteria as to many other countries.

The historical viewpoint of Gulf of Mexico design practice was given by Griff Lee, a pioneer in fixed offshore platforms ex chief engineer with McDermott, in 1982 after Hurricane Andrew came through the Gulf of Mexico. His recollections about a meeting held after Hurricane Hilda in 1964 was that it was the start of the establishment of the standards for offshore platforms. Following Hurricane Andrew in 1982 a 2nd such meeting was held. The 1964 meeting was characterized by Griff Lee:

The reason that meeting was held, the industry had, from 1948 to 1964, four Hurricanes that came through the area and the damage was almost negligible. That wasn't because of the platforms or the quality of the platform but because of the track of the storm. It just didn't go through an area with that much population of platforms. Then, here comes Hilda. After Hilda, 13 platforms collapsed. These are not mixed up with caissons or mobiles: these are fixed platforms - 13 collapsed, 2 leaned over, there are 2 others that I don't count because they were obviously collision damage and you can't really blame that on platform design, and there were 3 platforms that had major damage. So, after Hilda, 18 platforms had to be replaced. Of that 18, 17 of them had been designed for the 25 year storm. One was designed by the owner's maximum storm, but it was not considered adequate by the owner at the time. The Joint Cans were 3/8" thick. It didn't survive the storm. Of those 18 platforms, from information I put together afterwards, in at least 17, the wave had gotten into the deck. They were too low and the other one that might have been above was probably barely standing before the storm anyway; it was somewhat inadequate: so, it was really not at test. Then a year later, following Hilda, comes Betsy, which does about the same thing in another area. These 2 storms, one year apart, had gone through the two areas of the Gulf with the heavy platform population. These 2, plus the meeting which we had, I think, was the turning point in industry. Before then, it had almost been every man for himself. This put together a cooperative spirit. Prior to that, the industry had been complacent. You know, "It won't happen to me, it's going to happen to somebody else." We had one other problem, and that is that most of the people who made the decision regarding platform design said all we will use is the 25 year storm, without realizing the location effect of that decision. The opinion of most people is that the 25 year storm was only going to occur once in the whole Gulf of Mexico every 25 years, and if I'm lucky it will be over by your platform, not mine. The storm did something to change that attitude and we have, at least, following the storm, most of the operators in a somewhat follow the leader format, decided well, that wasn't good enough: let's upgrade the criteria, and moved up to the 100 year storm. Now, I had thought that we had throughout our industry really gotten across the idea that the location is important. You have a 4% or a 1% chance each year that the storm will occur through your particular platform not once in the Gulf. I am on the mailing list for a government publication, by one of the regulatory agencies, and in the last issue of their *publication, I want to read something. (Unfortunately after 28 years since that last meeting, I have to put on my glasses to read.) This is from a publication "MMS TODAY", the latest publication, "Hurricane Andrew was the category of storm that strikes the Gulf Coast once every 100 years." We still have a little homework to do explaining our criteria.* [Ref. 1.37].

In the early days of the North Sea, offshore structures, both fixed and mobile were designed to a "1 in 100 year" frequency storm. It was not until about 1974 when the first edition of the UK Statutory Instrument 1974/289 that the 50-year storm came into regulatory circles. In response to the widely varying submissions that were being made on the 100-year values being produced for design of fixed platforms and for site approval of MODUs by a number of metocean consultants: this leveled the playing field developing a consistency across metocean data. Laurie Draper, then Oceanographer with the Institute of Oceanographic Sciences was responsible for the derivation: however, with the urgency of producing the data what was on hand was only the 50-year return period values. Since the difference between 50-year and 100-year values of wave height and wind speed were small, at the time, and for the UK North Sea, it was deemed best to publish these and change the criteria rather than wait to have the 100-year values derived [Ref. 1.38].

The industry has progressed in its knowledge since those days toward reliability methods which calibrate the codes based on probabilities of failure and thus the situation today is somewhat more complex to chronicle.

Griff Lee points out a fundamental issue to be emphasized: that the 100-year metocean data that is derived is not the once in 100 year storm to enter the Gulf of Mexico, but the once in 100 year storm at your particular location [Ref. 1.37]. Thus several 100-year storms may enter the Gulf of Mexico in any one year or series of years: they are just not anticipated to go through the same location. This is perhaps more of an issue for installations off the East Coast of the US in that one severe hurricane may be able to impact several offshore wind farms.

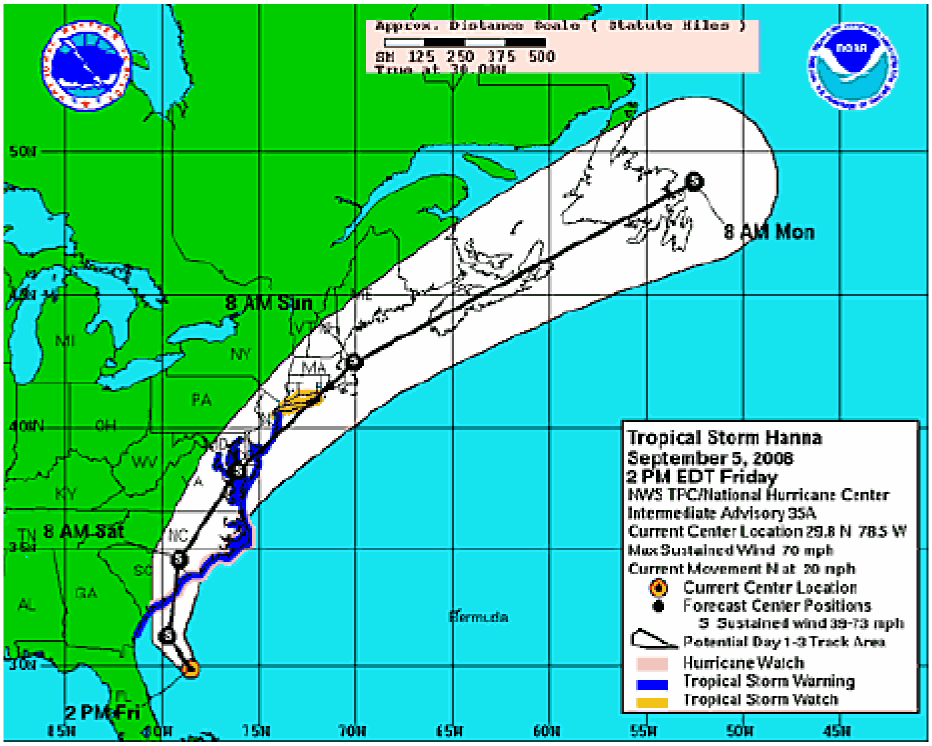

Figure 10: Example of a Hurricane Path that could impact multiple locations on the East Coast.

Another fundamental issue to be noted is that in the North Sea the difference between a 50-year storm and a 100-year storm is less than in an area subject to tropical revolving storms such as the Central Region of the Gulf of Mexico. Thus if the storm is exceeded by a small amount the consequences would be dramatically different for the different locations. This may be illustrated by a graph from a recent paper:

Hazard Curves – TRS Areas vs. CNS

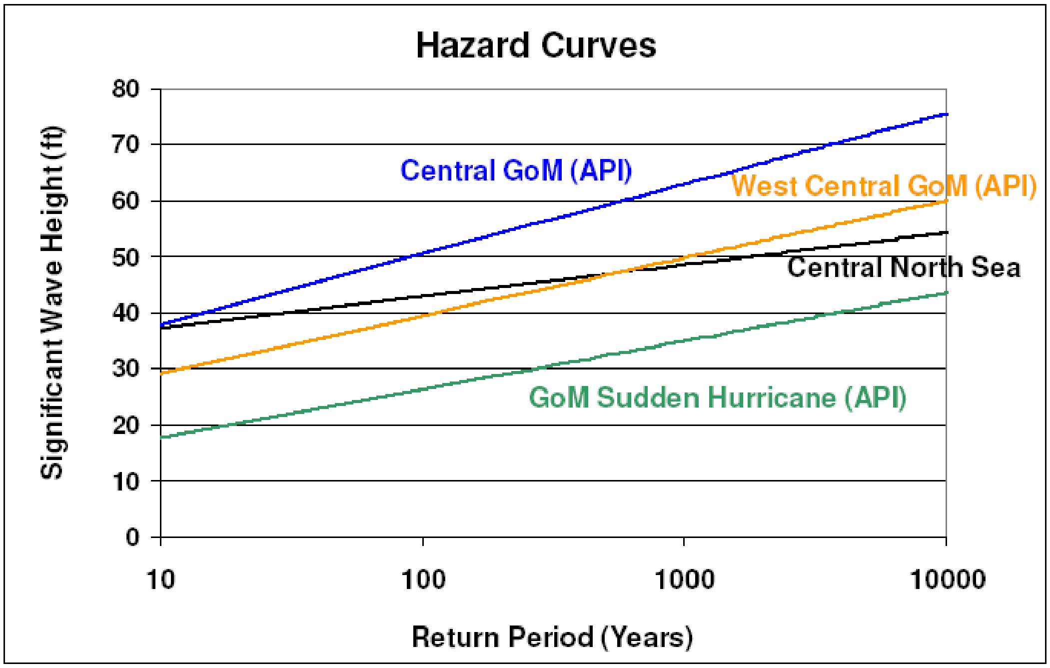

Figure 11. [Ref.1.39]

The reader will note that the increase in significant wave height from 10 year to 100 year in the North Sea is 38-42 feet, but for the Gulf of Mexico Central area is from 38 ft to 50 ft., considerably more. The same chart for Japan or the Philippines would show an even steeper curve.

Since Load Factors applied to the best estimate of loads is a function of assuring some protection against a greater metocean conditions then the load factor which might be used for the Gulf of Mexico would be much higher than that for the North Sea. For example to protect against 1000 year event the load factor on 100 year would be 1.14 in the North Sea whereas in the Gulf of Mexico it would be 1.24.

Thus the selection of the design event and the load factor are two crucial parts of the recipe: a third factor can be illustrated by considering whether the 1-minute mean or 10-minute mean is used in the calculation. It is common practice to note that the API RP2A uses a 1-hr mean wind speed in its calculation and that the wind turbine industry uses 10-minute mean wind speed. The relevant clause, however, is quoted below and one should note that fixed platforms are wave-dominant structures, which means that the wave force far outweighs the wind force: even for that situation API RP2A considers that if this is not the case a 1-minute wind speed should be considered:

API RP2A-WSD –

"*the associate 1-hr. wind speed .....occurs at an elevation of 33 feet and applies to all waterdepths and wave directions. The use of the same speed for all directions is conservative; lower speeds for directions away from the principal wave direction may be justified by special studies.*

The associated wind speed is intended to be applicable for the design of new structures where the wind force and/or overturning moment is less than 30% of the total applied environmental load. If the total wind force or overturning moment on the structure exceeds this amount, then the structure shall also be designed for the 1 minute wind speed concurrently with a wave or 65% of the height of the design wave, acting with the design tide and current.

As an alternate, the use of wave and current information likely to be associated with the 1 minute wind may be justified by site specific studies. However, in no case can the resulting total force and/or overturning moment used for the design of the platform be less than that calculated using the 1 hour wind with the guideline wave, current and tide provided in 2.3.4c".

For jack-up MODUs a 1-minute wind speed is the customary historic value used in the calculation. There the 50-year independent extremes are used, with the provision that directional 100-year extremes can be combined.

Other papers have referenced the issue [Ref.1.40]. There is an important perception by the public that design criteria are set to 100-year return periods for structural safety.

The return period issues are very different in the North Sea vs. Gulf of Mexico and very different in NE coastline than Gulf of Mexico although it is of note that tropical storm activity does affect the East Coast of the United States and not just the Gulf of Mexico viz.

API RP2A however does not address fatigue from wind, does not address grouted connections carrying significant moment and does not consider dynamics on the foundation/tower (pile) interaction to the extent needed by the type of structure envisioned for offshore wind turbine service.

An extensive study was carried out by MMI Engineering, Dan Dolan et al. "Comparative Study of OWTG Standards, June 29, 2009 by MMI Engineering, Inc., Oakland, CA [Ref. 1.41].

The results were reported in [Ref. 3.1.21].

"In the offshore wind turbine community, there has been extensive discussion on the 100-year storm condition design requirement. Table 2 shows the reliability indices for extreme wind and wave loads acting separately. From the results in the table, it can be seen that the β factors are higher for API when compared to IEC.

Table 2: Reliability indices for wind and wave loads

Code	Wind alone	Wave alone
API RP -2A (WSD)	3.35 (3.33)	3.38 (3.39)
IEC 61400-3 Ed.1	3.14 (3.10)	3.18 (3.20)

API & IEC COMPARISON FOR WIND PROFILE

The wind criteria included in API and IEC differ in terms of return period, averaging time and reference height. While the return period is typically viewed as the major source of difference in the standards, the other factors also play a significant role. As an illustrative example, we compare the wind speed profiles defined for API and IEC for a location that would experience wind speeds at the maximum levels allowed."

The results showed that the IEC 50-year wind speed at 100 m hub height would be about 12% less than that calculated using the API 100-year wind windspeed.

One conclusion of the study is *"that the IEC and API design methodologies generate similar levels of structural reliability for most offshore wind power applications".*

50-year or 100-year wind speed?

The question of the wind speed is a Societal Risk issue. Normally Societal Risk is dealt with by reducing the issue to one of fatalities or injuries but there are few such injuries and fatalities in the historical database of wind farms onshore and with appropriate provisions there are likely to be few offshore. The issue comes down to a more difficult philosophical basis.

If one single turbine structure was at risk it might be considered as a comparable risk to a jack-up platform that explores for oil and is not a fixed structure but moves from location to location (Mobile Offshore Drilling Unit (MODU)). In that case it would be sited to a 50-year return period worldwide and depending on location could be sited to as little as a 10-year return period storm in a hurricane area. If a fixed platform was a marginal oil platform without storage of oil and without being a major hub it may be able to be sited with as little as a 25 year return period storm and be found acceptable in the Gulf of Mexico. Why then should the survival criteria of a wind turbine be considered for a higher return period?

The fact of the matter is that Society in the United States is in a position to support Renewable Wind Energy projects. Much public money has been and is being invested in Research, and in promotion of Renewable Wind projects. The strategic initiative is to decrease the dependence of United States on foreign sources of oil, and where feasible to move toward renewables. This initiative has a high price tag. A single tower failure would make little difference to the initiative, as society appears to accept single failure events. The "picture" of a field of multiple turbines all being wiped out by an event such as a hurricane, lightning storm, or other natural phenomenon would probably have a major impact on Society and on strategic government initiatives. It would be considered a "national disaster" in that it would be a major setback for renewable wind projects.

The idea of multiple fields having tower failures from a single hurricane event, say, up the East Coast of the United States, would be an even greater impact on public perception.

What an acceptable picture of a field of wind turbines would look like after a major hurricane event is not easily predictable but it is probably clear that tower failure would be considered unacceptable. Multiple blade failures while devastating to the production of electricity from the field may not be such a devastating event in the public's eye. This might be perceived as a major maintenance event as opposed to a major catastrophe. Additional costs for these "maintenance" items needs to be balanced against the risk: but multiple towers collapsing would likely have major societal consequences.

One potential solution to this is question that the design basis information for the tower and foundation may be to submit the design information using site-specific data for a 100-year storm reporting 1-minute wind speeds, which are then directly comparable to storm wind warnings and hindcasts presented by NOAA. This will remove much confusion about the perception of underdesign arising from the reporting differences between the NOAA data and the design criteria in the code. (For the same storm the average wind speed over 10-minutes is always lower than over 1-minute, so media reporting of the wind speed of the storm (reported as a 1-minute average) always makes the design code look sub-standard (if it requires designs to a 10-minute average): a question of perception rather than reality. This would require a load factor adjustment in the reporting of the calculations: and such re-calibration would be in any case necessary to represent the slope of the extreme winds/waves to return period curves for the particular region i.e. the load factor will have a different value in the Central Gulf of Mexico than it would have offshore Delaware. It then remains to define a target reliability. As indicated in the conclusion of the report (Ref Dolan), the $\beta > 3.3$ will result which leads to an annual probability of failure of 10^{-5}, which should be a suitably acceptable number.

Reliability indices for wind and Wave Loads [Ref. 1.41].

<table>
<tr><th>Code</th><th>Wind Alone</th><th>Wave Alone</th><th colspan="2">Combined Wind and Wave</th></tr>
<tr><td rowspan="2">API RP 2A (WSD)</td><td rowspan="2">3.35</td><td rowspan="2">3.38</td><td>ά=0.025</td><td>ά =0.050</td></tr>
<tr><td>3.72</td><td>4.05</td></tr>
<tr><td>IEC 61400-3 Ed. 1</td><td>3.14</td><td>3.18</td><td>3.51</td><td>3.83</td></tr>
</table>

It is thus recommended that the 100-year, 1-min mean wind be used with the associated (site-specific developed wave heights and associated currents (and reciprocal parameters) maintaining the IEC load factors.

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2.0 EXTERNAL CONDITIONS

2.1 Metocean

There is much responsibility put onto the metocean consultant who may not know the conditions that are derived are being used for. The conservatism (or not) in the metocean predictions can vary depending on the experience and conservative nature of the investigator. It is thus recommended that the metocean consultant be very familiar with the load cases and consequences. This action together with those of the owner, manufacturer can be best done by involving them in a HAZID at the commencement of the design. There is clearly a need for a HAZID analysis prior to designing a wind farm, and for existing wind farms to review the design conditions to ensure they match not only the extreme values but other characteristics of a practical nature including knowing the return wind speed for ±180 degrees yaw angle. As a result of the HAZID there may be other design load conditions particular to the site that needs to be added: the IEC Code is meant as a minimum standard. The load cases should be clearly identified to all stakeholders so the risks being taken are clearly understood.

The approach BSH takes is recommended i.e. not limit the loading conditions to those in the IEC Code but *"The extreme loads shall include all events that can lead to the greatest possible loads, given consideration for the probability of simultaneous occurrence (e.g. "50-year gust", "50-year wave", extreme angle of approach of the rotor, collision with ship (service ship), ice pressure, etc., "*

If power is lost to the yaw system the expectation is that the tower may only be designed to survive a 1-year return period storm in offshore conditions. Presumably the situation could be the same with the blades though we have not ascertained whether the DLCs that control the tower design also control the blade design.

There is an additional drawback that many of the structures of a similar dynamic nature are designed to a 1-min steady state wind speed vs. a 10 min mean wind speed i.e. jack-up mobile drilling units (MODUs).

There is further discussion offered in Section 1.7 of this report on whether the 50-year return period is the appropriate benchmark for the OCS. The increase in values from 50 to 100 years in the North Sea is much less than the increase from 50 to 100 years either in the winter storms coming in offshore Maine, or the hurricanes coming in over the southern states.

A study carried out by MMI [Ref. 3.1.1] provided the following comparative information.

"The associated API values are calculated by first factoring the 50 year values to 100 year equivalents. ASCE-7 [Ref. 3.1.10] suggests a factor of 1.07 to convert a 50 year to 100 year wind speed. The results of this comparison are shown in Figure 3. It can be seen that the wind profile from API 100 year is higher than IEC 50 year return period."

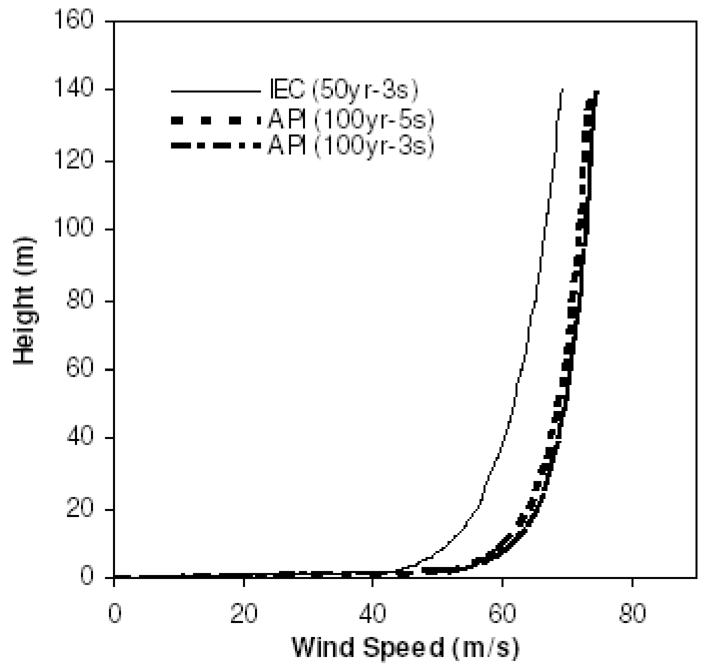

Figure 3: API and IEC comparison of wind speed

[Ref. 3.1.21]

The area of the difference in wind conditions for offshore turbine design has been addressed by GL. [Ref. 3.1.36].

"*In offshore standards, interest is focused on the extreme wind speed, since this is the design driving case. It is usually described by the 100-year return period wind speed. The wind forces according to offshore rules are often classified as:*

- *Gusts that average less than one minute in duration and*
- *Sustained wind speeds that average over one minute or longer duration.*

It has to be stated that gust wind speed (3-s gust) is used for local member design, while the sustained wind speed is sued for global structure design. In the offshore industry an averaging time of 1 hour is common but averaging times of 10 minutes or 1-minute are used too. " (i.e. MODU Design).

"In the wind turbine related standards and regulations a more thorough description of the wind speed is available. Since wind gustiness during normal conditions is essential for the structural loading, turbulence intensity of the wind speed and associated gustiness are described" [Ref. 3.1.36].

The wind turbine industry may have a more thorough description of the wind speed, however, the accuracy of that description requires a very much higher base of knowledge than may be available with short term measurements (short term i.e. less than 10-20 years for extremes). In the development of wind criteria for offshore structures it is well known that historical data often underestimates the actual over the long term. This has been the case in the North Sea offshore, and it has been the case in Gulf of Mexico hurricanes which have been underestimated by, as it turned out, some 35% until very recently. The accuracy of predictions for extremes should be examined carefully and with historical hindsight. Two cases illustrate the point: one for the North Sea and one for the Gulf of Mexico conditions.

Figure 12. [Ref. 2.9]

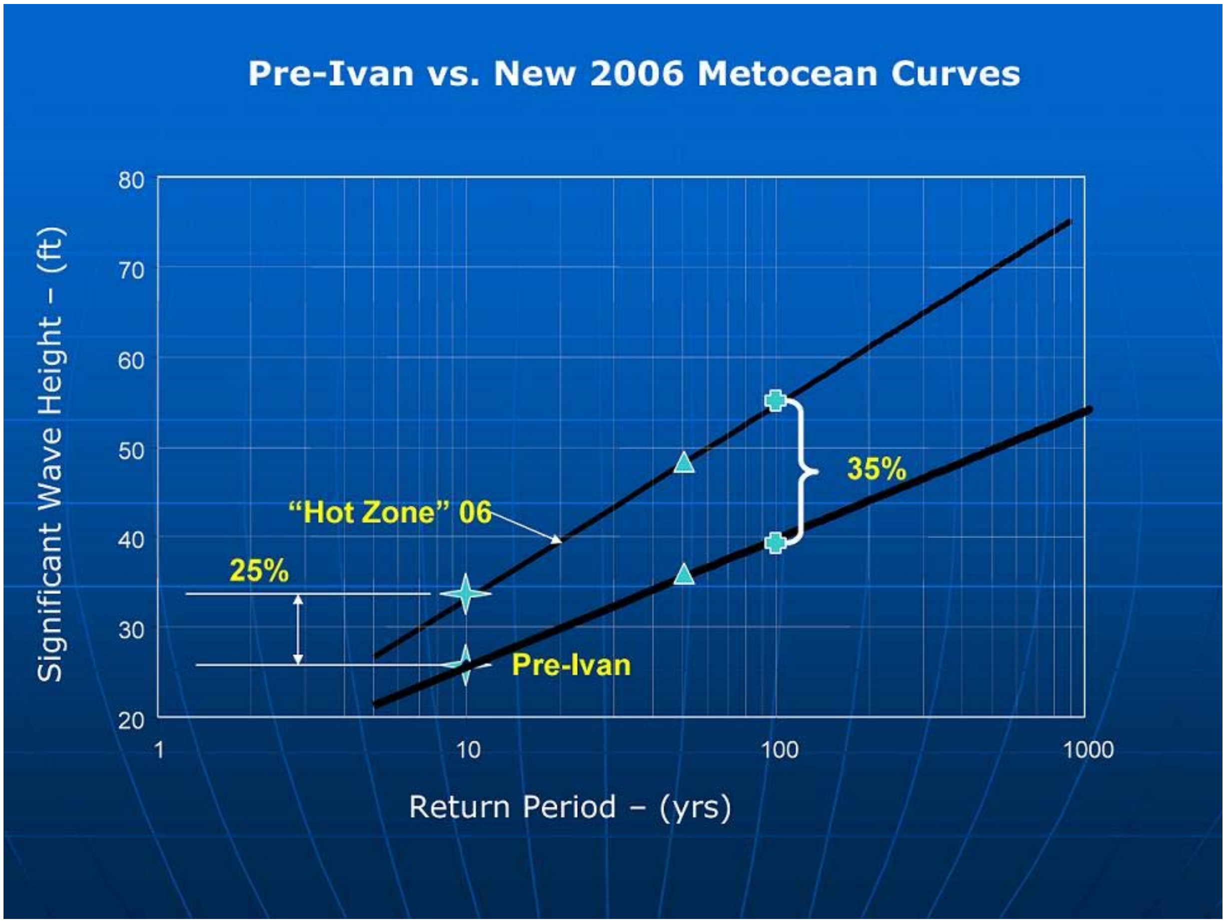

Figure 13 showing Pre-Ivan GoM wave height curves to 2006 data when re-examined. [Ref. 2.10]

The conclusion from Kimon Argyriadis [Ref. 3.1.36] is interesting:

"From the comparison of the existing standards and regulations it can be clearly seen that the different industry (wind and offshore) standards and methods show large scatter. Offshore standards are focused on extreme wind speed, methods not applicable for fatigue analysis, while for wind turbine related standards the low wind speed region is of major importance. …….Finally it is clear that further comparison of the assumptions made in the standards to measurements is required".

Since the offshore oil and gas criteria has been tested for a number of years on structures further distance from shore, it should be said that there is still substantial uncertainty about the loading combinations that might be appropriate for the near shore locations. The general engineering rule for such situations is to ensure conservative values until such time as the data confirms a more liberal interpretation is safe.

IEC 61400-3 Section 6 contains reduced wave height and wind speed numbers to be combined with extreme wind speed and wave height numbers respectively in carrying out analyses. While the offshore oil and gas industry does use "associated waves" with extreme winds and "associated winds" with extreme waves, there is no "rule of thumb" of a reduction as used in the wind turbine industry. Such a simplification has not been appropriate for calculations in the oil and gas sector. The results in the Gulf of Mexico analysis and several done by consultants off the east coast have developed higher numbers from the techniques they used than results from the IEC formulation. While it is not appropriate to express too firm an opinion without further study, it is an issue which may lead to unconservative results.

There are a number of other issues that require scrutiny when it comes to specific site approval of a particular turbine design. A fast moving small storm with peak winds of a given size may have significantly lower 1-hr average winds at a fixed site than a broad, slow moving storm with a large radius of maximum winds. The amount of time that the wind needs to act on a wind turbine will vary but will be comparatively small, so the adjustment to a wind speed of 1-minute may be a more relevant parameter. How those ratios are derived to predict future issues is as much of an art as it is a science. The more the metocean investigator knows about how those numbers are being used the better chance there is of being able to produce future values accurate for the load case being designed for.

Similarly, the wind profile over water varies due to a number of parameters.

Unfortunately, codes are often written by a relatively small group of like-minded people with similar experiences and access to the same published literature. The best result will occur from the early involvement of the metocean team and ensuring they understand how the figures will be used and to encourage conservatism.

2.2 Soil

2.2.1 MMS Requirements

The following are MMS requirements from the 30 CFR 285 for Soils:

§ 285.626 Supporting data for the SAP and § 285.645 GAP

Information.	Report contents.	Including.
(1) Geotechnical.	The results from the geotechnical survey with supporting data.	A description of all relevant seabed and engineering data and information to allow for the design of the foundation for that facility. You must provide data and information to depths below which the underlying conditions will not influence the integrity or performance of the structure. This could include a series of sampling locations (borings and in situ tests) as well as laboratory testing of soil samples, but may consist of a minimum of one deep boring with samples.
(2) Shallow hazards.	The results from the shallow hazards survey with supporting data.	A description of information sufficient to determine the presence of the following features and their likely effects on your proposed facility, including: (i) Shallow faults; (ii) Gas seeps or shallow gas; (ii) Slump blocks or slump sediments; (iv) Hydrates; and (v) Ice scour of seabed sediments.
(4) Geological survey.	The results from the geological survey with supporting data.	A report that describes the results of a geological survey that includes descriptions of: (i) Seismic activity at your proposed site; (ii) Fault zones; (iii) The possibility and effects of seabed subsidence; and (iv) The extent and geometry of faulting attenuation effects of geologic conditions near your site.

§ 285.626 Supporting data for the COP

Information:	Report contents:	Including:
(1) Shallow hazards.	The results of the shallow hazards survey with supporting data.	Information sufficient to determine the presence of the following features and their likely effects on your proposed facility, including: (i) Shallow faults; (ii) Gas seeps or shallow gas; (ii) Slump blocks or slump sediments; (iv) Hydrates; or (v) Ice scour of seabed sediments.
(2) Geological survey relevant to the design and siting of your facility.	The results of the geological survey with supporting data.	Assessment of: (i) Seismic activity at your proposed site; (ii) Fault zones; (iii) The possibility and effects of seabed subsidence; and (iv) The extent and geometry of faulting attenuation effects of geologic conditions near your site.
(3) Geotechnical survey.	The results of your sediment testing program with supporting data, the various field and laboratory test methods employed, and the applicability of these methods as they pertain to the quality of the samples, the type of sediment, and the anticipated design application. You must explain how the engineering properties of each sediment stratum affect the design of your facility. In your explanation, you must describe the uncertainties inherent in your overall testing program, and the reliability and applicability of each test method.	(i) The results of a testing program used to investigate the stratigraphic and engineering properties of the sediment that may affect the foundations or anchoring systems for your facility. (ii) The results of adequate in situ testing, boring, and sampling at each foundation location, to examine all important sediment and rock strata to determine its strength classification, deformation properties, and dynamic characteristics. (iii) The results of a minimum of one deep boring (with soil sampling and testing) at each edge of the project area and within the project area as needed to determine the vertical and lateral variation in seabed conditions and to provide the relevant geotechnical data required for design.
(5) Overall site investigation.	An overall site investigation report for your facility that integrates the findings of your shallow hazards surveys and geologic surveys, and, if required, your subsurface surveys with supporting data.	An analysis of the potential for: (i) Scouring of the seabed; (ii) Hydraulic instability; (iii) The occurrence of sand waves; (iv) Instability of slopes at the facility location; (v) Liquefaction, or possible reduction of sediment strength due to increased pore pressures; (vi) Degradation of subsea permafrost layers; (vii) Cyclic loading; (viii) Lateral loading; (ix) Dynamic loading; (x) Settlements and displacements; (xi) Plastic deformation and formation collapse mechanisms; and (xii) Sediment reactions on the facility foundations or anchoring systems.

§ 285.701 Supporting data for the Facility Design Report

Required documents:	Required contents:	Other requirements:
(6) Summary of the engineering design data.	(i) Loading information (e.g., live, dead, environmental); (ii) Structural information (e.g., design-life; material types; cathodic protection systems; design criteria; fatigue life; jacket design; deck design; production component design; foundation pilings and templates, and mooring or tethering systems; fabrication and installation guidelines); and (iii) Location of foundation boreholes and foundation piles; and (iv) Foundation information (e.g., soil stability, design criteria).	You must submit 1 paper copy and 1 electronic copy.
(8) Description of the loads imposed on the facility.	(i) Loads imposed by jacket; (ii) Decks; (iii) Production components; (iv) Foundations, foundation pilings and templates, and anchoring systems; and (v) Mooring or tethering systems.	You must submit 1 paper copy and 1 electronic copy.
(10) Geotechnical Report.	A list of all data from borings and recommended design parameters.	You must submit 1 paper copy and 1

It should be noted that MMS requirement includes:

> "*The results of a minimum of one deep boring (with soil sampling and testing) at each edge of the project area and within the project area as needed to determine the vertical and lateral variation in seabed conditions and to provide the relevant geotechnical data required for design*".

This is considered a minimum requirement and the number and location of borings will depend on the potential for site specific anomalies.

2.2.2 Guidance on Foundations for Jack-up Installation Vessels

BWEA Guidance, suitably adapted for the US OCS should be considered the marine procedure/ results produced for how the jack-up construction/installation vessels are suited to the site. Deviations from this may be appropriate since these domestic rather than international vessels may be used but the principles should be followed [Ref. 2.1].

Several quotes from a paper on this document and from the document itself are provided. Much of the background to this document was developed from work on a Joint Industry Study project carried out many years ago and this formed the basis for the SNAME 5-5A document on site specific assessment of MODUs.

"Foundation assessment is required where the jack-up is to be preloaded and elevated above the sea surface to a working air gap or to a minimum safe survival airgap on location. The scope of the assessment and the amount of data required will depend upon

the particular circumstances such as the type of jack-up, the soil conditions and variations in the soil across the site, and upon previous experience of the site, or nearby sites, for which the assessment is being performed. The jack-up foundation assessment shall be carried out in accordance with the Recommended Practice or in accordance with another recognized and appropriate code of practice that provides an equivalent level of safety. The assessment shall have due regard for the potential hazards listed in SNAME T&R Bulletin 5-5A foundation risks which are tabulated in Appendix F of the Guidelines.

Two of the most important considerations when assessing Jack-up foundations for wind farms are Punch Through and scour. It is recommended that foundation assessments should always be undertaken by a geotechnical engineer with experience in assessing geotechnical data for Jack-up operations and aware of the risks." [Ref. 2.7].

The BWEA Guideline itself offers information for Surveys for Jack-up construction/installation vessels to be recommended:

"8.6 Seabed Surface Survey

8.6.1 A seabed surface survey is required to identify natural and man-made seabed features, obstructions and debris. The survey should cover the approach to and the immediate area of the intended location (normally a 500 x 500 m square for offshore and near shore sites) and should be carried out using side scan or sector scan sonar, or other high-resolution techniques producing equivalent or better results.

8.6.2 A magnetometer survey is required to reveal the presence of buried pipelines or cables, lost anchors and chains, military ordnance or other metallic debris lying below the seabed surface. The requirement for a magnetometer survey may be waived in certain areas but the lack of this information should be justified in the site-specific assessment.

8.6.3 Site and location plans based on the seabed surface surveys should identify wrecks and important archaeological sites and/or marine conservation areas that are subject to protection. Sites where seabed or environmental disturbance should be avoided for any reason shall be identified. Specific information concerning the type of activity to be avoided and or seasonal limits or other qualifying conditions related to these areas should be provided.

8.6.4 The appropriate period of validity of the seabed surface survey should be considered in all cases having due regard for the site characteristics and any surface or subsea activity carried out on site since the last survey. As a general rule, the period of validity should be six months or less in uncontrolled areas and areas where no continuous system for reporting marine activity and lost objects exists……....."

and

"8.7 Geotechnical (Soils) Investigation

8.7.1 Site-specific geotechnical information is required. The type and amount of data required will depend upon the particular circumstances such as the type of jack-up, soil conditions and previous experience of the site, or nearby sites, for which the assessment is being performed.

8.7.2 For sites where previous preloading and elevated operations have been performed by jack-ups, it may be sufficient to identify the location of existing jack-up footprints. In this case the details of the previous jack-up footing design and the preload applied should be available and it should be verified that the foundation bearing pressure applied previously was in excess of the pressure to be applied by the jack-up under consideration. In the absence of such verification soil investigation involving boreholes or CPT is required.

8.7.3 The location and number of boreholes or CPT's required should account for lateral variability of the soil conditions, regional experience and the geophysical investigation. A borehole may not be required if there is sufficient relevant historical data and/or geophysical tie lines to boreholes in close proximity to the proposed jack-up location.

8.7.4 The geotechnical investigation should comprise a minimum of one borehole to a depth equal to 30 metres or the anticipated penetration plus 1.5 – 2.0 times the footing diameter, whichever is greater. Investigation to lesser depths may be accepted in cases where only small penetrations are anticipated in hard soils; however, in such cases the advance approval of an geotechnical engineer with appropriate experience with jack-up foundation assessments is recommended and the reduced depth of investigation shall be justified in the foundation assessment.

8.7.5 All layers shall be adequately investigated, including any transition zones between strata, such that the geotechnical properties of all layers are known with confidence and that there are no significant gaps in the site investigation record. Laboratory testing of soil samples may be required.

8.7.6 Geotechnical investigations carried out in connection with construction activities such as pile driving may be of limited use for jack-up site assessments. Care must be exercised to ensure that the soil investigation is adequate in scope and detail for jack-up site-assessment. If in doubt, a geotechnical engineer with appropriate experience with jack-up foundation assessments shall be consulted.

8.7.7 In virgin territory where there is no soil data available, seabed sampling may be carried out from suitable jack-ups prior to installation. In such cases appropriate precautions (Section 18.6) must be taken to ensure the safety of the jack-up during the initial period on location and until the soil investigation is complete.

8.7.8 The nature of the seabed surface soil, together with the water depth and the current and wave regimes shall be assessed to determine whether potential for scour may exist. The assessment should consider whether scour has occurred around existing fixed or temporary structures in the vicinity (if any) and records of previous scour that may have affected earlier jack-up installations. In the event that the assessment indicates that the integrity of the jack-up foundation could be adversely affected then seabed soil samples may be required and a scour analysis should be performed (Section 9.12).

8.7.8 The soil investigation must produce sufficient reliable data on which to base a competent analysis that will provide a recommended soil strength design profile giving lower and upper bound strength estimates. This will be carried forward into the jack-up site-specific assessment (Section 10).”

"9. Jack-up Foundation (Soils) Assessment

9.1 Foundation assessment is required in all cases where the jack-up is to be preloaded and elevated above the sea surface to a working air gap or to the minimum safe survival air gap on location. The scope of the assessment and the amount of data required will depend upon the particular circumstances such as the type of jack-up, the soil conditions and variations in the soil across the site, and upon previous experience of the site, or nearby sites, for which the assessment is being performed.

9.2 The jack-up foundation assessment shall be carried out in accordance with the Recommended Practice or in accordance with another recognised and appropriate code of practice that provides an equivalent level of safety. The assessment shall have due regard for potential hazards listed in SNAME T&R Bulletin 5-5A. Foundation risks are tabulated in Appendix F.

9.3 For jack-up locations where there is no history of previous jack-up emplacement a complete foundation assessment is required. The assessment shall include or refer to a geotechnical report containing the survey records together with their interpretation by a qualified soils engineer plus a leg penetration assessment for the proposed unit or a unit with similar footing design and load characteristics.

9.4 For jack-up foundation assessment at sites where preloading operations have been performed earlier by the same or another jack-up it may be sufficient to identify the location of existing jack-up footprints. In this case the details of the previous jack-up footing design and the preload applied should be available and it should be verified that the footing type was similar to the jack-up under consideration and the foundation bearing pressure applied during the previous installation was in excess of the pressure to be applied for the jack-up considered. In the absence of such verification a complete foundation assessment is required.

9.5 The combinations of vertical and horizontal load shall be checked against a foundation bearing capacity envelope. The resistance factor may be taken as 1.0 when the load-penetration curve indicates significant additional capacity for acceptable levels of additional settlement. Minor settlement not exceeding the limits contained in the Operating Manual may be acceptable provided that:

The jack-up can withstand the storm loading plus the effects of the inclination

The lateral deflections will not result in contact with adjacent structures

The jacking system will remain fully operational at the angle of inclination considered

9.6 Consideration shall be given to the operating limits of the jacking system. The capacity of any jacking system to elevate or lower the hull may be significantly reduced or eliminated by leg guide friction (binding) caused by small angles of inclination. Additionally, some hydraulic recycling jacking systems cannot usually be jacked at angles of inclination greater than 1.0 degree because even this small angle can result in inability to extract or engage the fixed and working pins (or catcher beams).

9.7 Extreme caution should be exercised if the soil profile reveals a risk of punch-through when it should be demonstrated that there is an adequate safety factor to ensure against punch-through occurring in both extreme (abnormal) storm events and operating conditions. Particular attention must be paid to the appropriate safety factor in cases where the jack-up's maximum preload capacity does not produce significantly greater foundation bearing pressure than that to be applied in the operating or survival modes (See Fig.9.1).

