Assessment of Offshore Wind System Design, Safety, and Operation Standards

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Technical Report
NREL/TP-5000-60573
January 2014

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Acronyms

ABS	American Bureau of Shipping
API	American Petroleum Institute
AWEA	American Wind Energy Association
BOEM	Bureau of Ocean Energy Management
BOEMRE	Bureau of Ocean Energy Management, Regulation, and Enforcement
BSEE	Bureau of Safety and Environmental Enforcement
BSH	Federal Maritime and Hydrographic Agency (Bundesamt für Seeschifffahrt und Hydrographie)
BV	Bureau Veritas
CFR	Code of Federal Regulations
CoV	Coefficient of Variation
CVA	Certified Verification Agent
DLC	Design Load Case
DNV	Det Norske Veritas
DOE	U.S. Department of Energy
DOI	U.S. Department of Interior
GL	Germanischer Lloyd
GOM	Gulf of Mexico
IEC	International Electrotechnical Commission
ISO	International Organization for Standards
LRFD	Load Resistance Factor Design
MMS	Minerals Management Service
NAS	National Academy of Science
OCRP	Offshore Compliance Recommended Practices
OCS	Outer Continental Shelf
USACE	U.S. Army Corps of Engineers
WSD	Working Stress Design

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1 Introduction

Federal regulation and approval of offshore wind projects has been mandated by the U.S. Government through the Energy Policy Act of 2005 (EPACT 2005). A national framework for offshore wind project regulation is intrinsically linked to the country's unique meteorological, ocean, and lake (met-ocean) conditions. European offshore wind project approval and regulation are based in part on offshore wind-specific design and certification standards. These standards and guidelines address numerous key project aspects, including safety; site condition assessment; design evaluation of wind turbines, blades, and support structures; manufacturing; transportation; installation, commissioning, and certification; and operation—all directly affected by the external environmental conditions. As the United States follows a similar path, industry and government will need to ensure that the standards and guidelines cited for national regulation are relevant and applicable to the country's offshore conditions. The development or adaptation of these standards is one of the most important applications of information for a national offshore wind energy resource and design database.

There are inherent differences in atmospheric, ocean, and lake conditions between Europe and the United States (Freedman et al. 2010). The most commonly cited differences that affect wind development are related to the characteristics and return periods of severe storms, e.g., hurricanes and extratropical cyclones that can drive key design and operational criteria. However, environmental conditions—and their corresponding certification criteria—can vary widely throughout U.S. waters and include other important design considerations, such as freshwater ice, which are not commonly treated in Europe. Consequently, international offshore wind standards and guidelines do not provide comprehensive guidance for offshore wind project design in the United States.

In this context, the offshore wind characteristics and design conditions particular to the United States necessarily play a key role in informing a national regulatory scheme for the nascent offshore wind industry. Developing or adapting appropriate offshore wind standards requires detailed analysis of current and pending wind and maritime design guidelines. The results of these analyses must then be synthesized with national offshore meteorological, ocean, and lake conditions to identify and bridge any gaps. This report reviews the pertinent international and domestic offshore design standards, discusses their relative applicability and shortcomings for U.S. offshore wind development, and provides a snapshot of industry and government efforts underway (or planned) to develop guidelines for U.S. offshore wind.

This report is a deliverable for a project sponsored by the U.S. Department of Energy (DOE) entitled *National Offshore Wind Energy Resource and Design Data Campaign—Analysis and Collaboration* (contract number DE-EE0005372; prime contractor—AWS Truepower). The project objective is to supplement, facilitate, and enhance ongoing multiagency efforts to develop an integrated national offshore wind energy data network. The results of this initiative are intended to 1) produce a comprehensive definition of relevant met-ocean resource assets and needs and design standards, and 2) provide a basis for recommendations for meeting offshore wind energy industry data and design certification requirements.

1.1 Scope

This report provides a review and assessment of U.S. and international standards, active and under development, which are related directly to the design and safety of offshore wind project components and activities such as manufacturing, construction, and installation of offshore structures. The assessment examines the influence of met-ocean conditions on the turbine and project designs. It primarily focuses on the International Electrotechnical Commission (IEC) standards for offshore turbines, including IEC 61400-1, IEC 61400-3, and the process of type certification, which is commonly used to certify turbines in Europe (IEC 2001, 2005, 2010a, 2010b). However, most industry stakeholders understand that IEC standards alone are not sufficient for designing and certifying an offshore wind project. Additional standards and guidelines from the American Petroleum Institute (API), International Organization for Standards (ISO), and class societies such as Germanischer Lloyd (GL), Det Norske Veritas (DNV), and the American Bureau of Shipping (ABS) are also considered essential to address key aspects of project development, deployment, and operation.

When considering the standards covered in this report, the opportunities for similarly addressing—or creating—related offshore-wind guidelines become attractive. Several other standards, such as those related to blade design, turbine availability, and turbine certification, may also be enhanced by augmentation based on U.S. met-ocean conditions. Furthermore, other offshore project development and design tasks affected by met-ocean parameters, such as wind resource assessment and measurement for site characterization, may benefit from standardization or more rigorous application of recommendations.

The scope of this document was purposefully constrained to addressing offshore wind design, safety, and operations standards in the context of the U.S. spectrum of met-ocean conditions. This family of standards is likely to form the basis of near-term offshore regulation, and influence the design of projects currently under development. Thus, their appropriateness relative to the U.S. environmental conditions is of real and present importance to industry development.

The standards and guidelines considered in this report have influence beyond their intended project or component certification applications. The environmental criteria and design conditions defined by these documents are often referenced throughout the offshore wind development process and can significantly affect how projects proceed. Specifically, project siting and constraints analyses are influenced by extreme wind and wave definitions. Similarly, turbine vendors often use the certification parameters as reference or starting points for independently assessing the suitability of equipment. The met-ocean parameters and definitions presented in these guidelines have broad impact throughout the development process—both directly through project and component certification, and indirectly through peripheral reference to the standards. This enforces the need for the recognized offshore standards and guidelines to be applicable to the atmospheric, ocean, and lake conditions in the United States.

The land-based wind energy industry in the United States has been largely unregulated by the federal authorities, governed mostly by local building codes and private third-party due diligence practices that defer significantly to the established international standards. The regulation and approval of offshore wind projects in federal waters have been assigned to the Bureau of Ocean Energy Management (BOEM) and the Bureau of Safety and Environmental Enforcement (BSEE). Under BOEM/BSEE rules, the process for establishing and demonstrating structural integrity for offshore wind turbines will be more heavily regulated than for land-based turbines. In 2009, BOEM/BSEE issued the rule 30 Code of Federal Regulations (CFR) 285 (now called 30 CFR 585), which provides a framework for approval of offshore wind turbines. However, 30 CFR 585 does not specify an approach for the use of offshore industry standards, but directs developers to use “accepted industry practices.” This leaves a fairly wide opening for interpretation in such a nascent industry where accepted practices are based largely on European experience. Many standards already cover the various stages of offshore wind project development, including design, manufacture, construction, installation, operation, and decommissioning. Presently, the method of achieving structural safety, verifying design integrity, and establishing “accepted industry practices” in federal waters is an ad hoc process created by the project developer, BOEM, and certified verification agents (CVAs, who are third-party engineers qualified to assess structural safety). BOEM approves the final plans for facility design and construction, but a transparent and well-defined process is still lacking.

In state waters (ocean zone inside three nautical miles and the Great Lakes), the process is even less defined and ostensibly left to the individual states and the U.S. Army Corps of Engineers (USACE) to determine. USACE retains primary federal jurisdiction for approving offshore wind facilities in the Great Lakes and state waters. This is pursuant to the Rivers and Harbors Act of 1899 (Section 10), which addresses shoreline structures in relation to the ordinary high water mark and the Clean Water Act of 1977 (Section 404), which addresses the permitting of dredging, structures, and deposits on the beds of navigable waters, and the permitting of various development-related activities in wetlands.

Throughout this range of jurisdiction, the USACE and states are responsible for a diverse spectrum of planned offshore wind projects—from pilot-scale bottom-fixed and floating projects, to utility-scale efforts. The range of meteorological, ocean, lake, and geologic parameters across this area of responsibility is enormous, and includes design conditions that are not thoroughly addressed in any wind-related guidelines. Among the unique design conditions that will have to be addressed for projects in state waters are freshwater ice (Great Lakes), earthquakes (West Coast), significant hurricanes (Gulf of Mexico [GOM]) and Southeast Atlantic coast), tsunamis (Hawaii and Alaska), and large hail (nationwide).

Developers of planned offshore wind projects in these waters—as well as of advanced projects in federal waters—are likely among the first to need and employ design standards that are relevant to these projects’ specific environmental conditions; such developers are also among the first to seek certification. The unique design and operating environments in state and federal waters further reinforce the need for nationally coordinated met-ocean characterization efforts to inform offshore wind development and operation processes.

In the coming years, new processes for wind facility engineering and deployment will evolve and be tested on the first U.S. offshore wind projects, and protocols for achieving safe offshore wind structures will be written by piecing together various standards, guidelines, and proven engineering practices. DOE, DOI, and other government agencies should stay abreast of these new developments and be aware of how their implementation may influence the technology in terms of cost, environmental impact, and innovation.

At the heart of all the governing design standards is an expectation that the external atmospheric, ocean, and lake conditions be well understood for the site where the turbines are to be deployed, because these conditions drive the load cases that act on the turbine structures and drive the material strength and design life. The offshore wind industry and DOE generally agree that this expectation is not met by the current met-ocean observational networks and datasets in the United States (DOE 2011). Though other reports referenced in this project identify available data sources, industry needs, and gaps in more detail, generally these met-ocean datasets are not wholly adequate to support U.S. offshore wind development, or the design of new industry guidelines, with a high degree of confidence. At present, entities exploring offshore wind development are burdened with designing and deploying site-specific met-ocean monitoring campaigns based on an uncertain framework of engineering and certification requirements, an exercise that is both time consuming and costly. Not only has this situation been identified as a market barrier, but the varying requirements can result in inconsistent data collection parameters and methods, particularly in the absence of regional or national coordination. Moreover, the site-specific data collected under such campaigns are generally proprietary and do not immediately enter into the national knowledge base. As such, the need for new or revised offshore wind guidelines for U.S. waters that are informed by a robust set of ocean-based measurements is seen as a prime driver to advance a national offshore resource and design data campaign.

Type certification, used by most land-based turbines, requires compliance with a predefined IEC design class corresponding to a prescribed extreme wind and turbulence level (e.g., IEC Class 1 A from IEC 61400-1). On the U.S. outer continental shelf (OCS), and elsewhere in U.S. waters, site conditions can easily exceed or deviate from current IEC classes because of severe tropical storms, Nor'easters, and other conditions that may challenge current assumptions about external conditions that are provided in the governing IEC standards. This report evaluates the applicable standards in the context of these extreme met-ocean conditions (i.e., 50- and 100-year return periods) in expected project locations in U.S. waters.

An offshore wind turbine with a 20-year design life may be reasonably expected to achieve a comparable reliability track record as land-based wind turbines, but offshore turbines may have to perform even better to avoid the higher cost of offshore maintenance. Future research will likely be needed to improve the current standards and increase their value to the U.S. offshore wind industry to achieve the needed reliability for achieving the broader DOE cost reduction goals. Ultimately, some modifications to offshore wind standards will likely be needed to achieve acceptable life and failure rates for survivability and reliability in U.S. waters. Such modifications should include methods to lower the uncertainty of estimating and evaluating critical offshore wind parameters in the met-ocean environment through analysis or testing methods.

This report builds, in part, on the work done recently by the National Academy of Science (NAS), which evaluated the applicability of current standards in a report commissioned by BOEM (NAS 2011). As a result of this study, the NAS committee recommended that BOEM develop a set of high-level, performance-based criteria to judge offshore structural integrity. This report also draws heavily from the American Wind Energy Association (AWEA) Offshore Compliance Recommended Practices (OCRP) (called AWEA OCRP 2012). AWEA OCRP 2012 provides a roadmap to guide developers and regulators through the standards to provide a viable approach to achieve adequate structural safety in U.S. waters.

1.2 Background

DOE's offshore wind energy program has initiated partnerships with private industry under its National Offshore Wind Strategy to harness the nation's offshore wind resource to supplement the United States' growing energy needs. For the industry to be successful, the wind turbine designs must account for the harsh environment where the turbines are installed. The available standards and guidelines may not provide adequate guidance on environmental design conditions to ensure structural integrity or 20-year design life on their own.

Regulators and developers will have to maintain a high level of vigilance and draw knowledge and resources from several industries and disciplines to overcome some of the uncertainties. A strong reliance on experience from the European offshore wind and offshore fossil fuel industries will be essential for structural design, and external conditions and weather events will need to be characterized from models and data developed in the United States.

The international standards developed under the IEC TC-88 are the primary standards governing the design of wind turbines and were primarily developed for land-based and offshore wind projects based on environmental characteristics that are applicable in Europe. However, given the U.S. offshore wind resource with different environmental characteristics and deeper water, the offshore standards to support the emerging U.S. market are not complete with respect to the design conditions in locations where domestic offshore projects are currently planned for development. IEC standards for wind turbines focus on design conditions and load cases using a Load Resistance Factor Design (LRFD) approach (Galambos et al. 1996; API 1997). This approach accounts for design load uncertainties and consequences of failure through a summation of partial safety factors. Galambos et al. did not develop criteria for design strength or stress calculations. Generally IEC adheres to a 50-year return period for extreme design conditions.

The API standards, started by the oil and gas industry 60 years ago, are the governing standards for design safety and operation in the production of offshore oil and gas on the U.S. continental shelf. These standards have gained international recognition and have been adopted by many oil-producing countries. In contrast to the IEC, API standards assume a 25-year, 50-year, or a 100-year return period for extreme events, depending on the life safety and consequence matrix.

