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Evaluation of Floating Wind Technology to Reduce Emissions in Newfoundland and Labrador's Offshore Hydrocarbon Industry

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Abstract

The move to reduce greenhouse gas emissions in the offshore hydrocarbons production industry has resulted in a growing interest in the possibility of using offshore wind to reduce on-platform power generation. While some offshore areas are progressing towards, or planning for, the use of offshore wind to electrify hydrocarbon producing platforms, they do not have some of the challenges associated with Newfoundland & Labrador's offshore environment.

The authors are undertaking a study to investigate the feasibility of, and the benefits associated with the use of offshore floating wind to displace power generation for offshore hydrocarbon production platforms, thus reducing GHG emissions. The work is focusing on the applicability of potential concepts, services, supply chain, fabrication, facilities, and operations, and how these tie into various floating wind concepts and technologies that might be fabricated and assembled locally, and operated offshore Newfoundland & Labrador (NL). Electrification of offshore oil and gas production facilities through offshore wind could reduce the requirement for local power generation via turbine generators under normal operation. This paper examines the suitability of potential offshore floating wind concepts in the NL offshore, using wind energy to supply power to offshore facilities, reducing the need for fuel powered turbine generators, and thereby decreasing GHG emissions from power generation. The study looks at the full-field approach, from suitability of design to construction to operations and maintenance of offshore wind technology.

Introduction

Energy Research & Innovation Newfoundland & Labrador is managing and administering the offshore research, development, and demonstration (RD&D) component of Natural Resources Canada's Emissions Reduction Fund (ERF). ERF applied research and innovation projects are looking at ways to reduce greenhouse gas (GHG) emissions in Newfoundland and Labrador's offshore oil and gas industry. The Intecsea study is looking at the use of offshore floating wind-turbines to provide power to offshore oil and gas production facilities. The Governments of Canada and Newfoundland and Labrador are also supporting projects through the NL Offshore Oil and Gas Industry Recovery Assistance Fund (OGIRA), where projects provide direct and indirect employment within the province and offshore sector, generate positive environmental benefits or co-benefits, and support the existing oil and gas installations and infrastructure linked to existing installations. OGIRA funds, which the Government of NL is managing, is augmenting the offshore floating wind-turbines study.

Intecsea and C-CORE are investigating the electrification of oil and gas production facilities offshore Newfoundland, Canada using floating wind power. Electrification of offshore host facilities reduces the requirement for local power generation via turbine generators at the host facility, decreasing operational expenditure and total emissions from the facility. The study is looking at selected floating wind power generation concepts currently promoted in the offshore renewables industry. These are being assessed in terms of operational suitability for areas of interest offshore Newfoundland. Potential projects could require an array of wind turbines to support/provide power to the current and/or future developments. A risk to existing concepts may be sea ice-structure interaction, iceberg impact, and atmospheric or sea spray icing. Installation, operation, and maintenance requirements, and the necessary local infrastructure is being determined to allow these structures to be operated offshore Newfoundland. Required services, supply chain, fabrication, and construction facilities, are being researched with respect to various floating wind concepts and technologies that might be fabricated and assembled locally/regionally. The project is also looking at environmental, regulatory, and permitting aspects of such a project. The ultimate long-term benefit of this project is that it could move Newfoundland and Labrador towards the reduction of GHG emissions in the offshore hydrocarbons industry. In addition, it will provide local capabilities/experience in the development, fabrication, installation, and operation of offshore wind turbines.

Offshore Floating Wind Concepts

Floating wind foundation concepts are primarily categorized as semi-submersible, spar, TLP and barge types as shown in Figure 1 below.

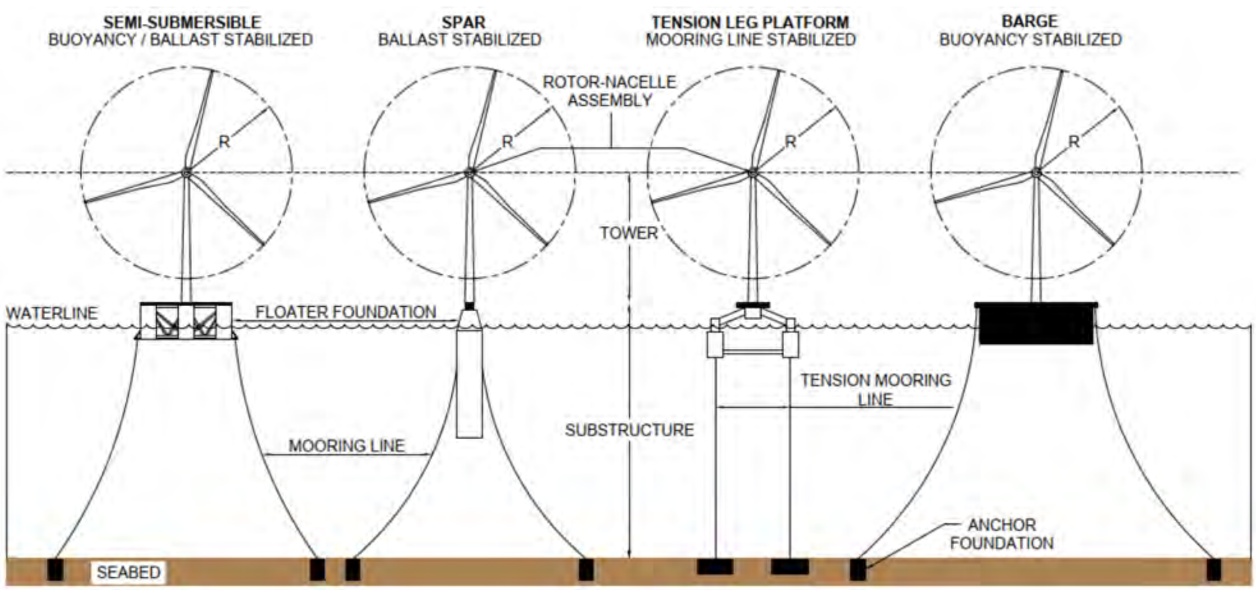

Figure 1—Floating Foundation Types

Semi-submersible type floating foundations often consist of 3 to 4 columns connected by pontoons/ braces and are stabilized through a separated water plane area distanced from the platform center. Additional buoyancy can be provided by the pontoons; with the foundation moored by mooring lines to the seabed.