9.8 *Calculation of the safety factor against punch-through should normally be in accordance with the Recommended Practice; however, alternative methods that may provide an equivalent or greater level of safety exist and therefore consideration should be given as to which method is appropriate in the circumstances. For this reason reference should be made to other sources of advice contained in UK HSE Research Report 289 - Guidelines for Jack-up Rigs with Particular Reference to Foundation Stability; Noble Denton 0009/ND Rev 4 Dated 16 Dec 2008 - Self-Elevating Platforms - Guidelines for Elevated Operations; and Det Norske Veritas Classification Note No. 30.4. Ultimately, the assessment of punch-through risk requires a high level of expertise and the exercise of sound judgment based on experience.*

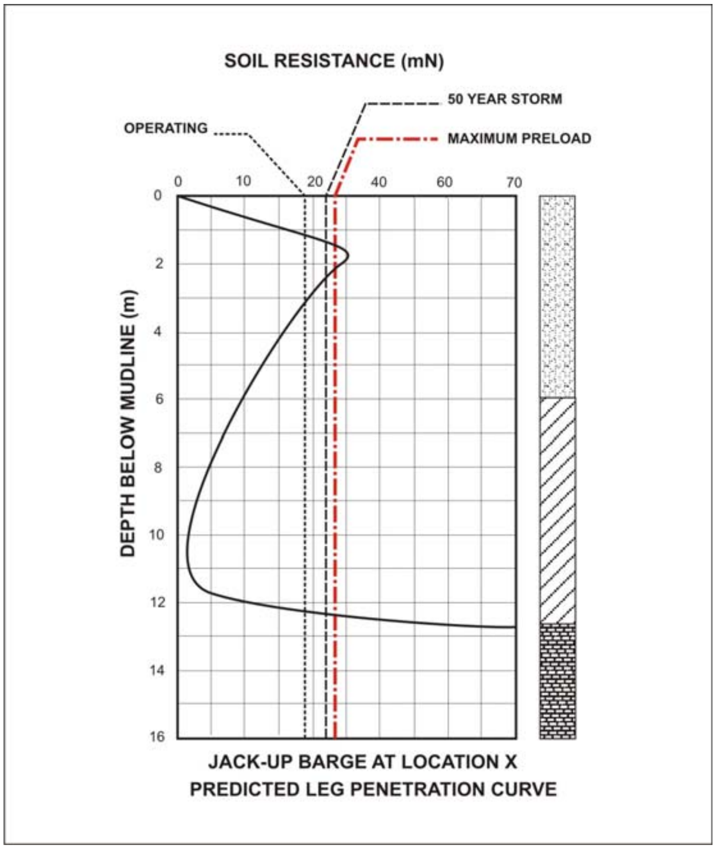

Figure 9.1

9.9 *Consideration should be given to the limits of maximum and minimum penetration as determined by the jack-up design or Operating Manual. In cases where the limits stated in the manual are related simply to a sample elevated condition and the leg length installed, it can be ignored provided the leg length is sufficient to meet the survival air gap defined in the Recommended Practice. An analysis should be carried out for any case where the maximum or minimum penetration limit stated in the manual is related to leg or spudcan structural strength or to the jack-up's capacity for leg extraction.*

9.10 *Particular consideration shall be given to the requirement for extracting the leg footings and the probable effectiveness of the leg jetting system (if fitted). Temporary inability to extract the legs from the soil may involve serious risk if the unit cannot be quickly removed to shelter and/or cannot achieve the elevated survival mode and remain on location.*

9.11 For jack-ups fitted with hydraulic recycling jacking systems there is the additional risk that the jacking system may become temporarily immobilised through inability to extract fixed or working pins during the leg extraction operation. If this occurs during a rising tidal cycle then damage or flooding may result.

9.12 Operations involving leg extraction from deep penetration may be considerably prolonged in cases where deep leg penetration has been achieved, particularly if the leg extraction operation is interrupted by periods of adverse weather. The onset of weather conditions exceeding the limits for refloating the unit will require the jack-up to be re-elevated and preloaded and if this becomes necessary any progress that had been achieved with leg extraction prior to such onset will be almost entirely reversed. In addition to the risk described in 9.9 above, this may have a serious commercial impact in terms of costs caused by an extended delay.

9.13 The potential for seabed scour shall be considered. Special consideration shall be given to the movement of seabed soils caused by currents or waves and the potential impact this may have on the integrity of the jack-up foundation over time. At locations where risk of scour is deemed to exist, the foundation assessment shall include an assessment of the potential depth and rate of soil removal and that may affect foundation stability. The assessment shall include a caution to the effect that special jacking procedures may be required to mitigate the risk of foundation instability and should also recommend scour"

For details of soil investigations and soil sampling guidance as well as foundation design the following is recommended for standard guidance:

- Geotechnical & Geophysical Investigations for offshore and Nearshore Developments International Society for Soil Mechanics and Geotechnical Engineering ISSMGE TC1 - Handbook September 2005.

2.2.3 Applicable Codes and Guidance for Soils and Turbine and Transformer Station Foundations.

The following code and guidance are also recommended:

- Ground Investigations for Offshore Wind Farms, Bundesamt Fur Seeschifffahrt uhd Hydrographie, 25, 2008. This document developed for Germany provides excellent information to be followed for wind farm soil requirements and analysis.

Note: The Marine Procedure for Site Specific Assessment of Offshore Construction and Installation jack-ups is called for in the Safety Management System Template documentation.

2.3 References

[2.1] Guidelines for the Selection and Operation of Jack-ups in the Marine Renewable Energy Industry, BWEA, Pre-Publication Draft October 2009.

[2.2] UKOOA Guidelines for Conduct of Mobile Drilling Rig Site Surveys Volumes 1 & 2 March 1997.

[2.3] Offshore Information Sheet 3/2008: Jack-up (self-elevating) installations: review and location approval using desk-top risk assessments in lieu of undertaking site soils borings, UK HSE, May 23, 2008.
[2.4] Petroleum and natural gas industries, Site-specific assessment of mobile offshore units, Part 1: Jack-Ups, ISO/CD 19905-1.9, ISO TC 67/SC 7/WG 7 Draft.
[2.5] Guidelines for Site Specific Assessment of Mobile Jack-up Units, SNAME 5-5A Rev 3, January 2008
[2.6] Dier A., Carroll B., Abolfathi S., "Guidelines for Jack-up Rigs with particular Reference to Foundation Integrity", HSE Research Report 289, 2004.
[2.7] Jack-up Installation Vessels, City University Paper 2009 by London Offshore Consultants.
[2.8] Ground Investigations for Offshore Wind Farms, Bundesamt Fur Seeschifffahrt uhd Hydrographie, 25, 2008. This document developed for Germany provides excellent information to be followed for wind farm soil requirements and analysis.
[2.9] Sharples, M., Weather Hindcasting: Relevance to the Ocean Engineer, CORE Conference, Halifax 1985.
[2.10] MODU Mooring Strength and Reliability Joint Industry Project managed by ABS Consulting after the Ivan, Katrina and Rita Hurricanes.

3.0 FACILITY DESIGN BASIS

3.1 Bottom Supported Fixed Structure

There are a variety of conditions that can cause failure in a wind turbine structure. The most serious of potentially anticipated incidents would be a tower buckling failure. Figure 8 in Section 1.4.8.5 shows one of several that occurred in Japan as a result of a typhoon where the design load was exceeded.

A common damage to occur to wind farms is from lightning strikes and from blade failures. The blade failures occur most often from conditions not related to the structural loading conditions, as far as can be ascertained. The basis of structural design is the designated design loading conditions (DLCs) set out in IEC 61400-3. These are similar to those of IEC 61400-1 except they account for hydrodynamic loads. DNV requirements follow these loading conditions. GL follow most of these loading conditions in the current 2005 document but add several of their own: and delete DLCs that they believe are not governing. In each case the certification process used allow them to add cases if that is the agreed arrangement made with the stakeholders.

While damage to blades may occur for a variety of reasons, it happens so frequently that it becomes more of a "maintenance" item than it does of a catastrophic failure. The same applies to gear boxes although gear failures have been minimized by the implementation of AGMA 6006 standard. If there is a gearbox failure on a ship, it is equally as damaging to the shipowner as is a gearbox failure on a wind turbine, however, the public does react more strongly to these wind turbine items because the attention currently on renewable energy, and partly because some of the issues have been serial failures.

The concentration on the design loading cases for regulatory purposes is primarily on the tower and foundation loads in this section. The design loading conditions for the jack-up installation vessels on site and the transformer substation are adequately laid out in SNAME 5-5A [Ref. 2.5] and API RP2A [Ref. 2.4] respectively.

3.1.1 Design Load Conditions

The load cases that are laid out in IEC 61400-3 in Section 7, Table 1 encompass a variety of situations.

While it would have been helpful within the IEC document for those crafting the document to point out the critical load cases for the tower itself, and for the blades, noting which load cases govern which component, it seems that Design Load Case (DLC) 2.3, 6.1 and 6.3 are three of the cases that will define the tower thickness for tower structural survival unless fatigue issues govern the tower cross-section. Further parametric study of the loadcases in extreme events likely in the US OCS would be helpful and lead to better understanding of the acceptability of the IEC loadcases for the US application.

The information provided is quoted:

"In DLC 6.1, a yaw error of up to ±15 degrees using steady extreme wind model or ±8 degrees using the turbulent model shall be assumed, provided that no slippage in the yaw system can be assured. If not, a yaw error of up to ±180 degrees shall be assumed."

Presumably it is assumed that the brakes hold the yaw position in the appropriate direction to the wind. If the wind were to shift by more than ±8 - ±15 degrees and the yaw position could not realign (because of strength of the yaw system without brakes, or failure of brakes or control system) then this DLC would not be governing the design.

A key question is how does the designer know if yaw slippage can be assured over the 20-year life of the turbine? If it cannot, it would be up to the designer to warn that conditions could happen outside the design if direction of storms might change more than ±8 - ±15 degrees while either the brakes are on, or the yaw gear cannot for whatever reason re-align the turbine. There appears to be no mechanism incorporated into the turbine information provided in the form in Annex A of IEC 61400-3 to disclose this eventuality. This case requires the wind turbine be lined up in the right direction before the storm and the direction of the storm not to change for the duration unless the yaw system can operate during the storm). Certainly in tropical revolving storm areas this could be an issue. Conditions checked are:

- reference wind speed and 50-year significant wave height (turbulent wind model) $< \pm 8^{o}$ yaw
- 50 year wind speed and associated wave (steady wind model) $< \pm 15^{o}$ yaw
- Associated wind speed and 50 year significant wave (steady wind model) $< \pm 15^{o}$ yaw

If holding the yaw position cannot be accomplished then the designer is forced to consider a ±180 degree yaw. The designer's assumption is not recorded in the information provided in Annex A.

"In DLC 6.2 a loss of the electrical power network at an early stage in the storm containing the extreme wind situation, shall be assumed. Unless power back-up for the control and yaw system with a capacity of 6 hours of continuous operation is provided, the effect of yaw error of up to ±180 degrees shall be analysed."

Conditions checked are:

- reference wind speed and 50-year significant wave height (turbulent wind model) < ±8^o yaw
- 50 year wind speed and associated wave (steady wind model) < ±15^o yaw

If holding the yaw cannot be accomplished then the designer is forced to consider a ±180 degree yaw: the designer's assumption is not recorded in the information provided in Annex A.

These conditions are the same as for DLC 6.1 if you have battery backup of 6 hours. If you don't have a battery backup then you are obliged to check the full ±180 degrees. What is not stated is whether this backup battery is on the turbine or on the offshore or onshore transformer station with the risks that go with a distant battery source (e.g. cable failure). It is also not clear that a 6 hr battery will solve the storm issue for locations in U.S. offshore service. If, for example, the power cable was lost to an anchor then the turbine would be out of power beyond 6 hrs: if there was a storm in the days it took to get repaired then the load could come onto the turbine in any direction and thus DLCs 6.1 and 6.2 may not be sufficient. Since this issue affects the turbine when parked it could lead to a false assumption about the safety of the tower when it is unpowered: thus it should be clearly stated in the documentation.

"In DLC 6.3, the extreme wind with a 1-year recurrence interval shall be combined with the maximum yaw error (yaw tolerance). If not justified otherwise, a yaw error of up to ±30 degrees using the steady extreme wind model or ±20 degrees using the turbulent wind model (to be defined) shall be assumed"

Conditions checked are:

- 1-year wind speed and 1-year significant wave height (turbulent wind model) < ±20^o yaw
- 1- year wind speed and 1-year associated wave (steady wind model) < ±30^o yaw

Under this condition there is no requirement to check the ±180 degree condition.

There is no information provided on load case 2.3 to guide the position for the yaw system. One may be able to presume that the direction of the nacelle is into the wind for this condition, in that it occurs during power production…and is not thusly misaligned: but that fact is not stated.

There is also a need to define whether the ±8 or ±15 degrees is measured at the turbine or at the meteorological tower in the field since these may differ in some storms.

The 1-year return period is in metocean terms defined as the wind speed at the site specific location that is exceeded, at least once per year but possibly more than once:

> Assume you have a wind regime defined by 30 knot winds every hour of the year except for the passage of hurricanes when the winds will be much stronger. So the wind many times goes to just beyond 30 knots but not higher, many times within the year. A 30 knot wind will then be the 1-yr wind and it also occurs many times in the year. 1-year return periods are useful in working with electrical codes and heating/cooling codes where the 1-year event is normally used for efficiency design, i.e. sizing cooling systems. For the few hours per year that the system is exposed to those conditions, it merely operates with reduced efficiency (and at a higher operating cost).

This is an extremely low criteria to apply for any offshore structural purpose and is usually only applied to situation which are temporary and within the period of a 24 hr weather forecast. The definition includes that this 1-year condition is at a specific location, not the worst in a region that historical statistics can predict. Quite often a severe thunderstorm may exceed the level of a 1-year storm.

Thus with this criteria one needs to proceed carefully to examine the assumptions.

Cases 7.1 (strength) and 7.2 (fatigue) refer to a parked and fault condition *"In the case of a fault in the yaw system, ±180 degrees shall be considered. For any other fault, yaw misalignment shall be consistent with DLC 6.1."* Load factors are set at Abnormal for this condition (A=1.1). A 1-year return period is used for this condition.

Design Load Case	Wind	Waves	Wind Wave Directionality	Sea Currents	Water Level	Other Conditions	Type of Analysis	Partial Safety Factor
6.3a	Extreme Wind Speed Model Turb. Wind model $V_{hub}=k_1 V_1$	Extreme Sea State: $H_s=k_2 H_{s50}$	**Misaligned,** Multidirectional in winds and waves can be taken into account	Extreme Current Model (either 1 yr or 50 yr as appropriate)	Normal Water Level Range over 1 year	Extreme yaw misalignment	Ultimate	N= 1.35
6.3b	Extreme Wind Speed Model Steady Wind model $V_{(zhub)}= V_{e1}$	Reduced Wave Ht $H=H_{red1}$	**Misaligned,** Multidirectional in winds and waves can be taken into account	Extreme Current Model (either 1 yr or 50 yr as appropriate)	Normal Water Level Range over 1 year	Extreme yaw misalignment	Ultimate	N= 1.35
7.1a	Extreme Wind Speed Model Turb. Wind model $V_{hub}=k_1 V_1$	Extreme Sea State: $H_s=k_2 H_{s50}$	**Misaligned,** Multidirectional in winds and waves can be taken into account	Extreme Current Model (either 1 yr or 50 yr as appropriate)	Normal Water Level Range over 1 year		Ultimate	A=1.1

The amount of misalignment of the wind and waves is not defined in the code, possibly because it varies from site to site, but it is a basic design assumption, and a conservative value should be advised.

3.1.1.1 Fault Conditions

There have been a number of fault condition anticipated or chronicled that lead to a need to examine the assumptions in the DLCs. Whether there is a battery or emergency generator backup is also noted.

Case 1: Horns Rev

"The transformer station is a three-legged steel structure with all the necessary equipment, including an emergency diesel generator. The weather in the North Sea is very rough and it is very likely that the electricity supply to the wind farm can be cut for prolonged periods at a time in case of cable faults. The generator can supply the station and the wind turbines with enough power to keep all essential equipment (climate conditioning, control and safety systems, yawing system etc.) operating during such periods".

[Reference: Grid Connection and Remote Control for the Horns Rev 150MW Offshore Wind Farm in Denmark, P.Christiansen, Knud Joregensen, Askel Gruelund Sorensen, http://www.owen.eru.rl.ac.uk/workshop_4/pdfs/owen_Christiansen.pdf].

Case 2: Nysted

ISC Innovative engineering brochure on the Nysted Transformer platform [Ref. www.isc.dk] states that they have a emergency generator (90kVA) and a battery backup.

Case 3: Alpha Ventus

Alpha Ventus wind farm offshore Germany has plans to install an emergency generator and diesel tank on board the transformer platform. [Ref: www.abb.com].

Case 4: The following report is typical of many in regards to Martha's Vineyard, which is a close example of expected ability to maintain power from shore:

The ability of the turbines to stay on line without a failure of the system is given in the following damage report: others are provided in the seabed cable section of this report.

Case 5: June, 2007 by Torgny Moller in Windpower Monthly

The world's largest offshore wind station, in the south Baltic Sea off the Danish coast Nysted, is offline, perhaps for several months, following a serious transformer failure on June 9. The transformer feeds the production of the four-year-old 165.6MV Rodsand plant of 72 Siemens 2.3 MV turbines into the Danish grid network. Located ten kilometers south of the large island of Lolland, the 140 ton transformer is being brought ashore for repair, probably in Germany or Sweden. It was supplied by Italian company Tironi.

The reason for the failure is not yet known, but a short circuit is probably to blame. The transformer platform's owner and operator, local electric utility company SEAS-NVE, has been working on solving the problem, particularly the logistics of transporting the huge transformer ashore and getting it repaired. "The failure at Nysted is serious. At SEAS-NVE we have worked with grid connection of wind turbines in most of the world and what has happened here at Nysted is statically very unlikely," says Steen Beck Nielsen.

Revenue losses while Rodsand is out of operation will be shouldered by the owners, electric power companies DongEnergy and E.ON. The transformer, which is insured, is still within its five year guarantee period. No decision has yet been taken about who will pay for the repair."

If 6 hours of battery power is provided, then the case of complete loss of yaw is avoided for 6 hours but if the backup line is cut (assuming the battery is in the transformer station), or the 6 hr limitation is insufficient, a good thunderstorm (may be similar to a 1-year return period site-specific storm) may bring the tower to the brink of the design values or exceed them.

If there is a desire/need to increase the survivability of the wind turbine to a higher level, presumably this may be able to be provided with a UPS system, but the UPS system would have to be appropriately sized.

Figure 14: "The SAFT NiCd cells have a power capacity of 3000 kw for 2 minutes"
Ref: Enercon Windblatt Magazine 03 2009.

On a point of discussion and perhaps a case for further research: it would also be useful to know the extra thickness required for the tower (and therefore cost) in making the tower so that it could withstand a wind load from a 50-year, and 100-year event with the yaw system ±180. The blades, while expensive, are more of a maintenance item than having to replace the entire tower and nacelle after a failure. The critical extreme load cases that determine the blade strength related to 50-year and 100-year criteria would also be useful.

It is up to the risk evaluators and stakeholders to decide if this is an acceptable risk: however, at the moment the code does not reasonably provide sufficient information for the evaluation to take place.

A yaw system (gears, and motor) requires a high reliability to ensure survival over a 25 year life since it has such a critical function.

The DLCs for the Transport, assembly, maintenance and repair is also worthy of scrutiny. The manufacturer designates the criteria appropriate for the equipment. Only if the activity is scheduled to last longer than 1 day is the criteria of a 1-year return period storm considered. This could mean that the transport and/or assembly could be less than the 1-year storm value (as indicated a value which could be equivalent to a severe thunderstorm). The value of the anticipated return period should be geared to a reasonable level – but this may vary depending on location. While it may be appropriate for some operations it may give misleading criteria on some potential activities and should be examined with a Failure Mode and Effect Analysis to substantiate the load case prior to imposing this load case alone.

Relative to East Coast application of offshore wind farms the following notes that there are typical electrical outages in the area:

"Martha's Vineyard loses power By Associated Press, 01/06/00

A large section of Martha's Vineyard is without power today because of an equipment problem on the mainland. Commonwealth Electric spokesman Mike Durand said the outage is affecting about 3,500 customers in Edgartown, Tisbury and West Tisbury. Durand said the equipment failure occurred at 9:45 this morning in Falmouth knocking out power that is fed to Martha's Vineyard through an undersea cable. The utility is hoping to get a diesel generator up and running on the island while repairs are made on the mainland."
[Ref: http://www.boston.com/news/daily/06/marthas_vineyard.htm].

In review of DNV-OS-J101 (2007) this standard has the same load conditions of IEC 61400-3.

In review of Germanischer Lloyd Certification of Offshore Wind Turbines 2005 the loading conditions quoted different from the IEC Standard:

- IEC Load cases 1.6 a and 1.6 b are missing;
- IEC Load cases 2.3 is missing;
- GL add cases on Temperature and Earthquake effects;
- IEC Load case 6.3 in GL are titled "Extreme oblique inflow" whereas in IEC and DNV they are called "yaw misalignment";
- IEC Load Case 7.1a is missing from GL;
- GL has added a load case for boat impact: their 8.5.

GL has indicated that a number of the load cases were not governing and so were omitted from their standard, whereas they believe some of the other ones are required. The issue of load cases requires further scrutiny and alignment: thus the recommendation for an FMEA to be performed on a site-specific basis, until it becomes clear the various appropriate load cases for US OCS application.

Nevertheless in the detailing of assumptions in the load cases there would be benefit to the regulatory in providing more clarity. It would also be beneficial to document for each of the load cases the critical component.

3.1.2 Foundations

3.1.2.1 IEC CODE

The IEC Code 61400-3 advises that:

"Account shall be taken of the soil properties at the site, including their time variation due to seabed movement, scour and other elements of seabed instability."

"Section 11: The foundation shall be designed to carry static and dynamic (repetitive as well as transient) actions without excessive deformation or vibrations in the structure. Special attention shall be given to the effects of repetitive and transient actions on the structural response, as well as on the strength of the supporting soils. The possibility of movement of the sea floor against foundation members shall be investigated. The loads caused by such movements, if anticipated, shall be considered in the design."

It goes further in section 12.15 – Assessment of soil conditions:

"The soil properties at a proposed site shall be assessed by a professionally qualified geotechnical engineer.

Soil investigations shall be performed to provide adequate information to characterise soil properties throughout the depth and area that will affect or be affected by the foundation structure. The investigations shall in general include the following:

- *geological survey of the site;*
- *bathymetric survey of the sea floor including registration of boulders, sand waves or obstructions on the sea floor;*
- *geophysical investigation;*
- *geotechnical investigations consisting of in-situ testing and laboratory tests.*

In order to develop the required foundation design parameters, data obtained during the investigations shall be considered in combination with an evaluation of the shallow geology of the region. If practical, the soil sampling and testing program should be defined after reviewing the geophysical results.
Soil investigations shall include one or more soil borings to provide soil samples for in-situ tests and laboratory tests to determine data suitable for definition of engineering properties. The number and depths of borings required shall depend on the number and location of wind turbine foundations in the offshore wind farm, the soil variability in the vicinity of the site, the type of foundation, and the results of any preliminary geophysical investigations. Cone penetration tests (CPT) and shallow vibro-core borings may be used to supplement soil borings in the soil investigation. Site-specific soil data shall in principle be established for each foundation within the wind farm. CPTs may be used for this purpose at wind turbine locations where soil boring is not undertaken. For calibration of the CPTs, one CPT shall be performed in the close vicinity of one of the soil borings.

The soil investigation shall provide the following data as the basis of the foundation design:

- *data for soil classification and description of the soil;*
- *shear strength parameters;*
- *deformation properties, including consolidation parameters;*
- *permeability;*
- *stiffness and damping parameters for prediction of the dynamic properties of the wind turbine structure.*

For each soil layer these engineering properties shall be thoroughly evaluated by means of appropriate in situ and laboratory testing.

The assessment of soil conditions shall also consider the potential for soil liquefaction, long term settlement and displacement of the foundation structure as well as the surrounding soil, hydraulic stability and soil stability characteristics."

Surveys are carried out as part of the SAP. Typical tests carried out include:

- Bathymetric surveys (sonar) locate wrecks, pipelines and other obstacles.
- Tests on the bottom material itself including Cone Penetrometer Tests (CPT) and Standard Penetration Tests (SPT), core drilling in soils and rocky materials, Menard –pressure meter tests, offshore vibrocoring and bottom sampling.

The support types for offshore oil and gas structures is not very different from the requirements laid out for offshore wind structures: the calculations, however, need to be more precise particularly for non-redundant structures such as monopiles which carry more cyclic loads with possibly severe consequences for the structure if reality is different from the calculated model in an un-conservative direction.

Most of the offshore oil and gas structures are dominated by the forces of waves, and only a steady state wind is generally used to design offshore structures and thus have not included the dynamic components necessary for offshore wind turbine structures. Wind turbine structures are in general more dynamic i.e. they oscillate more than a typical oil and gas platform as the forces are applied to them. The differences only serve to require somewhat more detail than is sometimes applied to offshore platforms, where the soil conditions may be assumed over a field. Precise data for each turbine location may be needed for individual turbines depending on the site-specific area.

Because of the oscillating loads the foundations of monopiles experience larger shears and bending moments and smaller axial loads requiring that the designer consider cyclic loading of the near-to-surface soils. This cyclic loading in the surface soils combined with the possibility of scour, particularly if the currents are reasonably large requires the designer's attention. Because of the lack of redundancy in the monopole foundations meticulous attention has to be paid to the issue of soils, more so than an "average" platform. Monopiles with minimum production equipment have been used in the Gulf of Mexico: many were destroyed in Hurricane Andrew probably due to lack of consideration of dynamic loads at the time. A number of lessons were learned: approximately 100 caisson structures were tilted during Hurricane Andrew [Ref. 3.1.30].

Guidance on piled foundation design and grouted connections is available in American Petroleum Institute, Recommended Practices for Planning Designing and Constructing Fixed Offshore Platforms (API RP2A), and NORSOK N004 Design of Steel Structures. The piles can be drilled and cemented or driven depending on the soils.

Pile driving is usually a less weather sensitive method of installation but maintaining heading with driven piles is more difficult. Transition pieces are used to assure that any pile angle is compensated for and grouting these in place in order to assure the tower is vertical is critical to the production of electricity.

Concrete gravity based structures have been successfully used e.g. Middelgrunden, Vindeby and Tuno Knob offshore Europe. ACI 318-08 is a suitable standard for design in Concrete. ACI 357R Guide for the Design and Construction of Fixed Offshore Concrete Structures also offers useful guidance.

The natural period of the wind tower is determined by the weights and distribution of weights, the stiffness of the tower and also by the soil characteristics and stiffness of the soil-tower interface. Knowledge of the soil data particularly near the surface is critical. Any variation within the field of turbines must also be known accurately thus sometimes requiring more boreholes than the minimum. Based on knowing the effect of the blades passing the tower, the rotor itself, the waves and wind characteristics, and the soil information it is possible to calculate the natural periods to be avoided in the design to ensure minimum possibility of resonant response.

One experience is noted *"it was observed at Lely that the behaviour of two of the OWECs (Offshore Wind Energy Converters) was stiffer than predicted…It was fortunate that the exclusion period was avoided, although it must be noted that this was purely chance".* (Ref: www.offshorewindenergy.org).

The foundation stiffness can be affected by scour which has occurred at several wind turbine sites e.g. Scroby Sands, and Prinses Amelia where granular soils and high currents were a factor.

"Following the bathymetric surveys some scour pits have been identified with a depth of 5 m and diameter of 60 m around each turbine, which were predicted by the original EIA. We now have an improved understanding of the extent of this scour and importantly the scour tails local to each turbine and in each area of the wind farm. This information will be useful in determination of the necessity for scour protection in future years." [Ref. 3.1.37].

Each of the turbine structures had been backfilled with rocks on original installation.

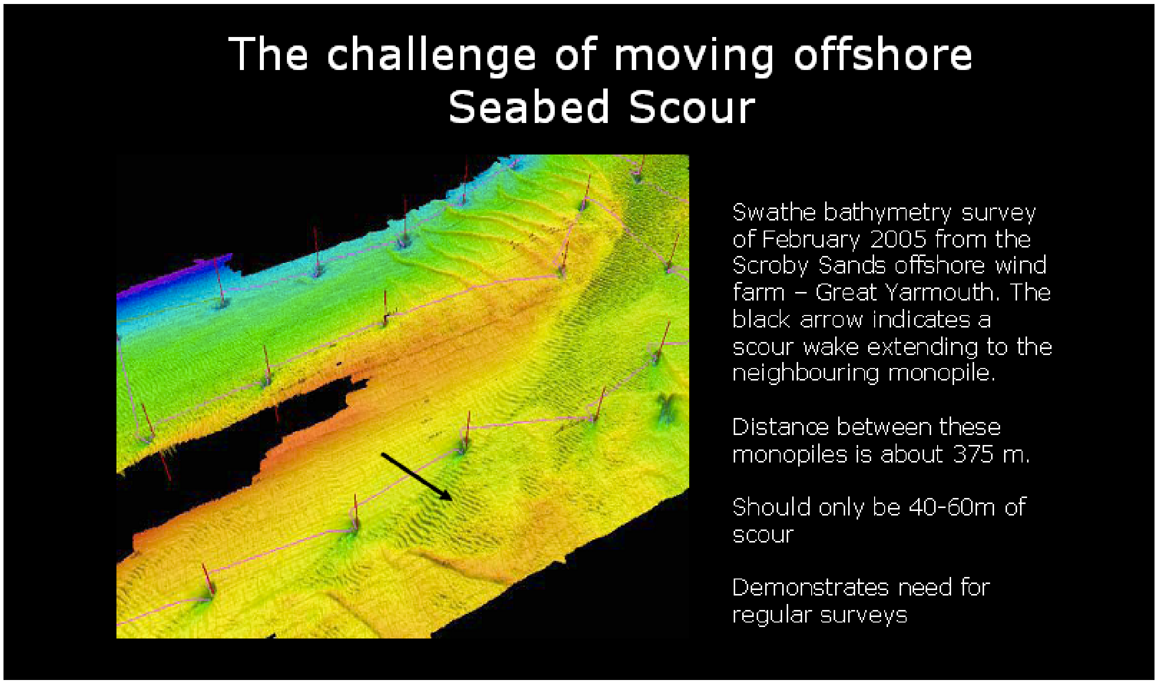

Figure 15 [Ref. 3.1.38]

Waves, as well as wind and currents affect the natural period of the structure. In shallow water there are many more cycles of low periods in a stress region where more cycles are available. As water depth increases, so the natural period increases and the stress region has less available cycles. This makes structures that have more than a single pile, and concrete structures a preferred solution as the depth of water increases. The effect of excitation and also damping is taken into account, or loads must be assessed conservatively if sufficient data is not available. The soil is an important factor in this evaluation.

3.1.2.2 Vibrational Characteristics of Foundations

In selecting the foundation it is appropriate to select it based upon an optimized combination of turbine and tower structure, and foundation structure. To a certain extent it is a balance because of the dynamic nature of the turbine structure:

- Gravity foundations are "stiff" and do not move to accommodate an oscillating tower (even though the oscillations are small). *"For this reason, the aerodynamic damping of the rotor cannot contribute much to a softer response of the structure so that the load spectrum remains relatively hard with respect to the fatigue strength."* [Ref. 3.4.2];
- Monopile foundations are considered "soft". *"The natural frequencies of the tower of the wind turbine can only be determined in the overall "tower with monopile" system. The soft response of the structure effectively reduces the fatigue load spectrum. Since this design is capable of vibration, however, the*

length and thus the range of application, is also restricted with regard to depth of the water to a maximum of 25m according to current opinion." [Ref. 3.4.2].

- The tripod structure, or jacket structure can be used in greater waterdepths, where the determination of how much it can be considered to soften the response for fatigue loading is a function of waterdepth and structural considerations.

Other possible foundations include the suction caisson also known as bucket foundations [Ref. 3.1.5], [Ref. 3.1.32].

For any of these foundations detailed soil information is needed and measured tests prior to developing the design calculations. The successful installation of many suction piles in the Gulf of Mexico as deepwater mooring anchors have depended on soils information at each suction pile location. There have been occasional failures of the suction pile to install correctly when the information was not sufficiently detailed.

Specifications by turbine manufacturers to the foundation designers are horizontal loads, vertical loads, bending moments and rotation stiffness. It may be possible to design foundations in a more efficient way if other parameters were specified such as the maximum displacement or maximum oscillating loads in the various operating situations. Designers mention this and it is also mentioned by Kirk Morgan:

> *"Horizontal stiffness as well as coupled stiffness (off-diagonal terms in stiffness matrices) are sometime specified in addition to rotational stiffness because they are necessary for design of other (deep) foundation types…."* [Ref. 3.1.28].

Because the wind turbine structures impose complex loadings on the foundation, much more complex than those of offshore oil and gas platforms, it is important to have a precise information about the soil conditions for which the foundations are designed.

Because of the requirement to be vertical within very tight tolerance over a long period of time it is important to be assured that there is no angular translation of the foundation.

"As relevant to the design, the geotechnical site investigations should provide the following types of geotechnical data for the soil deposits:

- *Data for soil classification and description of the soil*
- *Shear strength parameters*
- *Deformation properties, including consolidation parameters*
- *Permeability*
- *Stiffness and damping parameters for prediction of the dynamic behaviour of the wind turbine structure."* [Ref. 3.1.15].

3.1.2.3 Applicable Codes

A variety of codes provide adequate calculation methods for the appropriate foundation and thus it becomes largely a matter of choice. The BSH document [Ref. 1.2] provides guidance particularly suited to offshore wind farms. The Handbook of ISSMGE [Ref. 2.8] is particularly helpful in carrying out the soil investigation work. Any of the various standards are suitable for design of the foundation structure subject to the usual cautions. The GL and DNV Guidelines are updated on a regular basis and are also geared toward Offshore Wind Turbine structures. API RP2A is more relevant for the Offshore Transformer Substation.

Ground Investigations for Offshore Wind Farms, Bundesamt Fur Seeschifffahrt uhd Hydrographie, (BSH) [Ref. 1.2]. This document developed for Germany provides excellent information to be followed for wind farm soil requirements and analysis.

Recommended Practice for Planning, Designing, and Constructing Fixed Offshore Platforms. API RP 2A gives good information for piles as foundations which may be useful in determining the design requirements. It does not address what soil sampling or tests need to be done nor does it provide adequate guidance on what can be done. It does not address dynamics on the soil or give guidance on gravity structure foundations.

Recommended Practice for Planning, Designing, and Constructing Structures and Pipelines for Arctic Conditions API RP 2N 1995. This recommended practice contains considerations that are unique for planning, designing, and constructing Arctic systems. The systems covered in this recommended practice for the Arctic environment are:

- Offshore concrete, steel, and hybrid structures, sand islands, and gravel islands used as platforms for exploration drilling or production.

- Offshore ice islands used as platforms for exploration drilling.

For concrete structures:

Guide for the Design and Construction of Fixed Offshore Concrete Structures (Reapproved 1997), American Concrete Institute: ACI 357R-84.
Germanischer Lloyd Guideline for the Certification of Wind Turbines 2005: Chapter 6 deals with Foundations and Subsoil. Both piled and gravity type designs are covered. For load bearing of the soil API RP2A-LRFD 1993 is cited as being appropriate or comparable standards. GL load cases are virtually the same as IEC for cases that will affect the foundations plus some additional cases.

For soil information GL relies up on the work being done to the BSH standard [Ref. 1.2].

GL insist on the following:
- *"design of the permanent scour protection has to be backed up by model tests"*.
- Periodic inspection of the scour protection.

DNV Offshore Standard DNV-OS-J101 Design of Offshore Wind Turbine Structures June 2004 and DNV Offshore Standard DNV -OS-C502 Offshore Concrete Structures are suitable for steel and concrete foundations respectively.

DNV refers to the IEC loading conditions: "Practical information regarding wind modeling is given in IEC 61400-1 and in DNV/Risø Guidelines for the Design of Wind Turbines". DNV applies loading conditions of the 50-year extreme wind with the 10-year significant wave, and the 10-year wind with the 50-year significant wave, which is a different and possibly a better representation than the reduced wave height used in the IEC Code. They provide good rationale for the selection of load combinations.

For soil boring no specific document is sited for the soil investigation work however the following provides details of their position on acceptable soil boring information.

"For wind turbine structures in a wind farm, a tentative minimum soil investigation program may contain one CPT per foundation in combination with one soil boring to sufficient depth in each corner of the area covered by the wind farm for recovery of soil samples for laboratory testing. An additional soil boring in the middle of the area will provide additional information about possible non-homogeneities over the area.

For cable routes, the soil investigations should be sufficiently detailed to identify the soils of the surface deposits to the planned depth of the cables along the routes.

Seabed samples should be taken for evaluation of scour potential."

DNV covers the complete range of foundation types and calculation methods.

CVA

The loading cases and soil conditions affect the structural design of the wind turbines, thus the CVA when involved would be engaged in the process of examining the soil data, the assumptions, the design calculations, the manufacturing of the foundations and the installation in the same customary role as the CVA is used in oil and gas operations.

The CVA process may be used for site assessment of temporary jack-up structures on site provided the CVA offers and is skilled in marine warranty services or is similarly qualified to carry out such work.

Type Certification

Type Certification is inappropriate for this activity in the offshore context.

Project Certification

DNV or GL Guides are suitable for the purpose of project certification of soil conditions. It would be recommended that both use the BSH [Ref. 1.2] as additional guidance in the certification process.

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3.2 Floating Facility

The floating facility has the same load case requirements as in 3.1.1 above for the fixed platform tower structure and blades. The item of the "floating platform" requirements are substantially very similar to those issues in oil and gas floating installations. The effect of waves as close into the coast will have to be taken into account. The mooring system will have to be capable for a "permanent installation" currently considered for 100-year return period capability according to methods described in API RP 2SK.

3.2.1 Anticipated Requirements

The requirements according to 30 CFR 285 are as follows:

"(b) For any floating facility, your design must meet the requirements of the U.S. Coast Guard for structural integrity and stability (e.g., verification of center of gravity).

The design must also consider:

(1) Foundations, foundation pilings and templates, and anchoring systems; and
(2) Mooring or tethering systems.

(c) You must provide the location of records, as required in § 285.7 14(c).

(d) If you are required to use a CVA, the Facility Design Report must include one paper copy of the following certification statement: "The design of this structure has been certified by a MMS approved CVA to be in accordance with accepted engineering practices and the approved SAP, GAP, or COP as appropriate. The certified design and as-built plans and specifications will be on file at (given location)."

Floating systems in US require the approval of the USCG. The USCG has no specified requirements for offshore wind farms and/or their structures. The most probable path an owner would adopt would be to get classification approval from a Class Society e.g. ABS, Bureau Veritas, DNV, Germanischer Lloyd, or Lloyds Register of Shipping and have them designate a new "notation" for this type of unit. The stakeholder selected class society would then work with the USCG to develop the specific USCG requirements for the subject vessel.

Class Societies have a custom of providing "Approval in Principle" documents for the Concept stage of development and provide these for a reasonable review of the Concept at commercial prices.

3.2.2 Applicable Codes

Class Societies would typically cover the following issues – as would USCG.
There is currently no Memorandum of Understanding issued between MMS and USCG on the shared responsibilities, but it would probably be done as the first project requests approval. While it is impossible to know what systems would become whose responsibility, the following chart gives a "best guess" at what USCG might take responsibility for and which codes might be applied.

Item	System	Subsystem	Regulations	Potential Applicable Codes & Standards; Approval Process
1	**Design & Operating Overview/Plan**			
		Design Basis Document 1) Description of the facility and its configuration, 2) Design methodology, including method of analysis, design codes and regulatory, requirements and environmental criteria and loading, 3) Design overview of primary structure and mooring systems, 4) Design overview of electrical and control systems, 5) Design overview of marine and utility systems, 6) Design overview of fire-protection, lifesaving equipment and safety systems, 7) Design overview of the in-service inspection plan for the hull including philosophy, methodology and drawings of areas to be inspected, 8) Intact and damage stability calculations. 9) Description of any unique design aspects that alleviate the negative consequences of damage stability scenarios, facilitate safe operations or enhance maintenance and inspection requirements, and 10) For used or converted facilities, a summary of previous service, certifications and an overview of any structural modifications intended.		
		Design Met-Ocean Conditions - for intact and damage stability and for moorings		
2	**Structural Integrity**			
		Structural integrity, modifications for construction and repair requirements: 33 CFR Subchapter N would probably form the basis of fabrication, installations, and inspection of floating units. This aspect may also be reviewed by the MMS CVA.	30 CFR 250, Subpart I	API RP 2A, API RP 2FPS, ABS Rules for Building and Classing MODU'S, AISC, AWS D1.1
3	**Stability**			
		Design environmental conditions - intact and damaged stability	46 CFR 170	API RP 2FPS
4	**Station Keeping**			
		Mooring and tethering systems - also addressed under the CVA program	30 CFR 250, Subpart I	API RP 2SK, API RP 2I, API RP 2SM,
5	**Utility Systems**			

		Boilers, pressures vessels, waste heat recover (from any engine exhaust), water heaters and other piping machinery	46 CFR 56 & 58	Some equipment type approved
		Seawater supply includes sea chests and sea chest valves supplying water to such systems as ballast system, fire main system and engine cooling system	46 CFR 56 & 58	ASME B31.1ASME B31.3
		Compressed air	46 CFR 56 & 58	ASME B31.1 Start air receivers, start air piping
		Potable wash and sanitary water- FDA review of potable water	46 CFR 56 & 58; 21 CFR 1240 & 1250	
		Sewage unit & piping	46 CFR 56 & 58; 21 CFR 1240 & 1250	
		Diesel fuel	46 CFR 56 & 58	
		Bilge & ballast, including pumps and related control systems	46 CFR 56 & 58	
6	**Elevators for Personnel**			
7	**Fire Protection**			
		Fire protection, detection, and extinguishing systems	46 CFR 56, 58, 108 & 113	
		Structural fire protection for accommodations	46 CFR 108	
8	**Safety Systems**			
13.d		General alarm - for anytime the equipment is manned	46 CFR 113	
9	**Electrical Systems**			
		Emergency lighting power generation and distribution	46 CFR 112	API RP 14F
10	**Aids to Navigation**			
		Negotiated with USCG and other agencies at the specific site.	33 CFR 67, 46 CFR 111 & 112	
11	**Communications**		46 CFR 113	
12	**Pollution Prevention**			
		Garbage and plastics per the International Convention for the Prevention of Pollution from Ships MARPOL. 73/78	33 CFR 151	
13	**Cranes and Material Handling Equipment**			
		Crane design, certification, and operations Crane Design, construction, and testing will be certified by a recognized organization such as ABS or ICGB	46 CFR 58, 46 CFR 108	API RP 2D & Specification 2C

14	**Ventilation**			
		Accommodations and machinery spaces including ventilation of any emergency hold locations for personnel	46 CFR 108, 110 & 111 NVIC 9-97	
15	**Life Saving Equipment**		**46 CFR 108 & 160**	
		Equipment should always be USCG approved. Equipment provided will be based on occupancy and potential escape requirements on site specific basis.		
16	**Workplace Safety and Health**			
		Personnel protection equipment -may be governed by MMS requirements but may need to be measured against USCG requirements.	33 CFR 142, 46 CFR 108 & 160	Safety Management System Template
		Hazardous material storage & handling (if applicable e.g. diesel for generators)	46 CFR 147	
17	**Living Quarters and Accommodation Spaces**			
		Any permanent quarters will be specifically reviewed through the Marine Safety Center. Temporary approvals would be expected through local USCG OMCI.	46 CFR 108 NVIC 9-97;	NFPA 251, NFPA 252
18	**General Arrangements**			
		Access/egress & means of escape	33 CFR 142, 143 & 146, 46 CFR 108	
		Safety plan, fire control or fire equipment, and lifesaving equipment plans		
19	**Miscellaneous Systems and Operational Requirements**			
		Structural inspection requirements for the hull and structures relating to marine systems, life saving, accommodations, crane foundations and other appurtenances. Likely inspection requirements will correspond to at least API RP2 A	33 CFR Subchapter N & 30 CFR 250 Subpart I USCG Policy	API RP 2A MMS requirements may be met with possible USCG review based on (In-Service Inspection Plan) requirements per policy letter.
		Personnel requirements for marine and lifesaving operations	46 CFR 12 & 13, 46 CFR 109	
		Emergency Evacuation plans	33 CFR 146	
		Drill - fire, abandon, and lifeboat	46 CFR 109	
		Inspection and testing of marine and lifesaving equipment	46 CFR 107 & 109	
		Diving operations & equipment	46 CFR 197 Subpart B	
20	**Plans**			
		Emergency Evacuation Plans	33 CFR 146.140	
		Securing Plan		

		Mooring Inspection Maintenance Repair Replacements - if moorings are synthetic.		