Figure 1 illustrates a typical offshore wind turbine in water shallower than 30 meters. The IEC and ISO international standards, namely IEC 61400-1, IEC 61400-3, IEC 61400-22, and ISO 19900 series, are commonly used in Europe for offshore wind projects. Federal Maritime and Hydrographic Agency (BSH) standard from Germany and the API Series 2 standards from the United States can also be used for design of the sub-structure below sea level. This general framework is supported by several recent standards research efforts in the United States, including the NAS, AWEA, and a joint industry project sponsored by DOE and BOEM in 2009 (NAS 2011; AWEA 2012; MMI Engineering 2009). Additional class societies' guidelines have recently been issued from ABS, Bureau Veritas (BV), DNV, and GL that can be used to fill gaps and address aspects of offshore wind project development, but the guidelines are not consensus-based standards.

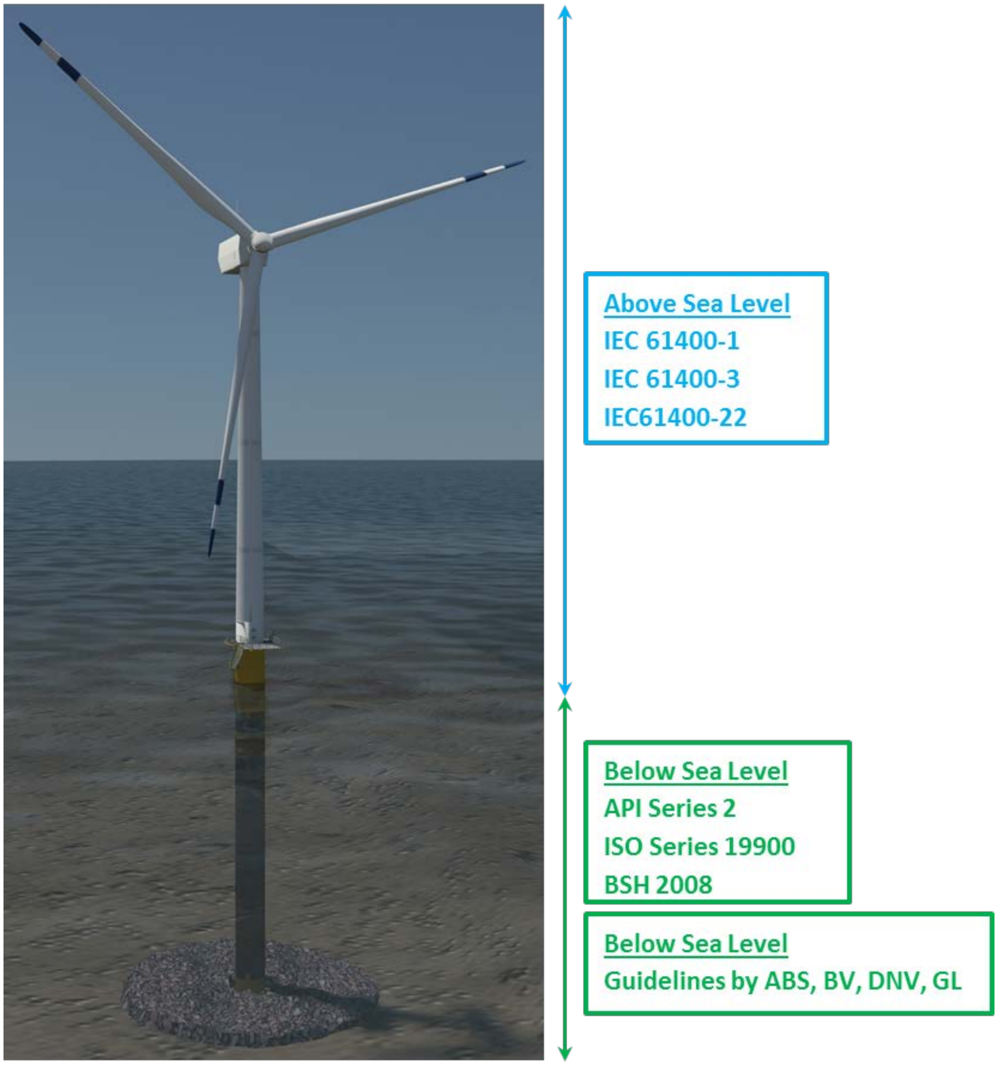


Figure 1. Standards and guidelines applicable to offshore wind system
Illustration by Josh Bauer, NREL

1.3 Met-Ocean Data

Offshore systems require detailed met-ocean data, preferably at site, both above and below the water surface for the system to be designed for the service lifetime for strength and fatigue. In lieu of detailed site-specific data, which are generally sparse for a given offshore wind project, relevant information is available from the oil and gas industry and is detailed in API Bulletin 2INT-MET for the GOM (API 2007). Table 1 illustrates an example from the API Bulletin 2INT-MET in the central region of the GOM. This kind of information is widely used for the design of offshore structures in the oil and gas industry. ABS acquired, for internal use, a similar dataset that was used in its study for the Atlantic coast (see Section 5).

Table 1. API Bull 2INT-MET—Central Region
(API 2007)

Return Period (Years)	10	25	50	100	200	1,000	2,000	10,000
Wind (10-m Elevation)								
1-h mean wind speed (m/s)	33.0	40.1	44.4	48.0	51.0	60.0	62.4	67.2
10-min mean wind speed (m/s)	36.5	44.9	50.1	54.5	58.2	69.5	72.5	78.7
1-min mean wind speed (m/s)	41.0	51.1	57.4	62.8	67.4	81.6	85.6	93.5
3-s gust (m/s)	46.9	59.2	66.9	73.7	79.4	97.5	102.5	112.8
Waves, WD ≥ 1,000 m								
Significant wave height (m)	10.0	13.3	14.8	15.8	16.5	19.8	20.5	22.1
Maximum wave height (m)	17.7	23.5	26.1	27.9	29.1	34.9	36.3	39.1
Maximum crest elevation (m)	11.8	15.7	17.4	18.6	19.4	23.0	23.8	25.6
Peak spectral period (s)	13.0	14.4	15.0	15.4	15.7	17.2	17.5	18.2
Period of maximum wave (s)	11.7	13.0	13.5	13.9	14.1	15.5	15.8	16.4
Currents, WD ≥ 150 m								
Surface speed (m/s)	1.65	2.00	2.22	2.40	2.55	3.00	3.12	3.36
Speed at midprofile (m/s)	1.24	1.50	1.67	1.80	1.91	2.25	2.34	2.52
0-speed depth, bottom of profile (m)	69.3	84.2	93.2	100.8	107.1	126.0	131.0	141.1
Currents, WD 10–70 m								
Uniform speed at 10-m depth (m/s)	1.09	1.61	1.97	2.30	2.60	3.23	3.50	4.05
Uniform speed at 70-m depth (m/s)	0.98	1.45	1.77	2.07	2.34	2.91	3.15	3.65
Water Level, WD ≥ 500 m								
Storm surge (m)	0.32	0.52	0.66	0.80	0.93	1.13	1.22	1.41
Tidal amplitude (m)	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42

The API met-ocean datasets are meant for use in the oil and gas industry, where the specific wind characteristics are less critical than for the wind energy industry. The offshore wind industry will need more detailed wind information for proper structural design, such as:

- Wind shear and veer—across the rotor plane as well as between the near-surface and hub height
- Turbulence and turbulence intensity—ideally at hub height
- Vertical wind speed
- Wind speed and direction frequencies
- Unique hurricane conditions.

In addition to the detailed wind information, other data could also be important during the design phase, such as:

- Air and water temperature and gradients
- Tidal, storm surge, and extreme waves
- Currents
- Atmospheric humidity, pressure, and density
- Icing characteristics
- Marine growth
- Hail and lightning frequency and severity
- Soil and seismic conditions.

The met-ocean parameters that are relevant for the design of an offshore wind system are illustrated in Figure 2.

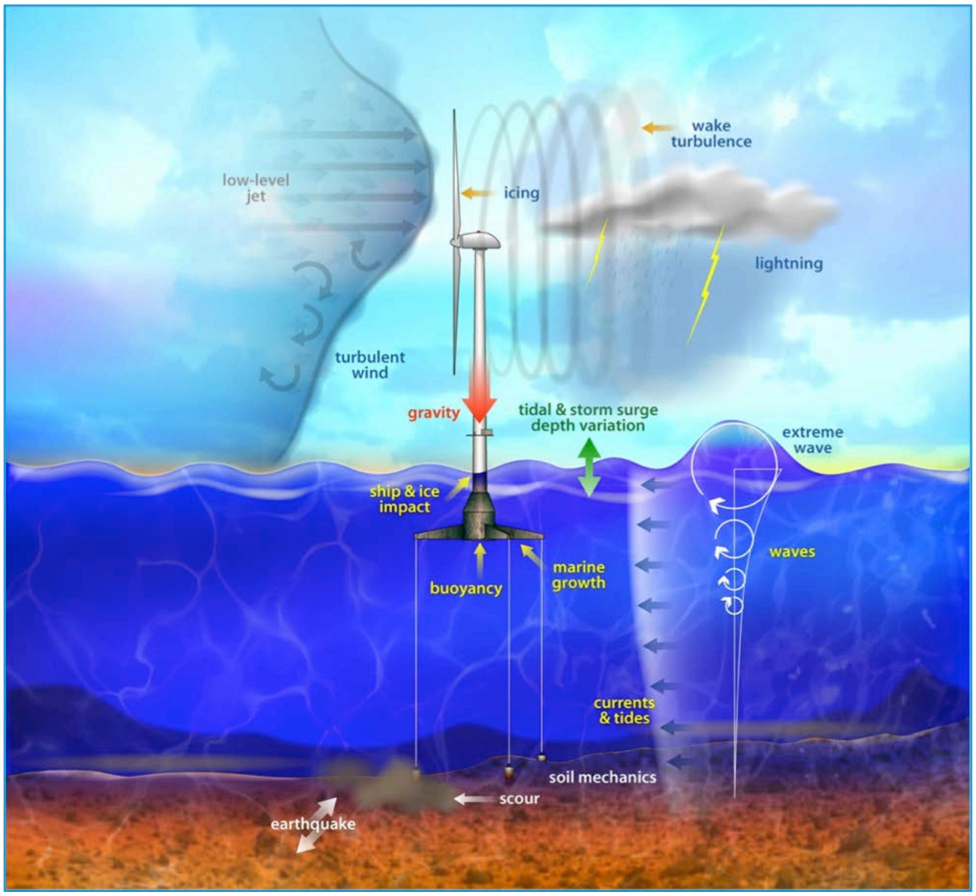


Figure 2. External conditions relevant for an offshore wind turbine system
Illustration by Al Hicks, NREL

There are no comprehensive, public met-ocean datasets for the U.S. offshore wind industry to fully study the design and economics of possible wind plant development. Developers, utilities, researchers and others seeking to explore offshore wind development and design are thus often required to proceed with inadequate information or deploy new measurements with significant time and cost implications. Therefore, there is a vital need to gather met-ocean data from existing and new data sources, and to provide those data in appropriate formats (maps, databases, etc.) that are tailored to the offshore wind industry. Efforts to address this need are underway at various national, state, and project levels, but further work is required to remove this hurdle for long-term industry development.

The need for consensus around met-ocean data collection and characterization will become important as the offshore wind industry evolves. The framework of best practices in the wind industry and methods suggested by other disciplines (meteorology, physical oceanography, the oil and gas industry, and so on) are expected to adequately serve the first round of projects in the United States. However, the refinement of design, safety, and operations standards for U.S. offshore environmental conditions will likely have implications for accepted methods of met-ocean data collection, analysis, reporting, and modeling to define those conditions. DOE and the wind industry have recognized this eventuality—as well as the larger need for quality data suggested previously—and have made initial strides in this direction. National and regional catalogues of offshore measurements have been established (AWS Truepower 2012; U.S. Offshore Wind Collaborative 2012) to serve as an industry resource and as a foundation for identifying needs. Efforts to identify key measurement parameters and define future data needs are in progress (DOE 2012). Logical next steps that should be considered in this area include: (1) expand documented wind resource assessment best practices for offshore environments; and (2) define standards for met-ocean measurement. These efforts are anticipated to bring additional value by aligning measurement practices, site characterization approaches, and design standards in response to the expected met-ocean conditions in U.S. waters.

2 Regulations, Standards, Guidelines, and Certification

The process for compliance with offshore wind regulations in the United States is unclear, because rules can be vague and appropriate design standards and guidelines are not specified. The lack of specificity with regard to standards leaves a multitude of options open to developers and increases uncertainty in the design without sufficient guarantee of structural reliability. Requirements for best practices and safety can be very subjective, leading to an ad hoc process of closed door negotiations between the developer and the regulator. With no offshore wind installations yet, this process is clearly still evolving and in a nascent stage, but with experience, more transparent rules are expected to emerge. To make the rules more objective, regulators will have to recognize and adopt specific design, safety, and operations standards and rely on societies that set classes or provide certification for the installations.

2.1 Regulations

Regulation is administrative legislation that constitutes or constrains rights and allocates responsibilities set by government authorities at the national and state levels. The codification of the general and permanent rules published in the Federal Register by the departments and agencies of the federal government are codified in the CFR. Appendix A contains a partial list of regulations that apply to offshore wind projects.