A Spar uses a long cylinder to provide buoyancy. The bottom part of the Spar foundation is usually filled with fixed ballast to bring its center of gravity below its center of buoyancy, hence providing stability to the whole floating system. The Spar is normally moored using a catenary mooring system to the seabed.

A TLP type floating foundation has a number of columns to provide buoyancy. It is connected to the seabed by rigid tendons. The buoyancy force of the foundation is much greater than the system's weight, which maintains tensions in the mooring system to ensure the stability of the floating system. Tension leg mooring systems are often piles driven into the seabed and have vertical and/or slanted tethers under tension providing large restoring moments in pitch and roll. It also restricts the vertical, or "bobbing" movements, improving overall stability.

Like the semi-submersible, a barge type floating foundation's buoyancy and stability is provided by a large water plane area with adequate distance from the structure center. Of all foundation types the barge has the shallowest draft, which can be beneficial for turbine installation alongside a shallow quay; however, the shallow draft results in greater wave induced motions, requiring a more robust mooring system. In efforts to reduce these motions, some barge designs incorporate a central moonpool or catamaran design.

While most of the above foundation types accommodate a single wind turbine, in some cases there are hybrid floating foundations that house combinations of wind, wave and solar energy generation systems, have multiple wind turbines on a single foundation or have the ability to use multiple mooring arrangements. For example, some foundations have been designed to use a catenary mooring setup but could also be moored using vertical tendons, similar to a typical TLP configuration.

As part of the evaluation during this study, current and future planned offshore floating wind concepts were identified through internet searches, communication with technology providers, review of open literature, and project team industry contacts. More than 50 foundation concepts were identified, with some technology providers offering multiple solutions/foundation types.

The concepts identified were qualitatively and quantitatively assessed against a list of criteria that included Project Experience, Development Stage, Technical Capability and Existing/Potential Local Content. From the preliminary assessment, a shortlist of Technology Providers from each foundation type was generated and sent a questionnaire requesting additional information for a more in-depth evaluation.

The Questionnaire included a Functional Specification developed for the study work, as well as assessment criteria as follows, including but not be limited to:

- Information on the Offshore Floating Wind Concept (non-proprietary);
- Ability to Meet Requirements of Functional Specification/Implications of Ice Environment;
- Previous and Planned Experience with Use of Concept;
- Constructability;
- Fabrication in Canada / Local Content;
- Installation Requirements including Foundations;
- Commissioning;
- Operations & Maintenance;
- Health, Safety & Risk; and
- Future Pilot Project Interest.

Information supplied from the solution providers on their concepts provided an overview of the current operational suitability of the various foundations and types for areas of interest offshore Newfoundland and Labrador (NL). One of the metrics considered was the Technology Readiness Level (TRL) as defined below in Table 1. It is evident that there are limited concepts that are commercially ready i.e., at a TRL of 9 or greater and able to supply energy to a grid or offshore facility. The majority of floating foundations evaluated ranged from TRL 3 to 6.

The majority of the foundation concepts are currently designed for a water depth range between 50-500m, with some designs stating capabilities well beyond this (up to 2000m). The spar is limited by a minimum water depth of approximately 100m while the semi-submersible, TLP and barge configurations are generally capable of operating in a minimum water depth of 40-50m according to the solution providers. Existing hydrocarbon production assets offshore NL are in water depths less than 100m, which bodes well for existing wind turbine foundation designs, but future offshore developments could be in water depths of 1000m or greater. With that said, as noted above, floating foundation designs are proposed for water depths >1000m and it should be technically feasible to achieve these water depths.

Table 1—Technology Readiness Level Definitions (Spearman et al., 2020)

TRL #	Level Definition	TRL #	Level Definition
1	Initial concept	6	1-5MW
2	Proof of concept	7	>5MW
3	Numerical modelling	8	Pilot (10-50MW)
4	Tank testing	9	Pre-commercial (50MW-200MW)
5	Scaled testing (<1MW)	-	Commercial (>200MW)

Most foundations are based on the use of steel as the primary material type. A number of concepts are also incorporating or using concrete as its main material for the foundation. A potential local benefit is Newfoundland's extensive construction and fabrication experience and infrastructure to use concrete in the offshore industry.

In the near term (year 2022/3), the maximum single turbine size anticipated on floating foundations is 10MW; however, there are designs ongoing to handle future turbine sizes up to 15MW (and greater). Increasing the size of the turbine on a single foundation will help improve the cost/MW, thus improving the feasibility of projects.

Ice and ice loads have not been incorporated into the design (in any detail) of the turbine foundations to date, which will need to be considered for operation offshore NL. This is discussed further below. Several designs incorporate a single point mooring system that allows the turbine to be disconnected/re-connected more quickly than traditional mooring systems. This could be advantageous for operation in an ice environment for, among other things, ease of installation and disconnection for maintenance.