All the major classification societies have specialized Rules for floating equipment. ABS has a variety of them as does DNV. GL also considers floating structures referring to GL Rules on Offshore Installations and Floating Production, Storage and Off-Loading Units for the guidance.

SMS

It may be necessary to review the Safety Management System in view of issue with the floating facility in that lifesaving equipment may need to be enhanced, and procedures for being boarding, and for being on board may need to be reviewed.

CVA

The CVA function would be carried out in the same way it is now for oil and gas facilities for the hull. The CVA process for the production plant (wind turbine and associated equipment) would be carried out as an industrial system so far as USCG is concerned and thus fire protection and lifesaving issues are addressed. So far as MMS is concerned the wind plant on the floating structure would be treated much the same as the process on a fixed structure.

Type Certification

Not Applicable

Project Certification

Project Certification is effectively the same as Classification: thus Classification will be of assistance in the approval process for the hull, similar to what now happens on classed structures that are in the oil and gas service. If the classification route were not chosen for the hull the foregoing documents would compel similar checks but to the USCG requirements for domestic vessels. Manning requirements would need special negotiation with USCG.

3.4 Blades

Blades are one of the most complex parts of a wind turbine design.

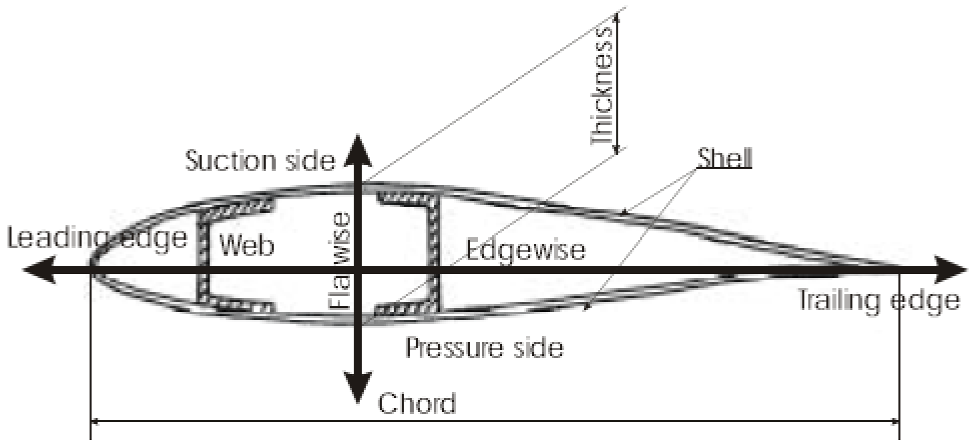

Figure 16 [Ref. 3.4.2]

The requirements on the blade manufacturer are many and varied:

- The blades need to be designed to a 20-25 year life;
- Since blades are subject to lightning, lightning protection must be embedded in them such that the strike can be transmitted through the blade/tower interface and into the ground. (Note: GL 2005 and DNV-OS- J-102 mandate lightning protection for blades);
- Deflection under extreme winds, need to be such as not to hit the tower;
- The edges must not erode;
- They are subject to inspection and cleaning;
- They must be tested to ensure that they will stand up to a lifetime (25 years) in the wind;
- Their quality control must be impeccable as moisture inside can affect the lightning resistance, and errors in bonding surfaces can affect strength: the consequence of which are high when considering the cost of replacement of blades offshore;
- The design needs to take in to account of the average strength, and gustiness of the wind: in some areas of lower wind the designs are different than for areas where strong winds blow constantly;
- They may have to resist extremes of temperature;
- They need to be robust enough to be transported by road, rail or sea, and there need to be fasteners for lifting and designated lift points;
- Accuracy needs to be sufficient that the blades always fit the rotor they are designed for as they are held on by multiple bolts;
- Protection from leading edge erosion needs to be considered;
- Blades for any specific turbine need to be as close to identical to ensure minimum requirements for balancing;
- It may be necessary to de-ice them in certain locations/conditions;

- o Ideally they should be monitored for deflection and fatigue and details recorded to be able to predict maintenance issues;
- o The blade needs to resist the loads imposed by various combinations of speed and braking according to various different load combinations.

The loading conditions are severe but generally it appears that fatigue is the main consideration rather than strength.

"Parked Rotor at Extreme Wind Speeds: it is generally when the rotor is parked that the wind turbine has to cope with the highest wind speed, the so-called survival wind speed. For turbines with pitch control it is assumed that the rotor blades are in the feathered position and that the rotor is aligned with the wind. Under these conditions, the load level is much lower than under cross-wind conditions. Naturally, the precondition for this is that the yawing system and the blade pitch control are functional when the survival wind speed occurs." [Ref. 3.4.2].

"Rotor emergency stop: ....With large rotors and under certain circumstances, this situation can increase bending stress on the rotor blades up to a strength limit."

Design Driver		
Component	Ultimate	Fatigue
Rotor Blades and Hub		●
Drive Train		
Low-Speed Shaft		●
Gearbox		●
High-Speed Shaft	● (breaking)	
Nacelle		
Bedplate	● (stiffness)	●
Yaw Drive	● (breaking)	
Tower	● (stiffness, stability)	
Foundation	● (breaking)	

Table 6.18 Typical situation of design drivers for the wind turbine components

[Ref. 3.4.2])

One manufacturer describes their process as follows: [Ref. www.lmglasfiber.com]:

"LM blades are built from the outside in. In fact, we start by painting the blades, before working our way into the structure in this order:

- *mould prepared*
- *gelcoat sprayed into the mould – creating the protective surface of the blade*
- *glass fibre laid out (supporting layer)*
- *bushings installed*
- *balsa/foam installed*
- *glass fibre laid out over the balsa and bushings *
- *vacuum film placed over glass fibre and balsa*
- *resin infused*
- *vacuum film removed*
- *sandwich web installed*
- *lightning conductor, etc. installed*
- *adhesive applied to edges of the shells and to the webs*
- *shells are bonded*
- *blade removed from mould and given final finish (cutting and grinding).*

After the blade is complete, if defects are found they need to be repaired before leaving the factory using ultrasonic techniques and infrared thermography".

Some production defect types for blades include:

- Delaminations
- Core-skin debonds
- Lack of bond between core sheets
- Dry zones and voids in laminates
- Face sheet wrinkles
- Geometric imperfections [Ref. 3.4.5].

The literature is extensive on blade failures which are often blamed on manufacturing issues. To introduce some of the issues we selected a presentation made at a recent reliability workshop on the subject by Dr. Wetzel where he outlines some common blade manufacturing issues:

Figure 17

The explanation given encompasses many issues to do with type approval of blades when there are only one or a few tests of the prototype.

As seen in these illustrative slides from the Sandia National Laboratory Workshop on Reliability 2009 [Ref. http://www.sandia.gov/wind/reliabilityworkshop_09.htm], lab quality material tested does not always reflect the material in production. The illustration also targets the certification process as occurring too late to be as helpful as it might be. Some of this may be a function of the selection of certifier by the manufacturer, instead of the selection and payment by the end user. Some of this may be due to the fact that this is a fast moving industry and the number of experienced personnel in the area of certification, as with the rest of the industry is likely to be difficult to keep up with. Pressing schedules is also likely to be a contributor as we move forward. This is summarized in a presentation by Gary Kanaby at Wind Energy Update Conference in March 2009 where the following were listed as Causes of New Wind Blade Problems:

- Accelerated production due to market demand
- Accelerated production due to the necessity of recycling molds once/day
- No time for long field & fatigue testing
- Design models need improvement
- Designs to lower costs
- Safety margins reduced
- Scaling up is not easy.

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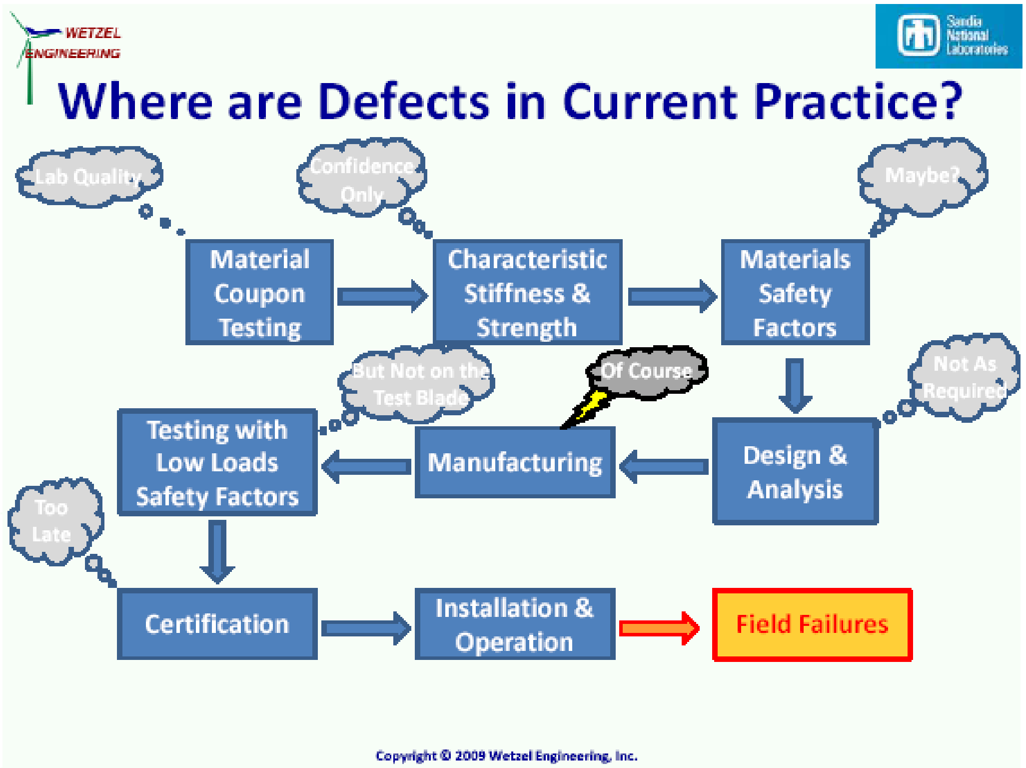

Figure 18

….and

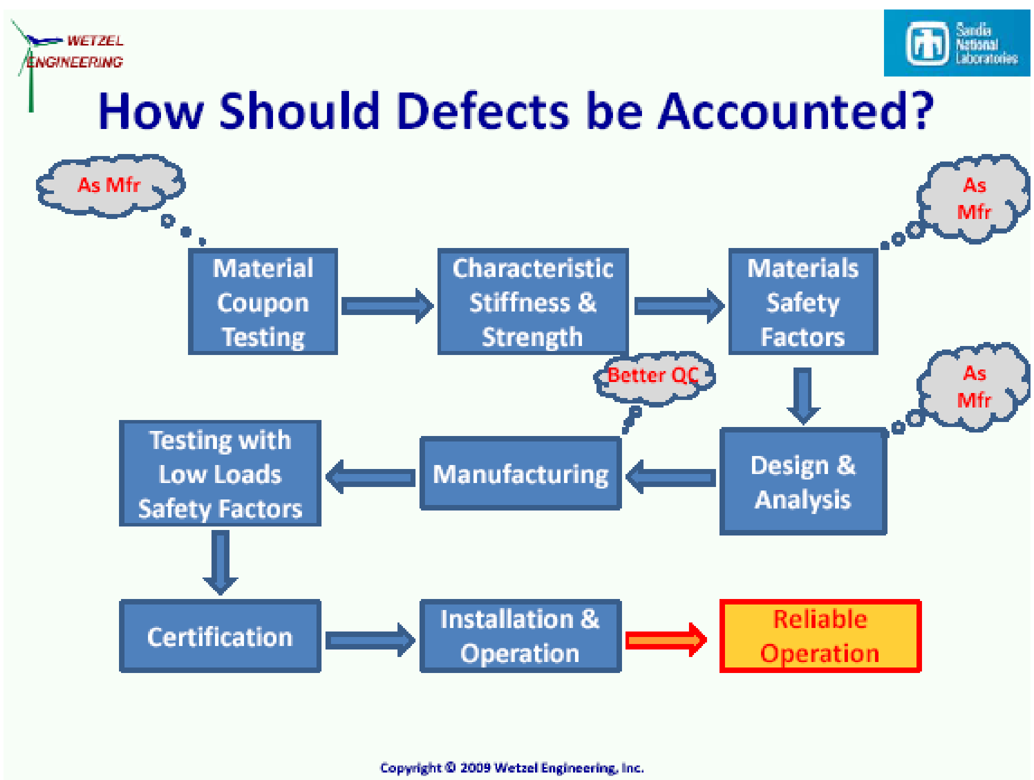

Figure 19

DNV presented a "white paper" which provides helpful insight to how the wind turbine blades differ from other structures such as metallic structures (e.g. airplane wings). [Ref. 3.4.6]

"The design procedures applied in the wind industry today are based on the methodology used for steel structures. Common steel structures are not very sensitive to material flaws due to the redistribution of stresses that take place when smaller flaws are overloaded by ultimate and fatigue loads. For this reason steel structural design practice use strict requirements to plasticity of the material expressed in delivery condition, process control and test requirements such as normalizing the steel before delivery, hardness control, test of elongation at fracture and Charpy testing for base material and welding etc. Design of steel structures is based on the huge experience database and important resistance descriptions for ultimate and fatigue loads can be found in technical standards. The NDT methods allow for very reliable measures for defects and damage progression in-service as steel is a homogenous material.

Composite structures differ from steel structures as they normally have very little plastic redistribution of stresses and become sensitive to defects and flaws. The damage progression is much more complex and has to be handled on a case to case basis. NDT is still not very well implemented in the composites industry due to the complexity of interpretation of the measurements in the complex non-homogenous material that further often allow for poor penetration of ultrasound or x-rays.

Control of defect and damage progression is a necessary part of wind turbine blade design in the future."

The idea is that you define the defects ahead of time expected in manufacturing and make predictions based on a flawed blade has far reaching effects. *" This is a huge evolution of the common approach today where S-N curves developed with coupons are representing material strength and highly empirical knock-down factors are used to compensate for defects in the blade structure. However, it is clear that further research into damage progression for composite materials and the inspection methods are required before the level of insight for steel structures is reached."*

According to IEC 61400-23 an "average" blade is tested whereas it may be more appropriate to test a flawed blade.

Another key point that the authors make is that *"test load directions must be specified more accurately as the complex deformation of the blade cross section leads to important strains and stresses."*

Since the CVA function may have a role in this process it may be possible to add value by doing more in the way of checking during the production process. There are many opportunities for damage to the blades during loading, transportation, and installation. There have been cases of damaging blades during shipping into U.S. ports, road transportation, installation and extreme care will be needed to ensure that does not happen on offshore sites where the probability of damage is likely higher without even more increased care.

It is thus up to the code checks to ensure a minimum standard. Marine procedures for loadouts and transportation are referenced in the Safety Management System template.

Criteria for loadout and transportation are available through insurance warranty surveyors such as Matthews-Daniel, Noble Denton, through DNV Marine Operations and other like publications.

The function of the IEC Code is well illustrated by a slide in Gary Kanaby's presentation at Sandia Reliability Workshop 2009 "Manufacturing Blades for Turbine Reliability"..

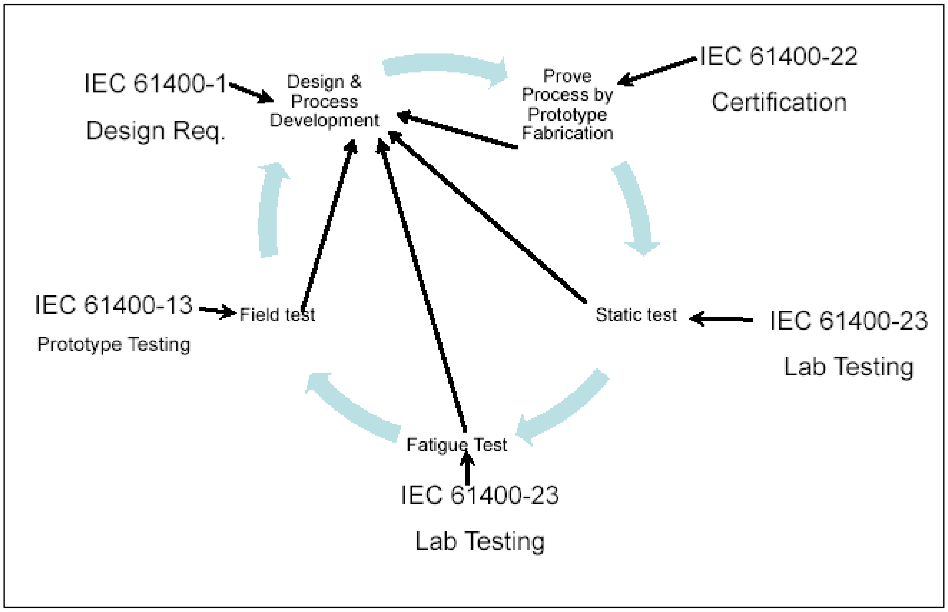

Figure 20

This slide illustrates that the design requirements are set out in the IEC 61400-1 code (and also the IEC 61400-3 code). The process is proved by prototype fabrication, lab testing in both static and fatigue tests using IEC 61400-23, in a prototype test using IEC 61400-13 and finally to approval for manufacture.

Another slide his presentation is also of note:

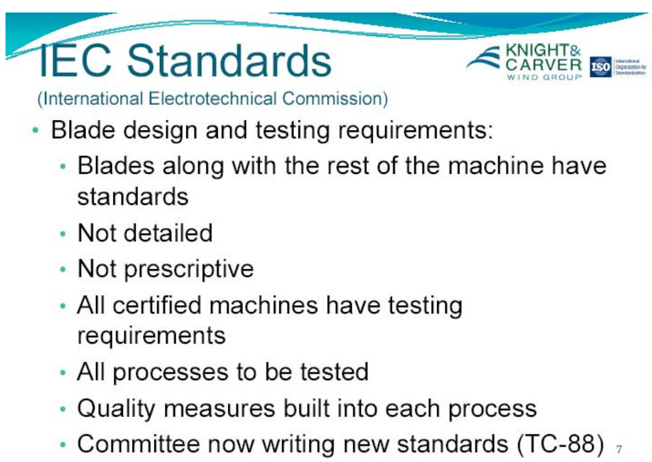

Figure 21

The IEC standards on Wind Turbines vary in what is mandated, what is suggested, and what is observed as the "state-of-the-art". While pulling these standards together in Europe, their application in the USA is sometimes a stretch and for local consumption may need to be reformulated using equivalent national codes. They none-the-less provide very useful guidance.

3.4.1 Blade Throw

Wind turbine blades can fail resulting in blades or blade fragments coming free and being thrown from the turbine. This may happen from overload but more likely happens from lightning strikes, quality defects in the blades, from fatigue, or from control error either by the control mechanism or the operator causing an overspeed situation.

According to Garrad Hassan:

- *The main causes of blade failure are human interface with control systems, lightning strike or manufacturing defect;*
- *Evidence suggests that the most common cause of control system failure is human error. Many manufacturers have reduced that risk by limiting the human adjustment that can be made in the field;*
- *Lightning strike does not often lead to detachment of blade fragments. Lightning protection systems have developed significantly over the past decade, leading to a significant reduction in structural damage attributable to lightning strikes;*
- *Improved experience and quality control, as well as enhancement of design practices, has resulted in a significant diminution of structural defects in rotor blades; and*

Garrad Hassan is not aware of any member of the public having been injured by a blade or blade fragment from a wind turbine. [Ref. 3.4.7].

"Blade failure can occur in high wind-speed conditions."

According to GE Energy:

"The mode of failure of a wind turbine due to an extreme wind event cannot be generalized and depends on the turbine type and configuration, as well as the specifics of the extreme wind event and site conditions. Examples of possible failure scenarios include blade failure or a tower buckling or overturning. When winds are above the cut-out speed, the wind turbine should have its blades idling in a position creating minimal torque on the rotor. This is the only safety mechanism other than the yaw control. If a grid failure were to occur in conjunction with an extreme wind event—which is a likely scenario—the yaw control will become inactive. The loss of yaw control could increase the likelihood of damage/failure in the case of an extreme wind event. Also, the grid components/structures could also be part of the potential windborne debris. At this time, GE has no modeling capability in place that can predict the impact made to a wind plant if an extreme wind event occurs" [Ref. 3.4.8].

"The safety system must have two mutually-independent braking systems capable of bringing the rotor speed under control in the event of grid failure (as required through IEC specifications)". [Ref. 3.4.9].

Professor Terry Matilsky of the Department of Physics and Astronomy, Rutgers University, has calculated that it is physically possible for broken blades to be thrown up to 1,680 feet horizontally [Ref. 3.4.10].

"Members of the Study Group had differing views as to the degree of setback that is warranted to protect against blade throw. Some WTSG members are of the view that the precautions and setbacks employed for protection against ice throw (that is, 1.5 x (hub height + blade diameter) from occupied structures, roads and public use areas) are also adequate to protect against blade failure. This view is based on risk-based calculations done for icing situations which consider the frequency of occurrence and the potential travel distance. Wahl, David & Giguere, Philippe, General Electric Energy, "Ice Shedding and ice Throw– Risk and Mitigation", April 2006.

"Using the recommended setback for ice is appropriate because the physics of anything breaking off the blades, including the blades themselves, is similar. Matilsky, Terry, Rutgers University, "Part I – Basic Kinematics" at p. 1.

Other WTSG members are of the view that a minimum setback of 1,680 feet is warranted based on the potential for broken blades to be thrown that distance. To protect safety and property on adjacent property, these members also believe that this setback should be measured from the adjacent property line" [Ref. 3.4.11].

3.4.2 Blade Tests

IEC 61400-23: 2001: Full-scale structural testing of rotor blades is a technical specification providing guidelines for the full-scale structural testing of wind turbine blades and for the interpretation or evaluation of results, as a possible part of a design verification of the integrity of the blade. Includes static strength tests, fatigue tests, and other tests determining blade properties.

The laboratories that exist to test blades:

- *"National Wind Technology Center – NREL USA*
- *WMC/TU Delft – The Netherlands*
- *Risø National Laboratory –Denmark*
- *NaREC - United Kingdom*
- *Private labs – LMGlasfiber, NEC Nikon, MHI and other manufacturers*

"Summary of Full Scale Blade Test Requirements (2004)

- *Static test is required in all international standards*

- *Fatigue test is required in IEC WT01 and DS 472*
- *Tests in flapwise direction and in lead-lag direction*
- *Performed by a recognized testing body or supervised by the certification body*
- *Blade shall withstand the tests without showing significant damage regarding safety for blade function*

[Requirements for Certification of Rotor Blades – Germanischer Lloyd]" [Ref.3.4.1].

The IEC document provides guidelines and good advice on the type of the tests to be carried out, and observes what has been typical practice in testing blades. The formulation is intended to prove that the blade will survive its design lifetime based on the loads for which it has been designed. In order to speed up the full scale tests so results are available within a year or less it is necessary to provide patterns and values of loading which attempt to reflect the real loading situation. This document standardizes the tests to the degree of pointing out what tests ought to be considered, depending on the blade, and analytical information available, and thus puts blade tests on somewhat of a uniform footing.

The IEC standards for wind turbine blades only cover load assessment, principles of structural safety and details of full scale blade testing. The GL and DNV standards are based on the basic IEC requirements and collect all relevant certification requirements such as material and manufacturing qualification, design calculation procedures, and testing of wind turbine blades.

Several important decisions are left outside the code to be decided by the wind farm owner, blade manufacturer, certifier, and/or regulatory authority. Whose takes the decision is not commented on. Some of these are outlined below:

- There is only an implied requirement that there will be a test in the IEC Code. GL and DNV both mandate at least 1 test. However DNV limit the requirement to one prototype blade and also state *"it is not necessary to test parts where the structural reserve factors have been verified to be sufficiently large through numerical calculations; or where the layout and loading is representative of similar parts that have been previously tested."* Additionally the "*sufficiently large reserve factors are the responsibility of the designer, and require justification if testing is to be omitted."*
- Tests are done on a *"limited number of samples"* (5.1) –it is not specified whether it is more than one blade of a type which is tested and whose decision that is. With one blade only there is no ability to see "scatter of the results" (5.4.2).
- Even minor modifications could compromise the validity of the tests: if the blades are type certified and not project certified who would determine if the tests are valid for a blade that has been changed even slightly e.g. glue specification changed (5.3). Changes in production or design may invalidate the Certification but that may not be known until later in the process (5.4.2). DNV (5-101) add *"Large adhesive joints shall normally be retested in case of changes in the*

adhesives or the surfaces to be joined". The selection of the blade to be selected is discussed by DNV-OS-J102.

- *"Loads on critical components such as tip brakes are often different in character from the general loads on blades and may need extra specification and specific tests"* (6.5.4). It is not obvious who decides on the extent of the testing.
- The number of tests carried out to check that stresses and deflections from analysis match the actual test results is not specified except to the most severe design load conditions (8.2.1.2). GL specify that *"at least four load levels between 40% and 100% of the maximum test loading"* be carried out.
- The amount of reduction in the time for fatigue tests that can be done without compromising accuracy is left vague in the guidance (8.5.1).

Some of the shortcomings of the tests are:

- Certain failures are difficult to detect (5.3);
- Tests are done at the temperature of the facility: this may not reflect the temperature or range of temperatures that the blades will be operated in.
- Fatigue testing is simulated based on analysis techniques which theoretically may give rise to similar loading (7.1 & 7.9). Since the load spectrum is very different from the design load it is not obvious who might best be in a position to decide acceptability of the test spectrum.
- *"the material strength and fatigue behaviour for the actual material in produced blades can be worse than the material in the test coupons on which the strength and fatigue formulation is based. The loads should not be increased by this factor because the material in the blade being tested is the actual material"*(9.2.2).

While there is no dispute that the material is the actual material other references (DNV and Kanaby) comment that the first test specimen may not contain typical manufacturing flaws and thus it may be appropriate to consider how the blade for test was selected prior to negating this in the formulation. The IEC code does point out that *"A stronger than average blade test specimen taken from a population of blades having strengths below design strengths could be misleading if it was believed that the test specimen's strength was closer to average"* (9.3.1).

It has generally been assumed by the IEC Code and the certification codes that 10 seconds is the minimum holding period to verify the load is held by the blade.

"Testing to destruction is neither sought nor required" in determining the design envelope.

There are some other issues worthy of noting:

"Detection of possible damage or failure during the test can be difficult because of the complex structure of the blades, which means that important structural elements are hidden and difficult to inspect and monitor. Further, the blade material can suffer local damage without showing it".

In this clause, only irreversible property changes of the blade are addressed as failure modes. Whether or not the blade fails to meet certain design criteria or standards is not a subject of this clause; only possible failure modes that have to be monitored are described. The failure modes for "catastrophic failure" and "superficial failure" are fairly obvious, however, the intermediate definition of "functional failure" is quite subjective e.g.:

- *"The stiffness of the blade reduces significantly or irreversibly (on the order of 5% to 10%)".* – so if it was 9% it would be still be acceptable.
- *"after unloading, the blade shows a substantial permanent deformation"* – but "substantial" is not defined.

The decision about whether the test results are acceptable to install the blades at the project location are left outside the document to be decided by owner, manufacturer, certifier, and/or regulator (or possibly the CVA).

It is not obvious that there would be identical results if:

- The identical blade was formulated by 2 designers that the test program would be the same
- 2 different laboratories were selected to test the same blade that the results would be the same
- 2 different certifiers were to review the results that the results would be equally acceptable.
- 2 different blades from the same production line some time period apart would have the same results as the prototype test.

It is therefore incumbent on the regulator to provide some oversight to the situation. As a minimum the test results in the documented form described by the IEC Code should be reviewed and ideally the "qualification" of the laboratory and its personnel to carry out the tests should be reviewed, as should the expertise of the testers. It may be appropriate to accept the laboratory based on it being ISO/IEC 17025 compliant. (Management requirements are primarily related to the operation and effectiveness of the quality management system within the laboratory. Technical requirements address the competence of staff, methodology and test/calibration equipment). Note: GL 2005 requires the laboratory "be accredited for the relevant tests or recognized by GL Wind".

Additional points from GL 2005:

The IEC code specifies that natural periods and damping can be measured (13.6 & 13.7).

GL require for rotor blades with a length of more than 30 m, *"it shall be additionally necessary to determine the second natural frequency in the flapwise direction, together with the first torsional natural frequency for torsionally soft blades. In the case of rotor blades for stall-controlled turbines, the damping in the edgewise direction shall be measured".*

The IEC code recommends measurement locations (13.5): GL specifies mandatory locations (6.2.5.2).

The IEC Code states that the fastenings at the end of blade be appropriately simulated, but GL recommends *"that rotor blade for offshore wind turbines be tested together with their adjacent structures so instrumented that the stress conditions of the bolted connections can also be determined"*.

GL additionally gives acceptable deviations in terms of % bending deflection, % of natural frequency and % of admissible strains (6.2.5.3).

While GL acknowledges the need to do fatigue testing there is little written on the requirements other than reference to IEC 61400-23.

Additional points from DNV-OS-J102 "Design and manufacture of wind turbine blades"

DNV require a final static testing after the fatigue test to *"verify that the blade has the residual strength to withstand the extreme design loads"*. And further that *"to facilitate examination of the blade after the final static test, it is recommended that the blade is destructively sectioned in critical areas."*

The documentation in DNV requirements request verification of the blades' *"resistance to hydraulic oils"* and *"verified resistance to wear from particles in the air"*. As well as *"identification of replaceable wear parts"*.

The complexity of blade designs and the materials they are made from will continue to be complex as the turbine sizes grow and the designs are optimized.

IEC 61400-13 Measurement of mechanical loads - Acts as a guide for carrying out measurements used for verification of codes and for direct determination of the structural loading. This standard focuses mainly on large electricity generating horizontal axis wind turbines.

The prototype testing of blades is specified in this standard. The requirements are specified in Table 8.

Load Quantities	Specification	Comments
Blade root loads	Flap bending Lead-lag bending	Blade 1: mandatory Other blades: recommended
Rotor loads	Tilt moment Yaw moment Rotor torque	The tilt and yaw moment can be measured in the rotating frame of reference or on the fixed system (for example, on the tower)
Tower loads	Bottom bending in two directions	

It is not clear as to whether certifiers also mandate the same requirements for their approval of prototype testing or whether prototype testing itself is mandatory. It seems sensible to consider having these data recorded as part of the control and/or condition monitoring process.

3.4.4 Blade Design

Blade design criteria come from the IEC 61400-3 document which tabulates the design cases in Table 1- Design load cases. It is useful to understand some of the loading concepts prior to review of the load cases. A good understanding of the assumptions made in the load conditions can be found in Wind Turbines by Erich Hau [Ref. 3.4.2].

"Start-up and Shut-down of the Rotor…

In larger wind turbines, the normal shut-down of the rotor is controlled by means of blade pitch control as the rotational speed varies, so that no special loads are involved. One exception ***is fast braking, the "emergency shut–down",*** *where the reversed aerodynamic thrust can cause increased loads".*

"Parked Rotor at extreme wind speeds…

For turbines with pitch control it is assumed that the rotor blades are in the feathered position and that the rotor is aligned with the wind. Under these conditions, the load level is much lower than under cross-wind conditions. Naturally, the precondition for this is that ***the yawing system and the blade pitch control are functional when the survival wind speed occurs****…….Some wind turbines do not stop the rotor at extreme wind speeds, because at rotor idling – using an appropriate blade pitch angle – the loads on the turbine are lower compared to fixed parked rotor".*

"Technical Fault…

In the case of a defect, for example a loss of the electrical system (generator release) or a fault in the control system, the rotor blades must be pitched very rapidly towards feather to prevent rotor "runaway". For this, the blade is pitched so fast that, for a short period of time, the rotor blades are subjected to negative aerodynamic angles of attack. The aerodynamic thrust then acts in the opposite direction. If the rotor blades are positioned at a cone angle to each other, the bending moments from trust and centrifugal force are superimposed in the same direction. Instead of compensating for each other as in normal operation, they add up with the consequence of an extreme bending moment on the rotor blades. A very careful analysis and optimization of the emergency shut-down procedure is required in order to remain within the given load limits under these conditions."

"Control system fault…"

*If the control system fails pitch angle is incorrect for the operating condition e.g. meteorological information mismatch, consequences can result, "***such as rotor overspeed".**

"A fault in the control system or in the yaw drive can result in extreme cross-winds acting on the rotor."

"Generator short-circuits…

The generator short-circuit torque can amount to up to seven times the value of the rated torque."

"Rotor unbalance…

In the case of damage to the rotor blades, loss of a structural part or the formation of ice on the rotor blades, an unbalance of the running rotor must be expected until the rotor stops. Therefore, a certain unbalance mass must be assumed, the magnitude of which must be related to the size of the rotor. The resultant load case must be verified with respect to strength as well as any vibration problems which may be present."

The number of load cases is "substantial", and there is much interpretation that can be different with the specifications for cases, while providing guidance, presumably based on extensive experience of calculations on many types of blades, successes and failures. The more complex the calculation, the more difficult it is to find errors if there are any, and verification by repeating the analysis, as is required in the independent check, may be onerous.

It is observed that detailed metocean data needs to be available, references to combining waves and winds from different directions, implies much more detail on available weather conditions than is likely to be available, or can be gathered in the timeframe prior to design, since this often requires years of observations. This is particularly true if the area is subject to tropical revolving storms where 50+ years of data is required.

It was not obvious from the design cases that the acceleration on the blades when an emergency stop is initiated is provided since this is a manufacturer-provided number as to how fast the brakes can take hold. No doubt this number can be obtained, but this is but one example of how assumptions might creep into the calculations.

No criteria are set in the IEC document for minimum clearance of the blade from the tower. DNV provide guidance on calculating clearance but provided no minimum. GL provide guidance *"To ensure maintenance of a minimum clearance between the rotor blades and other parts of the plant, a deformation analysis shall be performed in the serviceability limit state. If the analysis is performed by static means, a minimum clearance of 50% shall be verified for all load cases with the rotor turning, and 5% for load cases with the rotor standing still, in relation to the clearance in the unloaded state", "If the deformation analysis is performed by dynamic and aeroelastic means, at no time may the clearance be less than the minimum of 30% for the rotor turning"*.

Without further study and comparison it has not been possible to define the differences between the GL Rules on loading of blades vs the IEC Code. It is possible to make a few observations. They note:

- 4.1.3 *"before erection of the turbine, however, it shall be ensured that the design conditions adequately covert he prevailing external conditions at site"*
- 4.2.2.2 *"the measurement period shall be sufficiently long to obtain reliable data for at least 6 months"* – while measurement data is important it is unlikely that 6 months of data will even cover all the seasons and thus this statement needs to be taken cautiously.
- It is noted that GL propose marine growth be considered for the tower structure, and a thickness of 50 mm chosen.

- The reduced wave height to be combined with the extreme wind speed of 1.32 H_s, is significantly different than would be used in the oil and gas industry.
- GLs load cases are significantly different than IEC load cases, and in some cases allow lower partial safety factors for what appears to be the same case that is used in IEC. GL has added some cases and changed others.

The GL document adds specific guidance to the spirit of the IEC 61400-13 for loads on blades, without further study it is not possible to say that this is the document to recommend to certify to, however, it would be useful to add a regional annex for the USA to this document by examining what changes it would need to provide an acceptable level of confidence for the purposes of certification.

3.4.5 Icing

In any area subject to icing particular attention should be paid and it is often most appropriate to install de-icing equipment on the blades.

Icing damages the blades, damages the main gearbox, the bearings, and forces you to stop the turbine. Automatic re-start is not usually done because it is required to check the blade visually before a re-start.

Conditions leading to icing are low temperature, fog or high humidity, rain or snow combined with low wind speeds.

Applicable Codes

The IEC 61400 covers the design of the blades, however, the Certification Guidelines of GL or DNV should be followed in conjunction with this requirement. In reviewing the requirements for specifying the codes for a particular project it is recommended that the GL guideline be consulted.

Certification

It is expected that the blades will need to be type certified and project certified as a pre-cursor to approval. If this is not carried out the CVA should be involved early in the process in order to carry out the tasks normally involved with this process. Certification to either GL or DNV standards will be the basis of Certification, however, the updated assumptions and load cases should be reviewed by the CVA prior to testing commencing if possible.

SMS

Many parts of the Safety Management System address issues of the blades. Marine Transportation criteria is required for transport at sea or on land, lifting incidents have occurred when unloading at docks due to requirements of the stevedores not matching those of the manufacturer; the safety of those on safe access devices inspecting and repairing the blades is also handled by a robust SMS.

CVA

The CVA would be expected to review the Marine Transportation, and installation manuals: the CVA should be qualified and experienced in marine warranty surveying or a similar discipline. Additionally it is recommended that the CVA attend the blade tests and the transportation and installation of a representative number of blades on site.

3.4.5 References

[3.4.1] Walt Musial, Wind Turbine Testing and Certification, Wind Turbine Blade Workshop February 24, 2004 Albuquerque, NM.

[3.4.2] Erich Hau, Wind Turbines: Fundamentals, Technologies, Application Economics, 2nd Edition, Springer Publications, Germany.

[3.4.3] Danish Energy Agency Type approval Scheme for Wind Turbines: Recommendation for Design Documentation and Test of Wind Turbine Blades, Nov 2002.

[3.4.4] DNV-OS-J102 "Design and manufacture of wind turbine blades"

[3.4.5] Germanischer Lloyd Rules and Guidelines for the Certification of Offshore Wind Turbine Structures, 2005

[3.4.6] www.dnv.com/.../Damage_Tolerance-White_Paper_2008_tcm4-295072.pdf.

[3.4.7] Garrad Hassan Canada, Inc., "Recommendations for Risk Assessments of Ice Throw and Blade Failure in Ontario", May 31, 2007 at p. 12-13 (included in Champaign County Farm Bureau report 12/11/07).

[3.4.8] Ubarana, Vinicius & Giguere, Philippe, General Electric Energy, "Extreme Wind Speed – Risk and Mitigation", October 2007.

[3.4.9] Garrad Hassan Canada, Inc., "Recommendations for Risk Assessments of Ice Throw and Blade Failure in Ontario", May 31, 2007 at p. 12-13 (included in Champaign County Farm Bureau report 12/11/07).

[3.4.10] Matilsky, Terry, Rutgers University, "Part I – Basic Kinematics" at p. 2.

[3.4.11] Report of the Champaign Ohio Wind Study Group, May 2008.

3.5 Gearboxes

Comments made elsewhere in this report describe some of the issues with Gearboxes. There have been serial failures of gearboxes, notably those at Horns Rev, Scroby Sands, and Kentish Flats.

> *"Wind farm suffers gearbox faults*
>
> *A wind farm off the coast of Kent has suffered persistent mechanical failure in the four years since it began operating, BBC South East has revealed. Gearboxes in all 30 turbines on the Kentish Flats have been replaced with newer, improved parts. The cost of the repairs is unknown, but the amount of electricity they have produced has been reduced as a result.*

A wind farm off the coast of Kent has suffered persistent mechanical failure in the four years since it began operating, BBC South East has revealed.

Gearboxes in all 30 turbines on the Kentish Flats have been replaced with newer, improved parts.

The cost of the repairs is unknown, but the amount of electricity they have produced has been reduced as a result.

Vattenfall, the site's Swedish owner, said lessons learnt were being applied to its wind farm off the Thanet coast.

The turbines have been operating since August 2005 and provide power to houses in Whitstable, Herne Bay, and Canterbury.

In 2007, the gearboxes - which transfer the power from the blades to the generator - were all replaced because of bearing failures.

In 2008, 20 of them were changed again with an upgraded version, and now the final 10 are being upgraded too.

