Journal of Polish CIMAC
Gdansk University of Technology
The Faculty of Ocean Engineering and Ship Technology

INSTALLATION VESSELS OF OFFSHORE WIND FARMS AND THEIR TAKE-OFF SYSTEMS

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Abstract

Polish shipbuilder Crist S.A. is to build a heavy lift jack-up vessel named Vidar for German construction giant Hochtief Solutions. Like Hochtief's other heavy-duty equipment, the new special-purpose jack-up vessel will also speed up installation and servicing times for the latest generation of offshore wind farms. According to principal characteristics, Vidar will have 148 meters length and 90 accommodation places. The evident uncertainties of the regulatory situation for specialized offshore vessels hamper the timely development of the offshore wind energy. These installation and servicing vessels can be adequately regulated by Guidelines defining the appropriate application of existing requirements from the Special Purpose Ships Code (SPS Code). Due to amounts of the accommodation places, there is interface with SOLAS regulations for passenger vessels. But they are no passenger vessels, therefore specific passenger vessel requirements such SOLAS safe return to port requirements should be not applied. This situation yielded the shipbuilder Crist initiative to investigate the regulatory obstacles at International Maritime Organization (IMO) forum. Therefore, they have asked Polish department for Subcommittee of Ship and Equipment Design of IMO to review the applicability of the existing IMO instruments. This paper is an outcome of the carried out study concerning some aspects of offshore wind farm installation and maintenance issues.

Keywords: *power plant, heavy lift jack-up vessel, wind farm, installation and maintenance*

1. Introduction

Wind power is one of the most important and promising forms of renewable energy being developed. It produces no emissions and is an excellent and alternative in environmental terms to conventional electricity production based on fossil fuels such as oil, coal. It is common knowledge that the world electricity production is based primarily on fossil fuels. Burning of fossil fuels increases amounts of carbon dioxide in atmosphere what, in turn, contributes to climate change.
Moreover, we can observe the following global market tendencies:

- shortage of oil and gas reserves and natural resources in politically stable countries[1],
- growth of the world population to 9 billion by 2030 according to high scenario [2],
- security of energy supply for developed countries necessary for their economic sustainability [3].

The EU directive [4] on renewable energy sets ambitious targets for all member states, such that the EU will reach a 20% share of energy from renewable sources by 2020. It also improves the legal framework for promoting renewable electricity, requires national action plans that establish pathways for the development of renewable energy sources, and creates cooperation mechanisms to help achieve the targets cost effectively.

Renewable energy is energy which comes from natural resources such as: sunlight, wind, rain, tides, and geothermal heat, which are renewable (naturally replenished).
Land-based and offshore wind power refers to the construction of wind farms to generate electricity from wind.
Better wind speeds are available offshore compared to on land, so offshore wind power contribution in terms of electricity supplied is higher. The advantage is that the wind is much stronger off the coasts, and unlike wind over the continent, offshore breezes can be strong in the afternoon, matching the time when people are using the most electricity. However, offshore wind farms are relatively expensive.
The Swedish offshore wind farm Lillgrund in the Øresund is built between Malmö and Copenhagen. The wind farm with a total installed capacity of 110 MW is operated by the Swedish utility Vattenfall and officially came on line in June 2008 and produces enough electricity to supply 60,000 Swedish households. As of February 2012, the Walney Wind Farm in United Kingdom is the largest offshore wind farm in the world at 367 MW, followed by Thanet Offshore Wind Project (300 MW), also in the UK. The London Array Wind Farm (630 MW) is the largest project under construction. This project will be dwarfed by subsequent wind farms that are in the pipeline, including Dogger Bank at 9,000 MW, Norfolk Bank (7,200 MW), and Irish Sea (4,200 MW). For comparison, the total installed capacity of the largest power plant in Russia and the world sixth-largest hydroelectric plant (Sayano–Shushenskaya DAM located on the Yenisei River) is 6,400 MW (Dogger Bank - 9,000 MW).
Development of offshore wind farms is an emerging market, especially Europe, with many initiatives by several governments supporting this part of the renewable energy sector. With increasing demand for offshore wind farms, their components need to be manufactured, transported, installed, and maintained. At present, only a limited capacity of dedicated installation units is available on the market, resulting in the development and construction of new installation units. Ships and offshore structures, such as Offshore Wind Farm Construction Vessels and Service Crafts, could be purpose build or converted. These designs might deviate from existing ship types currently employed in the offshore oil and gas sector, such as Mobil Offshore Drilling Units and Offshore Supply Vessels.
This paper describes the recent and predicted trends concerning installation and servicing vessels of offshore wind farms and their take-off systems. Factors influencing technical limitations of both the vessels and the take-off systems will be presented as well.