Operational Ice Loads and Risk

While not in an Arctic environment, offshore Newfoundland and Labrador is a region that can be frequented by sea ice and icebergs during specific times of the year. Fixed platforms in the region have been designed to withstand loads and impact from ice; both sea ice and icebergs. Floating platforms have been designed to disconnect and move off station if ice loads become too great or if the threat from an iceberg is high.

It is unlikely that wind farms using fixed foundation turbines would be economical for offshore Newfoundland and Labrador given the risks from and need to design for ice (sea ice and icebergs). Certainly, one could envision gravity-based structures (such as those proposed for ice resistant hydrocarbons production platforms offshore Newfoundland) being used to support wind turbines, albeit an expensive solution that would likely make such a concept uneconomical except for shallow waters. This then suggests that a concept needs to be a less expensive floating solution.

Any floating structure offshore Newfoundland and Labrador will have potential risk from sea ice and icebergs (Figure 2). This will include floating wind farms. These floating wind turbines are currently not designed to be disconnectable and additional work would need to be done by proponents to check ice loads that might be sustained by a floating foundation and a typical (or re-engineered) mooring system. Ice detection and monitoring would need to be a part of the operation of any offshore wind farm, and an ice management program implemented to ensure the integrity of the facilities. Ice management might include the breaking of pack ice into smaller floes or the towing (deflection) of icebergs in an impact trajectory with wind facilities. Ice management on the Grand banks has been very successful. Ice detection, monitoring, and management for offshore wind facilities would most likely be combined with the same activities being carried out for a host facility.

Figure 2—Floating Turbines in an Ice Environment

In the Newfoundland and Labrador offshore, operators have in place ice management plans which outline how operators will detect, monitor, and manage sea ice and/or icebergs before they pose a threat to facilities. Floating Production Storage and Offloading vessels are strengthened to withstand sea ice loads but not iceberg impact. In the event of a situation where sea ice loads become too high or icebergs pose a threat, these FPSOs have a quick-disconnect feature, allowing them to safely disconnect and leave the area in the event of unmanageable ice. As mentioned above, floating wind turbines are currently not designed to be quickly disconnectable; none so far have been designed for ice environments.

It is anticipated that those same ice management activities could cover the wind energy facilities. However, even with regional ice management, the wind facilities would need to be able to withstand some level of ice loading and/or have the ability to disconnect in the event of an unmanageable threat; the latter would likely make the floating wind farm uneconomical. The risk would need to be assessed and the cost to mitigate that risk to an acceptable level calculated and evaluated.

The following studies in support of offshore floating wind turbines operating in an ice environment were carried out as part of this study. Further detail on that work is presented in an accompanying paper by King et al. (2022).

- Iceberg Interaction Loads: Iceberg interactions with floating wind turbines are being assessed, which may include spar, barge, tension leg platform, semi-submersible or other configurations. Iceberg contact rates are being calculated using average annual iceberg frequency, mean iceberg waterline length, mean drift speed, and the mean projected waterline width presented by each facility. Distributions of iceberg impact loads will be assessed for each structure considering the geometry of each wind turbine structure as well as the influence of mooring compliance.

- Pack Ice Interactions and Loads: The same selection of floating wind turbines is being considered as for the iceberg analysis, over the same geographical area. The objective of the proposed work is to provide a regional overview of sea ice severity, and to provide characteristic sea ice loads for relevant floating offshore wind turbine structures.
- Ice Management Requirements: Iceberg and pack ice global design and local loads for each structure type will be compared with the load capacities for each structure type, for the no ice management case. If capacities are not exceeded for the specified target reliabilities, then ice management or disconnection are not required. If capacities are exceeded, varying levels of ice management and/or disconnection will be evaluated in order to satisfy reliability targets.
- Operational Ice Related Requirements: Potential issues for floating wind turbine fabrication, tow out, installation, and access for servicing and maintenance associated with iceberg, pack ice and other metocean conditions (i.e., winds, waves, visibility) will be assessed. Once installed, icing of the turbines may be of concern, depending on location. Available models of atmospheric icing suitable for application to offshore wind turbines will be assessed and, if possible, with available hindcast environmental data, potential atmospheric icing issues for floating wind turbines in the area of interest will be assessed.

Floating Wind Platform Global Modelling & Analysis

A preliminary assessment of the capacity to withstand the unique environmental conditions offshore Newfoundland was desired. This was achieved by performing numerical analysis of the coupled system, using reference public domain designs, based on monitoring for relative performance impact due to two primary factors:

- Metocean severity, and
- Impact from drifting ice (sea-ice or icebergs).

Reference models were identified, then reconstructed and benchmarked using OrcaFlex (Orcina, 2021), and representative design environmental conditions investigated as detailed in the following subsections. These investigations focused primarily on global behavior of the floater and mooring system.

Reference Model Identification & Selection

This study was limited in scope to targeting and assessing existing reference designs, and as such bespoke developments were not considered. Several research institutions, most notably NREL, have developed and made available public models for the express purpose of facilitating further academic and industry development and study. Where turbines are concerned, these consist of 5, 10, and 15 MW variants, some of which include development and detailing of one or more floating foundations. Given the large variety of floating foundation types at play, and supporting a wide range of turbine sizes, it was necessary to limit the study to a consistent set of both as much as possible. Based on the current industry trends and available public domain data, it was decided to pursue a 10 MW turbine design supported by each of a semisubmersible, spar and TLP foundation for the analyses.

Multiple reference semisubmersible designs were identified, all of which featured the DTU 10 MW turbine design (Bak et al., 2013). Only one such candidate spar design was identified, again using the same 10 MW turbine which was ideal for comparison purposes. Sourcing an appropriate TLP design proved more difficult, and as such a compromise was made to utilize a version sized for a 5 MW turbine (Jonkman, 2009). It should be noted that this reflects the state of the industry, in which semi-submersible designs dominate the landscape, with spars and TLPs trailing. A summary of basic parameters for the chosen designs are summarized in Table 2. Only one basic mooring configuration was considered based on the reference design, without any optimization, for the purposes of benchmarking and baseline setting.