The Danish firm Vestas, which makes the turbines, said the new gearboxes were an improved design.

'Teething problems'

Andrew Dever, site manager, said: "This is one of the first offshore wind farms in the UK and we weren't sure of the effects the offshore wind would have on the turbine.

"Now we realise that, we've engineered our way through a solution, so we understand more now what the effects are onto the bearings, onto the gearbox, onto the whole of the turbine actually."

The final 10 gearbox replacements will get under way once there is an improvement in the weather.

Gaynor Hartnell, director of policy at the Renewable Energy Association, said any new technology "has teething problems".

"This doesn't pose any threat for the future development of wind energy in the UK, or indeed anywhere else in the world," she said.

Web link: http://news.bbc.co.uk/2/hi/uk_news/england/kent/83.. [Ref. November 25, 2009 in BBC News].

It is worthy of note that many of the issues with gear failures have been minimized by the implementation of AGMA 6006 standard: Design and Specification of Gearboxes for Wind Turbines. When IEC 61400-4 Design requirements for wind turbine gearboxes is issued it will also be helpful in the minimization of the issues.

Mike Woebbeking of Germanischer Lloyd summarized their view of the requirements to do appropriate bench testing of the gear boxes as new ones are developed minimizing the risk of serial issues:

This inspection data base shows that about 26% of all defects and damages result from the gearbox (especially bearings and toothing), about 17% from the generator (especially *bearings) and about 13% from the drive train (e.g. main bearing, coupling). These results are comparable to damage statistics of insurance companies or institutes.*

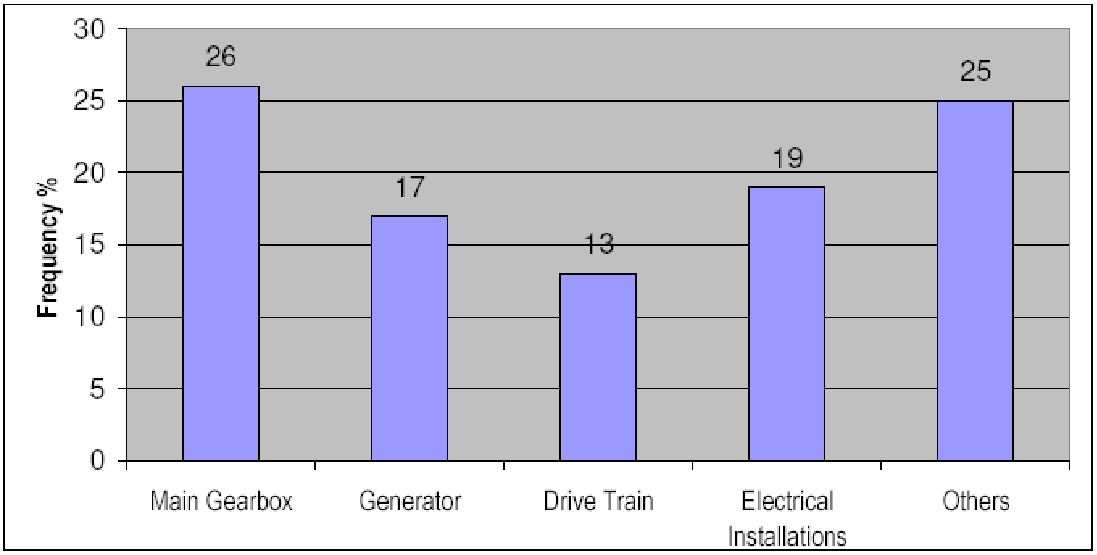

Fig. 1: Defects and damages of wind turbine components [Data base GL]

The industry experiences a lot of problems with gearboxes and bearings. To safeguard the operational reliability of gearboxes for wind turbines, a number of national and international standards and guidelines have been formulated in recent years. They provide fixed rules (e.g. for determining the load distribution of spur and helical gears) and requirements (e.g. minimum safety factors) when applying these standards, with a view to adapting them to the operating conditions of wind turbine gearboxes. For the verification of load capacity in respect of components for which there are no standardized rules (e.g. structural components), the method (e.g. FEM) as well as the boundary conditions (loads, stress concentration, material properties, equivalent stress hypotheses, partial safety factors etc.) are specified in detail.

The demands on wind turbine gearboxes are characterized by their special constraints. These can be subdivided into internal and external boundary conditions.
The external boundary conditions are:

- *Varying climatic conditions (temperature, humidity, ...)*
- *Lack of stable foundation*
- *Fluctuating wind speeds and directions, wind turbulence*
- *Frequent start-up and shut-down (braking), standstill*
- *High availability, cost-effective, light structure, H*

The internal boundary conditions are:

- *High speed-increasing gear ratio*
- *High loading of the individual components*
- *Stringent demands on the design, materials and quality*
- *Low noise emissions*

In addition to the computational verification of the load capacities and lifetimes of the individual components of a gearbox, the newer standards also prescribe a functional verification in the form of practical demonstrations and tests. Here a distinction is made between prototype trials, field tests and series tests. The aim of the prototype trial is to examine whether the assumptions and boundary conditions that were set in the design phase are indeed correct. In the field test of the wind turbine, the load assumptions are checked and the system response is studied. Finally, the series tests are intended to demonstrate that the series-manufactured gearboxes comply with the performance standard set by the successfully tested prototype. Further component tests and function tests (leakage, cooling and lubricating system etc.) may also be stipulated in the test specification.

The prototype trial may be performed on a gearbox test bench. The objective of the prototype trial is to verify the assumptions and boundary conditions that were applied in the design phase. In this test, the torque is increased in at least four steps up to the rated value. The gearbox is then operated at rated torque until steady-state temperatures have been attained in the oil sump and at the bearing points. In addition, an overload test is recommended. The parameters to be investigated include:

- *Measurement of the load distribution using strain gauges*
- *Measurement of the load distribution at the planetary stage using strain gauges at each load level*
- *Temperatures, vibration and noise at each load level*

Following the prototype trial, the gearbox must be dismantled and the condition of the various components evaluated.

The field test is performed with the gearbox mounted in the wind turbine. This test should include the following operational conditions:

- *Entire speed and torque spectrum to check the system response*
- *Starting at cut-in and cut-out wind speed*
- *Shutting down at cut-in and cut-out wind speed*
- *Braking procedure (reversing load)*
- *Emergency shut-down*

All gearboxes of a series should be subjected to an acceptance test. This acceptance test is best done at a series test bench. Only the original oil system may be used for this test, and the stipulated oil quality must be assured. Besides the usual measurements, the noise and vibration measurements play a special role in this test, because these results make it possible to identify any shortcomings.

The drive train of a wind turbine must be viewed as a complex topic. Because its operational reliability can no longer be assessed solely by verifying the strengths of the individual components, dynamic simulation of the drive train is becoming necessary to an increasing degree. In future, these simulations will come to represent an important factor in the further development of the standards and guidelines in the field of wind turbines.

In the simulations, the complex drive train is reduced to a spring-mass system to simplify the drive train for the global load simulation. It is necessary to prepare a detailed simulation model, for example with the aid of multibody or hybrid systems, to derive local loads from the simulations. Parameters such as the moments of inertia and stiffnesses of the individual components are determined with the aid of FE models or formulae derived from the field of mechanics. The drive train is represented by rigid elements and spring-mass elements. This model is then used to study the resonance behaviour of the drive train. This can be done in the frequency domain (modal analysis) or through simulation in the time domain. Analysis in the time domain has proved to be most demonstrative. Operational scenarios, such as a start-up procedure from standstill up to activation speed, are simulated here. Excessive load increases at the individual components can be identified by scanning the logs, and it is possible to draw conclusions about potential resonance points. A comparison with the analysis in the frequency domain is likewise possible. These simulations therefore constitute a further approximation of the model towards reality.

In future, the gearbox will not be considered as an isolated entity, but rather as an integral part of the overall drive train whose operational reliability can no longer be described solely through the separate verification of load capacity for the individual components.

Operational reliability is therefore increasingly being considered on the basis of the results obtained from dynamic simulations of the entire drive train. The approach used for such simulations is therefore an important factor in the ongoing development of the standards and guidelines in the field of wind turbines. [Ref. 3.5.1].

For a more detailed overview on the situation and development of standards for gearboxes the reference [Ref. 3.5.2] provides good insight..

3.5.1 References

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3.6 Control Monitoring & Condition Monitoring.

In order to operate a wind farm data from various sources is required. The data is received by way of computer systems interrogating sensors on the nacelle, inside the turbine, and at a meteorological mast in the field. The sensors communicate wind direction and wind speed data to the controller, which uses this data to regulate the yaw angle, the cut-in and cut-out speeds, and the pitch of the blades. Sensors need to be protected in a variety of ways and some are powered with heating to assure they do not ice over. The turbine is normally programmed to respond to these communications from sensors, but when there is a discrepancy the operator has to check and clear the fault condition. The type of control system used is determined by a host of factors including manufacturer, owner, and operator preferences. Because the information is critical, often redundant sensors are placed to determine specific action if one sensor goes down. The sensors need to be themselves protected from lightning, icing, which themselves need to be maintained.

For both the Control Monitoring and Condition Monitoring systems the safety of the installation in so far as meeting appropriate standards i.e. marine standards for cabling, connections, robustness, and appropriate quality control in the manufacture and installation, should be covered by the design basis document. All Monitoring System and Control system components should meet an appropriate marine industrial standard e.g. classification society rules.

A current potential gap, which may be covered by the quality management system is the monitoring and control of software and changes in software. This is an important subject and is often not specifically mentioned in the certification process particularly as it relates to management of changes of the software system.

The Control Monitoring is of interest to the CVA if the structural integrity depends on it, and the Condition Monitoring system is of interest to the on-going inspection of the turbine and structure particularly if periods of inspection are dictated by the results of the monitoring. These systems tend to be very complex and sophisticated. Certification of these systems becomes an important feature of safety, as well as efficiency.

The International Standard covering the finer details of the communications protocols is contained in IEC 61400-25-2 Wind turbines - Communications for monitoring and control of wind power plants.

One of the Certification documents covering Control Monitoring is Germanischer Lloyd's Guideline for the Certification of Condition Monitoring Systems for Wind Turbines. This is a very practical guide and recommended.

3.6.1 Control Monitoring

Control Monitoring is for measuring normal operational data and controlling the turbine for safety. The Control Monitoring System consist typically of measuring devices or sensors; cabling or transmission devices to a local information hub where the data is collected; cabling or transmission devices to a central hub where it is received by an operator supervised computer, which then interprets the data and feeds back instructions to the controllable items of equipment in the wind turbine i.e. the yawing mechanism, the rotor, blade positions and brakes in order to optimize the output of electricity to the grid. The system has the ability to cause the wind turbine to shut down and the blades to move to a load position that either maximizes the speed of the rotor or minimizes it – depending on which is appropriate. The speed of shut down may be controlled by normal or emergency application of the brakes.

Unlike most offshore systems the structural integrity of the wind turbine structure's survival is vested in being able to control the blade pitch, rotor speed, blade feathering functions, and yawing mechanisms at all times resulting from operational changes in the measured metocean data, including throughout any storms including tropical revolving storms. Safety against catastrophic collapse of the tower and loss of blades depends on an active (electrically live) system, whether this is by generated power, main power or by battery. Some systems have the ability to "fail safe" so far they have a hydraulic system to feather the blades to a safe position if power is lost provided it is maintained operational; power to the yaw system is still necessary in order to not be in an unfavorable position if the wind direction changes.
The hardware and software by which the control of the wind turbine system is affected is therefore safety critical.

The control system is expected to be an automatically controlled system for use with offshore wind farms. Erich Hau [Ref. 3.4.2] in Section 18.8 states:
"fast braking of the rotor provides an additional safety factor which can compensate for numerous other risks (fail-safe design).

A system's ability to shut down immediately is by no means a matter of course, particularly in energy generation systems." The rotor braking system is, therefore, the dominating safety system of a wind turbine.

"By pitching the rotor blades quickly towards feathered position, wind turbines with blade pitch control can brake the rotor aerodynamically and can bring it to a standstill within only a few seconds Blade pitching must start immediately with a high pitching rate to prevent rotor overspeed. When the electric generator loses synchronization, the entire rotor power becomes available for accelerating the rotor. Without immediate braking, the rotor speed would increase every rapidly and within seconds the rotor would be destroyed by the centrifugal forces. On the other hand, there are limits set to the pitching rate so that the bending moments developing at the blades during the aerodynamic braking do not become too great."

Metocean data collected and analyzed include wind direction readings, anemometer, wind speed, temperature etc. are required for this system to automatically activate the protection system. The location of the data sources e.g. metocean towers, and turbine sensors, needs to be checked for logic particularly in a tropical revolving storm area to ensure the accuracy for interpretation for all the turbines controlled.

The monitoring and control of this system is known as "the safety system" in some terminology in the literature, not to be confused with the safety management system (SMS). System Control and Data Acquisition (SCADA) is another name applied to this and the Control and Condition Monitoring system. All items in this system are mandatory by the manufacturer as part of the working of the system.

3.6.2 Condition Monitoring System

The Condition Monitoring System consists typically of measuring devices or sensors; cabling or transmission devices to a local information hub where the data is collected; cabling or transmission devices to a central hub where it is received by an operator supervised computer. The data is then analyzed by the operator for the purpose of anticipating and warning about potential issues with the breakdown of components. The alarm system then alerts the operator who will take a considered decision on action, e.g. shutdown, continue operating, and provide early warning to maintenance personnel for servicing /replacement of components.

Condition monitoring is the process of monitoring a parameter of condition in machinery, which provides early fault detection for a developing failure. The method acquires data of certain characteristic properties of the components e.g. vibrations, sound radiation, analysis of power output etc. The use of conditional monitoring allows shutdown, maintenance to be scheduled, or other actions to be taken to avoid the consequences of failure, before the failure occurs. A deviation from a normal reference value (e.g. temperature or vibration behavior) must occur to identify potential damages. It is typically much more cost effective than allowing the machinery to fail. These systems are important in wind farms because of cost and scheduling of maintenance offshore. Condition monitoring is also used to monitor the health of alarm systems, fire-fighting systems, etc.

In relation to monitoring to prevent fires:

"Condition monitoring systems – accessed remotely by PC – can greatly reduce the risk of component-induced damage. These systems typically monitor such things as oil and/or water temperature in critical components, (differences in) component vibration levels, and changes in acoustics levels, amongst other things.

"There may also be a useful role for automatic fire extinguishers, functionally coupled to key system functions. Some turbine manufacturers are believed to be looking at incorporating these systems into their products, and the controlled environment within modern nacelles could now make this easier than it might have been in the past. Other patented systems, as used in different industries, are now offering themselves to the wind market……….. installed along any part of the internal workings of the wind turbine (for instance, parallel to the hydraulic lines) and delivers CO_2 or another fire-suppressant to extinguish a fire within seconds of its starting. This reduces damage to a minimum. The systems are designed to work automatically, without the need for manual activation and monitoring." [Ref. 3.9.2] .

Further remarks in relation to fires the following comments apply to items to monitor:

"pressure and temperature at mechanical and electrical systems such as transformer, generator winding, gearboxes, hydraulic systems or bearings. If the limiting value is exceeded or is not

reached, there should be some kind of alarm and finally an automatic shutdown of the wind turbine. In the course of type testing and certification processes of wind turbines, the monitoring of operating parameters is usually taken into account.

Electrical installations and monitoring systems in wind turbines have to be examined by experts on site on a regular basis. At least every five years the gas and oil of the transformer insulation liquid have to be analyzed, amongst others.

The analysis allows drawing a conclusion on the quality of the insulating oil and provides information about possible electrical defects, thermal overloads of the transformer, and the condition of the paper dielectric. If there are any defects in the active component of oil transformers, there is the risk of an explosion due to large electrical currents in connection with the insulating oil as fire load resulting from rapidly increasing internal pressure in the boiler. With respect to dry-type transformers, the surface has to be controlled annually, and it has to be cleaned if necessary. Additional safety is provided by installations that serve the optical detection of partial discharge (spark switch)". [Ref. 3.9.3].

3.6.3 GL Certification of Condition Monitoring Systems

Germanischer Lloyd describes the Condition Monitoring System (CMS) as follows:

"(6) With a CMS, it is possible to detect relevant changes in the condition of the monitored components of the turbine. These changes represent deviations from the normal operational behaviour and may result in the premature breakdown of the components.

(7) The CMS measures vibration and structure-borne sound at the components of the wind turbine, for example at the components of the drive train and the tower and gathers operational parameters, such as power output, speed, and the oil and bearing temperatures.

(8) The acquired data is then compared with the established limiting values for the corresponding component. If the CMS determines that a limiting value has been exceeded, an alarm message is automatically sent to the responsible monitoring body. This monitoring body will then carry out an evaluation of the measured values, in order to take the necessary steps."

The term "monitoring body" is used to describe the contractor/ owner person using the CMS proprietary system which may have been developed by a different organization. The Certification process used by GL involves detailed tests with real data and actual turbines in order to "qualify" the equipment. The Monitoring Equipment can be certified, as can the Monitoring Body. Audits of any Certified CMS system lasts 2 years (Type Certified) and that of the Monitoring Body for 2.5 years (Type Certified, or Project Certified).

According to GL's scheme a behaviour requirement in case of a power failure is assured with backup power *"to ensure that the measured data are buffered within the CMS until the data can be transferred (e.g. to the monitoring body) once the power is reinstated"*.

Control Monitoring System		
Measured Information – Examples		**Comments**
Meteorological Information		
Wind Speed	●	
Wind Shear		*Recommended for prototype testing IEC 61400-13*
Wind Direction	●	
Wave Height	●	
Wave Direction	●	
Current Speed	●	
Current Direction	●	
Ambient Temperature	●	
Temperature Gradient		*Recommended for prototype testing IEC 61400-13*
Power Information		
Condition of Power Generated	●	
Amount of Power Generated	●	*Required for prototype testing IEC 61400-13*
Control Mechanisms – Examples		**Comments**
Blades Angle	●	
Yaw Position	●	
Hydraulic System	●	
Brakes	●	
Shutdowns	●	
Condition Monitoring System		
(may be Monitoring: over 100++ values per turbine)		
Alarm Information		**Comments**
Fire Detection	●	
Fire Protection Equipment Health	(●)	
Electrical System Health incl Transformer, switchgear, converter	(●)	
Power Management System Health	(●)	
Equipment Information		**Comments**
Tower Information	●	Determine fatigue deviations *Bottom bending in 2 directions required for prototype: IEC 61400-13*
Rotor Information	●	Monitor and record wind, direction, blade speed, vibration, lightning hits, etc. for fatigue determination; If 2 rotor bearings are provided both should be monitored. *Tilt moment, Yaw moment, and Rotor torque should be measured for prototype testing: IEC*

		61400-13 *Rotor speed, and rotor azimuth required for prototype testing*
Blades	●	Measured data may pick up blade defects, unbalances or yaw misalignment *Blade root loads: flap bending and lead-lag bending required for one blade and recommended for others; pitch angle and yaw position required for prototype testing: IEC 61400-13*
Brake Status		*Recommended for prototype testing: IEC 61400-13*
Nacelle Information	(●)	Nacelle temperature, vibrations, Main bed frame
Generator Information	●	Temperature of windings, differential in rotation angle
Transmission Information	●	Gearboxes may need at least 6 sensors
	●	Gearbox bearings
	●	Planet-helical gears may need 3 sensors: at the ring gear, at the level of the sun pinion shaft, at output gear level
Temperature of Equipment	(●)	Differential temperatures (input and output) may indicate wear
Vibration of Equipment	(●)	Vibration sensors may need to be screwed or glued on by means of ceramic glue
Lubrication Oil Quality	(●)	
Wear Debris content of oil	(●)	Size of metallic particles
Transmission Equipment		
	(●)	Monitoring the Monitoring and Transmission equipment sending signals to condition monitoring center
Software Information		
User requested time waveforms	●	
Event Recorder	●	
Backup Discs if Power failure	●	
Alarm message logic	●	Clearing multiple alarms without on-site inspection may lead to issues
● Regulatory Recommended (●) Optional		

Benefits

Avoiding catastrophic failures such as shown below are attributed to the benefits of the Condition Monitoring system [Ref. 3.6.10], and clearly, this has a benefit.

- **Hardware components in nacelle:**
  - Diagnostic Data Acquisition Unit
  - Vibration sensors on main bearing(s), all gearbox stages, generator bearings and main bed frame (tower vibrations). Speed sensor on generator shaft.

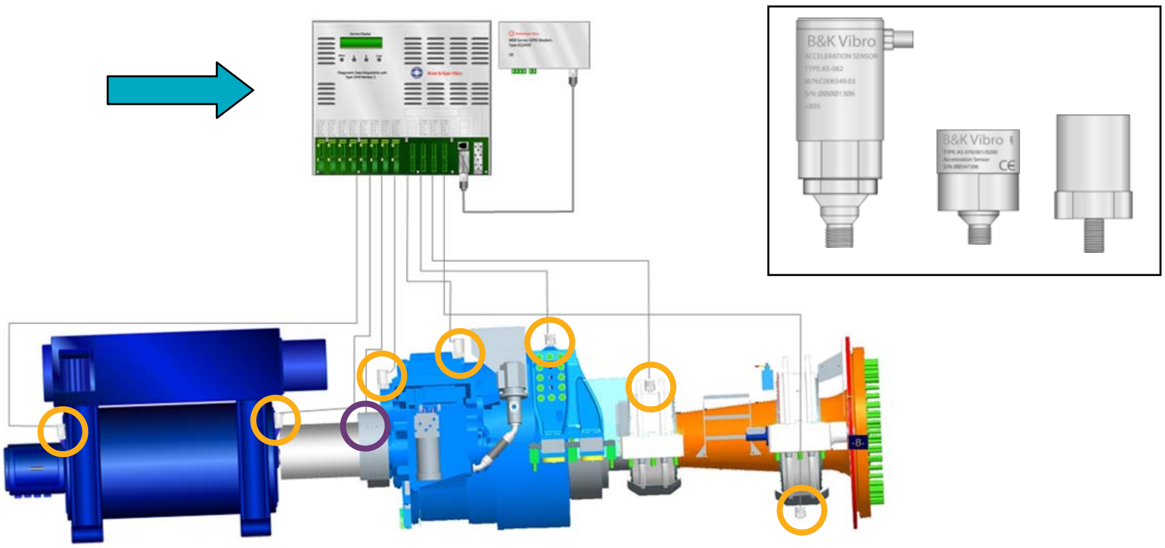
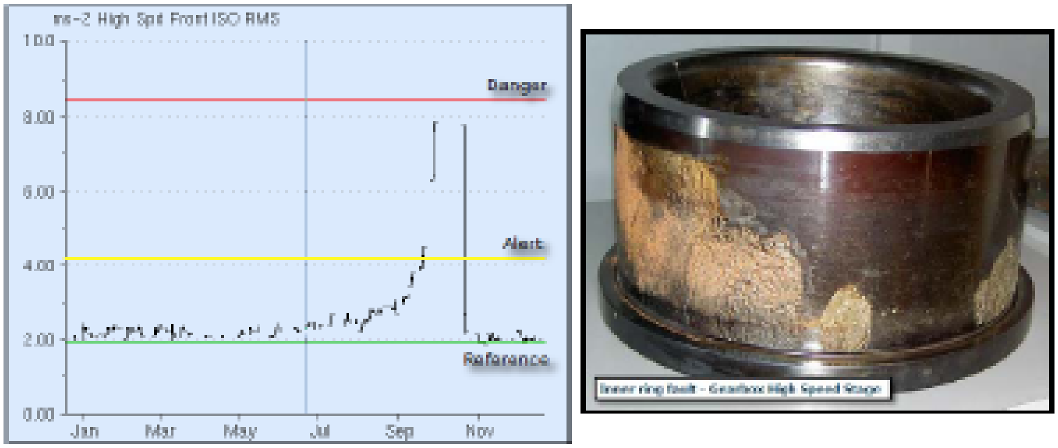


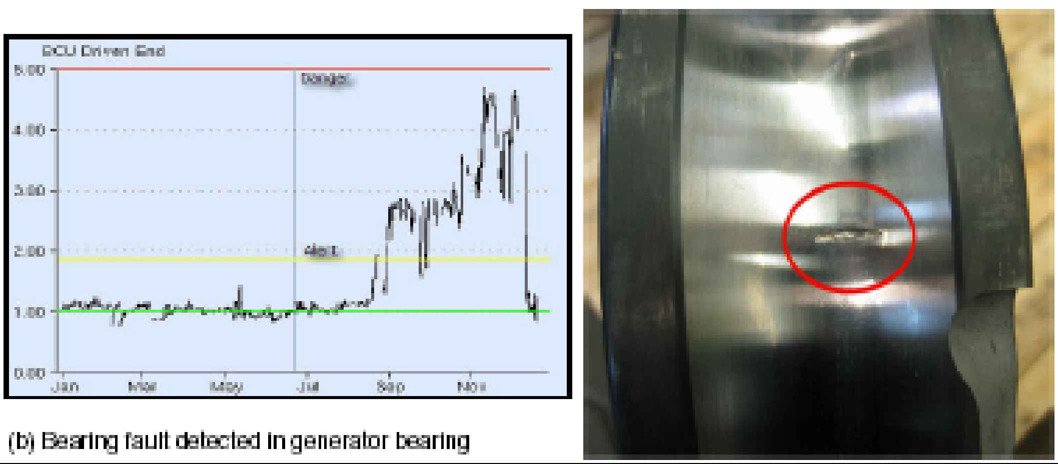
Figure 22: An Example: Condition Monitoring System [Ref. 3.6.1]

Figure 23: *"Catastrophic Failure of a Wind Turbine Condition monitoring systems will detect the onset of damage at an early state making it possible to avoid failures like these"* [Ref. 3.6.10].

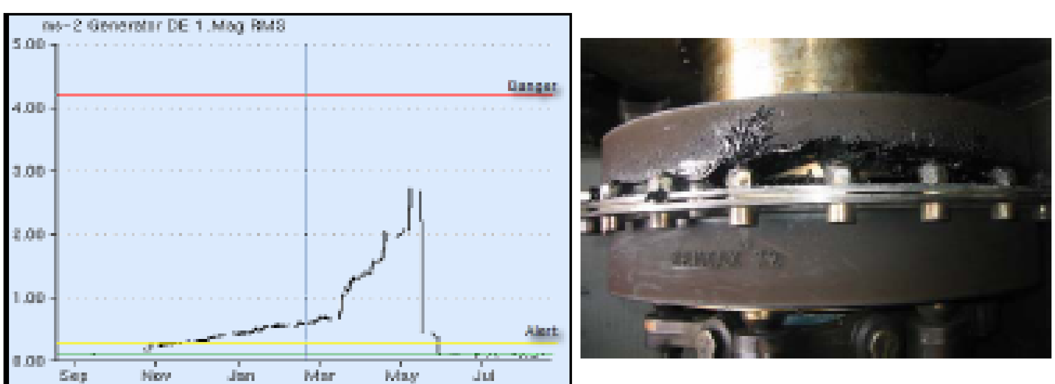
Less dramatic benefits are shown in a paper by Jacob John Christensen of Vestas, and Carsted Andersson of Bruel & Kjaer Vibro [Ref. 3.6.1], [Ref. 3.6.2].



(a) Inner ring fault detected in gearbox intermediate shaft bearing



(b) Bearing fault detected in generator bearing



(c) Coupling fault

Figure 4: Examples of mechanical faults detected using trending of fault symptoms

Figure 24

Analysis can lead to identifying

- o Bearing faults
- o Coupling Faults
- o Misalignment Faults
- o Gear Faults
- o Unbalance
- o Support Structure Faults

Reference [3.6.10] provides some insights into further benefits by component type that can be revealed with the use of a Condition Monitoring System.

"Figure 1: Percentage of Total Failures by Component Type

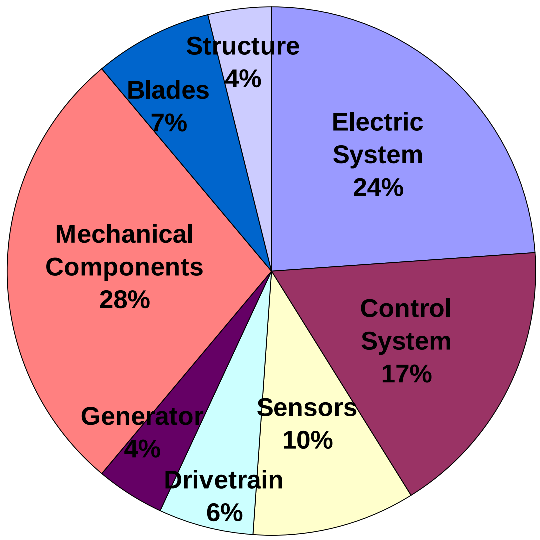
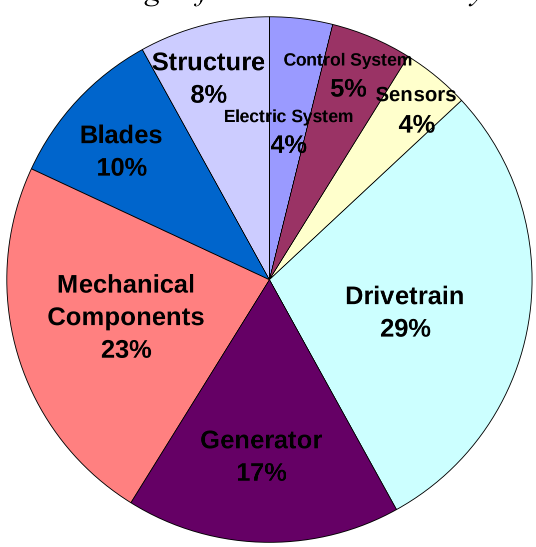


Figure 2: Percentage of Total Downtime by Component Type



Data source for Figures 1 & 2: J. Ribrant, "Reliability Performance and Maintenance – A Survey of Failures in Wind Power Systems," KTH School of Electrical Engineering, 2006.

3.6.4 IEC CODE

IEC 61400-13 Measurement of mechanical loads - Acts as a guide for carrying out measurements used for verification of codes and for direct determination of the structural loading. Focuses mainly on large electricity generating horizontal axis wind turbines. This appears to be most appropriate for prototype testing though it gives important information for control and monitoring as well. While specifying certain minimum requirements for prototype testing it takes the form of good advice rather than mandates. It does not clearly state what to do with the results.

The prototype testing of blades is specified in this standard. The requirements are specified in the Table 8.

Load Quantities	Specification	Comments
Blade root loads	*Flap bending Lead-lag bending*	*Blade 1: mandatory Other blades: recommended*
Rotor loads	*Tilt moment Yaw moment Rotor torque*	*The tilt and yaw moment can be measured in the rotating frame of reference or on the fixed system (for example, on the tower)*
Tower loads	*Bottom bending in two directions*	

Table 8 (from IEC 61400-13) Wind turbine fundamental load quantities

It is not clear as to whether Certifiers also mandate the same requirements for their approval of prototype testing or whether prototype testing itself is mandatory. It seems sensible to consider having these data recorded as part of the control and/or condition monitoring process.

– IEC 61400-25 Communications for monitoring and control of wind power plants:

This document was *"developed in order to provide uniform information exchange for monitoring and control of wind power plants. It will eliminate the issue of proprietary communication systems utilizing a wide variety of protocols, labels, semantics etc., thus enabling one to exchange information with different wind power plants independently of a vendor. It enables components from different vendors to easily communicate with other components, at any location and at any time."*

The IEC 61400-25 series deals with communications between wind power plant components such as wind turbines and actors such as SCADA Systems. It is designed for a communication environment supported by a client-server model.

IEC 61400-25-1: Overall description of principles and model: Gives an overall description of the principles and models used in the IEC 61400-25 series of standards.

IEC 61400-25-2: Information Models: Specifies the information model of devices and functions related to wind power plant applications. Specifies in particular the compatible logical node names, and data names for communication between wind power plant components, including the relationship between logical devices, logical nodes and data.

IEC 61400-25-3: Information Exchange Models: Communications for monitoring and control of wind power plants. Specifies an abstract communication service interface describing the information exchange between a client and a server for: data access and retrieval, device control, event reporting and logging, publisher/subscriber, self-description of devices (device data dictionary), data typing and discovery of data types.

IEC 61400-25-4: Mapping to communication profiles: Specifies the specific mappings to protocol stacks encoding the messages required for the information exchange between a client and a remote server for data access and retrieval, device control, event reporting and logging, publisher/subscriber, self-description of devices (device data dictionary), data typing and discovery of data types. Covers several mappings, one of which shall be selected in order to be compliant with this part of IEC 61400-25. The IEC 61400-25 series is designed for a communication environment supported by a client-server model. Three areas are defined, that are modelled separately to ensure the scalability of implementations: wind power plant information model, information exchange model, and mapping of these two models to a standard communication profile."

IEC 61400-25-5: Conformance Testing: Specifies standard techniques for testing of conformance of implementations, as well as specific measurement techniques to be applied when declaring performance parameters. The use of these techniques will enhance the ability of users to purchase systems that integrate easily, operate correctly, and support the applications as intended.

IEC 61400-25-6: Logical node classes and Data classes for condition monitoring.

The Code may not be as useful deciding what to acquire in the way of data, how much of it, and what to analyze as a mandatory measure. “Internal communication within wind power plant components is outside the scope of this standard”. “The standard excludes a definition of how and where to implement the communication interface”.

From a regulatory standpoint – ensuring that consistent electronic protocols is important – the actual recommended interfaces themselves are outside the standard, as is the SCADA collection system. It thus becomes important to recommend Certification as below.

3.6.5 Certification

It is recommended that both the Control Monitoring System and Condition Monitoring System by Project Certified to: Germanischer Lloyd Guideline for the Certification of Condition Monitoring Systems for Wind Turbines.

SMS

If the icing of the blades and other points on the structure is a risk, then the SMS system procedure on icing should be integrated with the condition monitoring system.

CVA

Since the control system is a key part of structural survival of the wind turbine structure it may be considered part of the CVA duties to review this. It may be prudent to have the CVA attend the commissioning of this system to ensure it is appropriately configured and tested.

Type Certification

Type Certification with commissioning surveillance may be suitable for the Condition Monitoring system.

Project Certification

Project Certification is recommended for the Control Monitoring system. Special consideration should be given to icing.

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3.7 Lightning

Wind farm structures are particularly susceptible to lightning strikes because of their height and location towering above their surroundings.

Figure 25 [Ref. 3.7.54]

While the statistics in the following reference are not recent they show an indication of the lighting issue in Germany [Ref. 3.7.56]

Wind Turbine Faults due to Lightning in Germany (1992-1999)

Year	1992	1993	1994	1995	1996	1997	1998	1999
Number of wind turbines	741	1058	1329	1475	1521	1509	1490	1473
Total number of wind turbine year (year unit)	575	898	1185	1409	1500	1504	1489	1473
Number of lightning strikes	58	79	149	120	70	111	127	106
Lightning rate per 100 wind turbine year	10	9	13	9	5	7	9	7

From the table the lightning strikes per year were about 10%. The author also notes that lighting strikes are about one quarter of all faults caused by external factors such as storm, icing, lightning strike, power grid fault etc.

A number of valuable papers are given in the references to this section of the report.

The purpose of a lightning protection system is to protect the turbine, blades, tower, electrical equipment, and any substation from direct lightning strikes and possible fire, or other consequences of lightning strike.

Figure 26: Examples of Lightning Damage [Ref. 3.7.8]

Figure 27: Example of Lightning Damage [Ref. 3.7.8].

Figure 28

McNiff [Ref. 3.7.2] quotes Dodd [Ref. 3.7.15] in his report "Wind Turbine Lightning Protection Project" carried out for NREL.

"Experience with unprotected fiberglass blades in service is that they do suffer lightning strikes at a disturbing rate, and that such strikes are generally catastrophic, causing

blade destruction. In these instances, the arc is generated on the inside of the blade, and the shock/explosive overpressures associated with the high-energy component of the lightning strike result in the damage. The lightning arc is often found to puncture through the center of the blade by formation of an arc channel through drain holes at or near blades tips, or through cavities, flaws, and bond lines. It is probable that the presence of moisture and dirt in the blades or in cavities can assist the formation of a current path. The explosive vaporization of moisture will contribute to the pressure increase and damage to the blade."

A good summary of the situation was put forward by the National Lightning Safety Institute, Louisville Colorado, by Richard Kithil, President & CEO in September 2007 [Ref. 3.7.4].

"USA Experience

1. At one southwestern USA Wind Farm lightning damage exceeded $50,000 in the first year of operation. Damage occurred to blades, generator, controller, control cables, SCADA, etc. A Lightning protection retrofit at site by manufacturer included air terminals, TVSS products and additional bonding & grounding measures.

Further lightning damage occurred after the retrofit. A consulting engineering specialist in lightning mitigation was hired. Recommendations for enhanced grounding measures are being implemented. TVSS, air terminal, shielding, nacelle, blade treatment, and personnel safety recommendations are not being implemented at this time.

2. Eighty-five percent of the downtime experienced by a second southwestern USA commercial wind farm was lightning-related during the startup period and into its first full year of operation. Direct equipment costs were some $55,000, with total lightning-related costs totaling more than $250,000.

European Experience.

1. A 1996 European retrospective study was conducted of some 11,605 wind turbine years experience in Denmark and Germany. Very accurate operational records were available for analysis. General findings indicated:

a) lightning faults caused more loss in wind turbine availability and production than the average fault;

b) ranking in descending susceptibility to lightning damage were turbine control systems, electrical systems, blades, and generators;

c) the number of failures due to lightning increases with tower height;

d) wood epoxy blades have significantly less damage rates than GRP/glass epoxy blades.

2. The German electric power company Energieerzeugungswerke Helgoland GmbH shut down and dismantled their Helgoland Island wind power plant after being denied insurance against further lightning losses. They had been in operation three years and suffered in excess of 800.000 German Marks damage.

Design and Testing

Many USA lightning codes and standards are incomplete, superficial, and provide more benefit to commercial vendors than to those seeking relief from lightning's effects. Devices that claim to offer absolute protection abound in the marketplace, confusing specifying architects, engineers, and facility managers. Safety should be the prevailing directive.

The time to review possible lightning effects upon wind turbines is during the site selection and design stages. A lightning mitigation plan can be derived from a hazard design analysis. Then, a testing and verification program can provide validation and certification that the protective measures will function as engineered. Frequently, lightning problems do not receive consideration during the design stage. It then requires a specialized lightning safety engineer to analyze the effects of lightning during operations, and provide a rationale for "safety-through-redesign" modifications to the wind farm facilities.

Lightning Realities

Lightning prevention or protection, in an absolute sense, essentially is impossible. However, hazard mitigation and threat reduction are achievable through an understanding of the lightning phenomenon and preparation for its effects."

The literature refers to certain locations e.g. Japan, China, which are pre-disposed to lighting strikes.

Japan wind farms suffer from winter lightning strikes. One citation states that during a particularly turbulent winter: *'Data collected from one winter season in Japan alone reveals losses of horrifying proportions. In just one season, and just one area of Honshu, at least 55 machines had blades destroyed by lightning. The total estimates [that] one year loss for those machines exceeded $5.5 million, and the cost of prevention is approximately one half that value'*[Ref. 3.7.9].

Damages in Japanese Wind Turbine Systems due to Winter Lightning were reported in a recent conference [Ref. 3.7.5].

"Damages in the wind turbine generator system caused by the lightning can be categorized as follows:

a. *wind turbine blades*
b. *power apparatuses and control systems inside a wind tower*
c. *distribution and telecommunication lines connected to the system…………*

The number of the damaged control equipments is larger than that of the blades. However, the damage of the blades due to the winter lightning makes the generator stop the operation for long period as is shown in Fig. 6. Thus, the damage of the blades is the most serious problem in the wind power generation."

Unlike most "standards" the IEC 61400-24 is a report on state of the art with lightning protection of offshore wind farms and the potential solutions as well as containing recommendations for future research. Extracts of this report are provided to give background and perspective to the requirement of including lightning protection as a regulatory requirement. Since lightning protection technology and products are quickly advancing, and since this is a fundamental structural strength issue it is appropriate to have the CVA function certify and confirm the appropriateness of the selected lightning protection. To that end the certification standard is selected as the best available technology at the time of writing of this report.

"During the last few years damage to wind turbines due to lightning strokes has been recognized as an increasing problem. The increasing number and height of installed turbines have resulted in an incidence of lightning damage greater than anticipated with repair costs beyond acceptable levels. The influence of lightning faults on operational reliability becomes a concern as the capacity of individual wind turbines Increases and turbines move offshore. This is particularly the case when several large wind turbines are operated together in wind farm installations since the potential loss of multiple large production units due to one lightning flash is unacceptable.

Unlike other electrical installations, such as overhead lines, substations and power plants, where protective conductors can be arranged around or above the installation in question, wind turbines pose a different lightning protection problem due to their physical size and nature. Wind turbines typically have two or three blades with a diameter up to 100 m or more rotating 100 m above the ground. In addition, there is extensive use of insulating composite materials, such as glass fibre reinforced plastic, as load-carrying parts. The lightning protection system has to be fully integrated into the different parts of the wind turbines to ensure that all parts likely to be lightning attachment points are able to withstand the impact of the lightning and that the lightning current may be conducted safely from the attachment points to the ground without unacceptable damage or disturbances to the systems."