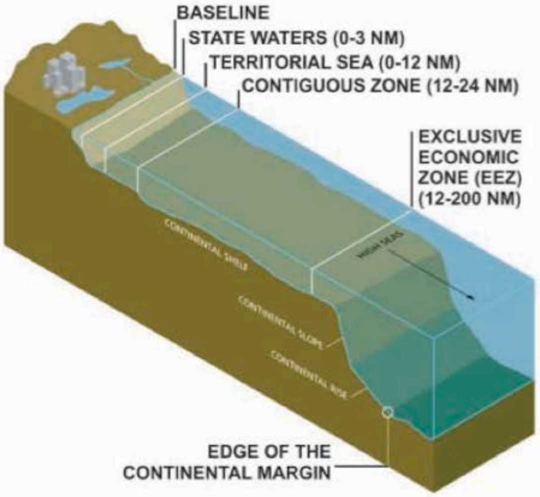
2.1.1 Jurisdiction

Regulation and compliance in U.S. waters can be under state or federal jurisdiction, depending on the water body and the distance from shore. State jurisdiction applies to all the Great Lakes' waters, and, for most states, three nautical miles seaward (3.5 statute miles or 5.6 kilometers) as shown in Figure 3 (Musial and Ram 2010). The exceptions are Louisiana, Texas, and the Gulf Coast of Florida. Specifically:

- **Louisiana** extends 3 pre-1954 U.S nautical miles (3.455 miles or 5.560 kilometers) seaward.
- **Texas and the Florida Gulf Coast** extend 9 U.S. nautical miles (10.4 miles or 16.7 kilometers) seaward.

The USACE is the agency with jurisdiction for permitting offshore wind structures in state waters and the Great Lakes, based on Section 10 of the Rivers and Harbors Act. This permit relates to structures that alter or obstruct navigable waters, but the permit has no specific reference to energy-related projects in the ocean. In the United States, there is no national renewable energy policy for offshore wind developments in state waters, nor is clear jurisdictional authority given to one federal agency. To date, private developers are leading the activities without a clear due diligence procedure in place and without any streamlined permitting process, and the process generally varies significantly from state to state.

Beyond state jurisdiction on the OCS, regulation and compliance are under DOI jurisdiction and specifically managed by BOEM and BSEE. BOEM has published federal regulation rules in 30 CFR 585, which governs renewable energy projects on the OCS, but does not specify standards or detailed requirements. Instead the regulations relies on CVAs to oversee an independent assessment of the facility design, fabrication, installation, operation, and decommissioning. Some CVAs are also class societies such as ABS, BV, DNV, and GL and have their own published guidelines to bridge gaps not covered in standards.



Baseline
The U.S. baseline is the mean lower low-water line along the coast. A key factor determining the jurisdictions for wind energy projects in the ocean is the project boundary line dividing the land from the ocean or the baseline. However, the baseline is not static and may shift and/or be contested because of natural erosion or seabed changes.

State Waters (0 to 3 nm)
Enacted in 1953, the Submerged Lands Act gave coastal states jurisdiction over a region of the ocean extending 3 nm seaward from the baseline, commonly referred to as state waters. The seaward boundary of the eight states bordering the Great Lakes is the U.S.-Canada International boundary. Generally, projects located within 3 nm of the ocean coast are designated to be in state waters. Because of legal histories, Texas and Florida are two states with exceptions, with their state boundaries in the Gulf Coast extending to 9 nm.

Territorial Sea (0 to 12 nm)
Under international law, every coastal nation has sovereignty over the air space, water column, seabed, and subsoil of its territorial sea, subject to certain rights of passage for foreign vessels and, in more limited circumstances, foreign aircraft. In 1988, President Reagan proclaimed a 12 nm (22 km) territorial sea for the United States, consistent with provisions in the LOS Convention. The proclamation extended the territorial sea only for purposes of international law, explicitly stating that there was no intention to alter domestic law.

Contiguous Zone (12 to 24 nm)
International law recognizes a contiguous zone outside the territorial sea of each coastal nation. Within its contiguous zone, a nation can assert limited authority related to customs, fiscal, immigration, and sanitary laws. In 1999, President Clinton proclaimed a U.S. contiguous zone from 12 to 24 miles (19–39 km) offshore, enhancing the U.S. Coast Guard's authority to take enforcement actions against foreign-flag vessels throughout this larger area.

Exclusive Economic Zone (12 to 200 nm)
The LOS Convention allows each coastal nation to establish an EEZ adjacent to its territorial sea, extending a maximum of 200 nm (370 km) seaward from the baseline. Within its EEZ, the coastal nation has sovereign rights for the purposes of exploring, exploiting, conserving, and managing living and nonliving resources, whether found in ocean waters, the seabed, or subsoil. Specifically pertaining to the topic of energy, these national rights include the commercial recovery of minerals and the production of energy from water, currents, and wind. These rights also grant nations jurisdiction to establish artificial islands, installations, and structures within their EEZ. In 1983, President Reagan proclaimed the U.S. EEZ, which occupies the area between 12 nm (22 km, the seaward limit of the territorial sea) and 200 nm (370 km) offshore, for international purposes. The United States does not generally assert control over ship transportation, air space, the laying of cables and pipelines on the ocean floor, or marine scientific research in the U.S. EEZ to the same extent that most coastal nations do.

Continental Shelf (12 to 200 nm or outer edge of continental margin)
The legal concept of the continental shelf has evolved over the past 60 years. The LOS Convention generally defines the continental shelf for purposes of international law as "the seafloor and subsoil that extend beyond the territorial sea throughout the natural prolongation of a coastal nation's land mass to the outer edge of the continental margin or to 200 nm (370 km) from the baseline if the continental margin does not extend that far." Thus, the legal definition of the continental shelf overlaps geographically with the EEZ. The term "deep seabed" is used to describe the seabed beyond these national jurisdictions.

High Seas (areas beyond national jurisdictions)
International law has long considered areas of the ocean beyond national jurisdiction to be the high seas.

Source: Energetics, adapted from U.S. Commission on Ocean Policy 2003.

Figure 3. Schematic of state, federal, and international ocean jurisdictions

BOEM manages the exploration and development of U.S. offshore resources. It balances economic development, energy independence, and environmental protection through oil and gas leases, renewable energy development, and environmental reviews and studies. Relevant BOEM programs and functions include the following.

- The Office of Strategic Resources is responsible for the development of the Five Year OCS Oil and Natural Gas Leasing Program. The office oversees assessments of the oil, gas, and other mineral resource potential and compiles inventories of oil and gas reserves, develops production projections, and conducts economic evaluations.
- Oil and gas lease sales along with sand and gravel negotiated agreements, official maps, and geographic information systems data are part of the BOEM purview.
- The Renewable Energy Program grants leases, easements, and rights-of-way for orderly, safe, and environmentally responsible renewable energy development activities.
- The Office of Environmental Programs conducts environmental reviews, including National Environmental Policy Act analyses and compliance documents for each major stage of energy development planning.
- BOEM reviews exploration plans and development operations and coordination documents, fair market value determinations, and geological and geophysical permitting.

The role of BSEE is to protect the environment and conserve resources offshore through vigorous regulatory oversight and enforcement. Following is a summary of associated programs and functions.

- The Offshore Regulatory Program develops standards and regulations to enhance operational safety and environmental protection for the exploration and development of offshore oil and natural gas on the OCS.
- The Oil Spill Response division is responsible for developing standards and guidelines for offshore operators' oil spill response plans through internal and external reviews of industry oil spill response plans to ensure compliance with regulatory requirements and coordination of oil spill drill activities. This division also plays a critical role in the review and creation of policy and guidance, direction, and oversight of activities related to the agency's oil spill response.
- The Environmental Enforcement Division provides sustained regulatory oversight that focuses on compliance by operators with all applicable environmental regulations, and ensures that operators keep the promises they make at the time they obtain their leases, submit their plans, and apply for their permits.
- The BSEE reviews each Application for Permit to Drill to ensure that necessary safety requirements are met. The BSEE also conducts inspections of drilling rigs and production platforms using multiperson, multidiscipline inspection teams. Inspectors issue Incidents of Non-Compliance and have the authority to fine companies through civil penalties for regulatory infractions. Field operations personnel also investigate accidents and incidents.

2.2 Standards

A standard is a document developed from best practices, lessons learned, and research, and is used by consensus of the stakeholders. A standard describes how a product is to be designed, built, tested, and operated. An ideal standard as described by Fields (2008) is:

- **Necessary** by providing specifics to benefit development of a product
- **Unambiguous** by not being subject to multiple interpretations
- **Consistent** by not conflicting with other documents within its family of standards
- **Auditable** with a quantitative exit criterion that the standard was followed.

Standards can be international, national, or industry specific. IEC and ISO are international standards organizations. API, on the other hand, is an industry-specific standard. Although API is not specific to the wind industry, it covers the design and construction of offshore structures. Appendix B contains a list of numerous regulations, standards, and guidelines that are relevant to the offshore wind industry, but the most relevant design standards for the U.S. offshore wind industry are:

- IEC 61400-1, Wind turbines—Part 1: Design requirements
- IEC 61400-3, Wind turbines—Part 3: Design requirements for offshore wind turbines
    - IEC 61400-3-2, Wind turbines—Part 3-2: Design requirements for floating offshore wind turbines (Pending)
- IEC 61400-22, Wind turbines—Part 22: Conformity testing and certification
- ISO 19900, General requirements for offshore structures
- ISO 19902, Fixed steel offshore structures
- ISO 19903, Fixed concrete offshore structures
- ISO 19904-1, Floating offshore structures—monohulls, semisubmersibles and spars
- ISO 19904-2, Floating offshore structures—tension leg platforms
- API RP 2A-WSD, Recommended practice for planning, designing and constructing fixed offshore steel platforms—working stress design.

2.2.1 International Electrotechnical Commission

The IEC, founded in 1906, organizes international standards for all electrical, electronic, and related technologies, including wind energy. All IEC standards are fully consensus based and represent the needs of key stakeholders of every nation participating in IEC work. The IEC formed Technical Committee 88 (TC 88) to develop standards for wind turbines.

A complete list of IEC international standards for wind turbines is given in Appendix B, but the most important IEC standards for offshore wind are:

- IEC 61400-1—Land based, but addresses structural design, design classes, and design load cases, and provides a detailed definition of turbulent wind.
- IEC 61400-3—Provides offshore requirements by addressing the equal importance of both wave and wind for fixed shallow water support structures and defers to IEC 61400-1 for above-water requirements.
    - IEC 61400-3-2—Pending technical specification for design of floating offshore platforms. The objective of this technical specification is to highlight the differences between floating offshore wind turbines and fixed-bottom wind turbines (IEC 61400-3). These differences include considerations for hydrostatic stability, mooring lines and tendons, tsunamis, earthquake loading on tension leg platforms, wave-tank testing requirements for model validation, new load cases for floating-specific faults (loss of a mooring line, one flooded compartment), application of frequency-domain methods, and modified simulation requirements (increased simulation length, 6 degrees-of-freedom floater motion, second-order hydrodynamics, etc.).
- IEC 61400-22—Describes and defines the methods for type certification, project certification, and component certification, which include requirements from IEC 61400-3 and IEC 61400-1.

2.2.2 International Organization for Standards

The ISO, founded in 1947, is the world's largest developer of voluntary international standards. Developed through global consensus, the ISO has published more than 19,000 international standards. The standards applicable to offshore wind are the 19900 Series listed in Appendix B. These are based on current API standards for fixed and floating structures and Norwegian standards for offshore concrete. Considerable ongoing work aligns ISO 19900 and API Series 2. AWEA Offshore OCRP 2012 recommends that ISO standards be used instead of API to conform to their procedure of adopting international standards first, if possible. European wind plant developers also use ISO standards, as referenced within the IEC standards.

2.2.3 American Petroleum Institute

The API is a leader in the development of petroleum and petrochemical equipment and operating standards. These standards represent more than 60 years of industry design experience. Many API standards have been incorporated into state and federal regulations and adopted by the ISO for worldwide acceptance.

API Series 2 addresses offshore oil and gas requirements for planning, installation, structures, operation, and decommissioning. This series focuses mainly on wave loading rather than wind, because 70% of offshore oil and gas platform loads come from waves (NAS 2011). For statically responding oil and gas facilities, a quasi-static wind load definition may be appropriate because inertial effects are negligible (time and inertial mass are irrelevant). Dynamically responding facilities such as wind turbines require careful consideration of wind loading generated by a wind spectrum, where inertial effects are important (time and inertial mass are relevant).

Complete lists of current API Series 2 standards are provided in Appendix B. The API is actively engaged with the ISO in developing the ISO 19900 series; as part of the process, API Series 2 is being restructured to align with the ISO 19900 series. Table 2 lists API and ISO documents that have been aligned with one another, as well as other documents currently undergoing alignment that will be available with the next release of API Series 2 standards. Extreme events are events that occur rarely during the life of the structure and are important in formulating maximum platform design loads per API definition. API assumes a 25-year, 50-year, or a 100-year return period for extreme events, depending on the life safety and consequence matrix. AWEA recommends the classification of offshore wind turbines as L2 structures (per API/ISO standards) requiring a 50-year return period extreme event similar to the IEC. In hurricane-prone regions of the United States, the bigger question is the partial safety factors dictated by IEC at 1.35, which may not be satisfactory to meet structural reserve strength per the API robustness check for L2 structures at a 500-year return period. How the partial safety factors affect the design in various U.S. offshore regions has not yet been fully studied and needs to be addressed.

Table 2. API Series 2 Alignment to ISO Series 19900

	API	ISO
General		
General	API RP 2GEN*	19900
Met-ocean	API RP 2MET*	19901-1
Seismic design	API RP 2EQ*	19901-2
Geotechnical	API RP 2GEO*	19901-4
Marine operation	API RP 2 MOP	19901-6
Station keeping	API RP 2SK / API RP 2SM	19901-7
Fire and ballast	API RP 2FB	19901-3
Structural integrate management	API RP 2SIM*	19904-1
Plates	API Bull 2V	
Shells	API Bull 2U	
Structures		
Fixed steel (WSD)	API 2A-WSD	
Fixed steel (LFRD)	API RP 2A-LFRD*	19902
Concrete	API RP 2CON*	19903
Floating	API RP 2FPS	19904-1
Tension Leg Platform	API RP 2T	19904-2
Jack-up		19905-1
Arctic	API RP 2N	19906

Notes: * undergoing alignment with corresponding ISO document

2.2.4 Federal Maritime and Hydrographic Agency (German Regulations)

Bundesamt für Seeschifffahrt und Hydrographie (BSH) is the Federal Maritime and Hydrographic Agency in Germany. Its role in Germany is similar to BOEM's in the United States. BSH approves offshore wind plant development beyond 12 nautical miles from the coast of Germany. In 2008, the BSH released a standard for offshore wind turbines (BSH 2008). The standard (BSH No. 7004) covers development, design, implementation, operation, and decommissioning. The other BSH standard listed in Appendix B, which is referred to as BSH 2008, is for geotechnical and route surveys (BSH 2003).

