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Cost Effective Offshore Concepts - Compact Semi-Submersible - A New Concept of Windfarm Service Operations Vessel

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Abstract

This paper details the process undertaken for the design of a novel windfarm Service Operations Vessel (SOV).
This paper covers:

- An offshore wind energy sector overview
- Characteristics of the Compact Semi-Submersible (CSS) platform
- Design and analyses required for concept SOV validation
- Design challenges, risks and solutions
- Approval in Principle (AiP) process with class

The information within this paper will be useful to design companies moving away from their typical knowledge base and vessel portfolio. Venturing into a new market sector or new type of vessel always presents risk. This early stage AiP process reduces that risk before a project and design gains too much momentum to be able to incorporate regulatory updates or interpretations at a later stage. Challenging area's based on the designer's and classification society's experience are discussed with proposed solutions as well as areas to focus on and develop with up and coming rule updates, guides and interpretations.

The CSS platform is classed as a Mobile Offshore Unit/Mobile Offshore Drill Unit (MOU/MODU) due to previous versions of the design being classed in such a manner for the offshore Oil and Gas sector. Applying a vessel designed for this sector to a new but similar sector which requires alternate regulations calls for clear interpretations and rule compliance. The relevance and applicability of more recent class notations such as "Ship Shaped Unit" are still being investigated and analyzed. This could allow for more relevant and typical vessel like criteria to be applied to the platform when transiting to and from shore and between turbines but then allows for MODU like notations to remain when gangway connected or operating on station and in Dynamic Positioning (DP) mode. HAZID workshops are highly recommended for novel concepts such as this to identify and eliminate "show stoppers" during initial design stages. Time spent undertaking such reviews at this stage pay for themselves in a reduction in design rework during class, functional and production design stages.

The relatively immature and rapidly evolving nature of this industry sector leads to many challenges for all involved and the willingness and cooperation that classification societies play during early stage designs to provide the necessary guidance to safely meet the developing market segments is critical. Offshore Oil and Gas regulations become the founding basis for many novel offshore designs but are not always entirely appropriate because the mechanical, structural, stability, safety and habitability requirements differ in many ways. The AiP process undertaken between designer and classification society for this project highlighted many of these areas and highlighted areas in which rules require development and careful interpretation.

Introduction

In 2016, the offshore wind energy sector plays a significant role in the present and future of renewable power generation. A large number of governments and non-government organizations have conducted and presented research the supports the effectiveness and low carbon footprint that wind turbine generated electricity can provide. Current estimates presented by the Global Wind Energy Council summarize the current generation capacity as such:

- 3.7% of global electricity is currently supplied by wind power
- Approximately 91% of the world's offshore wind generating capacity is installed in Northern Europe (3230 turbines).
- Europe's binding target is to provide 20% of final energy consumption from renewables (currently 11.4%).
- Ambitious targets have also been set by the governments of China, Japan, Korea, Taiwan and the US.
- Developing nations including Brazil and India are also known to have a raised interest.

This presents a truly global playing field for those involved in the industry or those looking to establish themselves in this growing sector.

The potential of offshore wind is enormous. It could meet Europe's energy demand seven times over, and the United States energy demand four times over. Hence, the motivation behind developing offshore wind turbine installations is primarily the accessibility of increased wind resources compared to those on land. This would result in a higher rate of generation from fewer turbines leading to both reduced CAPEX and OPEX. This offshore location however presents us with a number of obvious engineering challenges for those involved in the industry to solve and improve upon.

This paper focuses on one such engineering challenge and that is modification, optimization and implementation of existing offshore oil and gas technology into this sector. Primarily the growing field of offshore wind Installation, Maintenance and Repairs vessels (IMR), Operations and Maintenance (O&M) vessels and the more recently coined term of Service Operations Vessel (SOVs).