"Lightning protection of modern wind turbines presents problems that are not normally seen with other structures. These problems are a result of the following:

- *wind turbines are tall structures of up to more than 150 m In height;*
- *wind turbines are frequently placed at locations very exposed to lightning strokes;*
- *the most exposed wind turbine components such as blades and nacelle cover are often made of composite materials incapable of sustaining direct lightning stroke or of conducting lightning current;*
- *the blades and nacelle are rotating;*

- *the lightning current has to be conducted through the wind turbine structure to the ground, whereby significant parts of the lightning current will pass through or near to practically all wind turbine components;*
- *wind turbines in wind farms are electrically interconnected…."*

"Blades for large modern wind turbines are usually made of composite materials, such as glass fibre reinforced plastic or wood laminate. Lightning striking unprotected blades manufactured of these materials invariably causes severe damage since these materials are poor conductors of lightning current. Therefore, lightning protection of such blades is essential. Some nacelle covers are made of glass fibre reinforced plastic, and these should also be protected against direct lightning strokes.

The fact that wind turbines are rotating machines poses special problems. There is a risk of lightning flashes attaching at more than one point on rotating blades and even on more than one blade."……. "When lightning strikes the blades, the current passes through the entire wind turbine structure to the ground. This includes pitch bearings, hub and main shaft bearings, gears, generator bearings, bedplate, yaw bearing and tower. Lightning current passing through gears and bearings may cause damage, particularly when there is a lubrication layer between rollers and raceways or between gear teeth."

"6.3.1 Generic problem
The generic problem of lightning protection of wind turbine blades is to conduct the lightning current safely from the attachment point to the hub, in such a way that the formation of a lightning arc inside the blade is avoided. This can be achieved by diverting the lightning current from the attachment point along the surface to the blade root, using metallic conductors either fixed to the blade surface or inside the blade. Another method is to add conducting material to the blade surface material itself, thus making the blade sufficiently conducting to carry the lightning current safely to the blade root."

LM Glasfiber who is a dominant manufacturer of blades has the following remarks: [Ref. www.lmglasfiber.com].

"Lightning strikes are a wind turbine's worst enemy. Without effective lightning protection, both the blades and the turbine itself can be severely damaged by the powerful energy surges in lightning. "

"*A lightning strike on an unprotected blade can lead to temperature increases of up to 30,000°C and result in an explosive expansion of the air within the blade. This can cause damage to the blade surface, delamination, cracking on both the leading and trailing edge, as well as melted glue. Lightning strikes can also cause hidden damage that over time will result in a significant reduction of the blade's service life."*

The IEC standards *"state that the blades must be able to withstand 98% of all natural lightning strikes".*

"LM lightning protection is designed to safely and efficiently attract any lightning strike and conduct the energy from it down the wind turbine's tower via a conductive system within the blade."

"Protecting wind turbine blades against lightning is not about avoiding strikes, but attracting them. This makes it possible to direct the flow of the lightning and ensure that the components exposed to its effects can withstand the forces involved.

LM Glasfiber receptors are made of a special tungsten alloy that has excellent conductive qualities and is resistant to intense heat. The surface of most lightning receptors is normally damaged and gradually disintegrates after a lightning strike. This is not true of LM Glasfiber lightning receptors, which can withstand multiple lightning strikes before requiring replacement. They are also designed to be quick and easy to replace if necessary. "

"When lightning strikes a receptor, it must be conducted down the wind turbine's tower or into the ground. The lightning conductor system consists of a network of cables that lead the lightning current away. The design of this system of cables is crucial because of the need to conduct an enormous amount of electrical current without causing flashover to other conductive materials in the blades. It is also very important that the strong magnetic forces that arise when the current passes through the cables do not damage the blade. "

"LM Glasfiber lightning protection includes a magnetic card that registers lightning strikes. During routine service, we use special equipment to read this information. The magnetic cards can be used to assess whether there was any damage to the blades and the rest of the wind turbine following a lightning strike. These cards also provide our experts with valuable information about lightning strikes and their effect on LM blades. "

The above is not an endorsement of the LM Glasfiber product but their explanation is helpful and concise to give appropriate understand of lightning protection. Further information on this protection is available at their website www.lmglasfiber.com.

3.7.1 Safety Management System Input Information

Due to the nature of the lightning issue, part of the SMS should cover procedures for the detection of lightning, warning to the personnel working in the field, and if at all possible abandonment of the wind turbine structures and any control stations. The SMS system should designate safe areas for lightning protection and provide guidance and signage for the work crews to understand what is safe and what is not in regard to location for safety if in the field when lightning occurs. The location of the safest position on each structure should be known and signposted in case of personnel being caught offshore in a lighting storm.

The following guidance from IEC 61400-24 is quoted:

"Wind turbines are in principle safe to work in. However, during thunderstorms, personnel working on wind turbines can be exposed to additional risks. For unprotected wind turbines all lightning flashes are potentially harmful to personnel, therefore lightning protection should be part of the turbine design. Work should not be performed on wind turbines during thunderstorms. Safe operating procedures should include precautions for personnel safety during thunderstorms.
The risks related to personnel safety at the different locations in a wind turbine during thunderstorms are addressed below.

10.1.1 Nacelle

When lightning strikes a blade, current will flow through the nacelle to the tower. Part of the current may enter the nacelle through the low impedance path of the drive train. For wind turbine structures more than 60 m high the risk of receiving side flashes on the nacelle also has to be considered. Protection of personnel inside the nacelle can be provided for as follows:

- *when side flashes are to be expected due to the height of the turbine, an air termination system on the top of the nacelle may be insufficient to protect personnel inside. It is recommended that an air termination system be installed which encircles the interior of the nacelle like a Faraday cage;*

- *for wind turbines having an insulated drive train, provisions to install heavy earth connections to the drive train when entering the nacelle need to be available;*

- *personnel outside the protection area of the air termination system are endangered by a direct flash since they are in LPZ OA. It is highly recommended that provision is made to shelter any personnel in minimum LPZ 0B;*

- *personnel inside the nacelle may be at risk when touching or being close to metal parts.*

10.1.2 Tower

A large part of the tower itself and structures outside the tower can be struck by lightning directly and be part of the current path to earth. During a thunderstorm, protection of

- *personnel on or inside the tower can be provided for as follows:*

- *personnel inside closed towers (steel or reinforced concrete) are protected against a direct flash. The safest locations to be during a thunderstorm are on one of the tower platforms or inside at ground level. The use of ladders, even inside tubular towers, should be minimized;*

- *personnel on the outside of a tower can be endangered by a direct flash. Substantial protection cannot be provided in this case and the situation should be avoided;*

- *personnel climbing inside a lattice structure are endangered by parts of a lightning current, the resulting voltage differences and the shock wave resulting from a nearby flash;*

- *personnel on or inside a non-conductive tower structure are most endangered.*

10.1.3 Ground Level Area

The ground level areas of a wind turbine are:

- *inside or outside the wind turbine tower;*
- *inside or outside a building associated with a wind turbine.*

The lightning current flowing into the turbine structure will disperse from the tower into the foundation, the cabling and the earth. Depending on the shape and dimensions of the earth termination system, the current will cause a voltage gradient at ground level around the turbine tower. During a thunderstorm, protection of personnel at ground level can be provided for as follows:

- *personnel near open electrical panels are endangered during the flash by any catastrophic failures inside the panels. This situation should be avoided;*

- *personnel outside but near the tower are protected against a direct flash but endangered by the voltage gradient on the ground during the flash. Standing in the area of a high voltage gradient can cause a potentially hazardous current to flow through the body;*

- *personnel inside a protected building or shelter are safe; personnel inside a fully enclosed metal vehicle are safe.*

If a lightning flash causes a power system failure, this should not lead to extra danger to personnel. This should be dealt with by proper power system design.

10.1.4 Instructions for personnel

Safety instructions and warning procedures for site personnel during thunderstorms must be available. It should be made clear that personnel should only be in a safe location during a thunderstorm. The safety procedures should be included in an operations manual and provided for in standard operator training.

It should be noted that the level of danger is even higher during construction when a complete lightning protection system is not yet functional and special instructions may be required."

CVA

Since the lightning protection is a structural safety issue it is a task of the CVA to ensure that it meets the requirements of recognized and generally accepted good engineering practice.

The on-going Certification of the system if done by the CVA or the Project certifier is recommended.

"Lightning protection systems have to be inspected by an approved expert at regular intervals (annually). The inspection of the operability and condition of the lightning protection system includes a visual inspection of all air terminals and down conductors as well as measuring the contact resistance of the conduction path from the air terminals in the rotor blades to the ground terminal lug, and measuring the ground resistance of the foundation." [Ref. 3.7.10].

Applicable Codes

Standards and Technical reports issued by IEC:

IEC/TR 61400-24 Ed. 1.	Wind turbine generator systems: Lightning protection. Identifies the generic problems involved in lightning protection of wind turbines; describes appropriate methods for evaluating the risk of lightning damage to wind turbines; describes and outlines suitable methods for lightning protection of wind turbine components.
IEC 62305-1 Ed. 1.0 (2006-01)	Protection against lightning - Part 1: Provides the general principles to be followed in the protection against lightning of structures including their installations and contents as well as persons, and services connected to a structure. 135 pages
IEC 62305-2 Ed. 1.0 (2006-01)	Protection against lightning - Part 2: Risk management. Applicable to risk assessment for a structure or for a service due to lightning flashes to earth. Its purpose is to provide a procedure for the evaluation of such a risk. Once an upper tolerable limit for the risk has been selected, this procedure allows the selection of appropriate protection measures to be adopted to reduce the risk to or below the tolerable limit. Informative annex with simplified software for risk assessment for structures. 219 pages
IEC 62305-3 Ed. 1.0 (2006-01)	Protection against lightning - Part 3: Physical damage to structures and life hazard. Provides the requirements for protection of a structure against physical damage by means of a lightning protection system (LPS), and for protection against injury to living beings due to touch and step voltages in the vicinity of an LPS (see IEC 62305-1). This standard is applicable to: a) design, installation, inspection and maintenance of an LPS for

	structures without limitation of their height; b) establishment of measures for protection against injury to living beings due to touch and step voltages. 307 pages
IEC 62305-4 Ed. 1.0 (2006-01)	Protection against lightning - Part 4: Electrical and electronic systems within structures Provides information for the design, installation, inspection, maintenance and testing of a LEMP protection measures system (LPMS) for electrical and electronic systems within a structure, able to reduce the risk of permanent failures due to lightning electromagnetic impulse. This standard does not cover protection against electromagnetic interference due to lightning, which may cause malfunctioning of electronic systems. However, the information reported in Annex A can also be used to evaluate such disturbances. Protection measures against electromagnetic interference are covered in IEC 60364-4-44 and in the IEC 61000 series. This standard provides guidelines for cooperation between the designer of the electrical and electronic system, and the designer of the protection measures, in an attempt to achieve optimum protection effectiveness. This standard does not deal with detailed design of the electrical and electronic systems themselves. 201 pages

Certification

Lightning and surge protection should cover the nacelle and rotor blades of the wind turbine, and the transformer substation in particular, as well as any kind of electrical installations or equipment, including cable lines that are relevant for operation and safety.

It is recommended that the Certification standard used is as follows:

Germanischer Lloyd - Guideline for the Certification of Offshore Wind Turbines, Ed. 2005 - Chapter 8.9 Lightning Protection

This Guideline contains specific actions to be taken to assure that the facility is safe to protect against lightning strikes. It is made up of the following subjects:

- Definition of protection levels
- Definition of protection zones
- Execution of measures
- Foundation earth electrode for the tower
- Design of the tower
- Junction at the yaw bearing
- Connection of the machine foundation to the earthing system
- Connection of the generator and the gearbox to the earthing system
- Connection of other components in the nacelle
- Metallic housings of the nacelle
- Non-metallic housings of the nacelle

- Lightning protection of the rotor blades.

While the above is a recommendation if it can be shown that in site-specific areas, lightning protection is not necessary deviations may be considered. Deviations should follow a procedure for determining the severity of the hazard based on the SMS in place, and the considerations similar to those laid out in API RP 14J [3.7.6].

3.7.1 References

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3.9 Fire in Wind Turbines and Transformer Substations

In order to protect the offshore wind turbines and their associated structures fire protection measures for platforms, and marine facilities need to be adapted to the special conditions in wind turbines and transformer platforms. Accommodation platforms associated with the wind farm will need to follow the normal requirements for offshore oil and gas platforms.

Onshore facilities are not always equipped with fire protection. The situation for offshore wind turbines differs from traditional onshore wind farms. Societal values at the early stage of offshore development compel a high success rate with generating wind power without incidents that would shut-down the concept. There is a high concentration in the nacelle of potential ignition sources and there is no possibility of fighting the fire with generally available existing equipment because of the height of the nacelle. It is also important to ensure that attending maintenance personnel are protected against automatic fire suppression devices. It is thus compelling from a societal risk viewpoint as well as a financial viewpoint that fire protection is mandatory in offshore application.

Fires in wind turbines are caused by either a lightning strike or a technical fault. Both transmission fluids, and lubricating fluids, with or without nuisance leakage into the nacelle, provide fuel for the fire once started. The materials used in the nacelle covers may also be flammable. Lightning does not necessarily lead to fire, and as accounted for elsewhere it is normally a blade which is broken.

To illustrate the point, for onshore wind turbines, these firefighters below are following standard protocol for burning turbines. [Ref. 3.9.1]. This involves standing by and permitting the turbine to burn out while arresting potential spread from fragments that fall to the ground.

Figure 29

It is similarly expected for offshore wind farms that there may be little that can be done by firefighters. Because of the greater expense of offshore wind farms and the advance of fire suppression systems these are optimum for regulatory requirements.

Figure 30

Once a wind turbine has been on fire, it can lead to safety risks from personnel having to carry out repairs, and leads to up to a year of downtime and considerable financial loss.

To date the majority of offshore wind turbines have been developed using gearboxes and this type of system requires a large quantity of lubricant. Direct drive systems have no drive components that require a large amount of oil but the large ring generators often contain flammable resins.

Technical faults may lead to overheating, or sparking, in combination with flammable fluid or vapor. Fires may also be initiated by loose or broken electrical connections, which can introduce sparks or heat. In 2003 the nacelle of the German 1.2 MW Vensys 62 prototype burned down, apparently due to a short circuit in a fail-safe battery pack of the pitch control system [Ref. 3.9.2].

"It can also happen that a bearing starts failing and runs dry. The resulting heat build-up in the component can finally – especially if combined with oil and or grease – lead to disastrous fires and consequent installation damage. Insufficient lubrication oil, failing cooling systems and other operational imperfections can also lead to problems which, under certain conditions, may lead to fire. Finally, a fail-safe brake running hot during a sustained brake action could be a potential cause of nacelle fire. Again, a combination of oil with grease spills increases the probability."

"Thorough and systematic service and maintenance is essential," to avoid fire damage "and a thorough check of the entire installation is needed during each service and/or repair visit. It is important to make sure that cables are routed properly, avoiding situations in which a cable or a pipe can rub against rotating and/or vibrating components. (Damaged cable insulation can result in a short circuit.)" [Ref. 3.9.2].

Other references give insights as to how issues may arise: "The generator cables in the nacelle have reached too high temperatures, because the cables have been packed too tightly" [Ref. 3.9.4].

Further issues:
"A broken or worn-through oil-circulation pipe can cause an oil leak, which can in turn lead to a machine component running dry and hot. If leaked oil comes into contact with either electrical contacts or hot machine surfaces, it can cause a fire. Broken or worn-through water circulation pipes can also result in overheating of components and lead indirectly to a fire. Frequent checks are therefore essential.

"Condition monitoring systems – accessed remotely by PC – can greatly reduce the risk of component-induced damage. These systems typically monitor such things as oil and/or water temperature in critical components, (differences in) component vibration levels, and changes in acoustics levels, amongst other things.

"There may also be a useful role for automatic fire extinguishers, functionally coupled to key system functions. Some turbine manufacturers are believed to be looking at incorporating these systems into their products, and the controlled environment within modern nacelles could now make this easier than it might have been in the past. Other patented systems, as used in different industries, are now offering themselves to the wind market……….. installed along any part of the internal workings of the wind turbine (for instance, parallel to the hydraulic lines) and delivers CO_2 or another fire-suppressant to extinguish a fire within seconds of its starting. This reduces damage to a minimum. The systems are designed to work automatically, without the need for manual activation and monitoring." [Ref. 3.9.2] .

Since CO_2 can be dangerous to personnel it is important to have adequate warning systems unless these are disengaged when personnel are at the offshore structures. 20 seconds is typical warning for generators in offshore facilities, and this should be determined on a project-by-project basis.

"Today, in most new wind turbines, switchgear, inverter, control cabinets and transformer are placed in the nacelle. Thus, the risk of fire increases significantly there. Due to the high density of technical equipment and combustible material in the nacelle, fire can spread rapidly. Moreover, there is the danger that the upper tower segment is being damaged in addition. In case of a total loss of the nacelle, the restoration costs may well reach the original value of the wind turbine." [Ref. 3.9.3].

The cost of providing offshore cranes to repair the damaged turbines is a compelling argument for providing fire detection and fire suppression as a requirement.

Extracts of Reference [3.9.3] follow to put the issue of fires on offshore wind turbines in perspective:

"3.2 Examples of damages

3.2.1 Fire damage caused by lightning strike
During a heavy summer thunderstorm, the blade of a 2 MW wind turbine was struck by lightning. The turbine was shut down automatically and the blades were pitched out of the wind.

The burning blade stopped at an upright position and burned off completely little by little. Burning parts of the blades that fell down caused a secondary fire in the nacelle. Investigation of the cause of damage showed that the fire in the blade was caused by a bolted connection of the lightning protection system that was not correctly fixed. The electric arc between the arrester cable and the connection point led to fusion at the cable lug and to the ignition of residues of hydraulic oil in the rotor blades.

Figure 31

Fig. 1: Fire after lightning struck a 2 MW wind turbine in 2004 (Image source: HDI/Gerling) The nacelle, including the rotor blades, had to be referred to as a total loss. The upper part of the tower had also been destroyed due to the high temperature.

Operations were interrupted for approximately 150 days; the total loss amounted to approximately EUR 2 million……

3.2.2 Fire damage caused by machinery breakdown

The nacelle of a 1.5 MW wind turbine completely burned out after the slip ring fan of the double-fed induction generator had broken. Sparks that were generated by the rotating fan impeller first set the filter pad of the filter cabinet on fire and then the hood insulation. The damage to property amounted to EUR 800,000.

Fig. 2: Burnt down nacelle of a 1.5 MW wind turbine (Image source: Allianz)

3.2.3 Fire damage caused by failure in electrical installations

A low-voltage switchgear was installed within the nacelle of a 1 MW wind turbine. The bolted connection at one of the input contacts of the low-voltage power switch was not sufficiently tightened. The high contact resistance resulted in a significant temperature increase at the junction and in the ignition of adjacent combustible material in the switchgear cabinet. The fuses situated in front did not respond until the thermal damages by the fire were very severe. Control, inverter and switchgear cabinets that were arranged next to each other suffered a total loss. The interior of the nacelle was full of soot. Despite the enormous heat in the area of the seat of fire, the fire was unable to spread across the metal nacelle casing. The damage to property amounted to EUR 500,000….."

Offshore wind farms are subject to higher probability of lightning strikes as noted in the Lightning section of this report. Reference [3.9.3]) refers to other failure causes in offshore installations:

Causes of Failure:
"failures in electrical installations of wind turbines are among the most common causes of fire.

Fire is caused by overheating following overloading, earth fault/short circuit as well as arcs.

Typical failures include the following:

- *Technical defects or components in the power electronics (e.g., switchgear cabinet, inverter cabinet, transformer) that have the wrong dimension*
- *Failure of power switches*
- *Failure of control electronics*
- *High contact resistance due to insufficient contacts with electrical connections, e.g., with bolted connections at contact bars*
- *Insufficient electrical protection concept with respect to the identification of insulation defects and the selectivity of switch-off units*
- *No or no all-pole disconnection of the generator in case of failure/switch-off of the turbine*
- *Missing surge protection at the mean voltage side of the transformer*
- *Resonances within RC (resistor-capacitor) circuits (line filter, reactive power compensations)*

3.3.3 Hot surfaces

If all aerodynamic brakes fail, mechanical brakes, which shall slow down the rotor, can reach temperatures that result in an ignition of combustible material. In case of such an emergency braking, flying sparks that are caused by mechanical brakes without cover *also pose a high risk since flying sparks might also ignite combustible material that is further away. Defects at turbines or parts thereof, e.g., leakage of the oil systems and dirt, increase the risk of fire.*

Other risks exist in case of overloading and poor lubrication of generator and gearbox mountings. In these cases the mountings get too hot. Combustible material and lubricants can ignite when they get in contact with hot surfaces. For example, if a failure at the mounting leads to rubbing of rotating components, the flying sparks resulting thereof might cause a fire.

3.3.4 Work involving fire hazards

Work involving fire hazards relating to repair, assembling and disassembling work, e.g., welding, abrasive cutting, soldering and flame cutting, is a frequent cause of fire. Due to the high temperatures that occur during these activities, combustible material that is in the close or further environment of the working site may get on fire. Welding, cutting and grinding sparks are particularly dangerous since they can ignite combustible material that is at a distance of 10 metres and more from the working site. Many fires break out several hours after the completion of work involving fire hazards.

3.3.5 Fire load

A wide variety of combustible material that can cause an outbreak of fire and result in a fast spread of fire is being applied in the nacelle of wind turbines, e.g.,

- *internal sound insulation foam of the nacelle,*
- *parts or material contaminated by oil-containing deposits,*
- *plastic housing of the nacelle (e.g., GRP),*
- *oil in the hydraulic systems, e.g., for pitch adjustments, braking systems. If there are any damages or if the temperature is very high, high pressure in the hydraulic pipes can cause the hydraulic oil to escape finely nebulized, and this can cause an explosive spread of the fire,*
- *gearbox oil and other lubricants, e.g., for the generator bearings,*
- *transformer oil,*
- *electrical installations, cables, etc*

Hydraulic oils, oil-containing waste that has not been removed, and lubricants, which are stored in the nacelle are additional fire loads and not only increase the general risk of fire unnecessarily, but also increase the risk of a spread of fire, in particular."

In addition to fire safety measures for particular hazards as the examples note, it is also necessary to take into account other protective measures:

Minimizing flammable materials in the construction, and sources of fuel for the fire (e.g oily rags), limit the use of open flames etc.
During routine maintenance when shutting off safety devices alternative ways of preventing escalation of the fire should be considered e.g. portable extinguishers.

Mitigation of Hazards

Reference [3.9.3] further advises on the subject of minimizing combustible materials:

Hydraulic and lubricant oils should be chosen as being preferably non-combustible or have a high flash point which is significantly above the operating temperatures of the systems.

The application of combustible material, e.g., foamed plastics such as polyurethane or polystyrene as insulating material or glass-reinforced plastics for coverings and other components should preferably be avoided for fire protection reasons.

Closed-cell materials with washable surfaces should be used in order to avoid intrusion of impurities, oil leakage, etc., which otherwise would increase the risk of fire in the course of the operating time. Materials including cables should be of a type that does not cause much smoke and do not support the spread of fire when they burn.

"When working with components that contain flammable liquids or oils, it must be made sure that leaking fluids are collected safely, e.g., by installing trays or be applying non-combustible oil binding agents. Leakages are to be removed immediately.

After the work has been completed, the collected fluids should be disposed properly, and impurified oil binding agents should be removed from the system.

Combustible material as well as auxiliary material and operating material should not be stored within the wind turbine".

"Dirty cleaning cloths must be disposed when leaving the wind turbine." [Ref. 3.9.3].

Maintenance

"Fire caused by technical defects at electrical and mechanical systems represent the most frequent causes of damages. Means to reduce such kind of damage include regular maintenance according to the manufacturer's instructions (maintenance manual) and inspections of the systems as well as timely repair of identified deficiencies."

Condition Monitoring

Condition monitoring is discussed as a separate section however in relation to fires the following comments apply to items to monitor:

"pressure and temperature at mechanical and electrical systems such as transformer, generator winding, gearboxes, hydraulic systems or bearings. If the limiting value is exceeded or is not reached, there should be some kind of alarm and finally an automatic shutdown of the wind turbine. In the course of type testing and certification processes of wind turbines, the monitoring of operating parameters is usually taken into account.

Electrical installations and monitoring systems in wind turbines have to be examined by experts on site on a regular basis. At least every five years the gas and oil of the transformer insulation liquid have to be analyzed, amongst others.

The analysis allows drawing a conclusion on the quality of the insulating oil and provides information about possible electrical defects, thermal overloads of the transformer, and the condition of the paper dielectric. If there are any defects in the active component of oil transformers, there is the risk of an explosion due to large electrical currents in connection with the insulating oil as fire load resulting from rapidly increasing internal pressure in the boiler. With respect to dry-type transformers, the surface has to be controlled annually, and it has to be cleaned if necessary. Additional safety is provided by installations that serve the optical detection of partial discharge (spark switch).

Recurring inspections of electrical installations ……should usually take place every two years." Ref. [3.9.3].

"In addition to these inspections, thermography at the electrical installations should be examined on a regular basis, e.g., in the following areas:

- *Connection areas and, if possible, contacts of the LV HRC fuse switch disconnectors*
- *Clamping devices and terminal strips, respectively, in distribution boards as well as in switch terminal blocks and control terminal blocks*
- *Connection areas and, if possible, contacts of bus bars, contactors, capacitors, etc.*
- *Connection areas and surfaces of transformers, converters, and engines*
- *Power cable and cable bundles, respectively*
- *Surfaces of equipment which may pose a risk in case of heating."* [Ref. 3.9.3].

With thermal imaging, power lines maintenance technicians locate overheating joints and parts, a tell-tale sign of their failure, to eliminate potential hazards.

3.9.1 Fire Detection

In order to assure that the detection systems will be appropriate the owner should:

- Apply and adapt existing standards in planning the equipment to be provided
- Ensure that the planners and installers are competent (refer to SMS)
- Ensure that the equipment is certified, and installed to the satisfaction of a certified expert organization.
- Ensure that the equipment is periodically tested and maintained and the maintenance is documented.

The risks of fire can be limited effectively by automatic fire detection/ alarm systems and selection of non-combustible materials when possible e.g. nacelle materials. Upon recognizing that a fire has been detected automatic switch-off of the turbines and complete disconnection from the power supply system should be possible combined with firefighting using the automatic fire suppression system(s).

Note: automatic systems which would involve potential asphyxiation should be shut off during times personnel are on board in maintenance mode, if immediate egress is not possible, and this should be contained in the permit to work system.

The overall fire protection philosophy for wind turbines and associated structures should be proposed by the owner based on recognized and generally accepted good engineering practices and certified by an independent professional engineer.

The owner may select appropriate standards for each of the designated items in the design basis. An efficient method of making that selection would be to adapt existing requirements for similar situations to a basis that would be appropriate for the wind turbine structures. Such a basis is given below for fire detection requirements from USCG Subchapter N. The basis should also take into account the requirements of NFPA 72, National Fire Alarm Code [Ref. 3.9.8]

3.9.2 & 3.9.3 Fire Protection Equipment

Advice in the equipment from the German insurance industry is that : *"With respect to the application at wind turbines, extinguishing agents that are as residue-free, non-corrosive and non-electroconductive as possible, and which are suitable with respect to the prevalent environmental conditions at wind turbines (temperature, weather, impermeability of the installations and rooms to be protected) and the fire loads would be desirable."* [Ref. 3.9.3].
and

"Powder extinguishing systems as well as aerosol extinguishing systems cannot be recommended for application at wind turbines since they may cause consequential loss.

Type of Detector	Smoke detector			Heat detector (Index "R" according to DIN EN 54-5)		Flame detector		Multi-sensor smoke detector	
	Point-shaped	Multi-point-shaped	Linear	Point-shaped	Linear	IR	UV	Smoke and heat	Smoke and CO
Room Installation	Scattered Light	Aspirating	Light Beam						
Nacelle with transformer, including hub and raised floors	-	+	-	-	-	-	-	-	-
Central electric power substation, switch cabinet rooms	+	+	+	+	+	-	-	+	+
Tower base/platform with available instillations, if applicable	-	+	-	+	-	-	-	-	-
Switchgear cabinets	+	+	-	-	-	-	-	+	-
Hydraulic Systems	-	+	-	+	-	-	-	-	-
Transformer	-	+	-	Buckholz relay		-	-	-	-

+ basically suitable - not likely suitable

The data in this table refers to the basic suitability of several types of detectors with respect to functionality and general application conditions in the respective area of the wind turbine's system; it serves as orientation guide and does not replace the required proof of suitability as well as the object-specific technical planning by appropriate specialist planners, ...

Table 3: Information on the selection of fire detectors for monitoring rooms and installations"

Fire extinguisher

In order to fight initial fires it is necessary to provide a sufficient number of appropriate and operational fire extinguishers. They should be available in all rooms in which a fire may occur, amongst others in the nacelle, in the tower base and in the electric power substation which might be arranged externally.

The extinguishing agent is to be adjusted to the existing fire loads. Due to the negative impacts of extinguishing powder on electrical and electronic equipment it is recommended to refrain from using powder extinguishers if possible.

Extinguishing Systems (extinguishing agents)	Gas extinguishing system		Water extinguishing systems				Other extinguishing systems	
Room/Installation wind turbine	CO_2 (high pressure)	Inert gases	Sprinkler	Water spray	Fine spray	Foam	Powder	Aerosol(1)
Room protection e.g.,								
Nacelle with generator, transformer, hydraulic systems, gearbox, brake, azimuth drive	+	+	+	+	+	-	-	-
Hub with pitch drive and generator, if applicable	+	+	+	+	+	-	-	-
Raised floors with oil sump and cable and electrical installations	+	-	+	+	+	+	-	-
Central electric power substation, switchgear rooms, (without transformer)	+	+	-	-	+	-	-	-
Tower base/platform with available installations, if applicable	+	+	+	+	+	-	-	-
Installation protection, e.g.,								
Control, inverter, switchgear cabinets (ILV/MV), closed	+	+	-	-	+	-	-	-
Transformer	+	-	-	+	+	-	-	-
Control, inverter, switchgear cabinets (LV/MV), open	+	-	-	-	+	-	-	-
Hydraulic system, open	+	-	+	+	+	+	-	-

+ basically suitable - not likely suitable
The data in this table refers to the basic suitability of several fire extinguishing systems with respect to their functionality and general application conditions in the respective area of the wind turbine's system; it serves as a first orientation guide and does not replace the required proof of suitability as well as the object-specific technical planning by appropriate specialist planners…..

1) There is currently no empirical information available on the reliability and effectiveness concerning the application of aerosol extinguishing systems

Table 4: Information on the selection of fire extinguishing systems for room and installation protection

At least one 6 kg CO_2 fire extinguisher and one 9 litre foam fire extinguisher should be installed in the nacelle (pay attention to the risk of frost). And at least one 6 kg CO_2 fire extinguisher should be installed at the intermediate levels and at the tower base in the area of the electrical installations each.

5.2.3 Fault monitoring

Fire detection systems and fire extinguishing systems have to be monitored constantly in order to ensure their operational reliability.

Failures with traditional fire protection systems, e.g., failure of individual fire detectors or leakage at the extinguishing agent stock or shrinkage of the extinguishing agent supply, will be displayed directly at the fire protection system by means of an error message. Due to the operation without on-site staff and the remote location of wind turbines and the resulting non-identification of possible failures at the fire protection system on site, forwarding of all error messages to a permanently manned post (control post) is required. This control post will then initiate immediate recovery of the unlimited operational readiness of the fire protection system.

Any events have to be documented in the report book." [Ref .3.9.3].

The owner may select appropriate standards for each of the designated items in the design basis. An efficient method of making that selection would be to adapt existing requirements for similar situations to a basis that would be appropriate for the wind turbine structure or the associated structures. Such a basis is given below for fire protection requirements from USCG Subchapter N. The basis should also take into account the requirements of IMO Fire Protection Safety Systems (FSS) Code, 2007 Edition [Ref. 3.9.11], and the International Code for Application of Fire Test Procedures (FTP Code), 1998 [Ref. 3.9.12] as well as the appropriate portions of NFPA 101, Life Safety Code [Ref. 3.9.13].

It is expected that automatically initiated fire suppression systems will be used in the wind turbine generator area and at locations of switchgear, transformers and other likely fire locations in order to prevent escalation of a fire. The fire suppression systems can utilize clean agents such as FM 200, FE 13, Inergen, CO2, foam, dry chemical, water mist, or combinations of those systems. It is anticipated that systems which are a danger to personnel will be disconnected locally from operating when maintenance personnel are on board in such a way as to take account of the time to escape prior to them initiating releases. In order to mitigate fire risk during the time the automatic system is out of service, portable extinguishers may be substituted on a temporary basis while on board for the purpose of fighting a minimum fire and prevent it escalating.

Specific industry guidance may be used in conjunction with
API RP 14J Design & Hazards Analysis of Offshore Production Facilities [Ref. 3.9.14] and Pub 2030 Application of Water Spray Systems for Fire Protection in the Petroleum Industry [Ref. 3.9.17].

NFPA

- -10 Portable Fire Extinguishers
- -11 & 11 A Low, Medium and High Expansion Foam Systems
- -12 Carbon Dioxide Extinguishing Systems
- -13 Installation of Sprinkler Systems
- -15 Water Spray Fixed Systems
- -17 Dry Chemical Systems
- -20 Installation of Stationary Pumps
- -30 Flammable and Combustible Liquids Code.

3.9.4 Safety Management System Input Information

The SMS calls for a number of procedures including Emergency Preparedness and Response. For fires this may include personnel knowing what action to take, telephone numbers to contact, location of emergency services, and training in knowledge of how events can escalate if action is not taken. Shutdown of the wind turbine and disconnection from the power supply system may be one of the required actions. Provision of Warnings transmitted to personnel in the vicinity to keep distance may also be one of the actions.

Work involving fire hazards needs to be carefully planned since the wind turbine structure is a confined space.

The SMS training system also should include prevention of risks of fire, and functionality of fire protection systems installed and how to handle them. An interesting story makes the point of ensuring that any firefighters have appropriate equipment, in this case airpacks, and rehearse the potential problems. It also speaks to the issue of ensuring that the door at the bottom of the tower is closed if there is a fire which would be a “training” and “safety procedure” issue to be accounted for in the SMS.

Fire Traps Workers at Top of 213 – Foot Iowa Wind Turbine

Storm Lake Pilot Tribune
STORM LAKE, Iowa (AP) – A fire trapped two workers at the top of a 213 foot wind turbine until firefighters could reach them.

The electrical workers were working on a control panel inside the turbine’s support tube last week when the fire broke out. They were treated at a local hospital and released. Firefighters received a call about 7:35 p.m. on Nov 30 that there was a fire in the MidAmerican Energy wind turbine, just south of Schaler. Firefighter Armon Haselhoff said the doors to the turbine were shut to keep oxygen from feeding the fire, since the support tube could have acted like a chimney.

The workers were able to get fresh air through a hatch at the top of the tube, Haselhoff said. Firefighters extinguished the blaze, which appeared to have started from a short circuit during testing.

Once the fire was under control firefighters climbed to the top of the tube to help the workers down, Haseloff said.

Firefighter Jason Currie and another firefighter ran out of air in their packs before they reached the top, but kept going anyway. "It got worse every level we went up," Currie said. Firefighter Jeff Sandoff said he and Currie had zero visibility climbing inside the tube. "Once we climbed the tower, it was just your hands reaching in front of you", Sandhoff said. He said firefighters had radio contact with the trapped workers.

Mark Reinders, MidAmerican spokesman, said the turbine was still under construction. The employees were from M.A. Mortenson, a General Electric subcontractor.

The fire will not delay the project, which is scheduled to be completed by the end of this year, Reinders said. [Ref. 3.9.5].

CVA

The CVA function is not applicable to fire protection systems.

Type Certification

The fire detection and fire prevention equipment must be Type Approved to USCG standards. and meet the requirements of USCG Subchapter N (reviewed later) [Ref. 3.9.21].

Project Certification

From the research carried out, the most appropriate document to follow is the GL Wind Guideline, Certification of Fire Protection Systems for Wind Turbines, Certification Procedures Rev. 2, 2009 [Ref. 3.9.6]. This document refers extensively to the VdS 3523 [Ref. 3.9.3] which has been quoted extensively above. Project Certification to the appropriate parts of this GL Guideline adapting it to equivalent US marine requirements in areas such as extinguishing nozzles, detectors and other fire extinguishing systems with USCG type approval, instead of VdS approval would be recommended. The test procedure and frequencies would seem appropriate limited to the first turbine installed and type Certification of the components.

"Technical documents to be submitted
(1) For the certification of a fire protection system, the following components shall be submitted as a rule:

a. *description of the fire protection concept (see Section 5)*
b. *description of the fire protection system (implementation, sequence of events, behaviour of the wind turbine after triggering of the fire protection system, behaviour of the wind turbine in the event of a malfunction in the fire protection system) (see Section 6)*

c. *description of the individual systems of the technical fire protection, if applicable including the approvals (certificates) of the components, systems and installers*
d. *description of the fire detectors, sensors and, if applicable, the control boxes of the fire protection system (e.g. type designation, set values, set points, time constants)*
e. *general arrangement drawing showing the installation positions of the systems for fire protection, including the positions of the sensors and fire-extinguishing appliances*
f. *electrical circuit diagrams, insofar as electrical components form part of the fire protection system, with references to the circuit diagrams of the electrical system of the wind turbine*
g. *piping diagrams, insofar as piping forms part of the system*
h. *installation, commissioning, operating and maintenance manuals, as described in Section 6 "Manuals"”*

To assure the continuing suitability of installations past the first one which is installed and tested and witnessed by a Certifier the requirements of the manufacturer must meet ISO 9001.

The structure of the certification is shown schematically in Fig. 1 and explained in the following.

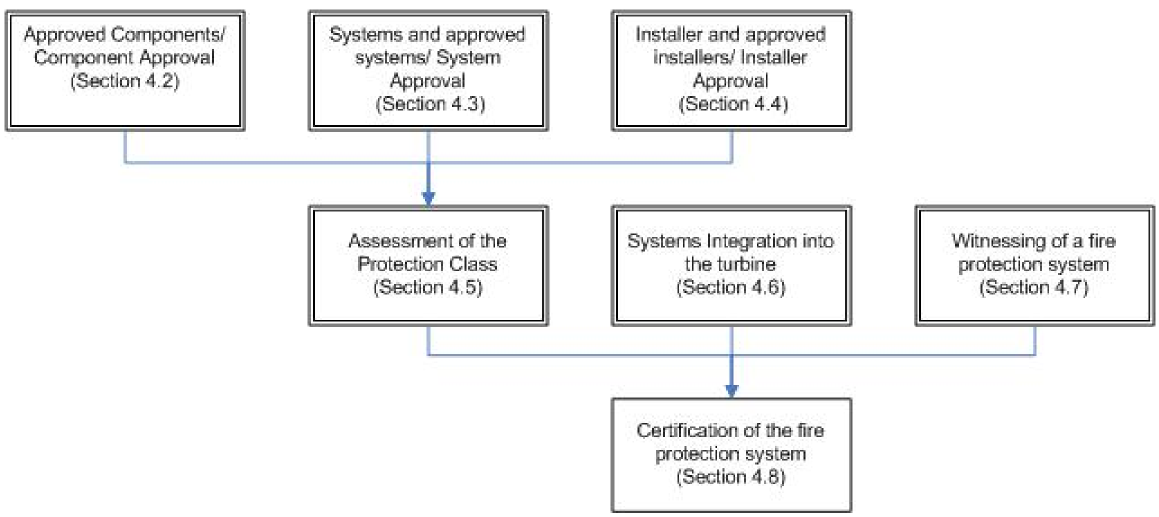

Fig. 1 Structure of the certification of the fire protection system by GL.

GL witnesses the fire protection system on the first fire protection system of the type that is installed and put in to operation. Thereafter it is assumed the document means this is Type Certified for the turbine type.

GL discusses the requirements for the hazard warning system: *“The control system of the wind turbine constitutes part of a hazard warning system. When the temperature limits of components (e.g. bearings or brake linings) are exceeded, the control system shall cause* *a shutdown of the wind turbine and the corresponding malfunction signal shall be stored."*

…and structural fire protection: *"The structural design measures include fire stopping (e.g. covers for brake discs to guard against flying sparks), fire –resistant cladding and fire protection coatings. If any structural design measures are taken to mitigate the fire risk, these shall be explained in the description of the fire protection system."*

The Certification document requirement includes Installation Manuals, Commissioning Manuals, and requires a signed record of the work carried out for the installation and commissioning steps. Operating and Maintenance manuals are also required.

These Certification requirements with deviations, is the most appropriate that have surfaced during the research for offshore application on the US OCS.

IEC Code

The IEC Code does not cover fire protection. It mentions, in passing, IEC 61400-1 & IEC 61400-3 Section 13.2 refers to "suitable fire protection for personnel".

Section 13.4. The emergency procedures plan states that it should take into account the risk of fire.

DNV 0S-201 - Offshore Substations [Ref. 3.9.7] has some provisions for fire protection and this is recommended for use with the Offshore Substation when used in conjunction with API 14G [Ref. 3.9.9] and API 14C [Ref. 3.9.10].

3.9.5 USCG

The USCG Subchapter N requirement may be adapted as follows:

33 CFR §143.1050 What are the requirements for a fire detection and alarm system?

(a) All accommodation and service spaces on a manned fixed facility <u>or in a space with the wind turbine generator or electrical gear</u> must have an automatic fire detection and alarm system.

(b) Sleeping quarters must be fitted with smoke detectors that have local alarms and that may or may not be connected to the central alarm panel.

(c) Each fire detection and fire alarm system must:

(1) Be designed to comply with API RP 14 G, section 4.
(2) Be installed to comply with API RP l4 C and NFPA 72.
(3) Have a visual alarm and an audible alarm ~~at a normally manned area.~~
~~(4) Be divided into zones to limit the area covered by a particular alarm~~

~~signal.~~

Note:
API RP 14G Recommended Practice for Fire Prevention and Control on Fixed Open-type Offshore Production Platforms [Ref 3.9.9]- This publication presents recommendations for minimizing the likelihood of having an accidental fire, and for designing, inspecting, and maintaining fire control systems. It emphasizes the need to train personnel in fire fighting, to conduct routine drills, and to establish methods and procedures for safe evacuation. The fire control systems discussed in this RP are intended to provide an early response to incipient fires to prevent their growth. However, this discussion is not intended to preclude the application of more extensive practices to meet special situations or the substitution of other systems which will provide an equivalent or greater level of protection.