2.3 Guidelines

Guidelines are recommended practice documents that are not subjected to a formal protocol or vote of constituencies. Such guidelines are typically established by classification societies and are solely dependent on the internal quality process and peer review of the originating society. Guidelines consist of recommended, nonmandatory controls that help support standards or serve as a reference when no applicable standard is in place. Guidelines should be viewed as best practices as judged by that society. Guidelines are not usually "requirements," but are strongly recommended in some cases. Guidelines in general can be issued more quickly, and rely on company-based review compared to a larger multi-organization, consensus-based standard process. Therefore, industry tends to adopt these guidelines sooner. Because classification societies also issue certificates, those societies readily use guidelines to fill in the gaps that standards do not yet cover.

2.3.1 American Bureau of Shipping

The ABS, founded in 1862, is a classification society for marine-related facilities. It has been at the forefront of developing guidelines for the offshore oil and gas energy sector since the industry's formative years. Although ABS is relatively new to the offshore wind industry, it is uniquely qualified to transfer its offshore and regulatory knowledge toward establishing guidelines for the offshore wind industry. Of the many ABS oil and gas guidelines that apply to the offshore wind industry, publication 176 (ABS 2010) is the first comprehensive guide for designing, manufacturing, installing, and operating (but not decommissioning) fixed offshore wind turbine substructures (monopole, jacket, gravity-based, and self-elevating units, and compliant towers). This guideline was published in 2010 and addresses tropical storm-prone areas. In 2013 the publication was updated (ABS 2013a) to distinguish the publication from a new publication for floating systems, publication (ABS 2013b).

2.3.2 American Wind Energy Association

AWEA is a U.S. national trade organization representing the wind energy industry. In October 2009, AWEA and NREL started to develop a recommended practice document to address gaps in design and safety standards by assessing national and international standards, and guidelines from classification societies. The focus was in the area of offshore wind facility development in U.S. waters (both state and federal) for fixed offshore structures (AWEA 2012). This document does not address deeper water wind plant development that requires floating structures. More than 50 stakeholders from offshore industries, including wind and oil and gas firms, participated in drafting the document. The AWEA committee prioritized its recommendations by using international standards first whenever possible, then national standards and classification society guidelines. Areas addressed were structural reliability, manufacturing, qualification testing, installation, construction, safety of equipment, operation and inspection, and decommissioning. AWEA released the final draft in October 2012. This document is being considered for adoption in DOE's recently awarded demonstration projects and may provide a good starting point to frame the more detailed discussions that relate to full project development.

2.3.3 Bureau Veritas

BV is an international classification society providing conformity assessment, certification, and consulting services to industries and governments. BV has a guideline for the classification and certification of floating offshore wind turbines, BV-NI572. The guideline specifies the environmental conditions under which floating offshore wind turbines may operate, the principles of structural design, load cases for the platform and mooring system, stability, and the structural division and design criteria for the top structure. The guideline covers single and multiturbine floating platforms for both horizontal and vertical-axis turbine designs. Appendix C contains a list of BV guidelines; the following are dedicated to offshore wind turbines:

- BV-NI572—Classification and certification of floating offshore wind turbines
- BV-NI567—Risk-based verification of floating offshore units
- BV-NI589—Wind farms service ships.

These guidelines address offshore floating wind turbines only; they provide no guidance for fixed-bottom offshore wind turbines. There is also no known effort to address the extreme environmental conditions in the U.S. market.

2.3.4 Det Norske Veritas

DNV is a classification society with a history that goes back to 1864, when it was established in Norway to inspect and evaluate the technical conditions of Norwegian merchant vessels. Today, DNV plays a major role in the offshore oil and gas industry by providing design guidelines and acting as a CVA. This society has a large collection of guidelines for offshore structures, which are listed in Appendix C. DNV has also been playing a leading role in developing standards and guidelines specifically for offshore wind, which include:

- DNV-OS-J101—Design of Offshore Wind Turbine Structures
- DNV-DS-J102—Design and Manufacture of Wind Turbine Blades, Offshore and Onshore Wind Turbines
- DNV-OS-J201—Offshore Substations for Wind Farms.

DNV is actively involved in IEC activities and is a major contributor to IEC TC-88 international standards.

2.3.5 Germanischer Lloyd

GL is a classification society based in Germany, which merged with DNV in 2013. Its technical and engineering services include the mitigation of risks and assurance of technical compliance for the oil and gas and wind energy industries. GL was the early leader with established guidelines for wind turbines, e.g., GL 2, (GL 2012). GL holds the monopoly as the certification authority for all German wind turbine installations, both land-based and offshore. This society has a strong presence in the certification of wind turbines worldwide. Its guidelines address all structures, systems, and components for offshore wind turbines and their support structures and foundations. A list of guidelines for land-based and offshore wind turbines is available in Appendix C. GL is actively involved in IEC activities and is a major contributor to IEC TC-88 international standards.

2.4 Certification

There are two kinds of certification addressed by IEC 61400-22: type certification and project certification. Type certification is strictly for the wind turbine design and performance assurance for a given wind class regime. Project certification encompasses the design of the whole wind plant, including the application of the site-specific external conditions and the support structure.

2.4.1 Type Certification

For fixed offshore systems, the certification process (IEC 61400-22) relies on technical standards (IEC 61400-1 and IEC 61400-3) for design parameters. A type certificate, defined in IEC 61400-22, provides assurance that the wind turbine (rotor, nacelle, assembly, and tower) is designed, documented, and manufactured using methods conforming to a design basis specified by the manufacturer (including design assumptions, specific standards, and technical requirements).

The type certification must consist of modules that include:

- Design basis evaluation
- Wind turbine design evaluation
- Type testing
- Manufacturing evaluation
- Final evaluation.

The foundation (support structure) design and manufacturing evaluations are optional modules to the type certificate. The certification of the turbine, independent of the optional foundation type module, has been used in many projects internationally. The original tenets of type certification were founded on land-based design principles, so rigid fixed foundations placed in solid ground were not considered a critical design change because they varied from site to site. This assumption can be problematic for offshore structures where water depth and support structure type are integral elements of the system design and critical to all aspects of the structure.

Performance-related characteristics (other than measurement of power performance) could be part of the type certification process, with the addition of an optional type characteristic measurements module.

The optional measurements include one or more of the following:

- Power quality test
- Low voltage ride-through tests
- Acoustic noise measurements.

Figure 4 illustrates the type certification process and its various modules. An evaluation report and a conformity statement document conformity to each module.

Wind turbines are often type certified before the exact conditions under which they are eventually deployed are known. Generic design classes are given in IEC 61400-1 that categorize design sites by their extreme winds and turbulence conditions. This system provides assurance to wind plant stakeholders that the certified turbine will perform as long as the site conditions do not exceed the generic design class parameters. In many offshore locations of the United States, extreme wind and turbulence conditions associated with tropical cyclones are expected to exceed these generic design classes. In cases where the envelopes of the defined design classes are exceeded, IEC 61400-1 makes provisions for a user-defined design Class S, which allows turbines to be type certified under unique conditions. However, no specific guidance is given on how a Class S turbine design could be applied to ensure safe hurricane ride-through.

Floating offshore systems have greater translational and rotational base motions than do land-based or offshore fixed bottom systems; these motions with respect to the wind are not covered within the scope of the current IEC certification process. IEC has just begun to develop the first standard to address floating wind turbines (IEC 2013).

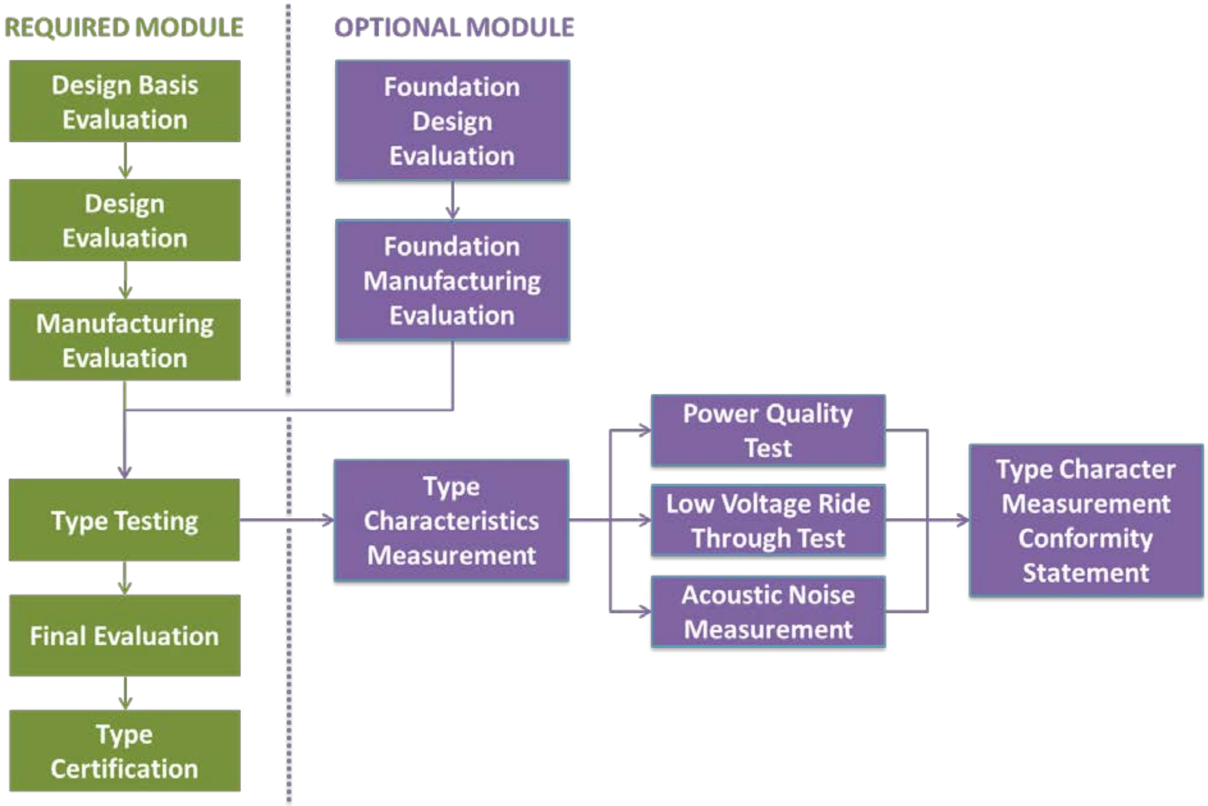


Figure 4. IEC 61400-22 type certification modules

2.4.2 Project Certification

Wind plant stakeholders—financial institutions, banks, insurance companies, owners, operators, and regulatory authorities—require structural reliability and safety assessments of wind facilities to accurately define the technical risk involved in project development and operation. Such assessments are the objective of project certification.

The IEC 61400-22 project certification process, outlined in Figure 4, begins with a type-certified wind turbine and combines the foundation with a site-specific design environment. This process considers manufacturing, and installation through the commissioning phase. The external physical environmental conditions, grid system conditions, and soil properties unique to the site are evaluated to determine whether they meet the requirements defined in the design basis set by the project.

In general, design requirements dictated by project-specific issues are separate from the type certification process. Type certification relies on IEC 61400-3 to specify offshore design requirements but is not site specific. IEC 61400-22 allows for the evaluation of the suitability of a type-certified turbine for specific site conditions under project certification.

The mandatory modules for project certification are:

- Site condition assessment
- Design basis evaluation
- Integrated load analysis
- Design evaluation of wind turbine, blades, and support structure
- Manufacturing surveillance of wind turbine, blades, and support structure
- Transportation and installation surveillance
- Commissioning surveillance
- Final evaluation.

Optional modules are:

- Design evaluation of other pieces not addressed in the project certification for mandatory modules
- Manufacturing surveillance of other pieces not addressed in the project certification for mandatory modules
- Project characteristic measurement
- Operation and maintenance surveillance.