Table 2—Basic Summary of Floating Foundations / Turbines

	Semisub	Spar	TLP
Reference	(NTNU, 2014)	(NTNU, 2016)	(Matha, 2009)
General	3x Pontoons with columns	Scaled Hywind variant	Basic cylinder
Diameter (m)	3×10.0 (offset) / 1×8.3 (central)	12.0 / taper to 8.3 near SWL	18.0
Draft (m)	20.0	120.0	47.89
Displacement (te)	~13,900	~13,400	~12,400
Mass with Ballast (te)	~12,600	~12,100	~8,600
Depth to Fairleads (m)	15.0	70.0	47.89
Radius to Fairleads (m)	50.0	6.5	27.0
Radius to Anchors (m)	880.0	855.0	27.0
Mooring Type	3x Chain Catenary		4×2 Tendons
Mooring MBS (kN)	20,000	7,680	Unspecified
Water Depth (m)	200.0	320.0	200.0
Turbine Design	DTU		NREL
Turbine Capacity (MW)	10.0		5.0
Hub Height (m)	119.0		90.0
Rotor Diameter (m)	178.3		126.0
Vin / Vr / Vout (m/s)	4.0 / 11.4 / 25.0		3.0 / 11.4 / 25.0
Peak Thrust (kN)	~1500.0		~750.0

Model Development & Benchmarking

Each system model was reconstructed in OrcaFlex, consisting of the floating foundation, mooring lines, tower, nacelle, hub, and rotor. Figure 3 shows an illustration of each of the models.

For the semisub and TLP, this required remodeling of the floating foundations according to the reference specification, and subsequent hydrodynamic analysis. The wave diffraction and simplified QTF computation were executed using OrcaWave (Orcina, 2021), and verified against available stiffness, mass, damping and RAO data. The spar design was modeled using the 6D Buoy (spar buoy) object as an approximation.

For the 10 MW turbines, the original controller (dynamic library) was found to be incompatible. In place of this, an open-source ROSCO (NREL, 2021b) controller was implemented, which required development and tuning within the OpenFAST (NREL, 2021a) framework.

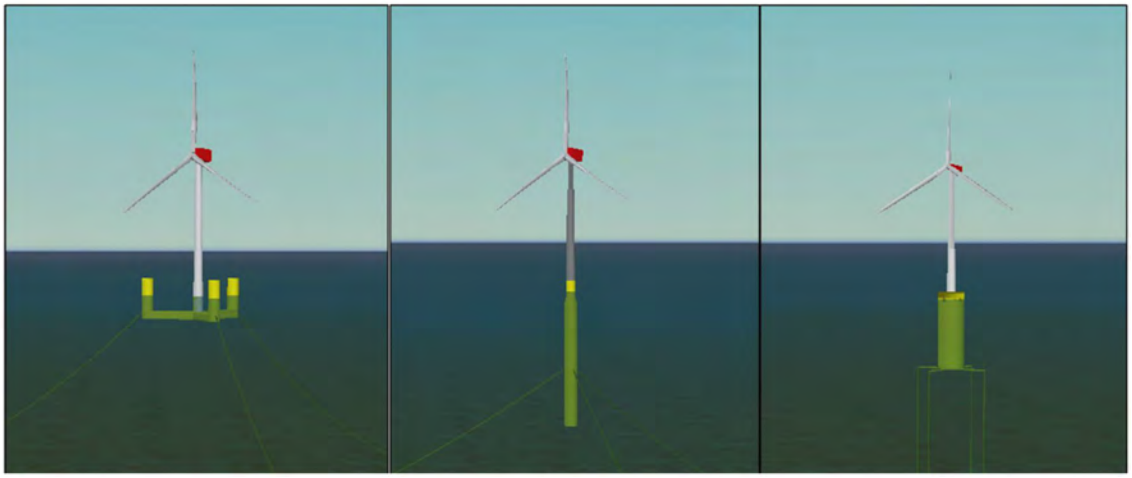

Figure 3—Orcaflex Models – Semisub (Left) / Spar (Middle) / TLP (Right)

Initial static equilibrium, offsets, and basic hydrostatic/hydrodynamic/eigenvalue benchmark analyses were executed to confirm expected model response and provide further verification against available reference data. Isolated constant wind speed benchmark analyses within the turbine operating range were used to confirm and verify thrust and power generation, as well as expected controller behavior. These benchmarks also add further confidence in the estimated blade/tower drag loads experienced within the parked extreme environment cases.

Load Case Selection

Due to schedule and scope constraints, priority was given to extreme environmental conditions, with operating (power production) cases deferred to future study. Using the CSA/IEC 61400 (CSA, 2021; IEC, 2019a; IEC, 2019b) codes as a guide, DLC 6.1 was identified as a potential governing condition. This load case is established to bound the environmental (wind, wave and current) loads on the upper end of the spectrum, without any mechanical or operational faults present, and serves as a comparative baseline against similarly prescribed ice loads (discussed further below).