API RP 14C Recommended Practice for Analysis, Design, Installation, and Testing of Basic Surface Safety Systems for Offshore Production Platforms [Ref. 3.9.10] - This document presents recommendations for designing, installing, and testing a basic surface safety system on an offshore production platform. The basic concepts of a platform safety system are discussed and protection methods and requirements of the system are outlined.

The NFPA 72 specifies "the application, installation, location, performance, inspection, testing, and maintenance of fire alarm systems, fire warning equipment and emergency warning equipment, and their components."

Figure 32

USCG requirements include fire detection and firefighting systems be of an approved type. Guidance on this can be found at http://www.uscg.mil/hq/cg5/cg5214/fesys.asp.

§ 143.1025 What are the approval requirements for a fire extinguisher?
All fire extinguishers must be of an approved type under 46 CFR part 162, subparts 162.028 and 162.039.

§ 143.1026 Must fire extinguishers be on the facility at all times?
(a) On a manned fixed facility, the fire extinguishers required by §143.1030 must be on the facility at all times.

(b) On an unmanned facility the fire extinguishers required by §143.1030 need be on the facility only when personnel are working on the facility ~~more than 12 consecutive hours~~.

§ 143.1027 What are the name plate requirements for a fire extinguisher?
All portable and semi-portable extinguishers must have a durable, permanently attached nameplate giving the name of the item, its rated capacity in liters (gallons) or kilograms (pounds), the name and address of the person or firm for whom approved, and the identifying mark of the actual manufacturer.

§ 143.1026 What are the maintenance requirements for a fire extinguisher?
All fire extinguishers must be maintained in good working order.

§ 143.1029 How many fire extinguishers do I need?
For each particular location, you need the number of fire extinguishers required by table 143.1029.

Table 143.1029 provides for areas with electric motors and generators as C-II one for each motor or generator; Helicopter areas as B-V one at each access route.

Note: NFPA 10 categorizes:
- Class C: Fires which involve energized electrical equipment
- Class B: Fires in flammable liquids, oils, greases, tars, oil based paints, lacquers and flammable gas.

3.9.10 References

[3.9.1] www.windaction.org
[3.9.2] Wind and Fire, Renewable Energy World, Sept-Oct 2004).
[3.9.3] Wind Turbines Fire Protection Guideline VDS 3523EN 2008-07
[3.9.4] Middelgrunden Offshore Wind Farm Presentation, www.slideshare.net.
[3.9.5] http://www.firetrace.com/images/pdf/iowawindfire.pdf
[3.9.6] GL Wind Guideline, Certification of Fire Protection Systems for Wind Turbines, Certification Procedures Rev. 2, 2009
[3.9.7] DNV 0S-201 - Offshore Substations
[3.9.8] NFPA 72, National Fire Alarm Code

[3.9.9] API RP 14G Recommended Practice for Fire Prevention and Control on Fixed Open-type Offshore Production Platforms

[3.9.10] API RP 14C Recommended Practice for Analysis, Design, Installation, and Testing of Basic Surface Safety Systems for Offshore Production Platforms

[3.9.11] IMO Fire Protection Safety Systems (FSS) Code, 2007 Edition [3.9.12].International Code for Application of Fire Test Procedures (FTP Code), 1998 as well as the appropriate portions of

[3.9.13] NFPA 101, Life Safety Code

[3.9.14] API RP 14J Design & Hazards Analysis of Offshore Production Facilities

[3.9.15] NFPA

-10 Portable Fire Extinguishers

-11 & 11 A Low, Medium and High Expansion Foam Systems

-12 Carbon Dioxide Extinguishing Systems

-13 Installation of Sprinkler Systems

-15 Water Spray Fixed Systems

-17 Dry Chemical Systems

-20 Installation of Stationary Pumps

-30 Flammable and Combustible Liquids Code.

[3.9.16] GL Guideline for the Certification of Condition Monitoring Systems for Wind Turbines, Edition 2007.

[3.9.17] Pub 2030 Application of Water Spray Systems for Fire Protection in the Petroleum Industry.

[3.9.18] J. Twiddle, and G. Gaudiosi, Offshore Wind Power, Multiscience Publishing Co., 2007.

[3.9.19] ABS Guidance Notes on Fire-fighting Systems, May 2005.

[3.9.20] Andersen, N., Marcussen J., Jacobsen E., Nielsen S.B., Experience gained by a Major Transformer Failure at the Offshore Platform of the Nysted Offshore Wind Farm, Proceedings of the 7th International Workshop on Large-Scale Integration of Wind Power into Power Systems as well as on Transmission Networks for Offshore Wind Farms, Energynautics, Langen German, May 2008.

[3.9.21] USCG Type Approval List http://www.uscg.mil/hq/cg5/cg5214/fesys.asp.

3.14 Lifting Equipment Man Riding and Material Handling

As an example of some of the expectations for the equipment for lifting:

- It is expected that all lifting points on the wind farm structures should be Certified to the loads being used: padeyes should be in accordance with the API RP2A

2.4.2 c and d certification requirement. Personnel work baskets should be to minimum requirements of ASME B30.23.

- There should be list of requirements for each part of the lifting tackle and frequency and documentation requirements for the testing and inspection of all equipment covered. Wire rope inspection criteria in accordance with API RP2D.

- All slings must be certified to API RP 2D and ASME B30.9. The maximum age for synthetic slings should be specified (one year is normal) before they must be taken out of service and destroyed.

- An up to date inventory of all lifting appliances must be available at all times for audit.

- Repairs should be carried out on cranes to be by a licensed API spec RP 2C repair shop

References

[3.14.1] American Petroleum Institute, Specification for Offshore Cranes, API Spec 2C, 5th Edition 1995.

[3.14.2] EN 13852, Offshore Cranes Part 1: General purpose offshore cranes, 2000.

3.15.4 Emergency Power/ UPS Battery Back-up

The IEC Code calls for a battery backup of 6 hours to maintain the yaw mechanism of the nacelle pointed in the direction of the wind, unless it has been designed such that it can take ±180 degrees.

The mission of the battery is fundamental and should be included in the design basis document and further stipulations as to whether its ability to provide power is crucial to the structural integrity of the wind tower. In addition a number of other offshore operations rely on the backup battery system. Nav-Aids, communications, switchgear control, generator control, instrumentation systems, rotor pitch system, emergency lighting all may rely on the battery system for normal and emergency operations. The maintenance of this battery, a safety critical item, should be dealt with meticulously.

Figure 33 *"The SAFT NiCd cells have a power capacity of 3000 kw for 2 minutes"* [Ref. 3.15.1].

U.S. Coast Guard regulations (46 CFR 109.211) require a minimum of testing on safety related battery system. These mandated practices only determine if the battery system will work at the time of the test; this is not predictive or preventative maintenance and will not ensure the battery system will work when needed.

Backup battery systems don't fail without warning. Particularly because of the dependence of structural integrity of the tower, it is important to detect and recognize the warning signs before battery reliability is affected. The battery system manufacturer should provide guidance on the specific test program details and the owner's system should rely upon IEE standards which are accredited by the American National Standards Institute (ANSI). These IEEE/ANSI standards describe the minimum maintenance requirements for stationary battery systems: battery capacity testing is an integral part of routine scheduled battery maintenance.

The introduction of the backup battery which the code does not stipulate the location of but is assumed to be either on the wind tower itself or on the transformer station may be designed considering a number of guidance documents.

The battery systems are guided by a number of code documents for large wet cell batteries and some of the provisions of those are provided.

NEC The National Electrical Code: back up power, emergency lighting, and/or telecommunications are not extensive in this document:

> ***"701-4 (c):*** *Battery Systems Maintenance. Where battery systems or unit equipment are involved…, the authority having jurisdiction shall require periodic maintenance.*

701-5 (d): *Written Record. A written record shall be kept of such tests and maintenance.*

480-1 through 480-9 Storage Batteries

This section provides a definition of what a battery is, and describes the types of batteries and how they are designed. It also lists other codes to reference. Sealed and wet cells are described along with ventilation, load requirements, and other topics."

IEEE The Institute of Electrical and Electronics Engineers has detailed requirements on the installation and maintenance of batteries.

"IEEE-450 *"Recommended Practice for Maintenance, Testing and Replacement of Large Lead Storage Batteries for Generating Stations and Substations" Maintenance inspection procedures are explained along with the proper parameters for various tests. Replacement criteria along with record keeping are detailed.*

IEEE-484 *"Recommended Practice for Installation Design and Installation of Large Lead Storage Batteries for Generating Stations and Substations" Many aspects of safety, mounting alarms, Nuclear 1E classification, installation criteria and procedures and record keeping are described in this section.*

IEEE-485 *"Recommended Practice for Sizing Large Lead Storage Batteries for Generating Stations and Substations" This particular section defines loads and duty cycle, and details the sizing of large stationary batteries, cell selection, determining battery size, etc.*

IEEE-1106 *"Recommended Practice for Maintenance, Testing and Replacement of Ni-Cad Storage Batteries for Generating Stations and Substations"*

OSHA The Occupational Safety and Health Administration has several specifications regarding storage battery installations.

OSHA 1926.403(A) *General Requirements -*

1. *Batteries of the non-seal type shall be located in enclosures with outside vents or in well ventilated rooms, so arranged as to prevent the escape of fumes, gases, or electrolyte spray into other areas.*
2. *Ventilation shall be provided to ensure diffusion of the gases from the battery to prevent the accumulation of an explosive mixture.*
3. *Racks and trays shall be substantial and treated to be resistant to the electrolyte.*
4. *Floors shall be of an acid resistant construction or be protected from acid accumulations.*

5. *Face shields, aprons, and rubber gloves shall be provided for workers handling acids or batteries.*
6. *Facilities for quick drenching of the eyes and body shall be provided within 25 feet of the work area for emergency use.*
7. *Facilities shall be provided for flushing and neutralizing spilled electrolyte, for fire protection, for protecting charging apparatus from damage by trucks, and for adequate ventilation for dispersal of fumes from gassing batteries.*

OSHA 1910.178 subparagraph (g) Changing and Charging Storage Batteries. This particular section deals more with motive power battery usage than with stationary battery installations, but several paragraphs may still apply.

2) *Facilities shall be provided for flushing and neutralizing spilled electrolyte, for fire protection, for protecting charging apparatus from damage, and for adequate ventilation for dispersal of fumes from gassing batteries.*

3) *When racks are used for the support of batteries, they should be made of materials non-conducive to spark generation or be coated or covered to achieve this objective.*

10) *Smoking shall be prohibited in the charging area.*

11) *Precautions shall be taken to prevent open flames, sparks or electric arcs in battery charging areas.*

12) *Tools and other metallic objects shall be kept away from the top of uncovered batteries."*

UFC The Uniform Fire Code

***"Article 64** requires six items for storage battery installations. These items are:*

- *Occupation Separation 64.104 (c)*
- *Spill Containment 64.104(d)*
- *Neutralization and Absorption 64.104 (e)*
- *Ventilation 64.104 (f)*
- *Signs 64.104 (g)*
- *Seismic Protection 64.104 (h) 64.104 (c)*

Occupancy Separation. Battery systems shall be located in a room bounded by an occupancy separation having a minimum one-hour fire-resistive rating, exterior walls, roof or foundation of the building.

***64.104 (d)** Spill containment. Each rack of batteries, or group of racks shall be provided with a liquid tight 4-inch deep spill-control barrier which extends at least 1 inch beyond the battery rack in all directions.*

64.104 (e) *Neutralization. An approved method to neutralize spilled electrolyte shall be provided. The method shall be capable of neutralizing a spill from the largest lead-acid battery to a pH between 7.0 and 9.0.*

64.104 (f) *Ventilation.*
Ventilation shall be provided in accordance with the Mechanical Code. Unless the ventilation is designed to limit the maximum concentration of hydrogen to .8 percent of the total volume of the room in accordance with nationally recognized standards, the rate of ventilation shall not be less than 1 cubic foot per minute per square foot.

64.104 (g) *Signs.*
Doors into rooms or buildings containing stationary lead-acid battery systems shall be provided with approved signs. The signs shall state that the room contains lead-acid battery systems, that the battery room contains energized electrical circuits and that the battery electrolyte solutions are corrosive liquids.

64.104 (h) *Seismic Protection.*
Battery systems shall be seismically braced according to the building code."

DOT The Department of Transportation regards lead-acid batteries as hazardous material, not hazardous waste. Lead-acid batteries are subject to all DOT regulations applicable to the packaging, labeling and transporting requirements noted in **Clauses 40 CFR** of the Code of Federal Regulation). Clauses **49 CFR 106 - 180** further define the packaging, placarding and transporting of hazardous materials.

Clauses 40 CFR
261.6 Requirements for Recyclable Materials.
(a) (1) Hazardous wastes that are recycled are subject to requirements for generators, transporters and storage facilities of paragraphs (b) and (c) of this section, except for the materials listed in paragraphs (a) (2) and (a) (3) of this section. Hazardous wastes that are recycled will be known as "recyclable materials."

Subpart G: Spent Lead-Acid Batteries Being Reclaimed (a)
The regulations of this subpart apply to persons who reclaim spent lead-acid batteries that are recyclable materials ("spent batteries"). Persons who generate, transport, or collect spent batteries, or who store spent batteries but do not reclaim them are subject to regulations under Parts 262 through 266 or Part 270 or 124 of this chapter, and also are not subject to the requirements of section 3010 of RCRA.

Clauses 49 CFR
172.101 Hazardous Materials Table
Provides a complete listing of hazardous materials, the classes or divisions of those materials, as well as specific identification and labeling procedures, and other special provisions.

173.159 Batteries, Wet (a - c)
Explains the proper packaging of batteries based on their weights and dimensions.

(d-h) Explains the proper packaging of wet non-spillable batteries.

When design details are known the code provisions should be reviewed for the applicable items. Germanischer Lloyd Certification of Offshore Wind Farms 2005 contains information about the battery backup systems.

References

[3.15.1] Enercon Windblatt Magazine 03 2009.

3.16 Corrosion Protection & Offshore Suitability Requirements.

There are many issues with corrosion protection:

- designing the structure in such a way as to minimize collection points for moisture, and salts to accumulate;
- Paint on the tower exposed to the atmosphere particularly in the splash zone;
- Cathodic protection to the underwater parts of the structure.

Period : July 2004 – December 2004

Project : Horns Rev, Denmark

Services : Failure analysis of coating problems on 80 offshore wind turbine foundations.

Source: SGS

Figure 34

Period: July 2004 – January 2005

Project: Arklow Bank Offshore Wind turbine farm, Ireland

Services : Failure analysis of coating problem on 7 offshore wind turbine foundations

Source: SGS

Figure 35

There is very little that is different about corrosion protection for offshore wind turbines than other offshore structures in principle. Repairs to numerous turbines, however, require great attention to surface preparation and coatings because of the difficulty of access for repair. Offshore oil and gas structures do not shut down for coating repair but safe access repairs for wind farms dictate that they do so. Construction and maintenance costs of fixed oil and gas platforms have a smaller effect on the overall economics. Wind farms tend to be located in windy areas which means a robust seastate making access more difficult than many Gulf of Mexico platforms. All this leads to the importance of ensuring that the surface is prepared properly, coated under right temperature and humidity conditions in order to protect the surface.

Turbines developed for the offshore usually include heating/ dehumidification in the nacelle. Even if the electrical system is disconnected in the tower for a short while it is really important to keep the heat going in the nacelles.

The corrosion protection standard of the rotor, nacelle, and tower is according to ISO 12944-2 for corrosion class C5-M (outside) and C4 (inside).

One caution that sometimes is an issue in offshore oil and gas practice is the mistake of allowing the direct contact between two different precious metals allowing electrochemical reaction between both different metals. Points at which moisture tends to concentrate causing corrosion should be eliminated as much as possible. Electrical and piping penetrations may be areas for attention.

On fixed platforms the oil and gas industry uses, unless otherwise specified by the designer the corrosion protection system of NACE RP-01-76 is generally used [Ref. API RP2A].

The literature summarizes the position in regard to corrosion protection:

"Offshore wind turbines have major technical requirements due to the more demanding climatic environmental exposure offshore, with greater risks of structural corrosion. In addition, there is the greater problem of access during bad weather, and greater expense when replacing larger main components. Wind turbines for offshore sites therefore require increased corrosion protection, with reduced maintenance and service requirements and an improved supervision and control system."

"The exterior corrosion protection of the various steel components (nacelle cowlings, tower, etc.) features a paint system fulfilling the standards required for North Sea offshore installations, drilling rigs and platforms. The surface of the fibreglass blades is similar to fibreglass boat hulls and therefore requires no additional corrosion protection for offshore use."

"Interior corrosion protection comes from improved painting systems and maintaining a dry environment inside the machine. A pre-requisite for a dry interior environment is a sealed machine. The gear and generator are cooled by heat exchangers recycling the air

used in the air-cooling system, instead of conventional air-cooled components on earlier turbines. "

"To maintain low interior air humidity, de-humidifying devices were placed in the tower and nacelle room. The de-humidifying system maintains the interior relative humidity below the limit of any steel corrosion risk limit (60%). For additional protection, the main electric components (generator, control systems, etc.) have standby heating systems, preventing condensation, even during sudden variations in temperature."

[Ref. http://www.power-technology.com/projects/middelgrunden/]

In relation to the painting system alone: "ISO 20340 compliance plus proven offshore credentials should constitute the minimum acceptance criteria when considering offshore coating specifications, especially given the potential cost of correcting inappropriate specifications.

By adopting ISO 20340 and understanding the nuances in the testing regimes contained within the standard, it is possible for offshore wind farm developers and operators to utilize the best practice developed for the oil and gas industry."

[Ref. International Paint www.international-pc.com]

Another useful standard is the Norwegian NORSOK MCR-501 Coating Specifications (Rev. 5, June 2004) which gives advice as follows:

Surface Preparation and Protective Coating: This standard gives the requirements for the selection of coating materials, surface preparation, application procedures and inspection for protective coatings to be applied during the construction and installation of offshore installations and associated facilities.

The manufacturer Siemans notes:

"Corrosion protection

All external turbine components are painted with offshore-grade painting systems that effectively minimize any corrosion caused by salty air and water. The nacelle and tower are fully enclosed, and climate control including dehumidifiers constantly maintain the internal humidity below the 60 percent corrosion threshold."
www.powergeneration.siemans ***.com***

Paint coatings are only used down to about one metre below Lowest Astronomical Tide, from there to the toe level if the structure is bare steel relies on Cathodic protection. In general flush mounted sacrificial anodes are used for cathodic protection however an impressed current system may also be applied. It is important to know the characteristics of the seawater in order to set various parameters necessary for proper protection. The area of Cook Inlet Alaska for example is prone to far more aggressive corrosion than other offshore waters in the United States.

Certification

Certification standards are usually DNV, GL or NACE standards. GL is the only one which specifically has a document geared to address the offshore wind farm issues (even though most of the requirements are the same or similar).

GL has some special requirements for offshore application features of which are noted:

- The relative humidity inside the offshore wind turbine should be less than 70% due to an increased corrosion rate above this limit;
- Internals of the room shall be protected against the outside air;
- The systems shall be monitored by the control system;
- Components and material specifications to be submitted for all components having an indirect access to outside air;
- All operating materials which are in contact, directly or indirectly with the offshore atmosphere need to be verified as suitable for an offshore location;
- All components not protected by a corrosion protection system are to be enumerated and verified as suitable for an offshore atmosphere;
- Lubricants, oils cooling fluids etc, shall be environmentally friendly.

DNV has a section in DNV-OS-J-101 in regard to corrosion protection.

- *"For a 20-year design life, a corrosion allowance of 3-5 mm should be applied to all primary steel structures in the splash zone for fatigue analyses. For secondary structures in the splash zone, a corrosion allowance of 2 mm can be applied."*

Code

MMS regulations for offshore fixed platforms incorporate by reference:

NACE Standard RP 01-76, Standard Recommended Practice, Corrosion Control of Steel Fixed Offshore Platforms Associated with Petroleum Production [Ref. 3.16.7] which may be considered a suitable reference.

SMS

The SMS should note that the offshore wind turbine will be shut down while maintenance is being done in the event of blade damage presenting a risk to the personnel engaged in the maintenance.

CVA

The CVA has historically not been report on long term coating or corrosion matters.

Certification

While it has not been customary practice for MMS to review and comment on corrosion protection systems or to accept only certified systems, it seems that GL Guidance is sensible and to be recommended and DNV standards on corrosion protection may also be acceptable.

3.16.1 References

[3.16.1] James Thick, Overview of Corrosion Protection of Wind Farms EWEC Conference 2004.
[3.16.2] Corrosion Protection for Offshore Wind Turbines, Malte Lossin, Germanischer Lloyd, RECOFF Project, www.risoe.dk.
[3.16.3] DNV RP B401, Cathodic Protection Design.
[3.16.4] EN 12495, Cathodic protection for fixed steel offshore structures, 2000
[3.16.5] Germanischer Lloyd Certification of Offshore Wind Turbines 2005 (Chapters 3 and 7).
[3.16.6] ISO/CD 19902, Draft, Petroleum and Natural Gas Industries – Fixed Steel Offshore Structures, 2001.
[3.16.7] NACE Standard RP0176-2003, Corrosion Control of Steel Fixed Offshore Structures Associated with Petroleum Production. (Referenced by API RP2A).
[3.16.8] NORSOK Standard M-501, Surface Preparation and Protective Coating, Rev.4, 1999.
[3.16.9] NORSOK Standard M-503, Cathodic Protection, Rev.2, 1997 NACE RP0176:1994.
[3.16.10] ISO 12944-2:1998 Paints and varnishes -- Corrosion protection of steel structures by protective paint systems -- Part 2: Classification of environments.
[3.16.11] DNV-OS-J-101 Design of Offshore Wind Turbine Structures, June 2004.
[3.16.12] ISO 20340:2009 Paints and varnishes - Performance requirements for protective paint systems for offshore and related structures

4. PERSONAL PROTECTION DESIGN CONSIDERATIONS

IEC Personnel Safety 62400-22: 8.3.14

The IEC contains a section on Personnel Safety and suggests several inclusions:

- *"safety instructions;*
- *climbing facilities;*
- *access ways and passages;*
- *standing places, platforms and floors;*
- *hand rails and fixing points;*
- *lighting;*
- *electrical and earthing system;*
- *fire resistance;*
- *emergency stop buttons;*
- *provision of alternative escape routes;*
- *provision for emergency stay in an for offshore wind turbine for one week; and*
- *offshore specific safety equipment for an offshore wind turbine"*

There is, however, insufficient guidance to reflect the specifics of how to consider these and to what standard.

The provision for a planned emergency stay in an offshore wind turbine for one week is problematic as it requires provision of suitable accommodation, lifesaving, firefighting, etc. USCG defines manned platforms and facilities in 33 CFR 140.10. Basically if a facility is routinely occupied for more than 12 hours/day it is considered manned and must adhere to all the requirements for a manned platform. If it is manned by more than a prescribed number of people (10) you must have sewerage treatment (Red Fox Unit): with less than that one may discharge directly overboard with no floating solids. The precise details of what is permitted must be obtained through a National Pollutant Discharge Elimination System (NPDES) permit from the applicable EPA region. Unmanned platforms can have facilities/shelter where records may be kept, a toilet (or bucket), and a horizontal surface for potentially remaining in some sort of emergency situation.

The supplies that are provided may best be taken care of by determination in a HAZID with a follow-up set of procedures in the Safety Management System.

4.1 Access to the Wind Turbine

The IEC Code recommends that the support structure be designed considering the maximum size support vessel impacting the wind turbine structure at a speed of 0.5 m/sec and provides factors for added mass coefficient. The GL Guidelines also provide for a similar collision load case but with somewhat higher added mass coefficients. DNV similarly has requirements for a potential collision.

It would be appropriate to consider the possibility of a collision and the vessel selected should reflect the issues at the field and protection provided for in the design which may be less than or greater than that recommended by the IEC Code. If less than the IEC Code value it is expected that a HAZID risk analysis provide justification for the selected values of vessels size and speed.

Information on limiting conditions on access to the offshore wind turbines are reported in the literature:

"The wind turbines are accessed using specially adapted transfer vessels. Transfer can take place at wave heights up to approximately 1.5 m depending on wind and wave conditions. Adverse weather and sea conditions can prevent safe access to the turbines, and when this occurs" [Ref. 4.1].

"To date, transfers of technicians from boat to turbine, which is the major access issue, have been by conventional ladder landings. However, the sites under construction and planned are mostly in more demanding wave conditions and this method offers poor

levels of safe accessibility. Hence, there are various different approaches under development to improve the access capability in bad weather" [Ref. 4.2].

Figure 36 [Ref. 4.3]

Referring to the Blyth Harbour project: *"The definition of availability is very important and in this case was a mixture of several definitions with modifications for the offshore environment. It was finalised during contract negotiations and not fully analysed for practical application. Several anomalies only became apparent when the calculations were performed as a result of serious generation time losses. The importance of good weather records including sea state, who records them and when, needs to be emphasised and budgeted for. Precisely what weather conditions are deemed unacceptable – it is easy to write these down, but in reality the access vessel and particular captain can have a big effect"* [Ref. 4.4].

While access methods are many and varied they have tended to be limited by boat to about 1.5 meters.

Figure 37 [Ref. 4.5]

It appears from the photo above that there is potential of damage to the turbine transition structure by attendant boats.

Some access is now done in Europe by helicopter. This is largely because of the increased up-time and the comparatively long distances by boat to the turbine locations.

Figure 38

Ramboll [Ref. 4.6] investigated several improvements to the boat access by the following methods:

- Selstair (Viking),
- Wave compensated boat (Seaservice)
- Offshore Access System, OAS (Fabricom),
- Wnd turbine crane (Grumsen's Makskinfabrik).

A final report is available on the Offshore Center Danmark website.

A University of Delft spinoff company has advanced the Amplemann device. It claims to be able to access platforms with a minimum requirement of 2.5 meters significant wave. The prototypes have been built and tested and these seem like a good device to provide safe access in higher seastates [Ref. 4.7].

Figure 39

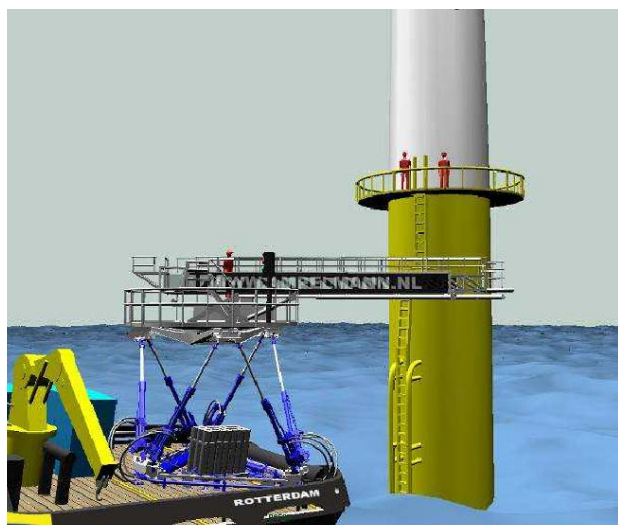

Figure 40

Figure 41: Ampelmann Device in Action

Various different kinds of service boats are available including including SWATH vessels and Catamarans which improve motion from ship-shape service vessels.

Compensated solutions for boarding include the Ampelmann, Offshore Access System (OAS), two developed by Momac named MOTS –a ship mounted system and SLILAL a turbine mounted system, and many other either developed or in development.

From a regulatory perspective all of these devices for boarding are permissible provided they can show reasonable safety precautions (not defined).

4.2.1 USCG Subchapter N on Life Saving at the Wind Turbine Structure

The owner may select appropriate standards for each of the designated items in the design basis. An efficient method of making that selection would be to adapt existing requirements for similar situations to a basis that would be appropriate for the wind turbine structure. Such a basis is given below for lifebuoy requirements from USCG 143.1341 Subchapter N. For an unmanned facility there are no requirements for permanent lifesaving gear but this should be available when personnel are on board. For the Offshore Substation they will meet the normal requirements of Subchapter N as for any fixed oil and gas facility.

§144.415 What are the requirements for ring life buoys?

(a) Each unmanned U.S. floating facility must have at least one ring life buoy meeting the requirements of § 143.850 of this chapter for every two persons on the facility, up to a maximum of four buoys.

(b) If there is no space on the facility for the ring life buoys, they must be on a manned vessel located alongside of the facility while personnel are on the facility.

The buoys may be transient and put on board temporarily while personnel are on board.

A facility such as a transformer station, or accommodation platform should follow the normal guidelines for oil and gas platforms for their lifesaving equipment which is a function of whether they are normally manned.

SMS

While procedures can define safe access; good hardware that makes the wind farm turbines more accessible is vital to keeping from having downtime from lack of access.

CVA

No Requirement.

Code

Except for the collision requirements noted and the provision to provide suitable fendering, no other code that we have located specifically determines any other requirements for access to the wind tower structure.

4.3 Access and Safety in the Tower

The design of the access system to transit up and down the tower is best carried out in the design phase of the tower since retrofitting could impact the tower design structural safety. The Safety Management System Template covers the issues of competence, PPE provisions, and training.

While it sounds relatively easy to position a ladder in a tower, and do reasonable things with the rung spacing and strength, this aspect of the wind turbine design is much more complex that at first it may seem, and there is little coordinated documentation available on the subject in the wind tower industry in United States. Complicating the issue is the height of the towers which presents an occupational health issue (muscular skeletal disorder) for those that have to climb them, as well as a safety issue.

Several countries have mandated elevators to overcome the occupational health issue: which leads to many further considerations to ensure safety is not compromised by designing in an elevator. Since the industry has advanced in Europe, elevator manufacturers there, have had an opportunity to develop elevators for wind turbines to European Standards. We have not been able in the scope of this report to be able to identify all the devices that may be used and identify which standards may be applied to those specific devices. The elevators used for the marine industries may be appropriate with minimum adaptation for the offshore wind turbine industry. There is little doubt that a document needs developing on this subject.

Figure 42: Windpower Engineering Sept 30, 2009
Article by Ralph Weinmuller

As wind turbines move offshore in the United States the requirements will become the responsibility of the lead regulatory agency, the Minerals Management Service. Many of the standards discussed have not been incorporated by reference in the codes that MMS has referred to as the USCG has often had jurisdiction over these items on fixed offshore platforms. The following discussion is offered to develop an awareness of some of the issues.

The conclusion reached is that for each installation at the design phase it will be important to convene a HAZID to document the decisions and standards being used for the installation. This will form part of the Design Basis document. What follows is some general thoughts on issues that require some consideration for those proposing to match the requirements to the standards. Part of the reason for this approach is because each owner will have their own level of concern.

There are 4 types of systems that are used for access all of which may be acceptable for offshore:

- Ladders (with fall arrest systems and intermediate platforms)

- Elevators
- Climb Assists and
- at some future time…..Helicopters

These may not be exclusive on any facility and all wind turbines have ladders. All ladders for offshore should be equipped with fall arrest systems.

In most countries ladders alone provide the most common access, but climb assists are being used in Germany and the USA. Denmark has passed legislation to ensure that elevators are incorporated when the tower is more than 45 meters high, and Germany for towers higher than 60 meters.

Risk studies have shown that the cost/benefit of installation of elevators, and risks pros/cons in general very comparable for new installations, particularly in the taller towers. Site specific variations determine the optimum solution: there are very many considerations in determining the appropriate optimum solution.

4.3.1 Protective Measures: Requirements for Design, Operation and Maintenance.

The research was unable to locate any one comprehensive U.S. standard that exists to specifically address all of the hazards and risks associated with access inside the towers by ladders, elevators and/or climb assist.

GL state that EN 50308 Wind Turbines –Labor Safety as the standard they use to Certify this aspect of offshore wind farms and is quite prescriptive in many of the requirements: it is an excellent code and directly applicable to the wind turbine industry.

This document covers among other requirements:

- Passages
- Rooms/ working areas
- Floors, platforms, standing, working places
- Climbing facilities
- Moving parts, guards and blocking devices
- Lifting
- Noise
- Emergency stop
- Power disconnection
- Warning Signs
- Manuals
- Operation and Maintenance

No comparable code was located in the US standards.

This document in Europe is used in conjunction with :

EN 353-1:2002 Personal protective equipment against falls from a height. Guided type fall arresters including a rigid anchor line; Safety lines, Safety anchorages, Restraint systems (protective), Safety devices, Occupational safety, Accident prevention, Falling (accident), Ropes, Fall arrest systems, Marking, Instructions for use.

ISO 14122-1 Safety of Machinery Part 1: Permanent means of access to machines and industrial plants – Choice of a fixed means of access between two levels.

ISO 14122-2: Working platforms and gangways.

ISO 14122-3: Stairways, stepladders and guard-rails.

ISO 14122-4: Fixed ladders (this standard cross-references EN 131-2:1993 incorporating Corrigendum No. 1 –Ladders- Part 2: Specification for requirements, testing, marking).

EN 1808: 1999 Safety Requirements on Hanging Personal Lifting Equipment: Calculation Stability and Building Tests.

EN 81-3:2000 Safety Rules for the Construction and Installation of Lifts – Part 3: Electric and hydraulic service lifts.

Some of the key standards for guidance in the USA which are of relevance are:

ANSI Z359.1-2007 Safety Requirements for Personal Fall Arrest Systems, Subsystems and Components which states the following:

"Design deficiencies often increase the risk for employees who may be exposed to fall hazards: examples are (1) lack of rail system to prevent falls from machines, equipment and structures; (2) failure to provide engineered anchorages where use of personal fall arrest systems are anticipated; (3) no provision for safe access to elevated work areas; (4) installation of machines or equipment at heights, rather than floor/ground level to preclude access to elevated areas; (5) failure to plan for the use of travel restriction or work positioning devices."

"Basic fall safety principles have been incorporated into these standards, including hazard survey, hazard elimination and control, and education and training. The primary intent is to ensure a proactive approach to fall protection. However, the reactive process of accident investigation is also addressed to ensure that adequate attention is given to causation of falls."

Other standards associated with this Fall Protection package – (amounting to a cost of over $1000.), are as follows:

ANSI/ASSE Z359.0-2007 Definitions and Nomenclature Used for Fall Protection and Fall Arrest

ANSI/ASSE Z359.12-2009 Connecting Components for Personal Fall Arrest Systems Price: $125.00

ANSI/ASSE Z359.13-2009 Personal Energy Absorbers and Energy Absorbing Lanyards Price: $125.00

ANSI/ASSE Z359.2-2007 Minimum Requirements for a Comprehensive Managed Fall Protection Program Price: $125.00

ANSI/ASSE Z359.3-2007 Safety Requirements for Positioning and Travel Restraint Systems Price: $125.00

ANSI/ASSE Z359.4-2007 Safety Requirements for Assisted-Rescue and Self-Rescue Systems, Subsystems and Components Price: $125.00

ANSI/ASSE Z359.6-2009 Specifications and Design Requirements for Active Fall Protection Systems Price: $125.00

Other standards:

ANSI A1264.1 : Safety Requirements for Workplace Walking/Working Surfaces and their Access; Workplace, Floor, Wall and Roof Openings; Stairs and Guardrails

ISO 3797:1976 Shipbuilding -- Vertical steel ladders
. . . concerned ladders to be fitted on board ships in small holds, between deck spaces, on masts, kingposts, trunks, deck-house tops,. .

ASTM F1166-07 Revises ASTM F1166-95a (2006)
Standard Practice for Human Engineering Design for Marine Systems, Equipment, and Facilities. . . Vertical Ladders, Ramps, Doors, Lightening Holes, Hatches, Kick-Out Panels, Passageways and Walkways, and Work Platforms) 11.1 Stairs, Ladders, and Ramps. . .

ANSI A14.3-56 Safety Code for Fixed Ladders, IBR approved for §§1910.68(b)(4) and (12); 1910.179(c)(2); and 1910.261(a)(3)(vi) and (c)(3)(i).

ANSI A17.1-65 Safety Code for Elevators, Dumbwaiters and Moving Walks, Including Supplements, A17.1a (1967); A17.1b (1968); A17.1c (1969); A17.1d (1970), IBR approved for §1910.261(a)(3)(vii), (g)(11)(i), and (l)(4).

ANSI A17.2-60 Practice for the Inspection of Elevators, Including Supplements, A17.2a (1965), A17.2b (1967), IBR approved for §1910.261(a)(3)(viii).

ANSI A90.1-69 Safety Standard for Manlifts, IBR approved for §1910.68(b)(3).

ABS Guide for Certification of Lifting Appliances: Chapter 5 Guideline for the Certification of Shipboard Elevators 2007.

The EU 50308 standard defines minimum and/or maximum values for doors, hatch openings, floors, climbing facilities or lighting levels for safety acknowledging that member states may have more stringent values. It also refers to several EN references including issues on:

- Safety of Machinery including stairways, working platforms, ladders and guard rails
- Personnel Protective Equipment against falls from a height including anchorages
- Acoustics

  ….among others.

There are yet other standards that may be applicable. EN 353 and a particular device that deals with climbing on ladders is being "discussed" at BWEA [Ref. http://www.bwea.com/pdf/safety/PH_5_09_0029_EN353-1_update1.pdf].

As an example of one of the provisions of EN353 the following figure is reproduced from that document.

These devices are used with fixed ladders or rungs attached to fixed structures. The system will have a rigid anchor line connected to and running the length of the ladders or structure (see Figure 1). The user is attached to the anchor line by a self-locking guided type fall arrester, which travels with the user as they ascend or descend. The guided type fall arrester is attached to the user's harness via a short lanyard. The system will have energy absorption within it either via the lanyard or fall arrester (or both). If a person falls while using the system, the guided fall arrester should detect the fall and lock onto the rigid or flexible anchor line, thereby safely arresting the fall.

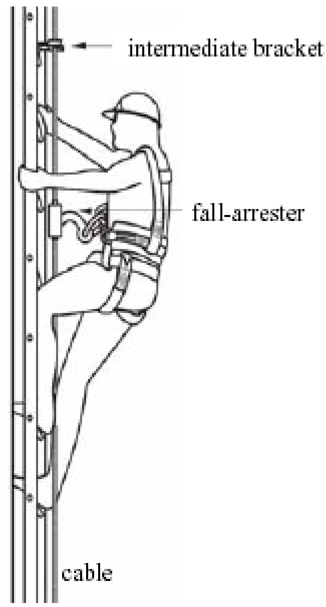

Figure 1. EN 353 Part 1 rigid anchor line

A number of other entities are working on US entities are said to be working on a comprehensive standard for wind farms including AWEA, and the American Society of Safety Engineers. Their draft documents were not yet in a stage to be released.

We have extracted particular issues from the DS/EN 50408 standard which may be useful in the design basis related to personnel safety issues. Other useful design advice is contained in this document besides the extracts given.

From Section 4.2.1: Access

"*Doors being the entrance to the turbine and/or to rooms with electrical switch gear (having an escape function shall have: ……*

- *The capability to prevent persons from being locked inside*
- *The capability of opening immediately, without the use of tools/keys,*
- *The capability of being secured in the open position."*

"Nacelle covers that can be opened, doors and hatches affected by wind or gravity shall be capable of being secured in the open as well in the closed position. They

shall be designed to be held securely open in wind speeds up to the maximum wind speed allowable for maintenance of the turbine, including allowance for gusts."

"Openings through floors and platforms shall have a hinged cover, which shall have two stable positions: open and closed".

From Section 4.2.2: Escape

"An alternative escape route from the nacelle shall be available if the normal access route can be blocked (e.g. by fire). The alternative escape route shall be indicated by signs and be described in the user (safety) manual……The means of escape can be a ladder or a descent device…A device shall be fireproof enough to allow escape from the nacelle to the ground in the event of a fire…….. Descent devices can be either permanently located in the turbine or brought by personnel."

"The escape route from working areas in front of electrical switch gear shall offer unobstructed passage according to the requirements of EN 50199".

"The nacelle shall have an extra hatch to the outside apart from the normal entrance. It shall be possible to open this hatch from both inside and outside."

From Section 4.3: Rooms/working areas:

"Auxiliary electrical connection points for light and power shall normally be provided in rooms or areas where work or inspections have to be done. Auxiliary power shall normally be available when the turbine itself is electrically isolated."

"Measures shall be taken to avoid the build up of hazardous toxic, flammable or explosive gases in any areas of the wind turbine. If a power transformer is installed these measure shall include sealing arrangements of the transformer room, or the provision of adequate ventilation, also in the situation of a grid loss."

Section 4.4 refers to loads and design parameters for floors, platforms, standing and working places. It requires *"a guard-rail if there is a danger of falling more than 0.5 m or be provided with grips and anchorage points for safety harnesses if a guard-rail is necessary but not practical for structural reasons".* Details are given for the guard rail requirements, which is similar to those specified by the USCG in their regulations.

Section 4.5 refers to climbing facilities and includes detailed requirements for heights and widths of rungs as well as tolerances and many details of the design including grips, and anchorage points for safety lines.

Section 4.6 deals with moving parts, guards and blocking devices.

Section 4.7 Lighting
"In closed rooms the wind turbine design shall include suitable levels of illumination for work lighting, guidance lighting and emergency lighting."

"Emergency lighting shall be provided to ensure that personnel can evacuate safety in the event that the supply to the main lighting system fails."

More details are given on the required light specification (e.g. lux) for various locations/ conditions.