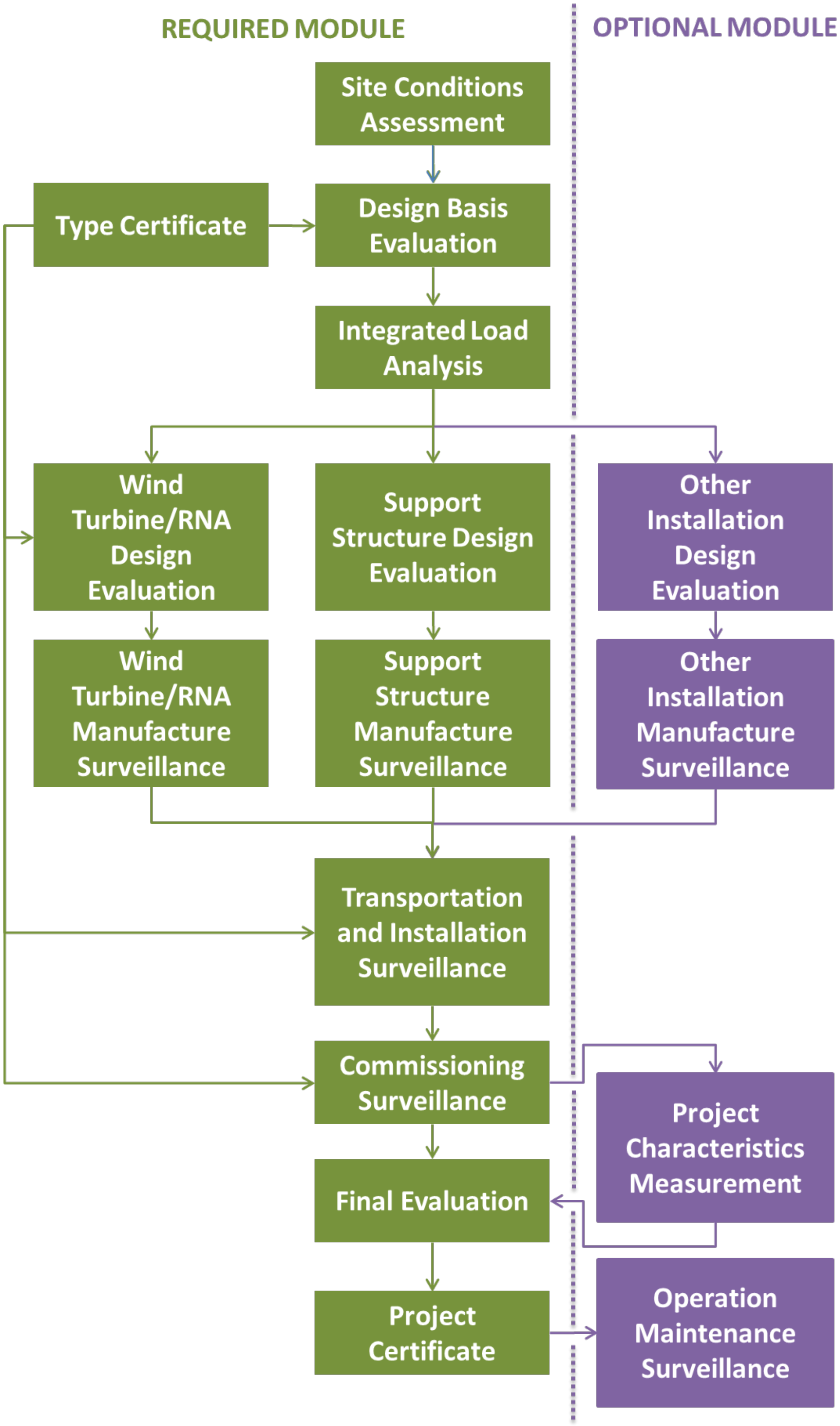


Figure 5. IEC 61400-22 project certification modules

3 Challenges in Adapting European Procedures

To date, offshore wind standards and guidelines have been largely based on European offshore wind experience and land-based wind. Most of the world's offshore wind projects, with a few exceptions in Asian waters, have been installed in either the North Sea or the Baltic Sea. Therefore, it is important to understand the major differences in design conditions between the United States and Europe before installing wind turbines in U.S. waters.

The coastal waters of much of the United States, especially in the south Atlantic and Gulf Coast, are prone to strong tropical and extratropical cyclones, which include tropical depressions, tropical storms, hurricanes, and some Nor'easters (NOAA 2013a). The oil and gas industry has for many years followed API standards to design fixed and floating platforms. These standards consider various return periods (25, 50, or 100 years, depending on life safety and consequence of failure) for extreme weather events (statistical estimate of the average time between equivalent events, the inverse being the probability that the event will exceed during any one year) to determine external extreme design conditions and hurricane loads in the design process for oil and gas structures. The IEC standard is based on a 50-year return period for extreme events, which is appropriate for L2 structures as defined in API RP-2A and as adopted by AWEA OCRP 2012. One challenge for the IEC standards development process is to determine if higher partial safety factors are necessary to meet API robustness requirements in U.S. hurricane-prone areas.

A study conducted by MMI Engineering (2009) examined the relative differences in structural reliability between the IEC and API standards, while recognizing that the occurrence of strong tropical cyclones in the United States is a key differentiating factor. A core question posed by the study was whether the 50-year return periods prescribed by IEC would result in significant differences in the structural reliability compared to the 100-year API return periods for extreme wind conditions. The levels of structural reliability were compared for various sites and characterized by different coefficients of variation (CoVs), a parameter used regularly by the oil and gas industry to assess the annual variability or uncertainty in the definition of severe events.

The study concluded that the levels of reliability achieved using the IEC versus API standards were significantly affected by the CoV (variability in predicting tropical cyclone severity) at a particular site. Areas such as the GOM exhibit significant annual variability in tropical cyclone severity, which results in a greater difference between the 100-year and 50-year events and hence a greater difference between the application of IEC versus API. For regions such as New England that are less prone to major hurricanes, which reach category 3, the CoV is lower and agreement between the standards is better. For the North Sea, the CoV is even lower than along the Atlantic coast of the United States and the IEC standards are more easily interchanged with API and other standards (MMI Engineering 2009; AWEA 2012).

Whereas IEC design load cases are prescribed for normal and abnormal cases tied to the wind turbine operational status, API's load cases are defined by environmental conditions for operating (generally a 1-year storm) and extreme cases. Thus, IEC keeps the same load level and adjusts safety factors based on the consequence of component failures. API, on the other hand, uses life safety and consequence of failure based on three levels of platform categories and environment criteria:

- Level 1 (L1) for high consequence of failure requiring a 100-year event for extreme design condition and 1,000-year event for robustness check.
- Level 2 (L2) for medium consequence of failure requiring a 50-year event for extreme design condition and 500-year event for robustness check.
- Level 3 (L3) for low consequence of failure with a 25-year event for extreme design condition and without a robustness check.

These differences are addressed in the ABS 176 guideline where the design load cases (DLCs) account for the operating and extreme 100-year events. This guideline is new and there are ongoing discussions about the recommended 100-year event requirement. Some in the U.S. industry believe that the reserve strength in the design per IEC standards will prevail in the United States, given that the CoV is higher in the United States compared to European waters. As such, the current API standards align with the IEC requirement for the API L2 consequence of failure. ABS, within its guideline, does allow use of a reduced event for extreme design condition subject to special considerations, as mentioned in Section 4.4.

4 Tropical Cyclone and Hurricane Provisions

For offshore wind projects, IEC 61400-1 defines extreme wind speed (V_{ref}) based on a 10-minute average. The 50-year extreme gust $V_{e50}(z)$ is defined to have a duration of 3 seconds based on the equation:

$$V_{e50}(z) = 1.4\,V_{ref}(z/z_{hub})^{0.11}$$

where z is the measurement height. The empirically derived exponent (0.11) in this formula is a coefficient that defines the change in wind speed with height, typically referred to as the wind shear profile. The shape of the profile and its associated exponent depend largely on the stability of the atmosphere, local terrain influences, and surface roughness upwind from the project. For offshore projects, stability conditions can be the primary drivers of the shear profile exponent. For typical land-based conditions at a flat smooth site with a well-mixed atmosphere (i.e., neutral stability), a common exponent value may be approximately 0.14. However, this exponent value may yield erroneous estimates where significant surface roughness (trees and buildings), terrain effects, or certain stability conditions are present. The exponent value of approximately 0.11 is more appropriate for neutrally stable conditions over open water (offshore wind plants) during nonstorm conditions. Wind profiles and gust behaviors during extreme events, namely tropical and extratropical cyclones, may not be accurately described by this relationship.

There are two areas in the IEC approach that need to be augmented for wind turbine design standards in areas affected by tropical and extratropical cyclones:

- The reconciliation of disparate measurement approaches. For example, tropical cyclone measurements typically reference peak 1-minute wind at the standard meteorological observation height of 10 m over unobstructed exposure (Schott et al. 2012). Wind parameters used by the IEC are defined at hub height on either 3-second or 10-minute averages. The temporal discrepancy in these approaches can usually be resolved mathematically, but may be complicated and result in increased uncertainty.
- The extrapolation of values (both sustained winds and gusts) to hub height by the method defined previously is further complicated by the poorly characterized wind shear profiles in tropical and extratropical cyclones. Shear profiles have been measured in hurricanes (Franklin et al. 2000), but the data and results haven't been adequately analyzed in the context of wind turbine design.

Both of these topics merit further investigation and could require modifications of the standards.

A Class I turbine can withstand the most severe winds and thus is in the "most severe wind class" as defined by IEC 61400-1. A Class I turbine has a V_{ref} 10-minute average value of 50 m/s at hub height. According to the previous equation, the Class I 3-second peak gust is 70 m/s without height adjustment. A gust of this magnitude represents the boundary between a Category 4 and a Category 5 hurricane, based on sustained winds (NOAA 2013b). This assumption may oversimplify the complex nature of a sustained hurricane event, which may last 12 hours or longer. Consequently, current methods for defining the spatial and temporal wind variation (shear, gusts, turbulence intensity, duration, etc.) during extreme events merit review and possible revision to accommodate conditions possible in U.S. waters. Further considerations undertaken in a special wind turbine Class S may define even longer duration load cases, power grid failures, extraordinary wind shear events, rapid wind direction changes, unusual wind/wave combinations, and higher gusts that may create design load cases that are not yet defined or understood.

The API provides 1-hour, 10-minute, 1-minute, and 3-second wind averages for the GOM. The 100-year extreme wind and wave conditions govern U.S. oil and gas development. In 2007, MMS (now BOEM) updated its met-ocean criteria as a result of Hurricanes Ivan, Katrina, and Rita (spanning from 2004 to 2005) when some offshore platforms suffered significant damage (although most performed well with only minor topside damage). This updated met-ocean criteria released by API as Bulletin 2INT-MET applies to the GOM region, subdivided into four sections as illustrated in Figure 6.

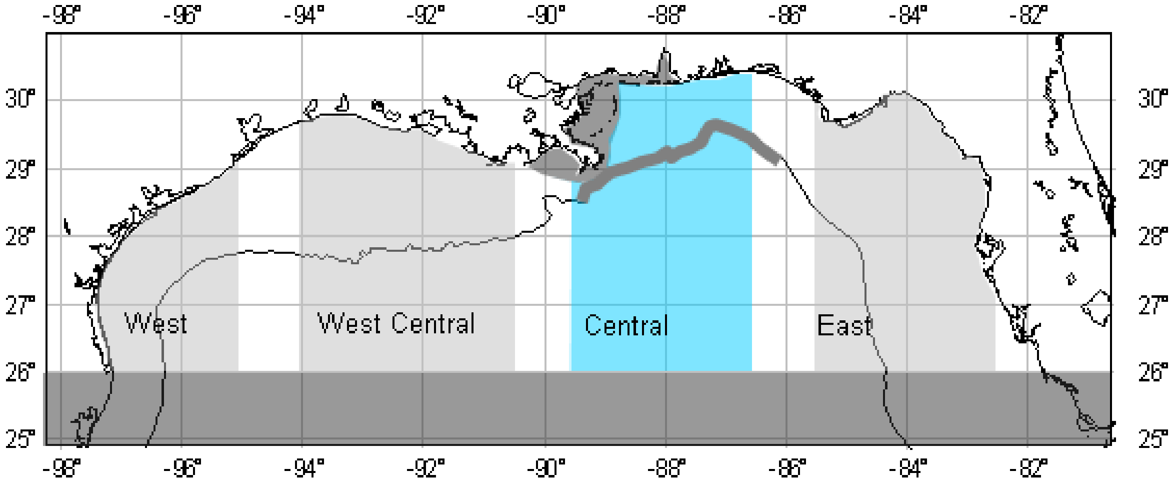


Figure 6. API met-ocean update for GOM
(API 2007)

The referenced bulletin revises the independent extreme values for hurricane winds, wave, current, and surge and the associated wind, wave, current, and surge combining factors for the GOM. The central section had the highest extreme values, setting the 100-year 10-minute average mean wind speed at 10 m above water to 54.5 m/s. These conditions are classified as category 4 per the U.S hurricane category given in Table 3.

Similarly, in the Atlantic, severe tropical storms and hurricanes have affected the East Coast, where the favorable wind resource and population centers may provide an attractive market for offshore wind developers. Early stages of wind plant development along the East Coast are already underway driven by relatively high power prices. Two recent tropical storms, Irene in 2011 and Sandy in 2012, widely impacted the East Coast and stressed the need to understand the met-ocean conditions in a way similar to the one provided by API for the GOM.

A gridded wind map of the Atlantic coast was used in the study conducted by ABS for the Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEMRE) (ABS 2011). The Atlantic coast was divided into four regions, region 1 covering the Northeast to region 4 covering South Florida, illustrated in Figure 7. This set of met-ocean data has shown reasonable agreement to available public data (API, ASCE-2010, and NOAA NDBC buoy standards), but the data set is not meant for use in actual design. In the report, two sites on the Atlantic coast and two sites in the GOM were considered—regions 2 and 3 in the Atlantic coast and West Central, and a Texas site in the GOM. The met-ocean data for these two regions are documented in the report for the 50-year and 100-year event. There is an urgent need to compile existing data and collect new data for the Atlantic coast to establish an accurate gridded met-ocean data map for the offshore wind plant industry.