2. Offshore wind turbines and their limitations

Windmills were used in Persia as early as 200 B.C. The wind-wheel of Heron of Alexandria marks one of the first known instances of wind powering a machine in history. The concept of using wind energy for grinding grain spread rapidly through the Middle East and was widespread long before the first windmill appeared in Europe. According to [5], the first electricity generating wind turbine, was a battery charging machine installed in July 1887 by Scottish academic, James Blyth to light his holiday home in Marykirk, Scotland. Some months later, American inventor Charles F. Brush built the first automatically operated wind turbine for electricity production in Cleveland, Ohio. 1951 - first utility grid-connected wind turbine to operate in the U.K. was built by John Brown & Company in in the Orkney Islands.
The wind turbine is actually rated at 6,15 MW [6] (wind company REpower and C- Power NV installed the wind turbine, the first of 48 for the Thornton Bank II wind farm, which is being constructed approximately 28km off the Belgian coast). The recent growth rate (size, power and cost) of offshore wind turbines is presented in Figure 1. The hub heights will be between 85m and 100m above sea level, and the total turbine height will not be greater than 175m. As a rule, the turbines have three blades because engineers have found that three blades is the most efficient and least troublesome way to harvest wind. Turbines with two blades are actually even more efficient

[7]. But because they are also lighter and tend to spin faster, they are also noisier. These designs also require a special tilting hub that acts as a sort of shock absorber, which is expensive. Having more than three blades raises other problems. For one thing, the extra material needed to build the blades raises the cost. And the more blades there are, the lighter and thinner they need to be. Relatively thin blades are more flexible, making them prone to bend and break. Three-bladed turbines are not perfect, but they avoid many of these problems.