Service Operation Vessels (SOV's)

Amongst all the current acronyms for various configurations of offshore support vessels, the SOV is one of the few solely aimed at the offshore wind sector. This type of vessel has existed in its current configuration for only the last 5 or so years. The relatively immature state of offshore wind means that almost every maintenance contract tendered in the last 8 years is an evolution of the previous one. Demands from windfarm owners for increased safety, crew comfort and maintenance uptime coupled with these installations moving further offshore in order to capture more consistent and stronger winds and the drive to force down operating costs leads the industry to evolve at an incredible pace. Compared to the last 50 years of offshore oil and gas, the pace at which the standards, operating normals and class society regulations have developed is impressive. However, there are some considerations on existing SOV's operational conditions and limitations:

- The typical offshore distance of these early offshore turbine installations was typically within a range of 3-15km. Modified jack up rigs and a low number of custom jack up monohulls completed these installations. Small Crew Transfer Vessels (CTV's) which ranged from 5m rigid inflatable hulls through to 12m custom designed and built aluminum catamaran style craft undertook the operations and maintenance. These daily crew transfers were undertaken first thing in the morning and at the end of the day with crews based on land and only a few hours of each shift being consumed by the "commute" to and from the ports to the turbines. The windfarms were also a lot smaller than those under construction today and these smaller vessels would loiter in standby mode for the duration of the shift.

- As wind turbine installations move further offshore in the last few years and with a significant number of sites proposed, approved and currently under construction, pushing out to 80+km at water depths of over 60m is the latest challenge. The time taken to transport teams of maintenance technicians out to these offshore sites, at distances more typically seen in the oil and gas sector, results in a huge reduction in hours available to undertake maintenance and repair.

- 2 or 3 hours each way in small and lightweight craft is no longer deemed a safe and economical solution. As CTV's grow larger and more stable in order to take on the harsher environmental conditions experienced at these more remote and further offshore locations the effectiveness and economics behind this method remains limited.

- Offshore installations are often located in environmentally harsh regions as a consequence of needing to be in consistently windy areas. Sea states are quickly exaggerated in areas of varying water depth and over sand bars where many wind farms are located. The result is often an area of confused and choppy seas with varying conditions, currents and swells. As effective as a modern monohull is in these conditions, safe personnel transfer is limited to the equipment used and the vessel's response to wind, waves and currents.

This became the trigger point for the birth of the SOV. Enough confidence, government investments and plans have been established for the industry to start looking at the next scale of vessel. This SOV market is in essence born out of the need to maximize the technicians working hours on a turbine and also the requirement to maintain and replace larger and larger components on the turbines.

The general philosophy behind the SOV is to provide a platform which can be based out in the field for up to a month at a time, carrying a full hold of spares and equipment. The net benefit of being positioned in the windfarms is a drastic reduction in the downtime spent running technicians to and from shore to worksite.

What has evolved to a now almost "standard" SOV vessel design is typically based on the followings features:

- a monohull of approximately 65 to 85m in length, DP-2 position keeping,

- accommodation for 40 service technicians (in single cabins) and 20 ships crew,
- a motion compensated “walk-to-work” type gangway,
- a crane with a reach of 5t at 20m and a workshop/stores/cargo hold for 30 days’ endurance.
- Some of the more advanced SOV’s also include a daughter craft or small CTV, a helideck, a stores elevator for reduced manual handling and significant design emphasis placed upon the layouts for workflow, crew comfort and safety.

There are approximately 12 of these wind farm specific SOV vessels in operation with another 11 known to be under construction at present with many variations and new designs being proposed to industry on a monthly basis. This segment is seeing steady growth with long term charters and repeat orders in a time of reduced ship building and design activity in other offshore support sectors.

Initially some preexisting PSV’s had been retro fitted with additional accommodations, smaller cranes and removable gangways as a temporary measure in order to satisfy immediate but short term demand as an interim measure. A number of laid up oil and gas assets were converted and put into work in other offshore wind supporting roles but once the level of SOV accommodation and vessel capability became a new standard the appeal of these converted vessels faded rapidly. Modifying existing oil and gas assets quickly became superseded by the charter requirements coming out of the most recent windfarm operations tenders. The drive towards SOVs with SPS notation, integrated level working areas, step free access and single cabins drives the market towards this brand new fleet of industry specific vessels.