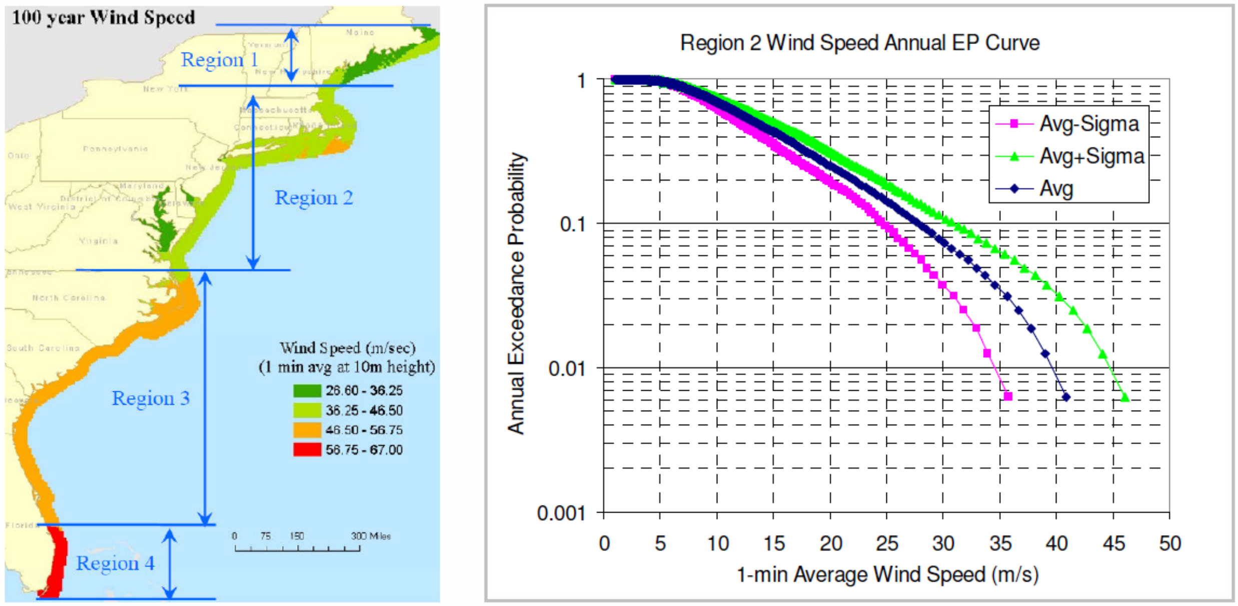


Figure 7. ABS regional wind condition in the Atlantic coast
(ABS 2011)

Wind plant developers on the Pacific coast face similar challenges from a lack of met-ocean data. A similar met-ocean dataset needs to be compiled and collected for the Pacific coast to establish a gridded wind map.

4.1 International Electrotechnical Commission

In 2011, IEC TC 88 convened a subcommittee (MT-1) to revisit IEC 61400-1, the primary wind turbine design standard, to address, among other things, the impact of tropical cyclones on wind turbine design. This is a concern not only for the United States, but for Asian nations that are regularly impacted by typhoons. As an example of how one might address hurricanes and typhoons in the IEC standard, the subcommittee is considering a proposal from the Japanese IEC delegation to address tropical cyclone-prone regions where the extreme wind speed can be higher than that specified in IEC61400-1. The Japanese proposal suggests a new Class-T with V_{ref} of 57.5 m/s.

Through working groups, project teams, and maintenance teams, the IEC continues to enhance current standards and develop new ones. Maintenance team MT-1 (focusing on design requirements for wind turbines) is considering a proposal from Japan to expand IEC classes to include tropical cyclones (Class-T), which are inclusive of cyclones, typhoons, and hurricanes. In addition to the work being done by MT-1, working group WG-3 (focusing on design requirements for offshore wind turbines) is simultaneously drafting the next edition of IEC-61400-3. Project team PT 61400-3-2 (working on design requirements for floating offshore wind turbines) is drafting a floating offshore wind turbine standard with an expected publication in 2014. The offshore wind design standard, IEC 61400-3, currently refers back to IEC 61400-1 for much of its foundation material. Hence, the modifications being made to IEC 61400-1 will carry over to IEC 61400-3.

Table 3 illustrates the proposed typhoon Class-T in context with IEC classes and U.S. hurricane categories. The U.S. hurricane category is based on the Saffir-Simpson hurricane damage scale, which uses 1-minute average wind speed information (Schott et al. 2012). However, IEC Classes are given at 10-minute averages. Powell et al. (1996) recommends that a 10-min value can be estimated from a one-minute value by reducing the latter by 12%.

Table 3. Comparing IEC Classes With Japan's T-Class Proposal to U.S. Hurricane Categories (10-min Averages at 10-m Elevation)

U.S. Hurricane Category	U.S. Minimum (m/s)	IEC (m/s)	U.S. Maximum (m/s)	IEC Class
1	30	37.5	38	3
2	39	42.5	44	2
3	45	50	52	1
4	53	57.5	62	T (proposed)
5	63	–	–	–

According to building standards in Japan, the proposed Class-T would cover almost all the potential sites in that country. Class-T designs are also being considered for other countries such as China, Korea, Taiwan, and the United States. However, some of these countries have indicated that the criteria may be too high for their respective regions. In the United States, from 1851 to 2004, 7% of the hurricane hits were in category 4 and 1% in category 5 (Stewart 2008). The United States is considering supporting Class-T adoption within IEC 61400-1.

In addition to this effort, the U.S. offshore shadow committee for working group WG-3 (focusing on design requirements for offshore wind turbines) has been discussing the U.S. perspective on the appropriate return period for hurricane-prone U.S. waters. There are two viewpoints on this topic:

- ABS outlined a recommendation (ABS 2010) suggesting a return period to be no shorter than 100 years, whereas IEC 61400-3 DLCs require a 50-year return period, unless appropriate justifications are provided to ABS for a reduction and such reduction is acceptable to the governmental authorities having jurisdiction over permitting wind turbine installations. This recommendation is also supported by the research performed under BSEE TA&R 670 (ABS 2011).
- MMI Engineering and Keystone Engineering suggest a different approach relying on safety and risk, keeping the 50-year return period as prescribed in IEC-3 DLCs, plus a load factor based on hazard curves, and robustness evaluation expressed by Reserve Strength Ratio, which is similar to what is being used by the oil and gas industry. This approach is familiar to BOEM, BSEE, and USACE in their evaluation of permitting and safety of offshore structures.

4.2 Det Norske Veritas

Although DNV guideline DNV-OS-J101 complies with IEC 61400-1 for normal and extreme wind conditions, it also acknowledges that areas prone to tropical storms are insufficiently addressed. In 2010, DNV launched a joint industry project to develop common design standards for floating offshore wind turbines. One of the project goals was to compile a document of best practices on technical requirements and guidance for design, construction, and inspection of offshore wind turbines. Participants include designers, developers, operators, and turbine manufacturers who work in a closed industry group setting. The project aims to draw on the experience of the offshore oil and gas industry to develop common standards governing load effects, mooring, safety, materials, floating stability, structural design, and other aspects of the deep-water industry. Part of the project objective is to address untapped wind resources in tropical cyclone-prone areas of the world.

4.3 Germanischer Lloyd

As an outcome of the aforementioned 2012 workshop on “The Influence of Tropical Cyclone Loading on Wind Turbine Design,” workshop participants are drafting a guideline to address tropical cyclones. The workshop includes participants from industry, academia, and national governments. The guideline was scheduled for completion in 2013.

GL has used typhoon design criteria internally (see Table 4) for evaluating land-based wind turbines. Per GL's criteria, loads increased by a factor of 17.5% for blades and 33% for towers; tower mass increased by 12%.

Table 4. GL Typhoon Class Internal Criteria Compared to IEC Class I

Description	IEC 1A	GL Typhoon
Safety factor	1.1	1.35
V_{ref}	50 m/s	50 m/s
Turbulence intensity	11%	17%
Max hub speed	70 m/s	70 m/s
Wind shear exponent	0.11	0.20
Upflow	0 m/s	0 m/s

4.4 American Bureau of Shipping

Guideline publication 176 (ABS 2010) incorporates additional requirements based on calibration studies that use regional and site-specific conditions in U.S. waters. The guideline incorporates refinements to the design environmental conditions and design load cases required by IEC 61400-3 to account for the effects of tropical cyclone conditions. Within this ABS guide, the DLCs developed by IEC 61400-3 are modified to account for strong tropical cyclones in U.S. waters. Appendix D highlights the DLC modifications.

The major modifications recommended by ABS follow:

- A minor change to the power production DLC 1.2, 1.6a, and 1.6b require the addition of using the normal wind profile in addition to the normal turbulence model.
- Site-specific extreme wind speeds with various combinations of return periods and averaging time durations are used to define the environmental conditions in DLC 6.1 to 6.4, DLC 7.1 and 7.2, and DLC 8.2 and 8.3. This definition differs from IEC 61400-3 (2010a) where reference is made to the wind turbine's Reference Wind Speed (Vref); conversion factors are prescribed for different averaging time durations or return periods. DLCs 1.6, 6.1, and 6.2 are amended to require a return period of 100 years for the extreme storm conditions. This return period is generally not to be shorter than 100 years, unless appropriate justifications (for example to use a 50-year return period per IEC 61400-3) are provided to ABS for a reduction and such reduction is acceptable to the governmental authorities having jurisdiction over permitting wind turbine installations. Any reduction to the return period of environmental conditions is to be subject to special consideration by ABS.
- Omnidirectional wind condition is required for turbines subject to tropical cyclones in DLC 6.2, part of the design load case in the event an offshore wind turbine loses its connection to the power grid during a hurricane.

5 Bureau of Ocean Energy Management and Bureau of Safety and Environmental Enforcement Activities

BOEM and BSEE are actively engaged at the federal level to review proposed projects to be sited in federal waters. The two bureaus are responsible for developing and regulating the proposed Cape Wind Energy Project and other projects, and have sponsored numerous studies to investigate offshore wind systems. This section gives an overview of some of the bureaus' recent involvement.

5.1 Cape Wind

The proposed Cape Wind Energy Project, located in federal waters in Nantucket Sound off the coast of Massachusetts, has been the flagship offshore wind project for the United States since 2001. This project was the country's first to trigger the exploration and study of the many development and permitting barriers to be faced by the U.S. offshore wind industry. At first the U.S. Army Corps of Engineers assumed the lead federal regulatory role for permitting the project. Following enactment of the Energy Policy Act of 2005, the former MMS (now BOEM) assumed the responsibility for regulation of offshore wind power projects in federal waters on the OCS and began a new process with Cape Wind. After 8 years of negotiations and compliance submissions from both agencies, the first commercial lease to construct and operate the offshore wind facility was approved by DOI for Cape Wind in April 2009. This project set precedence for leasing and operation of offshore wind plants in U.S. federal waters but construction has not yet begun as of the writing of this report.

5.2 American Bureau of Shipping Technology Assessment and Research

5.2.1 Design Standards for Offshore Wind Plants

On behalf of BOEMRE, currently known as BOEM and BSEE, ABS prepared a study document (ABS 2011). Its objectives were to:

- Study the governing load cases and load effects of fixed offshore wind turbines subjected to the hurricanes on the U.S. OCS.
- Review and evaluate the methods of calculating the breaking wave slamming load exerted on an offshore wind turbine support structure.
- Provide recommendations to support future enhancements to the relevant design criteria for offshore wind turbines.

The section of the study most relevant to this report is the characteristic response of fixed offshore wind turbines installed in hurricane-prone regions. The load cases account for IEC 61400-3 and API rules for hurricane-prone regions, which are compiled in ABS guideline 176. Monopile, tripod, and four-legged jacket foundations were the fixed offshore structures considered for shallow water installation, namely in the Mid-Atlantic, South Atlantic, and GOM coastal regions. The turbine used in the study is the NREL 5-MW offshore reference turbine (NAS 2011; Jonkman et al. 2009). The report contains recommendations for design environmental conditions, design load cases, and strength criteria drawn from a literature review, comparative studies, and case studies.

5.2.2 Floating Wind Turbines

On behalf of BSEE, ABS also completed a study on floating wind turbines (ABS 2012). The objectives were to:

- Conduct a state-of-the-art review of floating offshore wind turbine technologies.
- Explore technical challenges of deploying floating wind turbines in the U.S. OCS.
- Propose a draft design guideline for floating support structures and the mooring systems (station-keeping) of floating offshore wind turbines.

The third objective is most relevant to this report. The study considered three generic floating platform types (spar, semisubmersible, and tension leg platform) in three geographically different regions of the United States (West Coast, GOM Central Region, and Northeast Coast) where the waters are deeper and are considered potential sites for offshore floating wind systems. These platforms were evaluated using the NREL 5-MW offshore reference wind turbine (NAS 2011). The study relied heavily on ABS's experience in the GOM, on its guidelines and reports related to offshore wind facilities, and on other guidelines published for the offshore oil and gas industry. Load cases were derived from IEC 61400-3, keeping in mind the API requirements for applications in U.S. waters.

This study is the most comprehensive one done to date for design standard development and hurricane wind modeling for floating offshore wind turbines. This work has resulted in a recent release of the ABS guideline publication 196 (ABS 2013b). This guideline also contains sections to address ice and earthquake loads that maybe important in various U.S. offshore regions.

In addition, DNV has released its guideline for floating offshore wind turbines (DNV 2013) and GL already addressed floating wind turbines in its guideline (GL 2012). ABS, DNV, and GL are members of the IEC TC 88 project team (PT 61400-3-2) and are partially responsible for drafting standards for the forthcoming *Design Requirements for Floating Offshore Wind Turbines*.

6 Conclusion

This report summarizes the regulations, standards, and guidelines that apply to the design, safety, and operation of offshore wind projects, and the gaps within the documents. There is a strong need for more thorough characterization of the meteorological, ocean, and lake environments into which current and future projects will be deployed. These needs justify the development of offshore wind standards that are relevant to the U.S. market. The parameters and variables of particular significance to offshore wind standards and recommendations—hub height conditions, joint wind/wave conditions, atmospheric stability, etc.—are not adequately characterized by the current observational networks or datasets. As such, the development and advancement of regionally relevant offshore wind guidelines are key incentives to build a national offshore wind resource and design data base.

The IEC 61400 standards are well established in the wind industry internationally and are the primary standards that govern the design of land-based and offshore wind turbines. These standards have been used successfully on most European offshore wind installations in conjunction with local regulations, standards, and class guidelines for offshore wind turbines on fixed foundations. However, IEC 61400 standards do not cover several critical areas of an offshore wind turbine project. Moreover, the current IEC standards do not yet provide a comprehensive assessment of how to address tropical (and extratropical) events, freshwater ice, or deeper water deployments requiring floating structures, which are important for offshore wind plant development in U.S. waters. Nonetheless, several standards and guidelines are being developed to address these deficiencies.