Based on the nominal design water depth for each system, a subset of representative cells within the larger study region were identified for potential installation sites and collection of environmental parameters. Given the regional bathymetry, these locations were relegated to a relatively small transitional slope along the perimeter of the Grand Banks, moving from a near constant 100 m region towards much deeper (trending towards 1,000 m and deeper) water. From these cells relatively little variation in metocean parameters was found, and therefore focus was placed on one cell biased towards the North for further evaluation based on expected sea-ice and iceberg presence. The relevant metocean parameters from these regions for application to DLC 6.1 are summarized in Table 3, which are representative of 50 and 1-year (see ice loads below) return periods, including joint probabilities for wind and waves. Waves were assumed as JONSWAP with default spectral parameters, while full-field turbulent wind environments were generated from TurbSim (Jonkman, 2016) using the IEC Kaimal spectrum. For this study, loads were all assumed to be co-directional and aligned with the shared platform and turbine surge axis. Multi-directional and misaligned environment loading were deferred to future study.

Table 3—Summary of Metocean Parameters

Return Period (years)	Wind (1-hr)		Wave (3-hr)		Current	
	Wind Speed (m/s)	Ref. Height (m)	Sig.Wave Height (m)	Peak Period (s)	Surface Speed (m/s)	200m Speed (m/s)
50	28.2	10.0	12.9	15.0	1.61	0.48
1	25.7	10.0	10.6	14.0	0.40	0.13

At present, according to the codified DLCs specific to offshore wind turbines, the load cases considering drifting ice do not typically require wave loads to act concurrently, which likely stems from an assumption of complete ice coverage. However, marginal conditions feature prominently in the study region, and with enough severity to warrant consideration of wave contributions. Furthermore, many codes refer to ISO 19906 (ISO, 2019) for prescribing ice loads, which directly cites joint sea-ice and wave load effects (along with wind and current) and recommends scaling factors based on sea-ice concentrations. With that said, the relevant factors for companion loads suggested in ISO 19906 have been found to be overly conservative based on prior study of available statistics in the study region (Fuglem et al., 2018). It was therefore chosen to supplement the relevant DLC for limit state ice loads in a parked situation (IEC D6/D8), which normally calls for 1-year wind and normal current only along with 50-year ice, with the addition of 1-year wave conditions. Using the methodology described in (Thijssen et al., 2018), representative drifting sea-ice loads were estimated for each floating foundation base and are summarized in Table 4. A 1-year return period was also estimated (~50% of the 50-year value) to investigate the potential impact of 1-year pack ice acting along with the 50-year storm loads from DLC 6.1, as the most severe storms are expected to occur in the winter season and concurrent drifting ice is likely. These were introduced in a simplistic manner, as a constant force applied at the still water line. In addition, transient impact from a single large ice floe was assessed, using an estimated 50-year ice floe of 850,000 tonnes travelling at 0.3 m/s. In this case the mean offset from 1-year wind, wave and current loads was applied as an initial condition.

Table 4—Summary of Estimated Pack-Ice Loads

Return Period (years)	Force (MN)		
	Semisub	Spar	TLP
50	2.677	0.290	0.567
1	1.339	0.145	0.284

Analysis & Results

Each of the above load cases was executed using the Orcaflex implicit time-domain solver, with a 1-hour duration repeated across 6 random seeds, except for the transient ice impact which was a reduced duration single event. Results were processed to determine mean response as well as most-likely maximum values. These are summarized in the following subsections, with emphasis on relative impact from ice as an environmental load, rather than quantifying absolute performance against code criteria. Note that the results below consider only global response of rigid foundations, and do not consider local loads and associated structural integrity.

Baseline (50-year Environment Without Ice). The results from the baseline extreme 50-year storm loading appear to show most favorably for the semi-submersible design. Some relatively large peak tensions are seen, with possible exceedance of allowable design limits (depending on consideration of redundancy in the safety factor), however no anchor uplift or other clear violation of ultimate limit states was encountered.

High utilization and some exceedances are likely when conducting a complete evaluation but are likely to be easily resolvable with minor optimization of mooring configuration and sizing alone.

The spar design shows moderately worse performance, with much larger pitch motion and occasional uplift on the upstream mooring anchors, and definite exceedance of allowable line tension despite reduced dynamic tension amplitudes. This may be partially attributable to a relatively poor initial mooring design or modelling approach which used an equivalent line in place of a hybrid system featuring a mid-line clump weight. However, it is apparent that more work is likely to be required on both the mooring and floating foundation to effect an adequate spar design.

The TLP, while showing the expected benefits in terms of response motions, exhibited extreme dynamic tension amplitudes, including several instances of tendons becoming slack. This was somewhat expected as the reference publication highlighted such issues under extreme loading, and the original design was optimized around smaller waves.

Baseline with Pack-Ice (50-year Environment / 1-year Ice). The results across all platforms are summarized in Figure 4 in terms of response values normalized against the baseline load case. The most notable effects from addition of a pack-ice load appear to be increased tension and surge response, with the semi-submersible in general exhibiting the largest deviations. This is as expected given the relative magnitudes applied. The TLP appears most resistant to the increased ice loads; the larger deviations in mean heave and pitch can be neglected, as they are attributed to a low baseline value. For example, the normalized mean heave of 1.4 is relative to a baseline of 0.1m, so the heave of 0.14 m in absolute terms is a minor change.