In the offshore oil and gas sector large semi-submersible units are designed for operation in these extreme conditions. The North Sea experiences some of the largest swells in extreme northern areas which eventually sweep their way down towards the UK, Germany and the Netherlands. Semi-submersibles are designed to cope with these conditions and provide large safe working platforms for technicians and engineers to undertake drilling tasks safely.

The Compact Semi Submersible (CSS)

This concept took in a new direction in 2008 with the development of the CSS unit. Primarily focused on the offshore oil and gas sectors, a cost effective but capable semi-submersible design was developed in order to serve short term high volume accommodation needs to various IMR, commissioning and decommissioning contracts. The 84m long x 32m wide platform has since been successfully proven in the industry with 6 units constructed in 3 different configurations. This stable, multipurpose and comparably cheap platform is utilized to undertake a variety of tasks previously only possible by larger more expensive 120m x 120m platforms. With this proven platform the idea to develop a smaller and more cost efficient version of this design was implemented. The limits were to maintain it superiority in motions compared to a monohull and target the offshore wind sector. New concept CSS is shown in Fig.01.

Figure 01 New concept Compact Semi-Submersible SOV

Key features

The 65m x 28m variant of the CSS evolved from several rounds of size optimization, computational analyses and a full model testing program. The model testing program specifically targets data relevant to offshore wind operations, details of which will be discussed later in this paper. The main characteristics of this CSS concept are described below:

- Of more importance to this specific industry are the vessel motions and station keeping. SOVs use a passive or motion compensated (active) to transfer personnel, equipment and stores to a turbine. This process requires a vessel to come alongside a turbine and hold station accurately while the transfer takes place. In order to carry out this transfer in a safe manner regulations and processes exist which must be strictly adhered to.

- There is a minimum separation distance between the vessel and the turbine for example which must be maintained.

- There is a maximum sea state and wind limit over which gangway transfers cannot take place. The gangways themselves have excursion, motion and wind limits over which they cannot be safely deployed. A vessel typically approaches a turbine platform from downwind in order to minimize the amount of effect that side swells and wind have on it’s the roll and pitch.

- Once positioned, the vessel is put into a DP holding status in order to hold station, minimize excursion and be able to deploy the technicians. From arriving on station, deploying the gangway, transferring the 2 or 3 personnel to then recovering the gangway to its stowed position can take anywhere between 5 and 15 minutes depending on the vessel DP operators’ skills, equipment and environmental conditions. During this time vessel motions are very carefully monitored.

- First, second and third stage alarms points are calibrated in the gangway when deployed and should the vessel, pitch, roll or overall excursion exceed the second limit then a lift off procedure is initiated and the gangway withdrawn followed by the vessel withdrawal safely away from the turbine until such a time that position can be recovered and maintained. Monohull SOVs with their gangway typically positioned midships and off to one side are not so much affected by vessel pitch to the center of the vessels motions being typically around the midship region but a gangway located on the outboard edge would be vulnerable to exceeding the roll limits of the gangway. A slight sea state or wind off to one side or the other of the bow during gangway transfer operations could quite quickly lead to excess roll and lift off incident.

- The CSS vessel’s natural response to head seas, quartering seas and beam seas is a slow heaving motion. The unique hullform and its natural damping characteristics therefore lend itself extremely well to such an operation.

- Configured in a DP 2 system set up like any other monohull SOV but with 4 azimuthing type thrusters instead of the normal 2 stern propellers and 2 bow thruster set up results in a more flexible and capable response to excursion and redundancy.