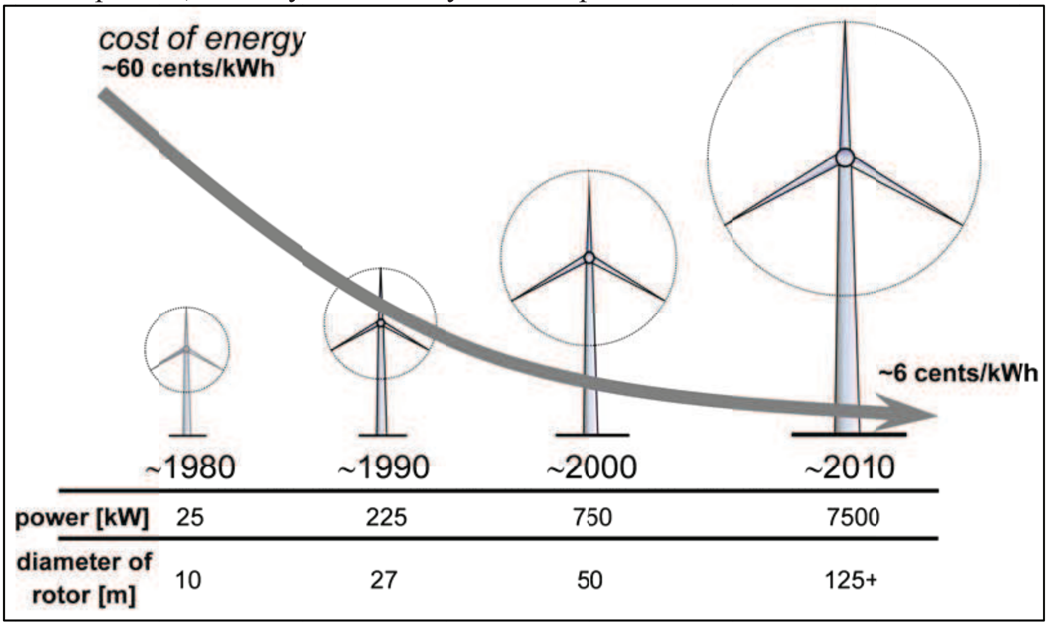

Fig. 1. Wind turbine growth: size, power and cost

Turbines typically begin generating electricity at a minimum wind speed of 3m/s, with full power being achieved from 13m/s. For safety reasons (Fig. 2) they will begin to shut down at wind speeds greater than 25m/s. Their typical rotation speeds varies between 5 to 20rpm.

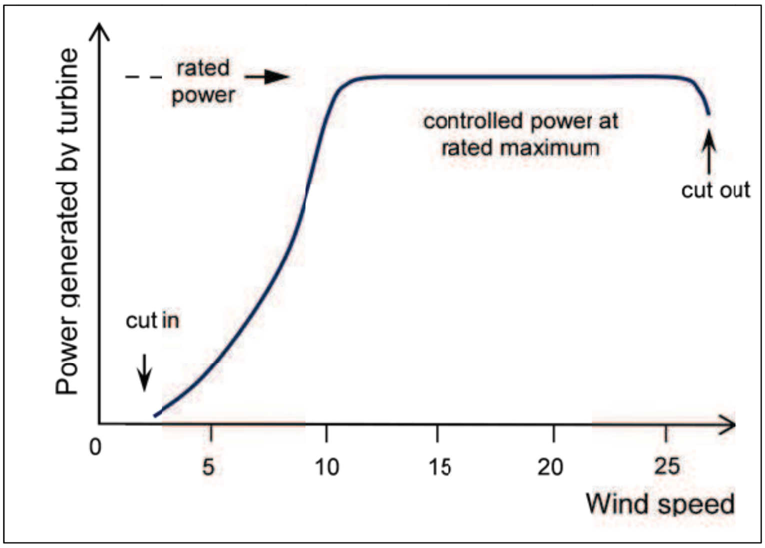

Fig. 2. Wind turbine power operating range

For large, commercial size horizontal-axis wind turbines, the generator is mounted in a nacelle at the top of a tower, behind the hub of the turbine rotor. Typically wind turbines generate electricity through asynchronous machines that are directly connected with the electricity grid. Usually the rotational speed of the wind turbine is slower than the equivalent rotation speed of the electrical network. Therefore, a gearbox is inserted between the rotor hub and the generator (750-3600 rpm). This also reduces the generator cost and weight.

Older style wind generators rotate at a constant speed, to match power line frequency, which allowed the use of less costly induction generators. Newer wind turbines often turn at whatever speed generates electricity most efficiently. This can be solved using multiple technologies such as doubly fed induction generators or full-effect converters where the variable frequency current produced is converted to DC and then back to AC, matching the line frequency and voltage. Although such alternatives require costly equipment and cause power loss, the turbine can capture a significantly larger fraction of the wind energy. In some cases, the DC energy is transmitted from the turbine to a central (onshore) inverter for connection to the grid.
The turbine represents just one third to one half of costs in offshore projects today, the rest comes from infrastructure, maintenance, and oversight [8].
Some of the environmental concerns that will need to be considered both in the planning process for individual farms, and as we move forward in general with offshore wind turbines are [9]: bird impacts, habitat disruption, fisheries impacts, potentially noise, and attitudes of people.
Generally birds are at risk from collision with the turbines. In addition, habitat use can be affected by construction and operation and maintenance. Birds can be displaced from ideal feeding or nesting grounds, or will avoid turbines during daily movement or migration. Lighting on wind towers might attract birds. The most of the habitat disruption will take place during turbine and transmission installation. When the trenches are being dug to bury the transmission cables, or during wind turbine installation, events known as frac-outs can occur (the condition where drilling mud is released through fractured bedrock into the surrounding rock and sand and travels toward the surface). Introduction of new artificial habitats with positive effects on fish communities after full development of artificial reef communities has been observed. No linkage between the strength of the electromagnetic field and the migration of selected fish species has been noticed. Noise from wind turbines will travel underwater and could disturb aquatic organisms. Studies from existing offshore turbines note that the noise is very low frequency, and many species are actually unable to hear it, whereas noise from construction activities could disrupt organisms in the short-term. According to Danish studies [9], more than 40% of investigated people stated that they preferred future wind farms to be moved out of sight.