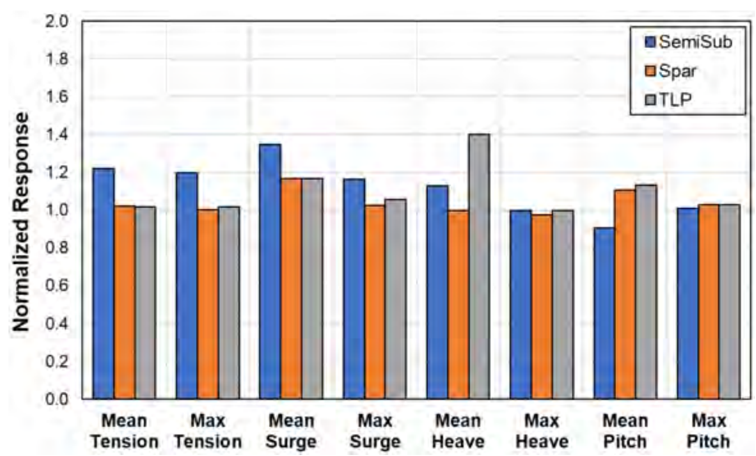

Figure 4—Normalized Mooring and Motion Response – Baseline with Pack-Ice

Dominant Pack-Ice (1-year Environment / 50-year Ice). The results from the dominant pack-ice load case are presented, similarly to those above, in Figure 5. In general, these show that this load case is not likely to govern the design, with the heaviest impacts seen mostly in terms of mean offsets, and slightly more pronounced for the semisubmersible. This is as expected due to the latter having by far the largest footprint and associated ice load. The TLP remained the most stable despite experiencing higher loads than the spar, although still exhibiting multiple occurrences of slack tendons.

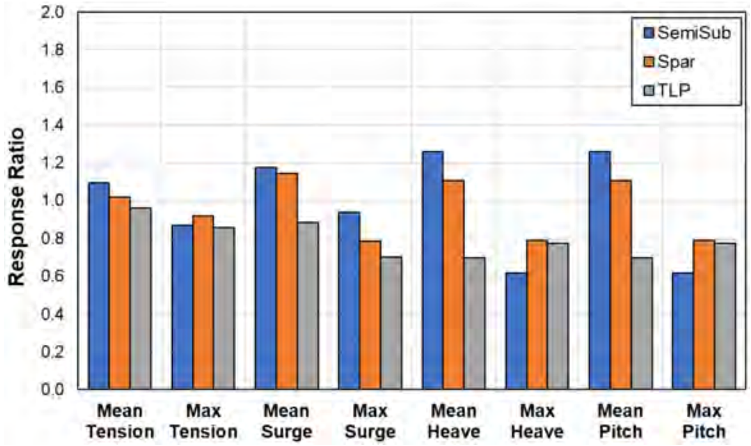

Figure 5—Normalized Mooring and Motion Response – Dominant Pack-Ice

Ice Floe Impact (1-year Environment / 50-year Ice). The impact simulation was set up as an idealized case, with a lumped mass 6D buoy representing an ice floe set on an impact course at the prescribed velocity. The floe was constrained from any lateral (sway) or rotational motions, with the main objective of transferring the full momentum to gauge the surge response and associated mooring loads. This reduced set of results is summarized in Figure 6 using the same baseline for normalized response.

These results show that all three foundation types with the reference mooring design appear to be able to cope with the imposed impact without significant issue. Only the spar design showed an increase in mooring load, which was due to the increased surge. Here the moderate increase in peak surge becomes critical – as the baseline response was sufficient to cause anchor uplift. All the additional motion in this case feeds into a significant (~12x) increase in anchor uplift force. For all foundation types, the heave and pitch responses were muted, which was mainly of relevance for the TLP as it meant that all tendons remained taut.

It must be noted that the lack of dynamic wave and wind action present in this idealized load case is of clear benefit to the maximum response, and further study may be warranted to include these effects. In addition, while the semi-submersible appears robust against this type of load, only a direct head-on impact was considered. Given its shape, it is uniquely prone to eccentric loading from such an impact, and the associated yaw response may produce more onerous system loads.

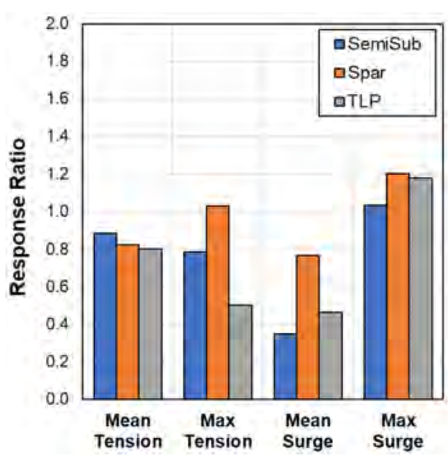

Figure 6—Normalized Mooring and Motion Response – Ice Floe Impact

Regulatory and Permitting Requirements

The objectives of this part of the project were to provide: an overview of federal and provincial legislation and regulatory processes that may be applicable to offshore wind farms; a preliminary list of potentially required federal and provincial permits including the identification and evaluation of materials, studies, environmental sensitivities, and data that may be required; and a comparative analysis of requirements and operations of global offshore wind farm that are currently existing or are planned.

A Permitting Road Map (PRM) has been developed that summarizes the federal and provincial regulatory and permitting requirements for authorization of an offshore renewable energy (ORE) wind project in Canada, particularly in the Newfoundland and Labrador offshore area. This PRM provides an approximate framework of the regulatory processes to identify necessary milestones, dependencies, and recommended timelines throughout project development and design phases to form the permitting strategy. As the development of ORE wind projects in Canada's offshore is relatively new, existing guidance from Regulatory Authorities is limited. An important component for regulatory approvals will be to engage relevant Regulatory Authorities well in advance and throughout the development and design phases to understand the regulatory process as the process develops and evolves. It is expected that once the Offshore Renewable Energy Regulations (ORER) comes into force that more defined procedures and requirements will be developed and in place for authorization of ORE wind projects in Canada.

Additionally, it will be important to undertake thorough and meaningful consultation with the public and interested groups during the development and design phases of a project. The development of ORE wind projects in Canada is still in its beginning phases and it will be important to provide information to those interested and affected on the potential impacts and effects the projects may have on the environment and the public. Once all interested parties and potentially impacted stakeholders are identified, the proponent should begin engagement as soon as possibly feasible.