A unique feature of this platform is inherited from the original 84m variant which is that it is classed as a Mobile Offshore Unit (MOU or MODU). As previously discussed the original version was tailored towards supporting offshore drilling operations and as such it was designed to this ruleset. The MOU or MODU code is typically applied to larger semi-submersible units and those undertaking drilling operations and the handling of hydro-carbons. This somewhat overly conservative ruleset was applied to the CSS design for a number of reasons. A flexible and multipurpose platform was a fundamental design philosophy and as such classing the vessel to the exact same requirements as the units alongside which it would most likely operate meant that no exemptions or additional surveys should be required prior to relocation, new charters or areas of operation. A self-mobilizing unit such as the CSS is a far more valuable asset if it can be relocated and on charter with the minimum of recertification. This same approach has been taken with the smaller SOV version of the CSS. Some of the regulatory challenges are discussed later in this paper but the principal behind a self-mobilizing and multi-purpose platform such as this is to bridge the gap between a monohull SOV, a jack up and a large accommodation barge. The MODU notation applied to this platform would also maintain the ability for it to undertake tasks in the offshore oil and gas sector. As much as there is a focus on offshore wind market as a growing segment today as oil and gas are still in recovery mode, the ability to switch between market segments is beneficial to any owner looking for long term returns on investment in such a vessel.

Concept Design Validation

Due to the unique nature of the concept, a large number of discrete aspects of the design require detailed research, investigation, analysis and validation.

In order to progress to the AiP stage of a concept a complete sweep through of vessel systems and arrangements is required. The electrical system is fundamental to the success of an SOV due to the complexity behind the DP system and the redundancy mitigation measures required to be integrated into such a vessel. The CSS lends itself exceptionally well to DP operations for a number of reasons. The twin hull style vessel and engine configurations naturally leads to a system with redundancy built in. 1 engine room and 1 switchboard room per hull with protected cross overs and trunking for cables and essential systems result in a vessel easily configurable for DP 2 and DP 3 set ups. The propulsion arrangement on the CSS also lends itself well to DP with 4 thrusters, one in each pontoon tip, result in large turning moments for excellent yaw control, heading consistency and stationkeeping.

As is typical in ship design, one of the first parts of the systems design focuses on propulsion and powering. Scaling factors and analyses are undertaken to scale down the hotel loads, bare hull resistance and DP power requirements. From this an electrical load analysis is completed and the propulsion equipment sizing selected and laid out. The model testing program included typical resistance and powering tests in the tank followed by computational validation and further rounds of optimization.

The unique hullform is difficult to analyze using existing seakeeping simulation tools but data from larger versions of the vessel were used a basis for preliminary validation. Vessel motions and station keeping are of utmost importance to this specific industry and as such additional testing is critical in order to accurately predict vessel operational limits. The positon of the gangway, crane, bridge and accommodations were identified and sensors positioned in these locations. Measurements of accelerations and excursions were recorded in these locations to validate the platforms suitability. Motions and seakeeping analyses were conducted at a range of sea state wind and current configurations. The model testing facility selected had a variable depth seakeeping basin. Motions were measured at a range of wave lengths and periods according to the vessel’s most likely area of operation. Shallow water and mid depth water testing was also conducted to validate the effect of shallow water on the motions in realistic and upper operational sea states. The large range of predicted operational environmental conditions were confirmed during these tests. As a result, additional testing at higher sea states was undertaken to validate upper range of operational conditions. The aim of gathering all this data is to present a solution to potential operators indicating that their current upper sea state limits for safe operations due to equipment and vessel limitations can be increased if this style of platform is considered.

There is huge emphasis on optimized workflow in the SOV market. Workshops, briefing rooms, change rooms and tool stations should all be located on a single deck with access to elevators, cranes, gangways and CTV’s all from a central deck setup. Step free access with minimal handling of equipment is strongly desired and more emphasis is placed on this with each new tender that is released. A recent development has been the introduction of external elevators which also form the pedestal for the gangway. Access to the stores and accommodation comes from below the main deck allowing technicians to travel from accommodation to gear and briefing rooms, then into the stores to collect tools and spares and then exit the elevator directly onto the gangway set at a pre-determined height allow for direct horizontal access to the turbine platform. Minimal manual handling of heavy spares and equipment is required in this configuration and has become highly desirable. With the trend for turbines becoming larger and more powerful, so the spares and replacement parts also increase in size and weight. This hands off approach lends itself well to the future of offshore turbine maintenance.