In addition, a vast collection of existing regulations, guidelines, and standards can already supplement IEC TC-88 standards to provide a safe and reasonable pathway to offshore development in the United States. Much of this collection comes from a wide group of offshore industries, the oil and gas industry, and the marine and shipping industry. In 2012, the AWEA Offshore Compliance Recommended Practices document was published and provides the industry with a consensus guideline for offshore wind facility design, manufacturing, construction, testing, commissioning, operation, inspection, and decommissioning by recommending specific application of existing guidelines and standards to the offshore wind design process.

While differences and gaps are being addressed in standards and guidelines, combining the U.S. experience in offshore oil and gas structures and the European experience in offshore wind can provide an interim pathway for wind plant developers in the United States. One guideline that addresses storm conditions in the United States for fixed offshore structures is ABS publication 176, which was updated in 2013 (ABS 2013a). In addition to that guideline, two comprehensive reports (ABS 2011, 2012) studying fixed and floating offshore structures released by ABS could be referenced as a design basis for U.S. offshore wind projects.

7 Recommendations

The following gaps have been identified in the data required to fully assess the design, installation, operation, and maintenance of a U.S. commercial offshore wind energy facility, thereby impacting its economic feasibility:

1. Lack of consensus in the scientific and engineering communities on met-ocean measurement protocols.
2. Lack of met-ocean data specific to the offshore wind industry in the United States
3. Lack of U.S. regional maps that provide met-ocean design information
4. Lack of load factors based on regional hazard curves
5. Lack of consensus on how to approach wind turbine design in coastal areas (some prone to hurricanes)
6. Inadequate characterization of tropical and extratropical cyclone characteristics and risks in the context of offshore wind design

Recommendations to bridge these gaps follow:

- Invest in regional met-ocean resource characterization activities to collect field test data and increase the basic physical understanding of key offshore conditions, including turbulence, stability, and rare events.
- Invest in analysis and research tools to better assess the impacts of extreme events of turbine loads.
- Support interagency collaborations and research to test design approaches and validate design assumptions for the first offshore wind projects in the United States.
- Support cross-industry collaboration on assessing tropical and extratropical cyclone characteristics in the context of offshore wind design, deployment, and operation.
- Integrate the current knowledge base with activities currently underway at both the federal and state levels. Special emphasis should be placed on seeking a uniform design approach to determine the intensity and frequency of various external design conditions to avoid varying levels of safety and reliability among the first offshore wind projects. [Gaps 4 and 5]
- Support the development and timely updates to all domestic and international standards relevant to offshore wind. [Gaps 1 and 5]
- Pursue consensus—in the form of best practice recommendations or standards—on met-ocean measurement and analytical approaches, and synchronize with other established scientific and industry norms. [Gap 1]
- Support BOEM and BSEE to help them achieve internal capabilities to assess the adequacy of offshore wind system designs and support a long-term exchange of technical information to inform this process. [Gaps 2 through 5]

- Address operational needs for hurricane survival (e.g., longer duration battery backup for yaw control during high wind directional changes), probably via the project certification process. [Gap 5]
- Provide national leadership to build consensus and disseminate critical information from wind experts and other industries to regulators and state agencies.
- Support research and testing opportunities to reduce uncertainty in establishing better understanding of external conditions and safety factors. [Gaps 2 through 4]

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Appendix A: Regulations

Code of Federal Regulations	
29 CFR Part 1910	Occupational safety and health standards
30 CFR Part 585	Renewable energy alternate uses of existing facilities on the outer continental shelf
33 CFR Part 67	Aids to navigation on artificial islands and fixed structures
33 CFR Parts 140 to 147	Outer continental shelf activities
33 CFR Part 322	Permits for structures or work in or affecting navigable waters of the United States
Federal Aviation Administration	
FAA AC70/7460-1K	Obstruction marking and lighting
FAA AC150/5390-2C	Heliport design
U.S. Coast Guard	
USCG COMDTINST M16672.2D	Navigation rules international-inland

Appendix B: Standards

American Institute of Steel Construction	
AISC 335-89	Specification for structural steel buildings—Allowable stress design and plastic design
American National Standards Institute	
ANSI/ICEA S-93-639/ NEMA WC 74	5–46 kV Shielded power cable for use in the transmission and distribution of electric energy
ANSI/ICEA S-94-649	Standard for concentric neutral cables rated 5–46 kV
ANSI/ICEA S-97-682	Standard for utility shielded power cables rated 5–46 kV
American Petroleum Institute	
API Bull 2HINS	Guidance for Post-hurricane Structural Inspection of Offshore Structures
API Bull 2INT-DG	Interim Guidance for Design of Offshore Structures for Hurricane Conditions
API Bull 2INT-MET	Interim Guidance on Hurricane Conditions in the Gulf of Mexico
API Bull 2U	Stability Design of Cylindrical Shells
API Bull 2V	Design of Flat Plate Structures
API RP 2A-WSD	Planning, Designing and Constructing Fixed Offshore Platforms—Working Stress Design
API RP 2FPS	Recommended Practice for Planning, Designing, and Constructing Floating Production Systems
API RP 2GEO/ISO 19901-4	Geotechnical and Foundation Design Considerations
API RP 2I	In-service Inspection of Mooring Hardware for Floating Structures
API RP 2MOP/ISO 19901-6	Marine Operations, Petroleum and natural gas industries specific requirements for offshore structures-Part 6: Marine Operations
API RP 2N	Planning, Designing and Constructing Structures and Pipelines for Arctic Conditions
API RP 2SK	Design and Analysis of Station-keeping Systems for Floating Structures

API RP 2SM	Recommended Practice for Design, Manufacture, Installation, and Maintenance of Synthetic Fiber Ropes for Offshore Mooring
API RP 2T	Recommended Practice for Planning, Designing and Constructing Tension Leg Platforms
API RP 2X	Ultrasonic and Magnetic Examination of Offshore Structural Fabrication and Guidelines for Qualification of Technicians
API RP 2Z	Preproduction Qualification for Steel Plates for Offshore Structures
API RP 95J	Gulf of Mexico Jack-up Operations for Hurricane Season—Recommendations
API Spec 2B	Specification for the Fabrication of Structural Steel Pipe
API Spec 2F	Mooring Chain
API Spec 2H	Specification for Carbon Manganese Steel Plate for Offshore Platform Tubular Joints
API Spec 2MT1	Specification for Carbon Manganese Steel Plate with Improved Toughness for Offshore Structures
API Spec 2MT2	Rolled Shapes with Improved Notch Toughness
API Spec 2SC	Manufacture of Structural Steel Castings for Primary offshore Applications
API Spec 2W	Specification for Steel Plates for Offshore Structures, Produced by Thermo-Mechanical Control Processing (TMCP)
API Spec 2Y	Specification for Steel Plates, Quenched-and-Tempered, for Offshore Structures
Bundesamt für Seeschifffahrt und Hydrographie	
BSH 2008	Ground Investigations of Offshore Wind Farms
BSH 2003	Standard for Geotechnical Site and Route Surveys- Minimum Requirements for the Foundation of Offshore Wind Turbines
International Electrotechnical Commission	
IEC 61400-1	Wind turbines—Part 1: Design requirements

IEC 61400-3	Wind turbines—Part 3: Design requirements for offshore wind turbines
IEC 61400-11	Wind turbine generator systems—Part 11: Acoustic noise measurement techniques
IEC 61400-12-1	Wind turbines—Part 12-1: Power performance measurements of electricity producing wind turbines
IEC/TS 61400-13	Wind turbine generator systems—Part 13: Measurement of mechanical loads
IEC/TS 61400-14	Wind turbines—Part 14: Declaration of apparent sound power level and tonality values
IEC 61400-21	Wind turbines—Part 21: Measurement and assessment of power quality characteristics of grid connected wind turbines
IEC 61400-22	Wind turbines—Part 22: Conformity testing and certification
IEC/TS 61400-23	Wind turbine generator systems—Part 23: Full-scale structural testing of rotor blades
IEC 61400-24	Wind turbines—Part 24: Lightning protection
IEC 61400-25-1	Wind turbines—Part 25-1: Communications for monitoring and control of wind power plants—Overall description of principles and models
IEC 61400-25-2	Wind turbines—Part 25-2: Communications for monitoring and control of wind power plants—Information models
IEC 61400-25-3	Wind turbines—Part 25-3: Communications for monitoring and control of wind power plants—Information exchange models
IEC 61400-25-4	Wind turbines—Part 25-4: Communications for monitoring and control of wind power plants—Mapping to communication profile
IEC 61400-25-5	Wind turbines—Part 25-5: Communications for monitoring and control of wind power plants—Conformance testing
IEC 61400-25-6	Wind turbines—Part 25-6: Communications for monitoring and control of wind power plants—Logical node classes and data classes for condition monitoring
IEC/TS 61400-26-1	Wind turbines—Part 26-1: Time-based availability for wind turbine generating systems

International Standards Organization	
ISO 19900	General requirements—Petroleum and natural gas industries
ISO 19901-1	Met-ocean design and operating considerations
ISO 19901-2	Seismic design procedures and criteria
ISO 19901-3	Topsides structures
ISO 19901-4/API RP 2GEO	Geotechnical and foundation design considerations
ISO 19901-5/API RP 2MOP	Weight control during engineering and construction
ISO 19901-6	Marine operations
ISO 19901-7	Station keeping systems for floating offshore structures and mobile offshore units
ISO 19902	Fixed steel offshore structures
ISO 19903	Fixed concrete offshore structures
ISO 19904-1	Floating offshore structures—monohulls, semisubmersibles and spars
ISO 19904-2	Floating offshore structures—tension leg platforms
ISO 19905-1	Site specific assessment of mobile offshore units—Part 1: Jack-ups
ISO 19905-2	Site specific assessment of mobile offshore units—Part 2: Jack-ups : Commentary and detailed sample calculation
ISO 19905-3	Site specific assessment of mobile offshore units—Part 3: Floating units
ISO 19906	Arctic offshore structures
ISO 81400-4	Wind turbines—Part 4: Design and specification of gearboxes

Appendix C: Guidelines

American Bureau of Shipping (ABS)	
6	Mobile Offshore Drilling Units
8	Single Point Moorings
10	Steel Barges

29	Offshore Installations
39	Certification of Offshore Mooring Chain
82	Floating Production Installations
90	Application of Fiber Rope for Offshore Mooring
114	Automatic or Remote Control and Monitoring for Machinery and Systems (other than propulsion) on Offshore Installations
115	Fatigue Assessment of Offshore Structures
120	Surveys Using Risk-Based Inspection for the Offshore Industry
126	Buckling and Ultimate Strength Assessment for Offshore Structures
160	Mobile Offshore Units
167	Environmental Protection Notation for Offshore Units, Floating Installations, and Liftboats
176	Bottom-Founded Offshore Wind Turbine Installations
196	Floating Offshore Wind Turbine Installations
American Wind Energy Association	
AWEA RP	Recommended Practice for Design, Deployment, and Operation of Offshore Wind Turbines in the United States
Bureau Veritas (BV)	
NI165	Ultrasonic testing of hull butt welds
NI198	Underwater welding—general information and recommendations
NI199	Cyclic fatigue of nodes and welded joints of offshore units
NI299	Guidelines on documents to be submitted for stability study
NI409	Guidelines for corrosion protection of seawater ballast tanks and hold spaces
NI422	Type approval of nondestructive testing equipment dedicated to underwater inspection of offshore structures

NI423	Corrosion protection of steel offshore units and installation
NI432	Certification of fibre ropes for deepwater offshore services
NI525	Risk based qualification of new technology—methodological guidelines
NI534	Guidance note for the classification of self-elevating units
NI538	Ballast water management systems
NI539	Spectral fatigue analysis methodology for ships and offshore units
NI543	Ice reinforcement selection in different world navigation areas
NI565	Ice characteristics and ice/structure interactions
NI567	Risk based verification of floating offshore units
NI572	Classification and certification of floating offshore wind turbines
NI589	Wind farms service ships
Det Norske Veritas (DNV)	
DNV-DSS-904	Type Certification of Wind Turbines
DNV-OSS-101	Rules for Classification of Offshore Drilling and Support Units
DNV-OSS-102	Rules for Classification of Floating Production, Storage and Loading Units
DNV-OSS-304	Risk Based Verification of Offshore Structures
DNV-OSS-901	Project Certification of Offshore Wind Farms
DNV-DS-J102	Design and Manufacture of Wind Turbine Blades, Offshore and Onshore Wind Turbines
DNV-DS-J103	Design of Floating Wind Turbine Structures
DNV-OS-C101	Design of Offshore Steel Structures, General (LRFD Method)
DNV-OS-C103	Structural Design of Column Stabilized Units (LRFD Method)
DNV-OS-C104	Structural Design of Self-Elevating Units (LRFD Method)
DNV-OS-C105	Structural Design of TLPs (LRFD Method)
DNV-OS-C106	Structural Design of Deep Draught Floating Units (LRFD Method)

DNV-OS-C201	Structural Design of Offshore Units (WSD Method)
DNV-OS-C301	Stability and Watertight Integrity
DNV-OS-C401	Fabrication and Testing of Offshore Structures
DNV-OS-C501	Composite Components
DNV-OS-C502	Offshore Concrete Structures
DNV-OS-D201	Electrical Installations
DNV-OS-D202	Automation, Safety, and Telecommunication Systems
DNV-OS-D301	Fire Protection
DNV-OS-E301	Position Mooring
DNV-OS-E302	Offshore Mooring Chain
DNV-OS-E303	Offshore Mooring Fiber Ropes
DNV-OS-E304	Offshore Mooring Steel Wire Ropes
DNV-OS-H101	Marine Operations, General
DNV-OS-H102	Marine Operations, Design and Fabrication
DNV-OS-H201	Load Transfer Operations
DNV-OS-J101	Design of Offshore Wind Turbine Structures
DNV-OS-J201	Offshore Substations for Wind Farms
DNV-OS-J301	Standard for Classification of Wind Turbine Installation Units
DNV-RP-A205	Offshore Classification Projects—Testing and Commissioning
DNV-RP-B101	Corrosion Protection of Floating Production and Storage Units
DNV-RP-B401	Cathodic Protection Design
DNV-RP-C103	Column-Stabilized Units
DNV-RP-C104	Self-elevating Units
DNV-RP-C201	Buckling Strength of Plated Structures