3. Foundation of offshore wind power turbines

Several factors should be taken into account during installation of wind power turbines:
- water depths,
- seabed conditions,
- environmental conditions.

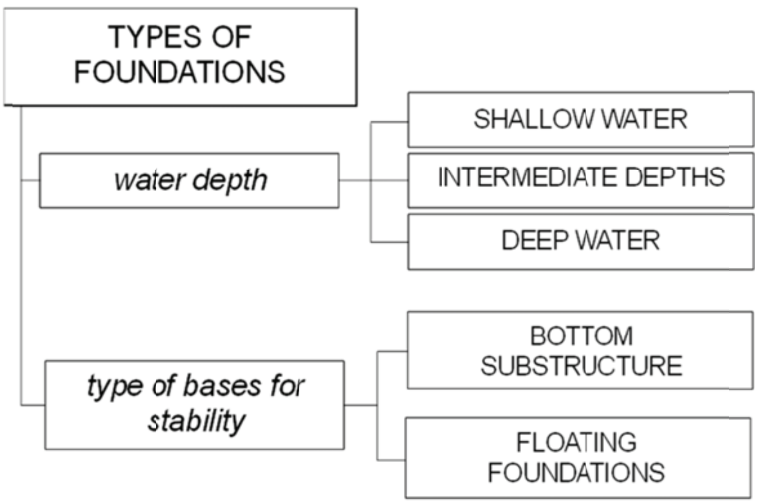

Fig. 3. Foundations of offshore wind power turbines

Foundation technology is designed according to site conditions. Water depth, maximum wind speed, wave heights currents, and surf properties affect the foundation type.
According to the water depth, we can distinguish shallow water, intermediate depths, and deep water types of the offshore wind turbine foundations, whereas their stability can be achieved by fixed bottom structures or floating foundations (Fig. 3).
We can distinguish the following fixed bottom substructures:

- a monopile (single column) base used in waters up to 30 meters deep,
- gravity base structures, for use at exposed sites in water 20-80 m deep,
- suction caisson structures, in water 20-80 meters deep,
- tripod piled structures, in water 20-80 meters deep,
- conventional steel jacket structures, as used in the oil and gas industry, in water 20-80 meters deep.