Range and endurance are key components of SOV design especially one that is destined to stay offshore for a month at a time. Sufficient fuel is of course one fundamental design consideration but with this comes efficiency. The ability to reduce the required fuel onboard and either allow for an increase in spares deadweight or a smaller lighter vessel is desirable. The design solution with 4 gensets and 4 thrusters allows for a significant amount of flexibility in operations which typically leads to the ability to optimize and tailor the configuration for maximum efficiency depending on the task underway. In addition to the ability to send power from any combination of genets to any combination of the thruster’s further enhancement of the propulsion system’s efficiency are still underway. The addition of 2 battery banks into the propulsion system design is proposed in order to create a hybrid solution. BATTERY POWER is a recent notation added by class which enables a vessel to account for battery power as part of its installed power capacity depending on the operations.

For the SOV market a hybrid battery power option would lend itself well to several different operational scenarios. The ability to arrive or depart port without having a number of gensets online reduce the amount of emissions emitted close to land. Once underway, the hybrid system can be used to optimize power loads via a peak shaving approach. If the desired cruising speed it slightly above the power able to be provided by any combination of gensets being online, then this “top up” peak shaving approach can be implemented. The most attractive option for the windfarm sector in utilizing a hybrid power system is while engaged in DP operations for equipment and personnel transfer. The requirements for windfarm DP operations are typically a DP-2 requirement. This means that during DP operations which would include personnel transfer via a gangway, equipment transfers via the crane or any operations in the vicinity of a turbine or involving personnel the vessel must be set up in a configuration such that any single system failure would not result in a loss of position and that the vessel remain in a condition whereby operations could be successfully terminated. This typically requires a vessel to operate with at least 1 if not 2 gensets online but on idle in case of a system failure that would lead to a genset being lost. In addition, redundant installed thruster equipment or oversized equipment is required such that if a system failure results in the loss of a thruster or shaft, again, the vessel can hold station by sending additional power to the remaining operational systems.

In order to replace these standby idling gensets and engines, a time to terminate operations assessment is required. This is an assessment of the amount of time typically required to safely terminate operations such as gangway personnel transfer, crane operations or crew transfer via ladders for example. This assessment is submitted to a classification society for review and agreement with descriptions of the operations, equipment limitations and vessel and environmental assumptions. A time to terminate is agreed upon based upon this assessment and then a power figure is calculated to cover the power required to top up that no longer available by the worst case system failure. For example, if the time to terminate operations is agreed upon as 15 minutes and post the worst system failure there is a shortfall of 400kW then a 100kWh battery bank system could be installed to cover the power required to safely terminate operations and remove the vessel from the vicinity of other vessels or turbines.

Challenges, Risks and Solutions

For the vessel to operate in international and many territorial waters, it must comply with statutory regulations and classification rules. This is also required to satisfy interest of other stakeholders, such as insurers, financing institution, vessel owner, shelf states, labor unions, and the general public. The rules and regulations are to large extent prescriptive based, and are based on accumulated industry experience. This can be a challenge for a novel concept. For the CSS SOV, the main regulatory challenges and ways to address them are discussed below.

- Lack of regulatory framework fully addressing specific vessel design and operational profile. From service perspective the vessel is a better fit to maritime ship regime, while semi-submersible design is better addressed by offshore regulation. While combining the two, one must take underlying principles and background of specific regulations to decide what should be applied. The regulatory basis shall be established early in design, consulted with, and to extent possible accepted by prospective flag state and classification society. This is an essential step to avoid surprises later. The basis shall also resolve conflicting requirements.

- Particular selection of the relevant codes will be entirely dependent on the flag state and they must be contacted on a case by case basis. In general, a vessel engaged in international voyages must comply with SOLAS, unless the flag state has agreed that the Special Purpose Ships (SPS) code or the Mobile Offshore Drilling Unit (MODU) can be used as an alternative.

- Maximum weather conditions for transit and while connected to the wind turbine should be established. This is essential for hull structural design, gangway design and to address HSE requirement.