4.9 Emergency Stop
"An emergency stop system is intended to divert danger both from persons and form the wind turbine".

"Emergency stop activation controls shall:

- *be installed on each machine at least in the tower base and in nacelles that can be entered;*
- *be red coloured, visible, clearly recognizable and easily approached from all locations where risks can arise from moving parts;*
- *Operate by means of forced switching and remain engaged after having been actuated;*
- *Not depend on electronic logic".*

4.11 Fire Protection

"for safety reasons certain materials must not be used and the design requirements below are to be applied.

Oil absorbing construction materials shall not be incorporated int eh nacelle or in the tower when leak oil could result in oil soaked material.

Escape routes including climbing facilities shall maintain their function for a minimum of 30 min in case of fire.

…….fire extinguishers for local use to extinguish a starting fire, shall have a minimum capacity comparable with a CO_2 -extinguisher of 2 kg content."

4.14.1.1 Operator's instruction manual and maintenance manual

"The operator's instruction manual and maintenance manual shall include the following information:

- *A description of the wind turbine system including operational limits and the electrical and mechanical installations,*

- *A description of any safety system, the shutdown levels and shutdown actions,*
- *Weight of relevant turbine parts, location of attachment points and methods of hoisting;*
- *Safety instructions including the remaining risks;*
- *Verification of the safety requirements and/or protective measures;*
- *Operating instructions*
- *Inspection and maintenance requirement"*

CVA
This section is not applicable for the currently defined CVA role.

Code:
It is recommended that certified equipment be used for access within the turbine and that the Project Certifier use the GL code [Ref. 1.35] in conjunction with EN 50308 suitably modified to US requirements.

4.3.2 USCG Guidance on Ladders

It is not yet clear if the USCG will have any input to the requirements for offshore wind farms. Their requirements for facilities on the OCS reflect the following in formation for vertical ladder requirements from USCG 143.1341 Subchapter N.

§143.1341 What are the vertical ladder requirements?
(a) Each fixed vertical ladder must have rungs that are:

(1) At least 41 centimeters (16 inches) in width;
(2) Not more than 30 centimeters (12 inches) apart and spaced uniformly throughout the length of the ladder; and
(3) At least 18 centimeters (7 inches) from the nearest permanent object in back of the ladder.

(b) Each exterior fixed vertical ladder more than 6 meters (20 feet) long must be fitted with a cage or a ladder safety device meeting sections 6 and 7 of ANSI A14.3-1992.

(c) For embarkation ladders, the following apply:

(1) Cages must have an opening on one side at least 50 centimeters (20 inches) wide for the full length of the ladder.
(2) Cages must be omitted from the portion of the ladder that extends from the still waterline up to 9.15 meters (30 feet) above the still waterline.

(d) Fixed vertical ladders must be made of a material other than wood.

4.3.3 Design Issues in Selecting Suitable Access System

Since there is no single solution to the issue in terms of choice of equipment of ladder and fall arrest system or elevator system the following are suggested as some of the design issues for consideration.

- Many of the turbine manufacturers are outside the USA and thus standards of systems they sell into the USA may not comply with US standards in any number of ways, but may have some of the features of the EU standards when suitable standards do not exist here.
- Turbine manufacturers selling into the US may not purchase an appropriate system for US.
- In design of the access devices the weight of the heaviest workers should be taken into account and there should be an awareness of the limits to which the equipment has been designed including the fall arrest equipment.
- Workers in wind turbine towers may use climbing helmets which may or may not be suitable as hard hats.

There are two types of elevators likely to be used in the offshore wind industry:

- Elevators integrated into the fixed vertical ladders: the ladder becomes the elevator guide.
- Elevators separate from the fixed vertical ladder that are guided by 2 tensioned steel cables for guidance.

By introducing an elevator into the turbine tower, it immediately introduces a complication to the construction process in that it may have to be installed in the tower section before being lifted, and any addition presents an installation and construction risk. Inspection by ladder will be necessary for the elevator (annual or bi-annual), and most likely it will not reach the top and thus there will be a necessity to consider transfer at top of elevator to ladder for entry to the nacelle.

The introduction of the elevator does however provide health benefits for the workforce and a saving of time for access, and provides less restrictions on fitness-for-personnel to be part of the workforce. Further considerations are chronicled which may provide insight into some of the issues:

Both Elevator and Ladder Considerations:

1. If the ladder is a rigid part of the elevator system, the elevator is on one side and the climbing area on the other: then if the elevator is not working, no equipment should be hauled up while the climber is on the exposed side of the ladder.
2. Understand the potential for multiple users on the ladder or elevator at the same time: weight, and for the ladder: safe climbing distances between users.
3. In most turbine tower structure designs the elevator cannot go all the way to the top: the last stretch has to be done by ladder.
4. Installation should be carried out by certified installers

5. Retrofitted materials attached to the tower may not only void the warranty but create a stress raiser for shortening the fatigue life or otherwise affecting the structural safety of the system.
6. Nacelle bunds should extend to protect ladder and elevator devices from any oil spilled.
7. Elevators and ladders need to be properly maintained and that may take more effort for one than for the other.
8. Rescue equipment for each site needs to be provided during visits and attachment points maintained.

Elevator Considerations:

1. Vibration may cause poor reliability in the elevator which may be more prone to fatigue from its location than in a normal land or shipboard location.
2. Temperatures may be outside specification of elevator components (particularly cold).
3. Elevator should consider that if a person trips that the cage does not have exposed bolts which could compound an injury e.g. protruding bolts, wing nuts, or fasteners.
4. Maintenance of elevator should be carefully considered: ideally for manufacturer to maintain.
5. Marginal increase in fire from elevator motor.
6. Ensure there is communication from the elevator i.e. cell phone may not work.
7. Consider alarms for the elevator in case of breakdown and potential to exit to ladder.
8. Consider any potential injury from attachment of person in the elevator to the ladder while affecting a transfer.
9. Ensure when purchasing that there is no disconnect between the certification of particular components and certification of the system.
10. Frequency of the elevator inspection to stay within warranty may require more visits than is appropriate for the installed turbine.
11. Evacuation and rescue procedures covering transfer of elevators to ladders
12. Limit switches should consider if someone could be injured at the top limit or bottom limit of the tower.
13. Preventing overload of the elevator for transporting equipment should be a consideration.

Ladder Considerations:

1. Fall arrest equipment normally requires a vertical drop to activate, thus leaning against the back of the tower may cause a fault.
2. Mixed and matched components (e.g. different cable diameter and clip-on), or copy components need to be guarded against.

3. Ladders may be equipped with square section and rungs with grips to avoid slips and trips particularly if oil from above is on the rungs or dirt on the bottom of boots.
4. Inevitably during construction the fall arrest system will have to be set up and bolted section by section to the ladders as construction progresses.
5. Features of the ladder at the landings, and protection of the access at the landings must be thought out for the worker to have safe passage to the platform on the way up and on the way down. Rest platforms should be located at suitable distances.
6. If climb assist is used it is important to ensure this will not interfere with the requirements of the fall arrest equipment.

4.4 References

[4.1] Department of Business Enterprise & Regulatory Reform, Offshore Wind Capital Grants Scheme – Scroby Sands Offshore Wind Farm 3rd annual report 2007.
[4.2] Garrad Hassan Report to US Corps of Engineers: Review of Offshore Wind Project Features Appendix 3-F.
[4.3] www.offshorecenter.dk.
[4.4] Blyth Harbour Wind Farm – Operational Aspects, Report of DTI, 2004
[4.5] Offshore Center Danmark, Presentation by Egon Poulson-Vestas
[4.6] Ramboll, Access to Offshore Wind Turbines, POWER Project presentation 2004-06-10, Offshore Center Danmark.
[4.7] Amplemann: Offshore access as easy as crossing the street, Jan van der Tempel,. The Offshore Wind Power Conference, Den Helder, Netherlands Feb 2009.
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[4.9] American Petroleum Institute, Recommended Practice for Planning, Designing and Constructing Heliports for Fixed Offshore Platforms, API Recommended Practice 2L, 4th Edition 1996.
[4.10] American Petroleum Institute, Specification for Offshore Cranes, API Spec 2C, 5th Edition 1995.
[4.11] EN 13852, Cranes Offshore Cranes Part 1: General purpose offshore cranes, 2000.
[4.12] Eike Lehmann and Florian Biehl, Hamburg University of Technology, "Collisions of Ships and Offshore Wind Turbines: Calculation of Risk Evaluation", Technical Paper 2004.
[4.13] Vattenfall and Swedish Energy Agency, Vindpilot Report, Methodology for Assessing Risk to Ship Traffic from Offshore Wind Farms, 2008.
[4.14] Peter Dalhof, Florian Biehl, "Ship Collision, Risk Analysis-Emergency systems-Collision Dynamics", Technical Paper.
[4.15] Delft 2005 report on Netherlands Chapter 22.

5.0 NAVIGATION LIGHTING, SOUNDS AND MARKING

The Record of Decision adopts initial Best Management Practices (BMPs) that were developed as mitigation measures in the Final Programmatic EIS. Among other requirements, the adopted BMPs include requirements for lessees and grantees to:

- comply with Federal Aviation Administration (FAA) and US Coast Guard (USCG) requirements for lighting while using lighting technology that minimizes impacts to avian species: (this may require deviations from existing regulations for lighting);
- avoid or minimize impacts to the commercial fishing industry by marking applicable structures with USCG approved measures to ensure safe vessel operation;
- avoid or minimize impacts to the commercial fishing industry by burying cables, where practical, to avoid conflict with fishing vessels and gear operation;
- inspect the cable burial depth periodically during project operation; and
- place proper lighting and signage on applicable energy structures to aid navigation per USCG circular NVIC 07-02 (USCG 2007) [Ref. 5.0.1]

While Navigation requirements are set by the USCG and are laid out in 33 CFR §67 lights and sounds for wind farms will need particular discussion with the USCG to get a final determination of the requirements in conjunction with the FAA and perhaps other agencies. The reason for this is the fact that numerous lights in a field of turbines all lit by penetrating lights may serve to distract birds and thus the requirements may be modified from what is strictly in the CFR.

The Navigation lighting, sounds and marking of the Offshore Transformer Platform may likewise be determined for the site.

As an example the Draft Environmental Impact Statement Section 5 for Cape Wind is quoted with the preliminary outcome as to the required navigation lights. Its differs considerably from the usual requirements:

"5.7.4.3 Lighting

Currently, the Project design plans call for lighting the WTG towers with flashing red lights and flashing amber lights to meet FM and USCG safety requirements, respectively. The proposed WTG lighting does not possess the characteristics that are known to attract birds and includes some of the features recommended by the USFWS in Guidelines for Communications Towers for reducing potential bird problems on land (USFWS, 2003); such as, only white (preferable) or red strobe lights should be used at night, and these should be the minimum number, minimum intensity, and minimum number of flashes per minute (longest duration between flashes) allowable by the FM. Night migrants have not been shown to be attracted to the type of lights used on wind turbines (flashing red lights at night), which are very different from light houses, tall communication towers (which have steady burning red lights), brightly lit buildings, and other brightly lit structures (such as offshore oil platforms and bright lights on *ships). Operational lighting of the ESP, including the helipad, and other lighting would only be switched on when the platform or the landing pad are in use. All lighting, with the exception of the FM and USCG navigational lights, would be used as little as possible and shielded from direct view from sky or ocean. These provisions apply to lights in emergency quarters as well as in working areas. Daytime and nighttime lighting has been designed to use the lowest intensity lighting considered safe for navigation by the FM and USCG. The USCG flashing amber lights on each perimeter turbine should not be visible to viewers at distances beyond 2 nautical miles (3.7 km). USCG lights on interior turbines should not be visible to viewers at distances greater than 0.5 nautical mile (0.9 km). For further detail on the lighting design for this Project, see Sections 4.0 and 5.12."*

It follows that each project will be determined separately by USCG and other agencies and thus the above should not be relied upon for guidance: it is only meant to illustrate one of the proposals in hand for a planned offshore wind farm.

The following general remarks apply:

> The FAA defines an obstruction to navigation as being 200 ft or taller above the ground level and within three miles of a runway longer than 3200 ft.
>
> FAA lighting requirements for wind turbines are specified in an Advisory Circular: AC 70/7460-1k. Obstruction Marking and Lighting. Daytime, twilight and nighttime lighting and/or marking of wind turbines is required. As painting in conspicuous colors is contrary to aesthetic considerations, this should be part of the discussion. The map of turbine locations should be sent to all local airports, whether FAA regulated or not.

Even after the determination USCG must be notified so that it is incorporated on to charts and given out in the Notice to Mariners local notifications during construction and when operational.

During discussions it should be kept in mind the appropriateness of compliance with International protocol e.g.:

> For aircraft: International Civil Aviation Organisation Annex 14, Chapter 6, Ref: www.icao.int
>
> For shipping: 33 CFR §62.21 General.
> (a) The navigable waters of the United States and non-navigable State waters after December 31, 2003, are marked to assist navigation using the U.S. Aids to Navigation System, a system consistent with the International Association of Lighthouse Authorities (IALA) Maritime Buoyage System. The IALA Maritime Buoyage System is followed by most of the world's maritime nations and will improve maritime safety by encouraging conformity in buoyage systems worldwide.

IALA International Association of Lighthouse Authorities - Recommendations. www.beta.ialahq.org

IALA Recommendations for the marking of offshore structures (World wide) Independent testing is one of the requirements.

During Construction – navigation lights and sounds as well as radar reflectors are also necessary.

Some of the experience of European offshore wind turbine structures can be researched:

"Paint – the offshore wind turbines had to be painted yellow up to a height of 8 meters above Mean High Water Springs for increased visibility."

"Battery Back-up – This provides a continuous source of low voltage DC power to feed the navigation lanterns or fog signals should mains power be unavailable. There is a battery back-up unit in each turbine tower."

"Installation of the NAVAIDS on Blyth Offshore wind farm was no easy task as it involved transporting and erecting scaffolding out at the turbines so that the lanterns and radar reflectors could be installed at the required height. This proved extremely difficult as the work had to be carried out within the confines of the access platform around the tower. To avoid these difficulties NAVAIDS should be fitted on turbines wherever possible before they are installed offshore."

The lights, colors, positions etc. were all different with the UK wind farm: which leads to its own risks in international navigation, when those in the United States are significantly different.

One site-specific issue cited by the Blyth report: *"Notices had to be posted within the harbour indicating that a cable now crosses the navigable channel and that anchoring in the crossing area is prohibited. Yellow diamond shaped cable marker beacons were recommended as being appropriate and were in fact used on both sides of the river. One marker was placed on the pier to show where the cable runs in and the other was placed on the wooden jetty to where the cable ran under and up onto land."* [Ref. 5.0.6]

USCG Rules for Navigation Aids is set out in 33 CFR §67

SMS

Navigation Lighting, Sounds (Fog Horns), and Marking information will be safety critical and thus incorporated into the safety critical equipment where procurement and maintenance of equipment has special attention.

CVA

This is a component which should be inspected by the USCG or MMS and consist of USCG approved devices. The equipment will be there during construction. If for any reason the USCG does not attend the tests and approval process, then it may be prudent to have the CVA attend those and report to MMS on the findings and compliance.

CODE

This will be a mixture as each facility will be negotiated separately.

- 33 CFR Aids to Navigation on Artificial Islands and Fixed Structures
- NVIC 07-02
- FAA 70/7400-1K

Certification

The equipment purchased should be certified to USCG requirements in 33 CFR 67, under the configuration and colors specified by the USCG for the site specific wind farm.

References

[5.0.1] USCG circular NVIC 07-02 (USCG 2007)
[5.0.2] Advisory Circular: AC 70/7460-1k. Obstruction Marking and Lighting
[5.0.3] International Civil Aviation Organisation Annex 14, Chapter 6, www.icao.int
[5.0.4] For shipping: 33 CFR §62.21 General.
[5.0.5] IALA International Association of Lighthouse Authorities - Recommendations. www.beta.ialahq.org
[5.0.6] Monitoring and Evaluation of Blyth Offshore Wind Farm, DTI Publication, AMEC, 2001 (Volume 2 Navaids).
[5.0.7] Australia Government Advisory Circular AC 139-18(0), Obstacle Marking and Lighting of Wind Farms, July 2007.
[5.0.8] U.S. Department of Transportation, FAA Advisory Circular AC 70.7460-1K, Obstruction Marking and Lighting. 2/1/2007.
[5.0.9] Cape Wind Draft EIS, Section 5.0 Environmental Resources and Consequences for the Applicant's Proposed Alterations.
[5.0.10] Summary of IEA R&D Wind – 46th Topical Expert Meeting on Obstacle Marking of Wind Farms, October 2005, Stockholm.
[5.0.11] Monitoring and Evaluation of Blyth Offshore Wind Farm: Navaid Requirements for UK Offshore Wind Farms, DTI Pub URN 01/787, AMEC Border Wind, 2001.
[5.0.12] Marking and Lighting of Wind Turbines in Wind Farms (Transport Canada).
[5.0.13] Report from the Bethany Wind Turbine Study Committee, 25 January 2007.
[5.0.14] Safety Marking of Offshore Wind Turbines, UK Offshore Wind 2007, David Cutler Civil Aviation Authority, Sally Edwards Orga Suisse S.a.r.l.

5.1 Helicopter Facilities

The standard to be used of the landing area for servicing personnel is not specified, so must be subject to a HAZID to determine the design requirements. Any Helicopter Deck needs to comply with the following requirements.

- 46 CFR §108.231-§108.231 Design, Construction and Markings.
- 46 CFR §108 Subpart D Fire Protection.
- CAA, CAP 437 – Offshore Helicopter Landing Areas – Guidance on Standards" December 2008
- Navigation Lights, Anchoring Lights, Facility Obstruction Lights in Place and Tested at proper angles and power source operational including any required for helicopters
- 33 CFR Part 67--Aids To Navigation On Artificial Islands And Fixed Structures
- American Petroleum Institute, Recommended Practice for Planning, Designing and Constructing Heliports for Fixed Offshore Platforms, API Recommended Practice 2L, 4th Edition 1996.

6. OFFSHORE SUBSTATION

There are generally available three options to connect offshore wind farms to shore (with some variations).

- Multiple 33 kV submarine cables
- One high voltage DC submarine cable
- One 132 kV-150 kV submarine cable with a 33 KV to 132 kV offshore substation: the interconnecting submarine cables from the turbines connect to the offshore substation.

Substations contain transformers and switchgear to step up the voltage for transmission. All and busbars are generally housed in grounded metal enclosures sealed and filled with sulfur hexafluoride gas (SF_6). The offshore substation contains the switching panels and other electrical facilities i.e. power-factor correction system. The high-voltage transformers are normally oil-cooled. Bus systems, cabling and an earthing system are all part of the component systems.

Volumes of flammable liquids should be documented as required in the SMS and pollution prevention methods should be considered in the design.

The transformer platform itself is of high value to the electricity generating capability since many/all of the turbines will feed electricity through it, the design to the criteria of an L-1 platform based on API RP2A will be appropriate: a 100-year storm airgap will apply. The high consequence of fire will require understanding of the fire risks in order to evaluate the appropriate design parameters for fire detection, prevention and submission. While it is expected that these facilities are not manned (meaning overnight accommodation), it may be appropriate to consider automatic fire suppression systems with appropriate personnel warnings. As a precautionary measure the SMS should provide guidance on manning during potential for lightning strikes and suitable information and training on safest locations on board in case of personnel being caught-out on board in a lightning storm.

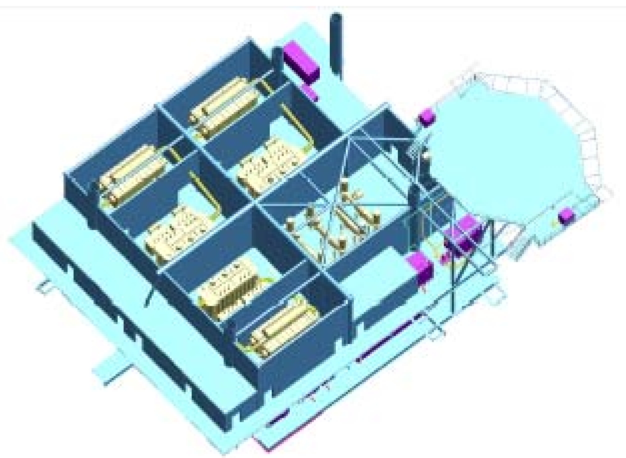
Project	Horns Rev I (DK) 	Nysted I (DK) 	Barrow (UK) 	Lillgrund (S) 
Wind farm size	80 x 2 = 160 MW	72 x 2.3 = 165.6 MW	30 x 3 = 90 MW	48 x 2.3 = 110 MW
Commissioning	Dec 2002	Jul 2003	Jun 2006	Jun 2008
Water depth	6 ... 14 m	6 ... 10 m	15 ... 20 m	4 ... 8 m
Distance to shore	14 ... 20 km	10 km	7.5 km	7 km
Foundation	3 piles	gravity	monopile	gravity
Voltages	33 / 150 kV	33 / 132 kV	33 / 132 kV	33 / 138 kV

Figure 43: Example of Existing Offshore Substations.

The distance from shore is one of the points that determines whether an offshore station is needed. As noted above it appears 7 km appears to be the lower end of the distance that might warrant a substation but this also seems to be a matter of preference and the cost-benefit for the specific project. These stations are "normally unmanned" but there is significant daytime manning particularly in the first 6-24 months of a project according to DNV. [Ref. 6.1]. These structures although quite large are not as tall as the wind towers themselves.

Figure 44. Lillgrund Sweden Transformer Station amid the Wind turbines.

Figures 45: Transformer Station for Greater Gabbard



Layout: 2140 ton deck package incorporating 3 – 180 mVa transformers and associated switch gear [Ref. 6.2].

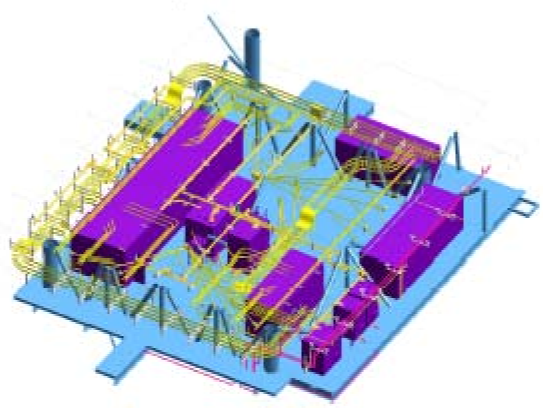


Figure 46: The Stanislav Yudin seen installing 2150 t Greater Gabbard substation off Harwich (Courtesy Adri Haasnoot-Piling Engineer Stanislav Yudin).

Figure 47: Areva HV/AC Transformer Substation: Barrow

Figure 48: Offshore Windpark Q7, Transformer station 23 km off the coast of IJmuiden, Netherlands.

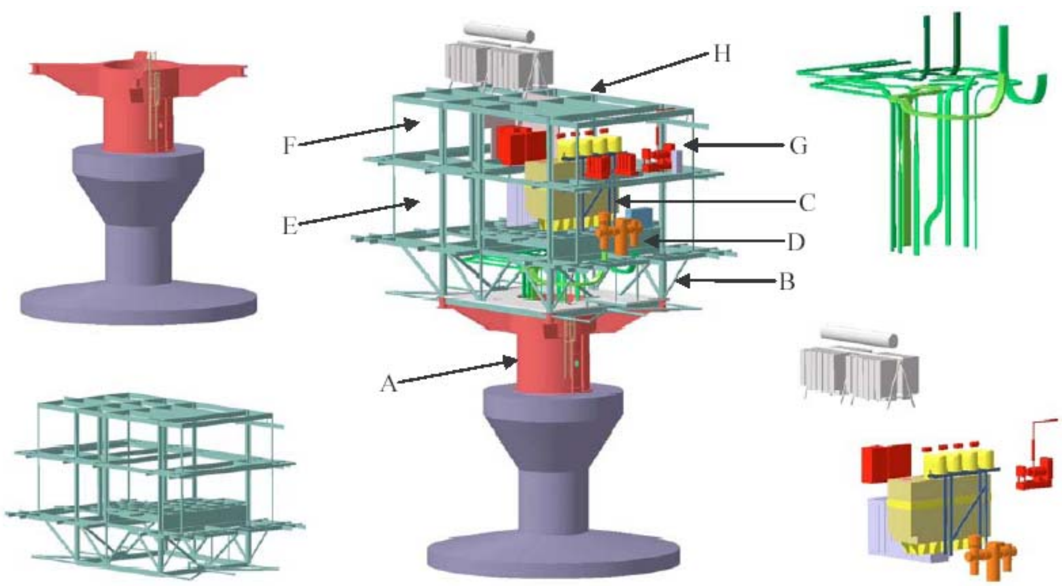


Figure 49: Parts of the Nystad Offshore Wind Park Transformer Platform

(A) Column with access stairway from Foundation Deck to Cable Deck, HV cable routing to Cable Deck, access to Sump Tank.
(B) Cable Deck with access to the closed module, HV cable raceways between the HV components, life saving equipment.
(C) Transformer Room, two storeys with Main Transformer (132 kV/33 kV) and Oil/water Separator.
(D) GIS Room with Gas Insulated Switch GIS (132 kV).

(E) HV Switchgear Room with HV Switch-gear (33 kV) and Auxiliary Transformer (33kV/400 V)
(F) Living Room for temporary staying. (Inflatable boats are available for emergencies). Low Voltage Room (F) with 400kV Panels, Wind Turbine Control Panels, Fire Safety Panel, Communication Panel.
(G) Utility Room with Emergency Generator (90 kVA), Battery Bank,
(H) Roof Deck with Cooling/Expansion Unit for Main Transformer, antennas.

It is interesting to note:

“ The transformer station is a three-legged steel structure with all the necessary equipment, including an emergency diesel generator. The weather in the North Sea is very rough and it is very likely that the electricity supply to the wind farm can be cut for prolonged periods at a time in case of cable faults. The generator can supply the station and the wind turbines with enough power to keep all essential equipment (climate conditioning, control and safety systems, yawing system etc.) operating during such periods“ [Ref. 6.3].

ISC Innovative engineering brochure on the Nysted Transformer platform states that they have an emergency generator (90kVA) and a battery backup [Ref. 6.4].

Alpha Ventus wind farm offshore Germany has plans to install an emergency generator and diesel tank on board [Ref. 6.5].

Proposed stations may see a growing in size and function as shown below for:

Figure 50: Troll Rosenberg Offshore Substation – Proposed for Norway

There have been issues with the transformer substations.

Middelgrunden in Denmark, as an example, had "*Problems with the switchgear and the transformers have been the main issue from the very beginning. In December 2002 the #9 transformer short-circuited. Six of the damaged transformers belong to Copenhagen Energy Wind and the last three to the Cooperative. One breakdown was caused by a misplaced phail.*" *Initially "the switchgears were leaking SF6 gas and had to be repaired."*

"The transformer of the Nysted offshore substation, for instance, experienced a significant failure in 2007, which led to a 4-1/2 month outage of the entire wind farms, see Andersen et al 2008" [Ref. 6.6], [Ref. 6.7].

Accommodation platforms may be placed next to the transformer stations as occurred at Horns Rev. A Presentation by Steve Kopits of Douglas Westwood chronicled the issue of housing personnel for work at the field [Ref. 6.8]:

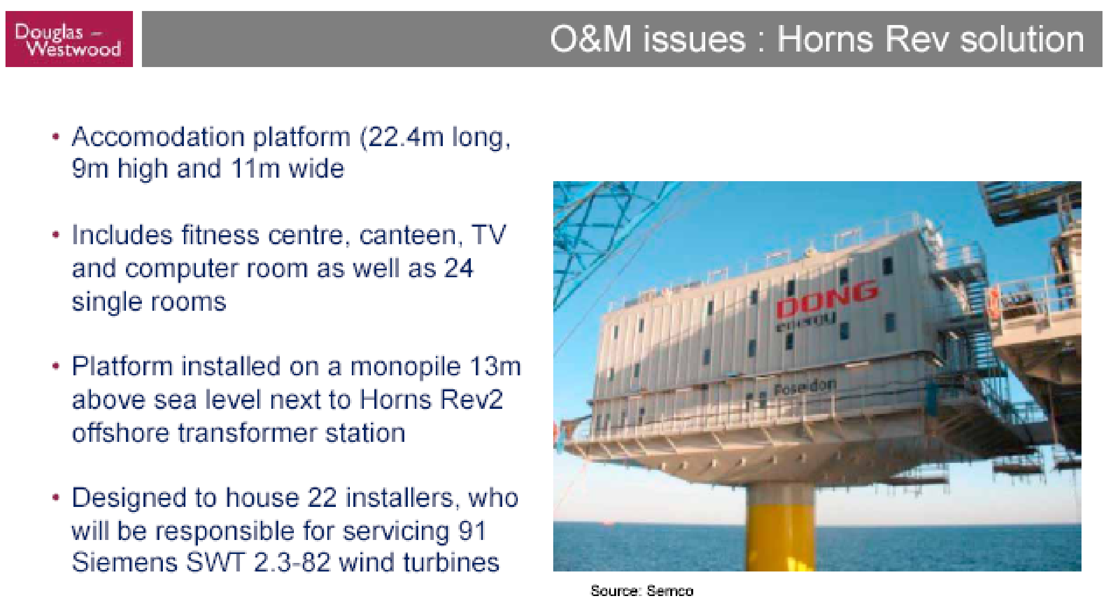


Figure 51

Accommodation platforms would be expected to follow the same standard as oil and gas platforms, namely API RP2A.

There is some collision risk involved with any platforms in the field and the provisions in the North Sea have tended to be a requirement to withstand a 5000 tonne displacement vessel with an impact speed of 2 m/s. The origin of this was the requirement for some of the North Sea concrete platforms to withstand collision during tow to location: unlike most vessels that have one compartment damage stability they had no damage stability should there have been a severe impact. The values appropriate for the Substation or for the wind turbines should be determined by the maximum likely collision event.

Germanischer Lloyd recommend using the value of an attendant supply vessel at a speed of 0.5 m/sec. This should be part of the design loading cases HAZID to take place prior to the completion of the design and form a part of the Design Basis document.

Issues of interest to be considered in the approval of the substation:

- The results of a complete layout risk assessment (HAZID), and results of a Failure Mode & Effect Analysis to identify potential failure modes;
- Since the structural safety of the wind farm structures may depend on the equipment in the substation an Emergency Systems Survivability Analysis may be necessary;
- Since there may be fuel on board for an emergency generator, and areas may need to be classified as hazardous and the hazardous-area diagram should be approved ensuring that the ventilation system is separate for hazardous areas.

The electrical requirements should be able to follow API RP 14FZ [Ref. 6.12].

A number of IEC Standards are provided and recommended by IEC. US Equivalency may need to be determined if needed in addition to API RP 14FZ depending on the content of the offshore substation:

IEC 60076 – Power Transformers

IEC 60092 – Electrical installations in Ships (Classification Society codes may be used here).

IEC 60332 – Tests on electrical and optical fibre cables under fire conditions

IEC 60529 – Degrees of protection provided by enclosures (IP Code).

IEC 60470 - High-voltage alternating current contactors & contactor-based motor-starters

IEC 62271 – High-voltage switch gear and control gear

IEC 61892 – Mobile and Fixed Offshore Units – Electrical Installations

EN 1838 - Lighting Applications – Emergency Lighting

A number of physical safety items should be considered e.g.

- Separate routing of high voltage cables, low voltage cables, and control cabling avoiding areas where there is accommodation;
- Mechanical locks on doors so that isolation is necessary prior to opening;
- Means of ensuring earthing is active prior to work;
- Sufficient space for allowing the technicians to back up from potential electrical issues in equipment being worked on;
- Monitoring of the SF_6 protection to ensure that it is active.

Another useful standard is provided by Energinet.dk, [Ref. 6.9]. It recommends battery standby power for 96hours duration. *"Batteries shall be maintenance free and have a lifetime of at least 10 years"*. For durability *"both main and secondary lights and the foghorn shall have 316 stainless steel enclosures"*.

CVA
Since the substation is a separate fixed platform, or potentially floating platform, the CVA tasks apply to those aspects as they would for an oil and gas platform. For structural requirements API RP2A latest edition is recommended for the CVA activities ensuring that the L-1 option is selected for the substation.

SMS
No special provisions except as laid out in the SMS Template. Volumes of flammable liquids should be documented as required in the SMS and pollution prevention methods should be considered in the design. It should be noted that being on board the substation should be avoided in lightning situations. An area plan should be developed and personnel trained in the issues of lightning, and designated areas as a safe haven should be marked in the substation. Section 4 of this Report deals with the issue of potential accommodation at the substation. If a helicopter landing is part of the design the fire-fighting provisions of fixed platforms should be applied which will include the associated PPE.

Certification
Certification would be required as is usual for structures in oil and gas operations. The suitable sizing and condition of the emergency generator should be of concern to the certifier since the ability to keep power on the critical control functions leads to a structural failure with out it. The essential equipment which needs powering includes climate conditioning, control and safety systems, and the yawing systems of the turbines.

Applicable Codes
Industry developed codes are as follows:

> The recommended documents for Certification are the Germanischer Lloyd - Guideline for the Certification of Offshore Wind Turbines, Ed. 2005 - Chapter 8 Electrical Installations. Equivalences may be established to US Codes.
>
> DNV-OS-J201 may have some useful requirements but a copy has not been purchased for review at this time. It has been advertised to contain the following requirements:
>
> - General
> - Safety Assessment
> - Arrangement Principles
> - Structural Design
> - Fire and Explosion Protection
> - Access and Transfer
> - Emergency Response
> - Manufacturing, Transport and Installation
> - In-Service Inspection and Maintenance

For structural requirements API RP2A latest edition is recommended together and the methods of API RP 14 FZ [Ref. 6.12] for establishing the requirements for electrical installations.

6.1 References

[6.1] Safety Principles and Requirements for Offshore Wind Farms - Tove Feld, DNV, Copenhagen March 2009.
[6.2] Michael Bateman – SPE Presentation, Greater Gabbard and the Offshore Wind Energy Industry, September 15, 2009, Houston, Texas
[6.3] Grid Connection and Remote Control for the Horns Rev 150MW Offshore Wind Farm in Denmark, P.Christiansen, Knud Joregensen, Askel Gruelund Sorensen, http://www.owen.eru.rl.ac.uk/workshop_4/pdfs/owen_Christiansen.pdf
[6.4] www.isc.dk
[6.5] www.abb.com
[6.6] Andersen, N., Marcussen J., Jacobsen E., Nielsen S.B., Experience gained by a Major Transformer Failure at the Offshore Platform of the Nysted Offshore Wind Farm, Proceedings of the 7th International Workshop on Large-Scale Integration of Wind Power into Power Systems as well as on Transmission Networks for Offshore Wind Farms, Energynautics, Langen German, May 2008.
[6.7] ISC Consulting Engineer’s Brochure on the Nystad Offshore Wind Farm Transformer Platform http://www.isc.dk/Internet/ISCPub2.nsf/0/19e3b632f9968f4ec125729000330eb4/$FILE/ISC_Nysted_Transformer_Platform.pdf
[6.8] Steve Kopits of Douglas Westwood ,Wind Energy Operations and Maintenance Summit, Dallas, Texas April 29, 2009.
[6.9] Offshore Transformer Platform, Technical Standard, Electrical Equipment and Installation of Lighting, Small Power and Navigation Lights. http://www.energinet.dk
[6.10] ANSI/IEEE 80-2000 Guide for Safety in AC Substation Grounding
[6.11] J. Twiddle, and G. Gaudiosi, Offshore Wind Power, Multiscience Publishing Co., 2007.
[6.12] API RP 14FZ: Recommended Practice for Design and Installation of Electrical Systems for Fixed and Floating Offshore Petroleum Facilities for Unclassified and Class 1, Zone 0, Zone 1 and Zone 2 Locations.

7. SUBSEA CABLES

The cable laid from wind turbines to shore presents a significant cost to the project. Since the cable carries the fibre optic control connection, lack of power and lack of connection may put the turbine and tower structure at risk of failure. The movement of the yaw mechanism to align with the wind is crucial to tower survival (based on load cases required by the IEC Code).

"In a wind farm, individual turbines are interconnected with a medium voltage (usually 34.5 kV) power collection system and communications network. At a substation, this medium-voltage electrical current is increased in voltage with a transformer for connection to the high voltage electric power transmission system.

Laying the main cable connecting the wind farm to the onshore grid is another challenge. Considerable care must be taken when laying new cables over existing pipelines, power cables or telephone lines to avoid damaging or impairing these" [Ref. 7.1].

Laying cables requires extensive experience: some of the cautions are reported [Ref. 7.32]:

"The preparation includes route survey, material checking …..and so on.

The geological structure along the route of submarine cable installation should be surveyed carefully before the installation. For the geological structure which will harm to the submarine cables, such as the exposed bed rocks"…high currents… *"and other factors, it is necessary to provide suitable protection measures for the submarine cables".*

"The cable should be inspected …to make sure that the cable has no mechanical damage. The electrical characteristics such as conductor resistance should be tested before shipment to make sure that they are perfect, and the attenuation of the fibers is in accordance with the specification"

"According to the requirement of sealing the cable end with lead, the submarine cable must be sealed and the pull-ff head must be mounted."

"After the installation is finished it is necessary to send divers …to check if there is any king along the route"…and if so straighten it.

"Cable Installation

When the cable to be installed by the machinery, a twisting preventer should be used.

When the cable is installed by the machinery, the pull-off force should not exceed the cable maximum pull-off force:

The allowable minimum bending radius of the cable will be 25 times of the cable diameter.

During installation the deviation between the cable installation bearing and the planed cable route should be measured regularly, and corrected at all times, so as to assure the cable being installed along the predetermined route.

It is advised to plot a relief map of the cable installation route……

….avoid the cable laid in sea-water being over tightened (Once the cable forms a catenary status due to its suspension it will become the places where the cable is subject to local damage), or over lax (having a tendency of kink).

The laying pay-off stand should let the minimum untwisting height of the cable not less than 1/2 drum winding length."

"After the installation is finished it is necessary to send divers …to check if there is any king along the route"…and if so straighten it.

"After the ending of the cable installation and accessory assembling, the whole system should be tested".

One of the cable types used is XLPE 3 –core, armoured submarine cables with optic fibers. XLPE is an acronym for "Cross-Linked Polyethelene". For a definition: *"There are two semi-conductive layers on high voltage cable. One is between the actual conductors and the XLPE. The other semi-con is on outside of the XLPE insulation underneath the concentric neutral. The semi-con is used to equalize the electrical stresses over a large area. For example, most conductors are made up of multiple strands of copper or aluminum. The outer edge of the conductor bundle is not smooth. It has several ridges on the outer edge where the individual strands meet one another. These high spots will stress the insulation leading to a premature failure. The internal semi-con makes a smooth voltage level for the XLPE where it meets the conductor strands."* [Ref. 7.2].

Several examples of the use of XLPE 3-core cable:

AC cable offshore applications:

- Thornton Bank Offshore Wind Farm, Belgium 38 km, 150 MW, 170 kV shore connection power cable with Al conductors and integrated optical fiber cable and 4 km 36 kV inter-turbine cables with Al conductors and integrated optical fiber cable.
- Q7 Offshore Wind Farm, the Netherlands 28 km, 120 MW, 170 kV shore connection power cable with Cu conductors and integrated optical fiber cables and 40 km, 24 kV inter-turbine cables with Al and Cu conductors and integrated optical fiber cable.
- Lillgrund Offshore Wind Farm, Sweden 33 km, 110 MW, 145 kV shore connection power cable and 36 kV interturbine cables with Cu conductors and integrated optical fibers.
- Burbo Banks Offshore Wind Farm, UK 40 km, 90 MW, 36 kV inter-turbine and shore connection power cables with Cu conductors.
- Yttre Stengrund Offshore Wind Farm, Sweden 22 km, 10 MW, 24 kV inter-turbine and shore connection power cables with Al conductors and integrated optical fibers.
- Utgrunden Offshore Wind Farm, Sweden 11 km, 10 MW, 24 kV inter-turbine and shore connection power cables with Al conductors and integrated optical fiber cable.
- Samsö Offshore Wind Farm, Denmark 7.5 km, 20 MW, 36 kV inter-turbine and shore connection power cable with Cu conductors integrated optical fiber cable.

- Nysted Offshore Wind Farm, Denmark 55 km, 165 MW, 36 kV inter-turbine power cables with Al- and Cu conductors and integrated optical fiber cable.

DC cable offshore applications:

- NordE.on 1 Offshore Wind Project, Germany 2x125 km, 400 MW, +/-150 kV HVDC Light® submarine power cables with Cu conductor and 2x75 km, 400 MW +/-150 kV HVDC Light® underground cables with Al conductors. [Ref. 7.3]

10-220 kV cable, optic fibers option

Depending on the distance to shore, there may be a transformer station which provides a facility to step up the voltage and thus have fewer cables transmitting to shore..

Figure 52: [Ref. 7.3].

Figure 53: This photo shows a cross-section of a typical cable [Ref 7.4].

For Thornton Bank *"each cluster of 6 wind turbine generators will be connected to each other via 33 kV cables buried in the seabed. Each cluster will be connected to the* *offshore transformer station. The generated electrical power will be transformed to 150 kV and supplied to the 150 kV grid system. The energy transport will be realized by two offshore 15- kV sea cables that link the offshore transformer station to the Slijkens high-voltage substation at Bredene……Another offshore cable will be crossed as well as 2 international shipping lanes. A landfall construction by means of a combination of a horizontal directional drilling and a cofferdam will be made and the marine cable connected to the onshore cable"*. [Ref. 7.6].