Given the knowledge gaps that exist with development of ORE wind projects in Atlantic Canada, it is also recommended that extensive baseline studies of the environmental and socio-economic conditions be completed to fully understand the existing conditions and identify and determine any potential impacts an ORE wind project may generate. The baseline studies should aim to identify the knowledge gaps and provide a thorough understanding of the environment and socio-economic condition. This will be a crucial step of the project development and design phase, as it will provide the basis for information during the engagement phases and for applications to regulators.

Supply Chain and Logistics

Planning and developing offshore wind farm projects offer a number of supply chain opportunities, some of which might be provided by Newfoundland and Labrador companies. The following table (Table 5) lists many of the components associated with the development of a floating offshore wind farm, and which have been broadly categorized as follows: Engineering; Procurement; Construction; Operations; and Decommissioning.

Some of these areas require specific experience/expertise with respect to offshore wind (e.g., some aspects of Engineering, Construction, Operations). The level of specific wind experience/expertise required might vary from item to item; the experience/expertise necessary might have been gained (and be transferable) from Newfoundland and Labrador's offshore oil industry or it might be gained through partnerships with companies in other parts of the world experienced in various aspects of the offshore wind industry.

Aspects of the work will require skilled trades, offshore survey vessels, access to technology, specialized facilities, offshore installation vessels, and industry-specific project management, which may or may not be available in Newfoundland and Labrador. The actual regional opportunities that might eventually be realized through offshore wind development will depend on the optimal solution determined for our offshore. The expertise, infrastructure, facilities, and skilled trades that have been developed as part of the offshore industry here, and in other industries, are potential areas that could be tapped into for offshore wind developments.

Table 5—Summary of Supply Chain Capabilities and Competencies Required

Engineering	Procurement	Construction	Operations	Decommissioning
Planning	Procurement	Topsides Engineering	Remote Sensing	Removal of Floater
Economic Analysis	Logistics	Topsides Modification	Remote Operations	Removal of Anchors
Feasibility Studies	Storage	Floating Technology	Inspections	Removal of Foundations
Regulatory & Permitting	Customs Brokerage	Floating Foundations	Modifications	Reeling of Power Cables
Environmental Studies	Transportation	Wind Turbine Generators	Maintenance	Dismantling Equipment
Metocean & Modelling	Subsea Cables	Offshore Substation	Repair	Disposal
Geophysical Surveys	Certifying Authority	Seabed Foundation	Replacement	
Geotechnical Programs	Fabrication	Seabed Anchors		
Site Assessments	Installation	Electrical Systems		
Engineering	Commissioning	Subsea Cables		
Construction Planning		Certifying Authority		
Operations Planning		Fabrication		
Maintenance Planning		Installation		
Project Management		Commissioning		

Construction and Fabrication Facilities

A review of the local network of construction and fabrication facilities was performed by NOSO and the project team to identify areas in Eastern Canada that have both the current/potential capabilities to host construction and fabrication activities to support the grassroot development and operation of offshore wind farms. The primary area of focus was near ocean access within Eastern Canada (PQ, NB, NS, PEI, NL) with the capabilities to support wind farm fabrication and construction. The local infrastructure used to support Newfoundland and Labrador's offshore hydrocarbons industry was also assessed for looking at the applicability to the offshore wind opportunity.

For locations with water depths over about 60 to 80 m, fixed foundations are generally uneconomical or technically unfeasible, and floating wind turbines anchored to the ocean floor are needed. These structures may require a deepwater facility to assemble the completed wind turbine assemblies prior to tow out; there are a number of candidate sites that could be used for these activities. The proximity of other fabrication/ construction infrastructure could also be used to assist in the construction of the floating foundation (whether concrete or steel), fabrication of seabed foundations, as a location for stockpiling other components (e.g., anchor chain/cables and power transmission cables), and as an installation base during offshore activity.

Operations and Maintenance

Operations and maintenance requirements, and the necessary local infrastructure, are being determined to allow these structures to be operated offshore Newfoundland and Labrador. Required services, supply chain, fabrication, and construction facilities are being considered with respect to various floating wind concepts that might be used offshore Newfoundland and Labrador. As part of the installation review, the project provides information on the following:

- Installation;
- Offshore Wind O&M;
- Substation Maintenance;

- Gearbox Inspection and Service;
- Blade Inspection and Service; and
- Statutory Wind Farm Inspections.

Demonstration Project Definition

Stakeholders may not wish to proceed with a fully operational project before doing an appropriate level of testing and verification. For example, lessons learned and optimizations from the Hywind Scotland project will be implemented on the Norwegian Hywind Tampen project, resulting in considerable cost savings as they move towards the world's first pilot project for electrification of offshore oil and gas fields using floating offshore wind and an essential step in reducing costs for future offshore floating wind power projects.

As part of the project, the project team investigated what an offshore floating wind demonstration project might entail. This included an execution narrative, schedule, order-of-magnitude costs, as well as environmental, regulatory, and permitting aspects of such a project. This work included potential demonstration platforms or approaches, fabrication facilities, testing site(s), operations, required instrumentation and data analysis. Information was also supplied regarding other recommendations for follow-up work in advance of a pilot program, such as data collection, numerical and/or physical modelling. Any potential structure modifications for optimizing ice resistance were identified and documented. The project team solicited input from technology solution providers.