- Dynamic positioning, including redundancy requirements and economical aspects. This also affects design of the gangway, including potential emergency disconnect. Novel concepts such as hybrid power systems for DP are in the early concept phase, and rules are still under development.

- Working environment, including crew accommodation and crew comfort.

- Safety of frequent navigation around congested wind farms. This may be addressed by additional class notations such as DNVGL's NAUT-OSV

- Stability requirements. With fore and aft columns "merged", the semisubmersible looks more like a catamaran, however HSC code requirement does not fit operational profile. On the other hand, MODU is applicable to 4 and more column configurations, hence requires specific interpretations. MODU also addresses operations with non-navigation personnel on-board, where SOLAS would require compliance with SPS code stability requirements. Such would not be practical as SPS code is relevant for mono hulls.

- Life-saving equipment. Providing life boats is costly due to space constrains. SOLAS only requires life rafts for vessel length up to 85m. However, that would be unreasonable as the 85m single hull vessel is much smaller than the 65m semi-submersible, accommodates more people and operates farther from the shore. MODU principle is more appropriate even it requires much more space.

When establishing regulatory framework, it is essential to ensure all safety aspects are covered. At the same time, it should be done in an economical manner, so for instance requirements relevant for drilling units are not unnecessarily enforced. The result would need to be presented to relevant stakeholders, such as prospective owners, flag authorities, investors, etc. A good way to achieve that is to perform an independent assessment with a classification society, who has established methodologies to address novel designs. Class also has extensive experience with technical aspects and well established relationships with flag authorities. The process followed for this project is outlined in the following; the methodology can also be applied to other novel designs.

AiP Process with Class Society

- Approval in Principle (AiP)

An Approval in Principle (AiP) is an independent assessment of a concept within an agreed requirement framework confirming that a design is feasible and that no insurmountable obstacles would prevent the concept from being realized. An AiP is typically carried out at an early stage of a project to confirm its feasibility towards the project team itself, company management, external investors or future regulators. Since it is carried out at an early stage of design it will have to be based on a limited level of engineering detail, and therefore will only focus on the major hazards to a project.

It should be noted that the Approval in Principle statement does not constitute classification of the design. The AiP will typically identify a number of areas that will need to be addressed during detail design in order to prepare the design for final Classification Approval.

The scope of the AiP is to assess the overall feasibility of the concept and to find any potential 'show stoppers' in the design.
Figure 02 shows the methodology of the Approval in Principle process.

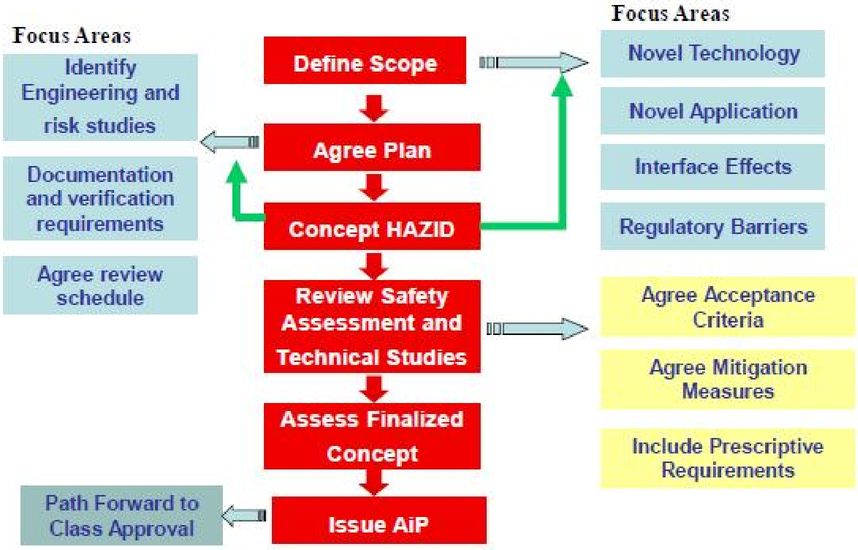

Figure 02 Methodology and process of AIP

- Concept HAZID

HAZID (Hazard Identification) is a method to systematically collect experience with regards to risks for a design, equipment, system or operation. With the objective to identify and classify all possible hazards by cause, failure mode and consequence related to concept design, a risk methodology process was used as illustrated in Fig. 03. The discussion was made with a group of people who are familiar with the rules/regulation, equipment and system process as HAZID involves multiple interfaces and is a truly multi-disciplinary subject.
The main focus included in the concept HAZID was:

- Global performance
- Hull and structural strength
- Marine systems
- Safety systems
- Construction and installation
- Operational aspect

After identifying the main hazards and their associated scenarios relevant to the problem under consideration, a qualitative ranking is further undertaken to prioritize them and to discard scenarios judged to be of minor significance. The work is based upon the cumulative experience of people, and the discussions are based on general impressions and generic challenges related to cold climate operations.

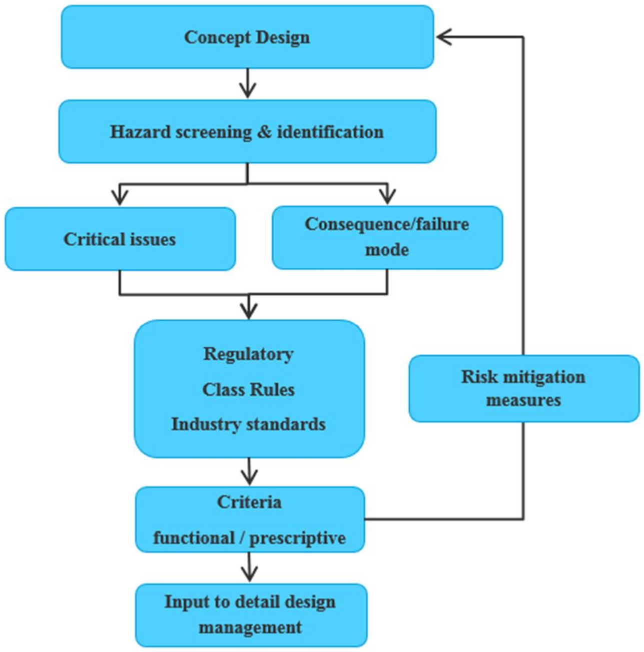

Fig. 03 Risk methodology process

Followings are some of critical issues identified during the HAZID workshop that must be properly managed and mitigated at the detail design phase.

Global performance:
- True operating and survival sea state for global motion performance and crew comfort, upper limit sea state not defined at concept stage but further investigated considering site specific metocean data
- Model testing to study of wave induced motion response characteristics and to validate new numerical models. Further to confirm that no important hydrodynamic action has been overlooked for new concept of design

Hull Structures:
- True operating and survival sea state for global and local structural integrity
- Potential negative airgap and impact assessment on underdeck structure
- Model test to measure physical parameters and the magnitude of the impact pressure
- Fatigue capacity of column to pontoon connection joints

Marine & safety systems:
- Additional direct access to the lifeboat area from living space
- Additional escape door at the aft bulkhead of ware house
- Fire main connection for fire-fighting purpose
- Fire pump capacity considering demand of the gangway deluge

Construction and installation:
- No major issues as a similar type of vessel has been built

Operation:
- Gaps between design and real operational limit, operating philosophy to be implemented into the

hull design basis document

Conclusion

In such a fast developing sector of the offshore energy market, developing designs to meet ever changing requirements takes significant research, planning and client communication. The first step is to really gain a thorough understanding of the market, client operations, the operating environment and vessel capabilities and limitations. Having a knowledgeable classification society on board with the same ambition and drive to succeed is another fundamental part of the puzzle. The AiP process with a HAZID workshop allows for the identification of issues in the early stages of the design when rectifying problems is often still a paper exercise and not cutting out steel. The main focus of the effort being put in at the early stages is risk mitigation and more productive final design stage. Lessons learned from alternative sectors of the offshore industry can play a significant part in identifying solutions for emerging energy support markets.