The following is the arrangement at Horns Rev showing the layout of the turbines, the location of the transformer station and the route to shore:

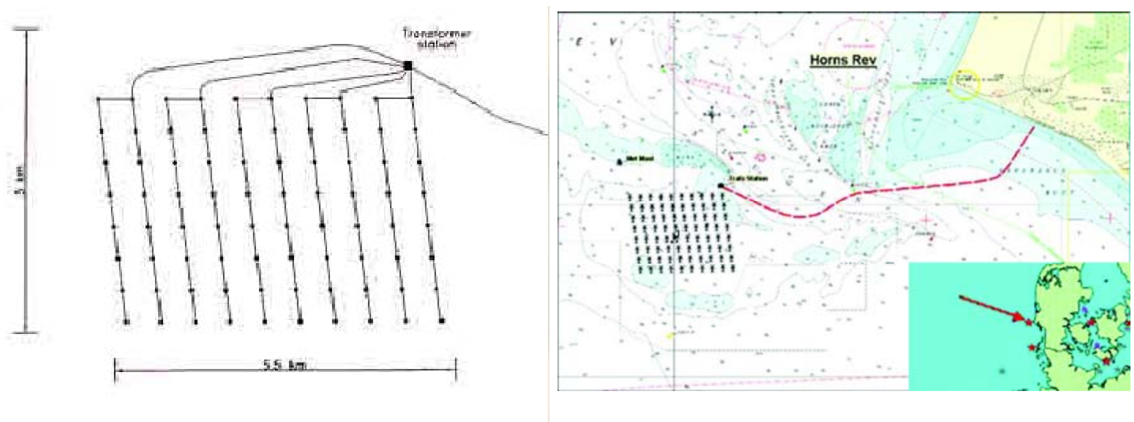


Figure 54

The cables are buried about six feet below the seabed to carry the electricity to offshore transformers and then to the shore. The amount of burial depends on the traffic in the area and the results of the risk assessment as to how much is needed to protect the cable, the seabed composition etc. In rocky areas mat coverings may be required.

The Greater Gabbard subsea cables had over 200 km of inter-array cable, 100 km of main line to onshore tie-in, routed through large J-Tubes, then laid on the seabed with diameters 18" to 24", with bundled Fiber Optics for Turbine and Platform Controls.

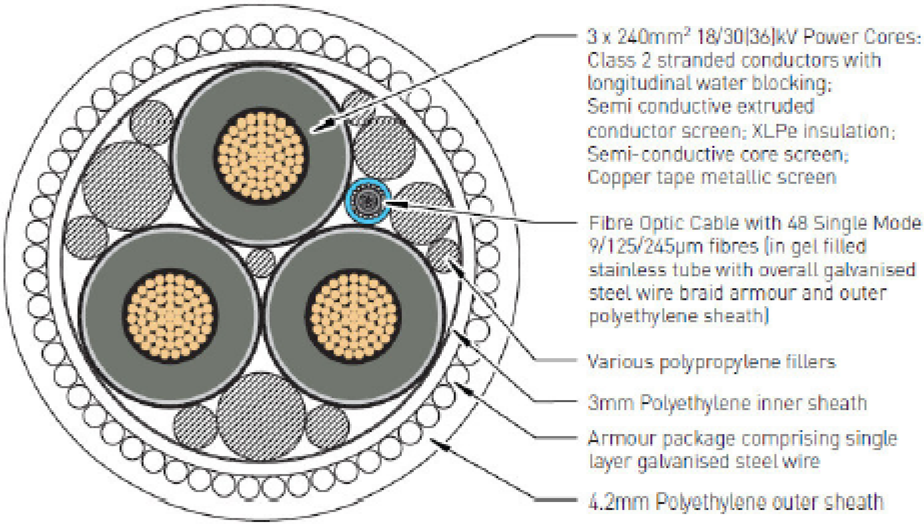


Figure 55: Mike Bateman, Heerema Fabricators presentation to the Society of Petroleum Engineers, Houston, Sept. 2009 [Ref. 7.5].

In order to get the cables to the seabed they are fed through J-Tubes and arrive horizontally to the seabed. This area needs to be protected from scour around the foundations.

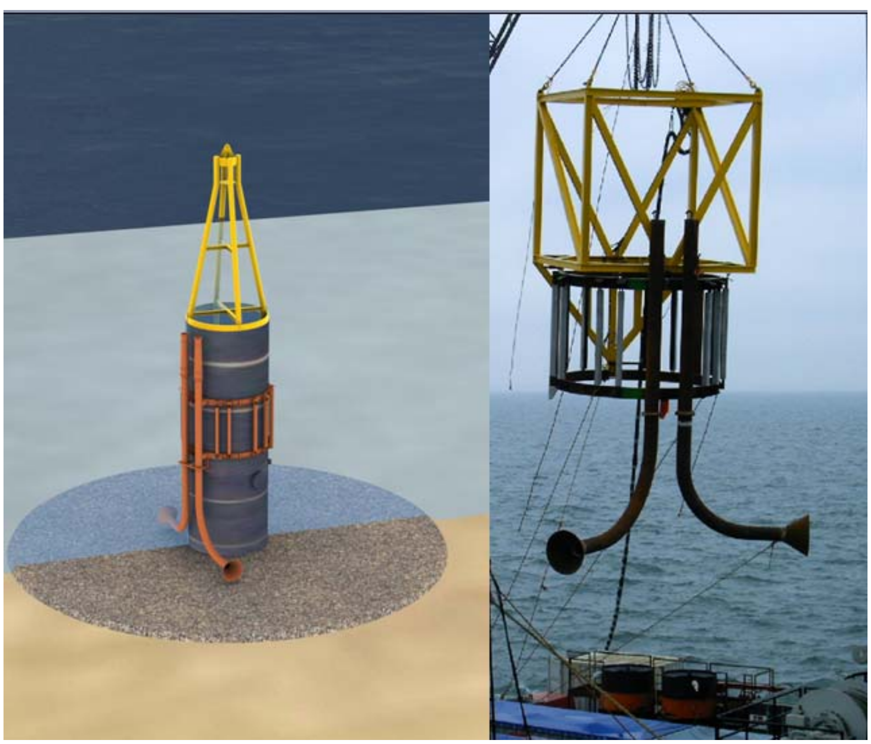


Figure 56: Arrangement of J-Tubes [Ref. 7.9].

A variety of photos available on the internet show the actual operation:

Figures 57

Figure 58

As an example: the route into shore may have to cross other cables and pipelines. The photo above shows "Crossing the PEC Telecom cable: With its jack up pontoon "Buzzard", GeoSea will protect the PEC telecom cable by placing GSOA (Fibered Open Stone Asphalt) mattresses covering, a system licensed from DEC. That way, the cables will never touch each other". [Ref. 7.6].

Concrete mattresses and other techniques have been used for the same purpose, as a function of the site specific requirements.

Cables that carry the electricity can be either AC or DC the cost of the various items of equipment and benefits of one vs. the other are discussed extensively in the literature. DC is more expensive except when the distances are very long.

Figure 59

A variety of techniques can be used for burial of the cables depending on the site specific bottom data which ranges from soft clay to sand to rock.

Cables are buried to avoid damage by vessel anchors, and trawler nets. This can be done by burying as the cable is laid or after the cable is laid. The cable laying device has to be capable of traction of typically 100 tons in order to move along the seabed.

Various cable burying machines can be used depending on the depth, distance and seabed geological conditions.

Figure 61 : Subsea cable burial devices [Ref. 7.7].

Figure 60 : ROV (CARBIS II)

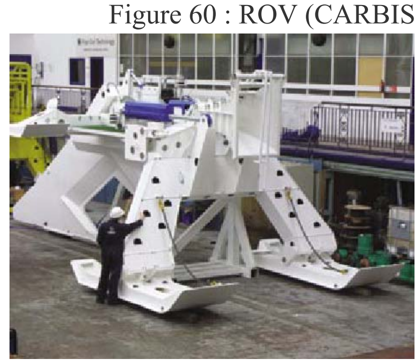


Figure 62

Figure 63

This is a view of a cable burying machine once the cable gets to shore [Ref. 7.8].

Figures 64: Cable laying vessel and cable deployment equipment [Ref. 7.9].

Figures 65: Cable deployment photos [Ref. 7.3].

After the cables are laid tests are carried out on the installed cable to identify localized problems which could have occurred during installation. The most likely defects are splices and terminations, and the cable sheath. The International Council on Large Electric Systems has a number of guidance notes on testing electrical systems which may be applicable. The cables go onto shore to connect to the grid.

Figure 66: Cables on shore: Nuon offshore wind farm: [Ref. 7.9].

7.1 Issues

A number of issues have arisen in relation to the transmission cables from offshore wind farms. Olthoff [Ref. 7.9] said an issue with the Nuon wind farm was that significant movement of subsea sand dunes, moving 4 meters per year caused the cable to become unburied.

1. Horns Rev May 2002.

" During installation, a construction vessel destroyed one of the interconnection cables in the wind farm: the anchor hit the cable, which laid unprotected on the seabed. The costly repair was performed by a Dutch specialist company; the EUR 2 million repair costs were covered by insurance. This accident turned out to be the biggest event in the construction phase." [Ref. 7.10].

2. *"Cambois turbines stalled again":*

"Plans to get Britain's first offshore wind farm producing power again after a gap of almost three years have been stalled by a further technical hitch.

Rotor blades on the two turbines off Cambois, Northumberland have not turned since March 2006, when the seabed cable connecting them to the mainland snapped.

Two months ago power company E.on said it was about to switch them on again after replacing the damaged cable.

Now it says it will be several weeks before the turbines are ready to become fully operational again, after a brief trial run revealed an internal technical problem which needs to be put right.

The turbines – built in 2000 to generate enough power to meet the needs of 3,000 homes – are now being fully serviced to ensure they are ready to go when switched back on permanently.

Yesterday an E.on spokeswoman said: "The seabed cabling has all been repaired and re-installed and we switched the turbines back on for a short period to warm them up, after they were off for more than two years. During the warm-up process we discovered an extra internal problem which is being fixed.

"They were off for a long time and got a bit damp inside so we are now doing a full service and hope to have them up and running again, and producing electricity, in the next few weeks.

"It has meant a delay in getting the blades turning again and we are dependent on the weather to get on and complete the service."

The two turbines were built at a cost of £4m but have been out of action since the undersea power cable was snapped by the rocky seabed. Now E.on has replaced the cable, using a different route to allow sections of it to be buried in sand.

The two turbines were previously owned by a green power consortium. In 2002, a rotor blade had to be replaced after it was hit by lightning and in 2005 one of the turbines was out of action for several months after a cable connecting the two machines failed. [Ref. 7.11].

3. Blyth Harbor Wind Farm UK

"In early 2001, there was a cable fault on the link between the two turbines. This was the result of poor installation. The attachment of the cable to the seabed was to be carried out by divers. The installation of the cable was carried out in October and the visibility became poor. The contractor thought enough had been done to secure the cable for the winter and planned to finish the work in the spring. Unfortunately this was not the case.

The cable protection where the cable left the J-tube came loose and slipped down the cable. The current then caused the cable to wear on the end of the J-tube and the cable was cut through. There was sufficient spare cable in the link to allow the damaged section to be pulled into the tower and cut off. However the spare length was at the far end and had to be worked along to the appropriate end. There were three attempts to do this, mainly frustrated by combinations of weather and tides. In the end the entire length of cable was suspended on floatation bags and pulled along with a small tug. Again this was a diver operation and required good visibility. The cable was out of service for approximately three months.

The cable was then secured at intervals to the sea-bed and the supports at the entrance to the J-tubes were supported by shaped cement filled bags. A video of the cable route and securing arrangements was made for reference.

Spare cable for a repair was available but was not needed in this case.

The lessons learned from this problem were;

- *try to use installation methods with no or very little diver intervention*
- *the detail of the cable entry is very important and requires close cooperation between the steelwork designer and the cable laying contractor*
- *detailed repair strategies need to be worked out in advance."*

"During the video survey it was noticed that the polypropylene outer layer was worn off as a result of current action in a few places during the first winter. The wire armour was not damaged and the cable was secured properly after that winter."

"HV Switchgear: The only issue has been that condensation has been observed in the cable termination boxes. The dehumidifier has cured this." [Ref. 7.12].

4. Scroby Sands

"Generating capacity was affected following a transition joint failure on one of the three export cables, causing the circuit to be taken out of service for repairs. A replacement joint was promptly installed in the beach. However, during commissioning tests a fault was identified on the sub-sea portion of the cable. The replacement of the sub-sea section of the cable is planned for spring 2008.

Until the permanent repair is affected, the power output is shared between the two remaining export cables. This does not affect turbine availability as the system is designed to facilitate cable maintenance. However there is a reduction in generation as a reduction in maximum capacity applies when wind speeds are particularly high." [Ref. 7.13].

5. Horns Rev 2

"After just two months of operation technical problems have forced the blades of the world's largest offshore wind farm to stop turning.

But it isn't Dong Energy's Horns Rev 2 itself that is the problem. Rather, there are problems with the terminal strip on the 56-kilometer-long power land cable that sends the turbines' energy on to the grid along the West Coast.

The wind farm has not been producing energy since last weekend and Dong Energy, which owns the wind farm, is losing approximately 1.1 million kroner each day the turbines stand still.

Kim Kongstad, maintenance manager at Energinet.dk, which is responsible for the cable, said the turbines would probably not be back in operation until the end of the month.

'We hope to have all terminal strips repaired by 29 November, after which the cable can be reconnected so the turbines can start turning again and provide power to the grid,' Kongstad said. Kongstad said that the terminal strips have been a problem since before Horns Rev 2 opened this past summer, where 24 were repaired prior to setting the turbines in operation.

Dong's information states that the farm's 91 turbines produce an average of 2.2 million kWh each day – energy sold on to electricity customers both in Denmark and abroad."

Ref: The Copenhagen Post www.chpost.dk 20 November 2009

6. Others

Middelgrunden: *"3 accidents with damages of the subsea cables"* [Ref. 7.14]

Arklow Bank experienced a cable fault due to an anchor dragging over it. It took a week to repair [Ref. 7.10].

"A number of new technologies were developed and implemented to make the offshore wind farm Bockstigen (Sweden) technically and economically feasible. Through the whole construction process only one genuine technical problem was encountered which was the anchoring of the sea cables. The water current was larger than assumed due to an acceleration of the flow over a ridge and the difficulty to anchor the sea-cable to the sea bed was underestimated. Where large areas of the seabed were free from loose layers it proved necessary to anchor parts of the sea-cable with the use of steel hoops. The first attempt was to use concrete sacs as weights. The second attempt was to anchor the cable with hooks made of 12 mm steel. Both failed and first the third attempt employing 25 mm U-shaped hooks anchored in two holes in the sea bed was successful." [Ref. 7.15].

Other potential issues can arise as noted by John Foreman, ETA in a recent seminar [Ref. 7.4]:

Figure 67: Clearing debris off the seabed

Figure 68: Ensuring there are no kinks in the line

Figure 69: Ensuring that the joint housings are appropriate and to good quality.

His further advice was not to underestimate the strain that tides might put on your planning and execution.

After construction periodic monitoring is required. As one example:

"Whilst sediment mobility does not present a direct hazard to cables, it can have a significant effect on the level of protection provided by burial against other hazards, such as fishing gear and ships anchors. Therefore, the risk assessment should also address the ongoing maintenance requirements throughout the lifetime of a project and in particular, the risk of sediment mobility and cable exposure.

The potential for sediment mobility should be addressed at an early stage of a project. Areas of high mobility, for example where sandwaves and megaripples are observed, should be avoided. In addition to detailed sediment mobility studies, it may be necessary to undertake a series of bathymetric surveys at regular intervals (6 monthly) to assess the seasonal changes in seabed level.

Once the depth of any mobile layer has been determined, appropriate allowance for deepening the cable burial depth can be made. However, it should be noted that in areas of significant mobility (e.g. sandwaves) it may not be possible to install the cable sufficiently below the mobile layer. In addition, there are other issues such as *conductivity and overheating that need to be considered. Therefore, ongoing maintenance and remedial burial may be required.*

In this example, off the East coast of Ireland, bathymetric surveys were carried out at a 6 monthly interval following the installation of the export cable. The surveys clearly demonstrated that significant changes in seabed level had occurred in an area of sandwaves.

Migration of a sandwave over a relatively short distance can leave a previously buried cable exposed at the seabed. As the crest of the sandwave migrates over a cable buried to a nominal depth of 1 m below seabed, the cable may become exposed. Over time, the sandwaves will migrate and cover the cable again; however the cable remains exposed to threats such as fishing and anchors until this happens." [Ref. 7.16].

The following computer graphic illustrates the consequence of scour which can effect the cabling around the foundation [Ref. 7.18].

- Image from a recent survey at Scroby Sands Offshore Wind Farm in UK
- Red cylinder: 4.2 m diameter monopole
- Image illustrates scour around protection work

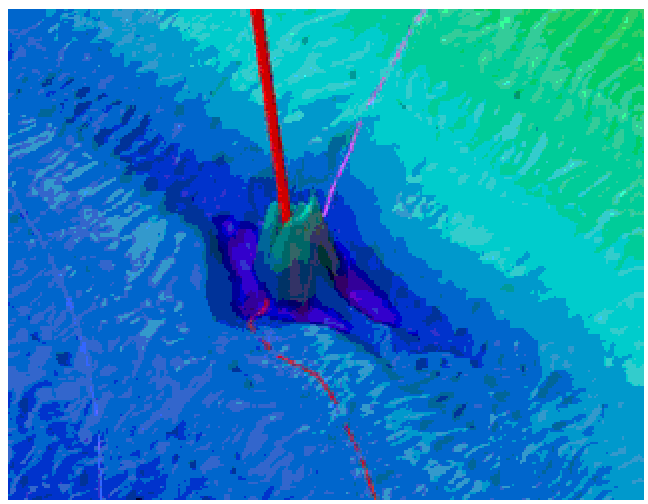


Figure 70

At the Barrow Offshore Wind Farm an April 2007 survey of the export cable identified some exposed sections of the export cable. Further work has been undertaken in May 2007 at exposed sections along the export cable in order to bury these sections. The collected data is now evaluated and the need for further work on the cable will be considered [Ref. 7.19].

So far as the cable routes go the power cable route burial assessments are addressed best in BSH publication and this represents the current “state-of-the-art” [Ref. 7.30].

SMS

The Safety management system has provisions for safety of third parties (e.g. divers), bridging documents (e.g. with cable laying vessels in the field), and no extra special requirements are foreseen for the laying of the subsea cable.

Certification

Project Certification to GL document – or equivalent certification scheme containing at least all of the issues that GL has in their document is recommended. Project Certification should include not only the approval of the installation manuals, but also periodic attendance by qualified personnel.

Applicable Codes

The IEC 61400 series does not cover subsea cables. GL has included the provision to certify cables in their Guidelines.

Germanischer Lloyd Certification 8.10.5 refers to their requirements including those of cable testing during installation. Their requirements follow CIGRE Electra Recommendations: International Council on Large Electric Systems which has a number of guidance notes on testing electrical systems which may be applicable, however, it appears to be a "member only" organization so the guidelines were not accessible.

Germanischer Lloyd does address a number of issues of interest – some of which are quoted below:

> *"For calculation of cable length, sufficient extra length shall be installed. In the case of a subsea cable damage it is necessary for cable repair above sea level to have reserve length.*
>
> *"The distance between parallel running cables shall beat a minimum two times the water depth plus laying depth to allow future cable repair.*
>
> *"The burial depth of cables shall be in accordance with local requirements concerning sea bed warming."*

For calculation of cross-section design they refer to IEC 60287 and IEC 60949 and for fiber optic cable to ITU G.650.

> *"During cable laying no unacceptable forces shall occur at the cable."*
>
> *"In no situation the allowed maximum bending radius of the respective cable shall be exceeded. The following both bending radii have to be taken into account:*
>
> - *the bending radius of the cable from horizontal to vertical orientation (into the ground)*
> - *the bending radius of the cable from vertical to horizontal orientation (in final position)."*

CVA

There are, of course, many issues that may go wrong during the installation of the cable, however, if proper planning and quality control is carried out the probability of the CVA catching the issues, any more than would be caught by the investors, insurers etc. is remote unless the CVA has on board personnel familiar with marine operations since that is the most likely area that issues will arise.

The above remarks are made assuming that the control system is not necessary for survival without power in an extreme storm of "design" magnitude. If a lower return period would affect the structural survivability of the tower then a CVA is recommended be in attendance during the laying of the cable to the location as the backup system may control structural survivability.

7.2 References

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8. TRANSPORTATION CERTIFICATION (IEC 61400-22 8.3.11)

The requirements state *"The Certification Body shall verify that the turbine can be transported according to any requirements identified in the design documentation"*.

It is not clear which parts of the turbine will need to be Certified for transportation i.e. components such as gear boxes or blades, or just road transport and/or sea transport and perhaps only from the shore marshalling site to the location or perhaps all the way from the factory to the marshalling site and then on to the offshore site.

In order to carry out the task to Certify that the plans are there to Certify, the Certifier will have to know the barge, planned sea conditions for the area and season, and know what limits the manufacturer has imposed. Manufacturers normally issue requirements as they see it for the loads that should not be exceeded on the equipment they manufacture. Whether the project picks the suitable truck, ship or barge for transportation and transports in reasonable weather conditions is often outside the manufacturer's control.

Reading the statement more carefully it becomes obvious that the Certification Body only verifies the manufacturers stated limits of transportation loads and motions: not the actual loads and motions likely to be experienced! The Certification of this issue then is picked up by the Project Certification documents.

Further examination of the Project Certification documents shows that the only point related to transportation and installation is *"transportation and installation surveillance"* *"Surveillance*" itself is defined as *"continuing monitoring and verification of the status of procedures products and services, and analysis of records in relation to referenced documents to ensure specified requirements are met."* ….or not as the case may be. The project Certifier can only watch and possibly report on what happened during the transportation. Whether the Certifier follows the components and which components from manufacturing site to the installation location is not clear and must be expected to be negotiated on each project.

Further issues on transportation arise when reviewing the Surveillance requirements: *"If a quality management system is in place for the transportation and installation processes, surveillance may be carried out by auditing. If not the Certification Body shall perform the surveillance by inspection".* Clarity on whether this means the quality system of the "owner" of the transportation responsibility, or the manufacturer, or the truck owner and barge owner, is not completely clear.

*"For offshore projects, surveillance shall include: monitoring of the sea-transportation…."*etc. Action to be taken might be that the Captain's log of weather condition, roll, pitch and heave be accounted for to see if issues were logged that might have exceeded the load condition specified by the manufacturer- but this is not clear. In many instances the Captain's log in US marine practice is a minimum of information unless specific instructions are given prior to the voyage on what information is required to be presented on arrival by the Captain to the certifier.

The interpretation for transportation requirements in the IEC Code has been for the certifier to review documents of the manufacturer to only confirm that they have specified the values not to be exceeded and that the documentation reflects that. The IEC Code Certifier and the CVA role is not to prevent damage, only to observe if the structure is free of damage before production starts. This is clearly different from the role of the Insurance Warranty Surveyor whose duty of care is to the owner and insurer to notify them and necessarily warn on threat of breaching insurance requirements if the manufacturer's specified load limits, for example, are likely to be exceeded during the transportation process.

9. INSTALLATION

Similar remarks as above in the Transportation section relate to Installation.

10. SUMMARY

None of the currently available standards documents can be directly applied to the USA-OCS as new complete offshore wind standards. Several sources of information should be used in design, construction, installation, operations and demolition of offshore wind farms on the US OCS.

European countries have based their standards on the International Electrotechnical Commission standards series 61400 which are a result of a consensus from all participating European countries. They give an overview of key issues to be taken into account, but do not cover all the technical details. The IEC is an international standards and conformity assessment body for all fields of electrotechnology. Many points are not covered including material and resistance factors, rotor design and testing, control and condition monitoring testing, and though there is much guidance the lack of specificity as to whether the recommendations are mandatory lead to issues with application as a code in the historically prescriptive environment of the US OCS. Certification for the wind turbine lifetime has not been successful in that there have been serial failures: though perhaps the system has prevented more of these.

In developing offshore wind farms on the US OCS, European experience in offshore wind turbines should be sought when dealing with specific issues.

Experience from the offshore oil and gas industry should be sought since there is much history and lessons learned which are directly applicable, however, several of the standards while applicable may also need to be significantly adjusted for the different structures, and industry approaches in the offshore wind turbine industry.

Other sources of information are available from certification companies such as Det Norske Veritas (DNV) and Germanischer Lloyd (GL).

Germanischer Lloyd in particular offers the most complete set of offshore guidelines. They are an important reference in offshore wind project development. They should be consulted when technical details are needed on a specific topic regarding offshore wind standards for the US OCS. Some tailoring of the standard may be needed to provide confidence that the standard is applicable to the US OCS site specific conditions e.g. load cases. Procedures for design, testing, transport, installation, operation and maintenance are all specified in the GL standards.

Of the National bodies approving offshore wind farms the German approach by the Maritime and Hydrographic Agency (BSH) seemed to provide the methods most similar to what has been the US approach to oil and gas structural safety. The following documents reflecting that approach are recommended for further study and potential application as they reflect a similar approach to that outlined in 30 CFR 285.

- Design of Offshore Wind Turbines Bundesamt Fur Seeschifffahrt uhd Hydrographie (BSH), December 27, 2007.
- Ground Investigations for Offshore Wind Farms, Bundesamt Fur Seeschifffahrt

uhd Hydrographie (BSH), February 25, 2008.

From the study differences between onshore and offshore became apparent and include:

- The marine atmosphere, must be considered for all components for corrosion and salt effects;
- Collision should be considered based on the site-specific location and traffic;
- Design reliability is due to limited access for maintenance and repair is critical; specially designed motion compensated equipment may lead to a higher accessibility;
- New load case combinations in addition to those in IEC 61400 and GL may need consideration;
- Site-specific consideration of the soil parameters must be emphasized in the design;
- Metocean considerations for extreme storms very much subject to interpretation and should be considered cautiously to have a national interpretation based on historic and NOAA and other data and take into account the offshore oil and gas industry techniques.
- Offshore access, rescue equipment, must be considered for operation and maintenance;
- Lightning protection should be considered mandatory;
- Fire protection should be considered mandatory;
- Condition monitoring may be considered mandatory depending on circumstances;
- Quality control systems in design, selection of components, manufacture etc. cannot be overemphasized;
- Because of the remoteness and consequences meticulous attention to the safety management system is mandatory.

One key simplification to the technical issues in the regulatory approval process recommended is the addition of a load case for the turbine structures not currently in the IEC DLCs: that of determining the return period applicable to a 100-year extreme storm reported using a 1-min mean wind speed with site specific associated waves, and currents, with no power and accepting the worst loading direction. Depending on the results the regulator would be in a position to understand the consequences of such a storm on one or multiple wind towers in the field. The results can be reported giving a lower load factor, or can be reported as a reduced return period with normal load factors. Without this additional load case it is our opinion that it is not possible to judge the robustness of the structural system. A research project involving a parametric study of likely turbine structures used in the US OCS determining the effect of such a load case on the industry may be able to put the issue in perspective.

APPENDIX A: STANDARDS

A.1: American National Standards Institute (ANSI)

ANSI 6006-A 03: Design and Specification of Gearboxes for Wind Turbines (2004)

This standard is intended to apply to wind turbine gearboxes. It provides information for specifying, selecting, designing, manufacturing, procuring operating and manufacturing reliable speed increasing gearboxes for wind turbine generator system service. Annex information is supplied on: wind turbine architecture, wind turbine load description, quality assurance, operation and maintenance, minimum purchaser gearbox manufacturing ordering data, lubrication selection and monitoring, determination of an application factor from a load spectrum using equivalent torque, and bearing stress calculations.

A.2: INTERNATIONAL STANDARDS

A2.1: International Organization for Standardization (ISO)

ISO/DIS 81400-4: 2005. Wind turbine generator systems; Part 4: Gearboxes for turbines from 40 kW to 2 MW and larger

Offshore Petroleum Industry References:

- ISO/DIS 19901-1: Petroleum and natural gas industries – specific requirements for offshore structures: Part I: Metocean design and operating considerations.
- ISO 19902 – Fixed Offshore Platforms
- ISO/DIS 19901-3 Topsides structure
- ISO 19901-4 Geotechnical and Foundation Design Considerations
- ISO 19901-5 Weight engineering
- ISO/FDIS 19901-6 Marine operations
- ISO/DIS 19901-7 Stationkeeping systems for floating offshore structures and mobile offshore units
- ISO 19903 Fixed Offshore Concrete structures
- ISO19904-1 Floating Offshore Structures
- ISO/DIS 19905-1 Site-specific assessment of mobile offshore units: Jack-ups
- ISO/CD TR 19905-2 Site-specific assessment of mobile offshore units: Jack-ups commentary
- ISO/DIS 19906 Arctic offshore structures

A2.2: International Electrotechnical Commission (IEC)

- IEC 61400-1 ed.3 Design requirements (+ amendment)
- IEC 61400-2 ed.2 Design requirements for small wind turbines
- IEC 61400-3 ed.1 Design requirements for offshore wind turbines
- (IEC 61400-4 Design requirements for wind turbine gearboxes)
- (IEC 61400-5 Rotor blades)
- IEC 61400-11 ed.2.1 Acoustic noise measurement techniques
- IEC 61400-12-1 ed.1Power performance measurements of electricity producing wind turbines
- IEC/TS 61400-13 ed.1 Measurement of mechanical loads
- IEC/TS 61400-14 ed.1 Declaration of apparent sound power level and tonality values
- IEC 61400-21 ed.2 Measurement and assessment of power quality characteristics of grid connected wind turbines
- IEC/TS 61400-23 ed.1 Full-scale structural testing of rotor blades
- IEC/TR 61400-24 ed.1 Lightning protection
- IEC 6 1400-25 1 -5(+6) Communications for monitoring and control of wind power plants
- (IEC/TS 61400-26 1-3 Availability for wind turbines and wind turbine plants)
- IEC 61400-22 ed.1 Conformity Testing and Certification of Wind Turbines

IEC 61400-1: Wind Turbine Safety and Design
This international standard deals with safety philosophy, quality assurance and engineering integrity, and specifies requirements for the safety of Wind Turbines including design, installation, maintenance, and operation under specified environmental conditions. Its purpose is to provide the appropriate level of protection against damage from all hazards from these systems during their planned lifetime. Is concerned with all subsystems of wind turbines such as control and protection mechanisms, internal electrical systems, mechanical systems and support structures, foundations and the electrical interconnection equipment. The standard applies all sizes of wind turbine generator systems connected to electrical power networks with swept area equal to or larger than 40 m^2.

IEC 61400-3 Wind turbines - Part 3: Design requirements for offshore wind turbines
Specifies additional requirements for assessment of the external conditions at an offshore wind turbine site and specifies essential design requirements to ensure the engineering integrity of offshore wind turbines. Its purpose is to provide an appropriate level of protection against damage from all hazards during the planned lifetime. Focuses on the engineering integrity of the structural components of an offshore wind turbine but is also concerned with subsystems such as control and protection mechanisms, internal

electrical systems and mechanical systems. It should be used together with the appropriate IEC and ISO standards, in particular with IEC 61400-1.

IEC 61400-11 Acoustic noise measurement techniques. Presents measurement procedures that enable noise emissions of a wind turbine to be characterized with respect to a range of wind speeds and directions. Allows comparisons between different wind turbines. May be applied by wind turbine manufacturers, purchasers, operators and planners or regulators.

IEC 61400-12 Power performance measurements of electricity producing wind turbines
Specifies a procedure for measuring the power performance characteristics of a single wind turbine and applies to the testing of wind turbines of all types and sizes connected to the electrical power network. Also describes a procedure to be used to determine the power performance characteristics of small wind turbines (as defined in IEC 61400-2) when connected to either the electric power network or a battery bank.

IEC 61400-13 Measurement of mechanical loads - Acts as a guide for carrying out measurements used for verification of codes and for direct determination of the structural loading. Focuses mainly on large electricity generating horizontal axis wind turbines.

IEC 61400-21 Covers the definition and specification of the quantities to be determined for characterizing the power quality of a grid connected wind turbine; measurement procedures for quantifying the characteristics; and procedures for assessing compliance with power quality requirements, including estimation of the power quality expected from the wind turbine type.

IEC 61400-22 Certification

IEC 61400-23 Full-scale structural testing of rotor blades Is a technical specification providing guidelines for the full-scale structural testing of wind turbine blades and for the interpretation or evaluation of results, as a possible part of a design verification of the integrity of the blade. Includes static strength tests, fatigue tests, and other tests determining blade properties.

IEC 61400-24 Lightning protection. Identifies the generic problems involved in lightning protection of wind turbines; describes appropriate methods for evaluating the risk of lightning damage to wind turbines; describes and outlines suitable methods for lightning protection of wind turbine components.

IEC 61400-25 Part1: Communications for monitoring and control of wind power plants - Overall description of principles and models Gives an overall description of the principles and models used in the IEC 61400-25 series of standards. The IEC 61400-25 series deals with communications between wind power plant components such as wind turbines and actors such as SCADA Systems. It is designed for a communication environment supported by a client-server model.

Part 25-2: Information models. Specifies the information model of devices and functions related to wind power plant applications. Specifies in particular the compatible logical node names, and data names for communication between wind power plant components, including the relationship between logical devices, logical nodes and data.

Part 25-3: Information exchange models. Specifies an abstract communication service interface describing the information exchange between a client and a server for: data access and retrieval, device control, event reporting and logging, publisher/subscriber, self-description of devices (device data dictionary), data typing and discovery of data types.

Part 25-4: Mapping to communication profile. Specifies the specific mappings to protocol stacks encoding the messages required for the information exchange between a client and a remote server for data access and retrieval, device control, event reporting and logging, publisher/subscriber, self-description of devices (device data dictionary), data typing and discovery of data types. Covers several mappings, one of which shall be selected in order to be compliant with this part of IEC 61400-25. The IEC 61400-25 series is designed for a communication environment supported by a client-server model. Three areas are defined, that are modelled separately to ensure the scalability of implementations: wind power plant information model, information exchange model, and mapping of these two models to a standard communication profile.

Part 25-5: Conformance testing. Specifies standard techniques for testing of conformance of implementations, as well as specific measurement techniques to be applied when declaring performance parameters. The use of these techniques will enhance the ability of users to purchase systems that integrate easily, operate correctly, and support the applications as intended.

A2.3: Institute of Electrical and Electronics Engineers (IEEE)

IEEE 1547: deals with Standard Interconnecting Distributed Resources with Electric Power Systems.

A3: GERMANY

A3.1: German Commission for Electrical, Electronic & Information Technologies (DKE)
Uses IEC standards

A3.2: Bundesamt Fur Seeschifffahrt uhd Hydrographie, The Federal Maritime and Hydrographic Agency (BSH).

- Design of Offshore Wind Turbines Bundesamt Fur Seeschifffahrt uhd Hydrographie (BSH), December 27, 2007 which includes specific requirements including color of paint being *"a low-reflectivity light grey, not withstanding regulations on aviation and shipping identification."*

- Ground Investigations for Offshore Wind Farms, Bundesamt Fur Seeschifffahrt uhd Hydrographie (BSH), February 25, 2008 which includes requirements for cable burial assessment.

The BSH requirements include:
- Safety in the Construction phase
- A state-of-the-art geotechnical study,
- Use state-of –the-art methods in the construction of wind turbine, prior to start up
- Presentation of the safety concept
- Installation of lights radar and the automatic identification system (AIS) on the turbines,
- Use of environmentally compatible materials and non-glare paint
- Foundation design minimising collision impact,
- Noise reduction during turbine construction and low-noise operation
- Presentation of a bank guarantee covering the cost of decommissioning.

Ref: www.bsh.de

A4: Germanischer Lloyd (GL)

GL Guideline for the Certification of Offshore Wind Turbines 2005

- Chapter 1: General Conditions for Approval (Scope, Extent of certification, Basic principles of design and construction)
- Chapter 2: Safety System, Protective and Monitoring Devices (General, Control and safety system, Protective and monitoring devices, Interaction of the control and safety systems)
- Chapter 3: Requirements for Manufacturers, Quality Assurance, Materials and Production (Requirements for the manufacturer, Quality management, Materials, Production and testing corrosion protection, Steels suitable for welded offshore structures, Thickness limitations of structural steels)
- Chapter 4: Load Assumptions (Fundamentals, External conditions,

Calculation of loads, Description and coordinate system, evaluation of the loads, Fault in the power system, Design parameters for describing an offshore wind turbine, Wind generated and water depth limited wave spectra, Directional distribution of waves in a sea state, Computation of wave kinematics, Evaluation of design wave loads for rigidly positioned structures, breaking waves loading on piles, Combination of wind and wave distributions)

- Chapter 5: Strength Analyses (General, Determination of stresses, Metallic materials, Concrete and grout materials, Fiber reinforced plastics and bonded joints, Wood, Strength analyses with the finite element method)
- Chapter 6: Structures (General requirements, Rotor blades, Machinery structures, Nacelle covers and spinners, Connections, Steel support structures, Foundation and subsoil, Concrete structures, Floating structures, Detail categories for the fatigue Assessment)
- Chapter 7: Machinery Components (General, Blade pitching system, Bearings, gearboxes, Mechanical brakes and locking devices, Couplings, Elastomer bushings, Yaw system, Hydraulics systems, Offshore applications)
- Chapter 8: Electrical Installations (Area of application, Electrical machines, Transformers, Static converters, Medium voltage, Charging equipment and storage batteries, Switchgear and protection Equipment, Cables and electrical installation equipment, Lightning protection, Offshore grid devices)
- Chapter 9: Manuals (Manuals for sea transport and offshore installation, Documents for commissioning, Operating manuals, Maintenance manuals)
- Chapter 10: Testing of Offshore Wind Turbines (General, Power curve, Noise emission, Electrical characteristics, Test of turbine behavior, loads measurements, Prototype trial of gearboxes, Witnessing of the commissioning)
- Chapter 11: Periodic Monitoring (Scope and execution, Technical experts, Documentation and actions)
- Chapter 12: Marine Operations (Lifting, Towing and installation)
- Chapter 13: Condition Monitoring (General, Offshore application)

GL Wind Guideline, Certification of Fire Protection Systems for Wind Turbines, Certification Procedures Rev. 2, 2009

Guideline for the Certification of Condition Monitoring Systems for Wind Turbines, Edition 2007

GL Wind Technical Note 067 Certification of Wind Turbines for Extreme Temperatures (Cold Climate), Scope of Assessment, Revision 3, Edition 2009

A.5: Det Norske Veritas (DNV)
DNV-OS-J101: OFFSHORE WIND TURBINES
The standard focuses on structural design, manufacturing, installation and follow-up during the in-service phase for the support structure, i.e. all structural parts below the nacelle including the soil. The standard covers: Design principles, Site conditions, Loads and load effects, Load and resistance factors, Materials, Design of steel structures, Design of concrete structures, Grouted connections, Foundation design, Inspections during manufacturing, Corrosion protection, Transport and installation, In-service inspection, maintenance and monitoring.

DNV-OS-J 102: Design and Manufacture of Wind Turbine Blades

DNV-OS-J 103: Offshore Wind Electrical Systems in development.

DNV-OS-J 104: Offshore Wind Turbine Gear Boxes (in development).

DNV-OS-J 201: Offshore Substations

A.6: DENMARK
A6.1: Danish Standards Association (DS)
DS472: Code of Practice for Loads and Safety of Wind Turbine Constructions

Amendment 1 (1998)
The standard deals with load and dimensioning of the load-bearing construction for propeller windmills with horizontal shafts with a rotor diameter of more than 5 meters and placed in an environment corresponding to Denmark exclusive of the Faroe Islands and Greenland.

Amendment 2 (2001)
This is amendment 2 to DS 472, Code of practice for load and safety for wind turbine design and structures. The standard deals with load and dimensioning of the load-bearing construction for propeller windmills with horizontal shafts with a rotor diameter of more than 5 meters and placed in an environment corresponding to the Danish exclusive of the Faroe Islands and Greenland. This amendment to DS 472 is a consequence of the adaptation of the Danish code of practice for the design of structures to Eurocodes.

DS449: Code of Practice for the design and construction of pile supported offshore steel Structures
The standard forms together with DS 409, DS 410, DS 412, and DS 415 the basis for design and construction of pile supported offshore steel structures in the Danish sector of the North Sea. Loads, materials, safety, protection against corrosion, transportation, installation and inspection; Safety regulations for structural design, method of partial coefficients, method of safety index, dead load, load, natural load, imposed load, accidental actions, snow load, wind load;

DS 409. 410. 411. 412. 415: Danish National construction standards
Used in offshore wind construction; referred to in offshore wind Danish recommendation.

A6.2: Danish Energy Authority (and Risø) Recommendations
Recommendation to comply with the requirements in the technical criteria for the Danish approval scheme for wind turbines foundations
Issued: August 10th, 1998

Wind turbine performance testing supplementary requirements for the application of IEC 61400-12 under the Danish approval scheme for wind turbines
Issued: March 7th, 2000

Danish recommendation for technical approval of offshore wind turbines (Rekommandation for teknisk godkendelse af vindmøller på havet) Issued: December 2001

Requirements to cup anemometers applied for power curve measurements under the Danish approval scheme for wind turbines
Issued: January 2002

Recommendation for design documentation and test of wind turbine blades
Issued: November 2002

Recommendation to Comply with the Requirements in the Technical Criteria for the Danish Approval Scheme for Wind Turbines; Gearboxes
- Section 2, Loads (October 2002)
- Section 3, Housing and bearings (April 2002)
- Section 4, Gear sets and shafts (January 2004)
- Section 5, Lubrication (February 2002)
- Section 6, Operation, monitoring and maintenance of gearboxes (March 2004)
- Section 7, Tests and commissioning (August 2002)

Offshore: Risk & Technology Consulting Inc.

CORPORATE HEADQUARTERS

506 Nottingham Oaks Trail, Suite 200,

Houston, Texas 77079

Tel: 713-922-8170   Fax: 281-840-5691

Principal: Malcolm Sharples, B.E.Sc, Ph.D., FSNAME, P.E.