Gaps in Floating Wind Technology for Use Offshore Newfoundland

From this study, the primary technology gap identified for use of floating turbines offshore Newfoundland and Labrador was designing for loads imposed from potential contact from pack ice or icebergs. Some foundation designs inherently have some ability to withstand some additional loads from ice, or its shape makes it more conducive to reducing the impact loads of ice on the foundation (or mooring line contact). Feedback from technology solution providers indicates that ice loads have not been specifically considered or incorporated into the foundation design, or any other part of the complete system. However, this is understandable as there has not been a need to date for floating wind turbine foundations designed for an ice environment. The risk of ice contact continues to be evaluated to arrive at probabilistic ice loads to be used in design. To reduce the risk of damage to floating wind turbines, and to maintain high up-time (staying on location/connected), ice load consideration will need to be incorporated into the floating wind foundation design for our offshore.

Atmospheric icing is also a factor to be considered. Some solution providers suggested special coatings on non-rotating parts, and additional stability to combat heavy spray icing. Again, detailed assessments of the impact of icing will need to be incorporated into the overall site-specific design of the wind turbine concept.

Offshore Newfoundland is known to have challenging seabed conditions: soft to hard clay; sand & gravel; glacial till; hardpan; bedrock; and boulders (could be up to 5 m in diameter). In terms of mooring the turbines to the seabed where piles may be required, it will be important to understand the seabed and soil conditions in the wind farm region. Depending on the area, the mooring design may have to change to be more technically viable and better suit the soil conditions.

Subsea cables located in ice environments and in a certain range of water depths may need to be protected from potential ice gouging (also known as ice scouring) created when a moving ice keel interacts with the seabed. The integrity and operability of the cable can be affected by direct contact between the ice keel and the cable, or from loading imposed on a buried cable through soil deformation caused by ice gouging. Subsea cables may also be subjected to 3rd party risks from fishing activities depending on location and water depth. Depending on the risk, cables may need to be buried for safety and protection. The typical method considered for protecting against the risk of damage caused by ice gouging or 3rd party activity is through cable burial. Conventional methods of cable burial use equipment such as dredges, ploughs, mechanical trenchers, and jetters.

Newfoundland is known for its centuries old fishing industry. An assessment of the risks to wind facilities and cables due to the presence of fishing activity is beyond the scope of this study and would be a study unto itself. If further work is carried out to more fully evaluate the feasibility of wind energy to electrify oil and gas production facilities, then this topic warrants further study.

Summary

Floating wind turbines have the benefit of being able to rely on existing design methodologies and technologies that have been derived from the offshore industry and/or proven in offshore floating wind pilot projects. The foundation types (for the most part) are based on existing foundations already proven in the oil and gas industry. In addition, the turbines, electric cables, and mooring systems have also been proven for use offshore. This is not to take away from the complexity of designing a complete "system" or wind farm. While limited, there are commercial floating wind farms currently in operation and have shown to be technically feasible; for example, Hywind Scotland, Windfloat Atlantic and the Kincardine Offshore Windfarm. As the demand for renewable energy increases, bigger turbine designs are being considered (15MW+), and larger wind farms (greater number of floating foundations/turbines). In addition, future projects will continue to push out into greater water depths. While generally technically feasible, floating wind concepts will benefit from further advancements in technology to make wind farms more economically.

The project described in this paper is looking at the more developed floating wind concepts in the industry which are being assessed in terms of operational suitability for areas of interest offshore Newfoundland and Labrador. The most significant technical risk identified affecting existing concepts is sea ice-structure interaction or the possibility of iceberg impact. Installation, operations, and maintenance requirements, and the necessary local infrastructure are being evaluated to allow these structures to be operated offshore Newfoundland and Labrador. Required services, supply chain, fabrication, and construction facilities are being investigated with respect to various floating wind concepts and technologies that might be fabricated and assembled locally/regionally. The project has also looked at Canadian/Provincial environmental, regulatory, and permitting aspects of such a project as well as carrying out an energy benefits analysis. As a fully operational project may not proceed without additional testing and verification, details around what an offshore floating wind demonstration project might look like were investigated.

There are no existing projects with floating wind turbine foundations designed for an ice environment. A floating wind turbine offshore Newfoundland and Labrador would need to be designed to accommodate some ice loading. Ice can increase the environmental loads on the turbine foundation and requires a special mooring system and foundation structure design. If icebergs are too large for turbine foundations and anchoring to withstand resulting impacts/loads, ice management programs may need to be put in place. In order to develop an economical ice resistant floating wind turbine foundation, additional research, engineering, and proof of concept work would need to be carried out.

The analysis work conducted to date represents a preliminary look at the performance of typical offshore wind turbine designs subject to extreme environmental loads prevalent in the Newfoundland and Labrador offshore region. While there is likely a need for some design modification and minor improvements, many of the typical or standard floating foundation designs should be expected to accommodate the extreme wind, wave and current climate with relatively minor design optimizations required. In particular, the results from the work conducted to date indicate that global system loads arising from the addition of seasonal ice do not appear to be a major impediment which might render an offshore floating wind turbine in this region infeasible.

With that said, requirements for local structural reinforcement have not been considered, and there are several other scenarios pertaining to the offshore Newfoundland environment that have not yet been investigated and may prove challenging to overcome while remaining cost-effective. One such example which is the subject of ongoing study is the impact from a seasonal iceberg rather than a large ice floe, which may require a shift in perspective towards allowable risk and/or reliance on ice management strategies. It may also drive selection of foundation types, as shallow fairleads and lower departure angles may possibly leave some mooring configurations more prone to ice interactions. Significant work also remains in characterizing the impacts and potential loads under power production, as well as possible additional complications from atmospheric icing.

While much work remains to be done, based on the work carried out to date it appears that the use of offshore floating offshore wind turbines to provide power to hydrocarbon producing platforms offshore Newfoundland is feasible.

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