DNV-RP-C202	Buckling Strength of Shells
DNV-RP-C203	Fatigue Design of Offshore Steel Structures
DNV-RP-C204	Design against Accidental Loads
DNV-RP-C205	Environmental Conditions and Environmental Loads
DNV-RP-C207	Statistical Representation of Soil Data
DNV-RP-E301	Design and Installation of Fluke Anchors in Clay
DNV-RP-E302	Design And Installation of Plate Anchors in Clay
DNV-RP-E303	Geotechnical Design and Installation of Suction Anchors in Clay
DNV-RP-E304	Damage Assessment of Fiber Ropes for Offshore Mooring
DNV-RP-F205	Global Performance Analysis of Deepwater Floating Structures
DNV-RP-F401	Electrical Power Cables in Subsea Applications
DNV-RP-H102	Marine Operations during Removal of Offshore Installations
DNV-RP-H103	Modeling and Analysis of Marine Operations
DNV-RP-H104	Ballast, Stability, and Watertight Integrity—Planning and Operating Guidance
DNV-RP-J101	Use of Remote Sensing for Wind Energy Assessments
Germanischer Lloyd (GL)	
GL 1	Guideline for the Certification of Wind Turbines, Edition 2010
GL 1 Continued Operation	Guideline for the Continued Operation of Wind Turbines, Edition 2009
GL 2	Guideline for the Certification of Offshore Wind Turbines, Edition 2012
GL 4	Guideline for the Certification of Condition Monitoring Systems for Wind Turbines, Edition 2007
TN 065	GL Wind Technical Note 065 (TN 065) Grid Code Compliance Certification procedure, Revision 7, Edition 2010
TN 066	GL Wind Technical Note 066 (TN 066) Grid Code Compliance (GCC) Test procedure for Low Voltage Ride Through (LVRT), Revision 7,

	Edition 2010
TN 067	GL Wind Technical Note 067 Certification of Wind Turbines for Extreme Temperatures (here: Cold Climate), Scope of Assessment, Rev 4, Edition 2011
TN Fire Protection	GL Wind Technical Note Certification of Fire Protection Systems for Wind Turbines, Certification Procedures, Revision 2, Edition 2009
TN Service Providers	GL Wind Technical Note Certification of Service Providers in the Wind Energy Industry, Scope of Assessment, Revision 6, Edition 2009

Appendix D: International Electrotechnical Commission/American Bureau of Shipping Design Load Cases

The comparison of IEC 61400-3 and ABS "Guide for Building and Classing Bottom-Founded Offshore Wind Turbine Installations" publication 176, Design Load Cases (DLCs). The highlighted terms in ***bold italics red*** (given in parenthesis are replacement and without parenthesis are addition) are the changes recommended by ABS for U.S. waters.

Design Situation	DLC	Wind Condition	Waves	Wind and Wave Directionality	Sea Currents	Water Level	Other Conditions	Type of Analysis	Partial Safety Factor
1) Power production	1.1	NTM Vin < Vhub < Vout RNA	NSS Hs = E [Hs | Vhub]	COD, UNI	NCM	MSL	For extrapolation of extreme loads on the RNA ***(not in ABS load cases as it is turbine related)***	U	N 1.25
	1.2	NTM, ***NWP*** Vin < Vhub < Vout	NSS Joint prob. distribution of Hs,Tp,Vhub	COD, MUL	No Current ***(NCM)***	NWLR or ≥ MSL		F	* ***(FDF)***
	1.3	ETM Vin < Vhub < Vout	NSS Hs = E [Hs | Vhub]	COD, UNI	NCM	MSL		U	N
	1.4	ECD Vhub = Vr – 2 m/s, Vr,Vr + 2 m/s	NSS (or NWH) Hs = E [Hs | Vhub]	MIS, wind direction change	NCM	MSL		U	N
	1.5	EWS Vin < Vhub < Vout	NSS (or NWH) Hs = E [Hs | Vhub]	COD, UNI	NCM	MSL		U	N
	1.6a	NTM, ***NWP*** Vin < Vhub < Vout	SSS ***Hs= $Hs_{,SSS(n\text{-}yr)}$***	COD, UNI	NCM	NWLR	***n = 50 in general; n = 100 for tropical cyclone-prone sites***	U	N
	1.6b	NTM, ***NWP*** Vin < Vhub < Vout	SWH ***$H = H_{SWH(n\text{-}yr)}$***	COD, UNI	NCM	NWLR	***n = 50 in general; n = 100 for tropical cyclone-prone sites***	U	N
2) Power production plus occurrence of fault	2.1	NTM Vin < Vhub < Vout	NSS Hs = E [Hs | Vhub]	COD, UNI	NCM	MSL	Control system fault or loss of electrical network	U	N
	2.2	NTM Vin < Vhub < Vout	NSS Hs = E [Hs | Vhub]	COD, UNI	NCM	MSL	Protection system or preceding internal electrical fault	U	A
	2.3	EOG Vhub = Vr ± 2 m/s and Vout	NSS (or NWH) Hs = E [Hs | Vhub]	COD, UNI	NCM	MSL	External or internal electrical fault including loss of electrical network	U	A
	2.4	NTM Vin < Vhub < Vout	NSS Hs = E [Hs | Vhub]	COD, UNI	No Current ***(NCM)***	NWLR or ≥ MSL	Control, protection, or electrical system faults including loss of electrical network	F	* ***(FDF)***
3) Start up	3.1	NWP Vin < Vhub < Vout	NSS (or NWH) Hs = E [Hs | Vhub]	COD, UNI	No Current ***(NCM)***	NWLR or ≥ MSL		F	* ***(FDF)***
	3.2	EOG Vhub = Vin, Vr ± 2 m/s and Vout	NSS (or NWH) Hs = E [Hs | Vhub]	COD, UNI	NCM	MSL		U	N
	3.3	EDC Vhub = Vin, Vr ± 2 m/s and Vout	NSS (or NWH) Hs = E [Hs | Vhub]	MIS, wind direction change	NCM	MSL		U	N
4) Normal shut down	4.1	NWP Vin < Vhub < Vout	NSS (or NWH) Hs = E [Hs | Vhub]	COD, UNI	No Current ***(NCM)***	NWLR or ≥ MSL		F	* ***(FDF)***
	4.2	EOG Vhub = Vr ± 2m/s and Vout	NSS (or NWH) Hs = E [Hs | Vhub]	COD, UNI	NCM	MSL		U	N

5) Emergency shut down	5.1	NTM Vhub = Vr ± 2m/s and Vout	NSS Hs = E [Hs | Vhub]	COD, UNI	NCM	MSL		U	N
6) Parked (standing still or idling)	6.1a	EWM Turbulent wind model Vhub = k1 Vref ***(Vhub = k1 V10min,n-yr)***	ESS Hs = k2 Hs50 ***(Hs = k2 Hs,n-yr)***	MIS, MUL	ECM ***(n-yr Currents)***	EWLR ***(n-yr Water Level)***	***n = 50 in general; n = 100 for tropical cyclone-prone sites***	U	N
	6.1b	EWM Steady wind model V(zhub) = Ve50 ***(V(zhub) = V3sec,n-yr)***	RWH H = Hred50 ***(H = r2 H,n-yr)***	MIS, MUL	ECM ***(n-yr Currents)***	EWLR ***(n-yr Water Level)***	***n = 50 in general; n = 100 for tropical cyclone-prone sites***	U	N
	6.1c	RWM Steady wind model V(zhub) = Vred50 ***(V(zhub) = V1min,n-yr)***	EWH H = H50 ***(H = H,n-yr)***	MIS, MUL	ECM ***(n-yr Currents)***	EWLR ***(n-yr Water Level)***	***n = 50 in general; n = 100 for tropical cyclone-prone sites***	U	N
	6.2a	EWM Turbulent wind model Vhub = k1 Vref ***(Vhub = k1 V10min,n-yr)***	ESS Hs = k2 Hs50 ***(Hs = k2 Hs,n-yr)***	MIS, MUL	ECM ***(n-yr Currents)***	EWLR ***(n-yr Water Level)***	Loss of electrical network, ***n = 50 in general; n = 100 for tropical cyclone-prone sites***	U	A
	6.2b	EWM Steady wind model V(zhub) = Ve50 ***(V(zhub) = V3sec,n-yr)***	RWH H = Hred50 ***(H = r2 H,n-yr)***	MIS, MUL	ECM ***(n-yr Currents)***	EWLR ***(n-yr Water Level)***	Loss of electrical network, ***n = 50 in general; n = 100 for tropical cyclone-prone sites***	U	A
	6.3a	EWM Turbulent wind model Vhub = k1 V1	ESS Hs = k2 Hs1	MIS, MUL	ECM ***(NCM)***	NWLR	Extreme yaw misalignment	U	N
	6.3b	EWM Steady wind model V(zhub) = Ve1	RWH H = Hred1	MIS, MUL	ECM ***(NCM)***	NWLR	Extreme yaw misalignment	U	N
	6.4	NTM Vhub < 0,7 Vref ***(Vhub ≤ V10min,1-yr)***	NSS Joint prob. distribution of Hs,Tp,Vhub	COD, MUL	No Current ***(NCM)***	NWLR or ≥ MSL		F	* ***(FDF)***
7) Parked and fault conditions	7.1a	EWM Turbulent wind model Vhub = k1 V1	ESS Hs = k2 Hs1	MIS, MUL	ECM ***(NCM)***	NWLR		U	A
	7.1b	EWM Steady wind model V(zhub) = Ve1	RWH H = Hred1	MIS, MUL	ECM ***(NCM)***	NWLR		U	A
	7.1c	RWM Steady wind model V(zhub) = Vred1 ***(V(zhub) = V1min, 1-yr)***	EWH H = H1	MIS, MUL	ECM ***(NCM)***	NWLR		U	A
	7.2	NTM Vhub < 0.7 V1 ***(Vhub ≤ V10min,1-yr)***	NSS Joint prob. distribution of Hs,Tp,Vhub	COD, MUL	No Current	NWLR or ≥ MSL		F	* ***(FDF)***
8) Transport, assembly, maintenance and repair	8.1	To be stated by the manufacturer						U	T
	8.2a	EWM Turbulent wind model Vhub = k1 V1	ESS Hs = k2 Hs1	COD, UNI	ECM ***(NCM)***	NWLR		U	A
	8.2b	EWM Steady wind model Vhub = Ve1	RWH H = Hred1	COD, UNI	ECM ***(NCM)***	NWLR		U	A
	8.2c	RWM Steady wind model V(zhub) = Vred1 ***(V(zhub) = V1min,1-yr)***	EWH H = H1	COD, UNI	ECM ***(NCM)***	NWLR		U	A
	8.3	NTM Vhub < 0.7 Vref ***(Vhub ≤ V10min,1-yr)***	NSS Joint prob. distribution of Hs,Tp,Vhub	COD, MUL	No Current ***(NCM)***	NWLR or ≥ MSL	No grid during installation period	F	* ***(FDF)***

In the ABS Design Load Cases the term ***S*** is used to signify U in IEC, and it refers to the same strength for type of analysis.

IEC/ ABS Partial Safety Factors

All Design Situation	0.9
N	1.35
A	1.1
T	1.5

Fatigue

*	Other Codes	
FDF (Inspectable & Repairable)	***Y***	***N***
Critical	***1.000***	***3.000***
Non-Critical	***3.000***	***5.000***

COD	co-directional (aligned) wind and wave direction
DLC	design load case
ECD	extreme coherent gust with direction change
ECM	extreme current model
EDC	extreme direction change
EOG	extreme operating gust
ESS	extreme sea state
EWH	extreme wave height
EWLR	extreme water level range
EWM	extreme wind speed model
EWS	extreme wind shear
MIS	misaligned wind and wave directions
MSL	mean sea level
MUL	multi-directional wind and wave
NCM	normal current model
NTM	normal turbulence model
NWH	normal wave height
NWLR	normal water level range
NWP	normal wind profile model
NSS	normal sea state
RWH	reduced wave height
RWM	reduced wind speed model
SSS	severe sea state
SWH	severe wave height
UNI	uni-directional wind and wave directions
F	fatigue
U	strength
N	normal
A	abnormal
T	transport, assembly, maintenance and repair
FDF	***fatigue design factor***
H	deterministic design wave height
Hs	significant wave height
Hs1, Hs50	significant wave height with a recurrence period of 1 and 50 years
Hred1, Hred50	reduced wave height with a recurrence period of 1 and 50 years
H1, H50	individual maximum wave height with a recurrence period of 1 and 50 years
Hs,n-yr	***significant wave heights with return period of n years***
H,n-yr	***maximum wave heights with return period of n years***
k1	simulation time scaling factors for 10-minute mean wind speed
k2	simulation time scaling factors for significant wave height
r2	reduction factor for extreme wave height
Tp	peak period of wave spectrum
Vhub	10-minute mean wind speed at hub height
V(zhub)	steady wind speed at hub height, zhub
Ve1, Ve50	extreme wind speed (3 seconds average) with a recurrence period of 1 and 50 years
Vin	cut-in wind speed
Vout	cut-out wind speed
Vr ± 2 m/s	sensitivity to the wind speeds in the range is to be analyzed
Vred1, Vred50	reduced extreme wind speed (3 seconds average) with a recurrence period of 1 and 50 years
Vref	reference wind speed
V1	turbulent extreme wind model (10 minute average) with a recurence period of 1 year
V10min,n-yr, V1min,n-yr, V3sec,n-yr	***n-year return wind speed at hub height with various averaging time durations***
V10min,1-yr, V1min,1-yr	***1-year return wind speed at hub height with various averaging time durations***