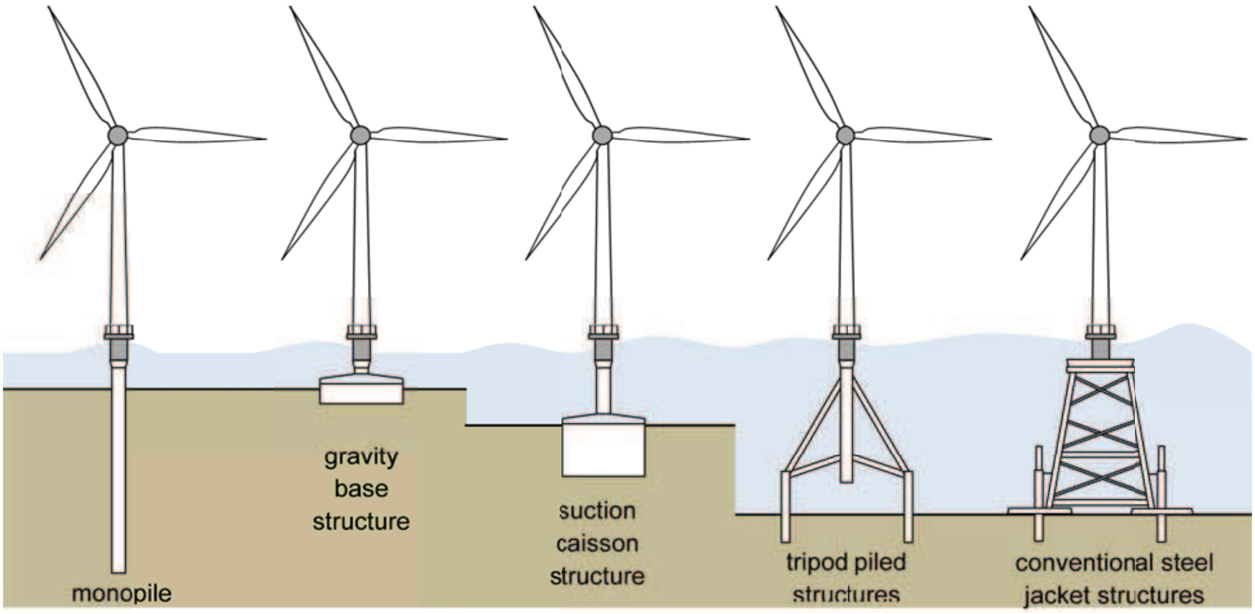

Fig. 4. Fixed bottom substructures of offshore wind power turbines

The monopile consists of a steel pile which is driven approximately 10 - 20 meters into the seabed. The foundation consists of a steel pile with a diameter of between 3.5 and 4.5 meters.

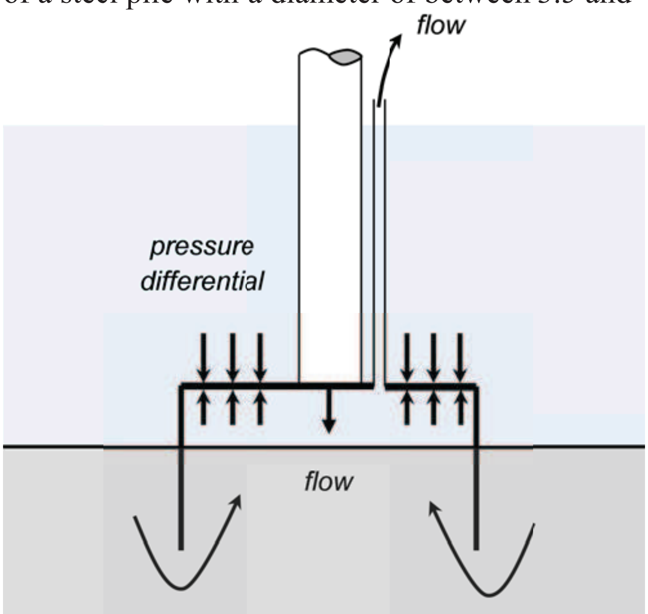

Fig. 5. Graphic representation of achieving hydrostatic pressure difference

The pile is driven some 10 to 20 meters into the seabed depending on the type of underground.
The gravity foundation consists of a large base constructed from either concrete or steel which rests on the seabed. Steel is lighter and normally filled with granular material or concrete.
A suction caisson structure have tubular steel foundation installed by sealing the top of the steel bucket and creating a vacuum inside. Hydrostatic pressure difference and the dead weight of the structure cause the bucket to penetrate the soil (Fig. 5).
The tripod foundation structure based on technology used by the oil and gas industry. The piles on each end are typically driven 10 -20 meters into the seabed, depending on soil conditions. This technology is generally used at deeper depths.
The conventional steel jacket structure used a jacket foundation, similar to a lattice tower. The jacket foundations allow to install its turbines 10-15 miles offshore.
In the offshore oil and gas industry, the water depth limit for fixed platforms is about 450 m. In the offshore wind industry, the limit is likely to be less than 100 m because of economic conditions.
Floating structures consist of a floating platform and an anchoring system. There are several alternative designs for floating turbine foundations all of which are variations on the spar and tension-leg concepts in the oil and gas industry.
Floating turbine foundations can be (Fig. 6):

- barges,
- spar buoys,
- tension leg platforms (TLP).
- The barges achieves stability from the large water plane area-to-volume ratio that allows it to remain buoyant in water.

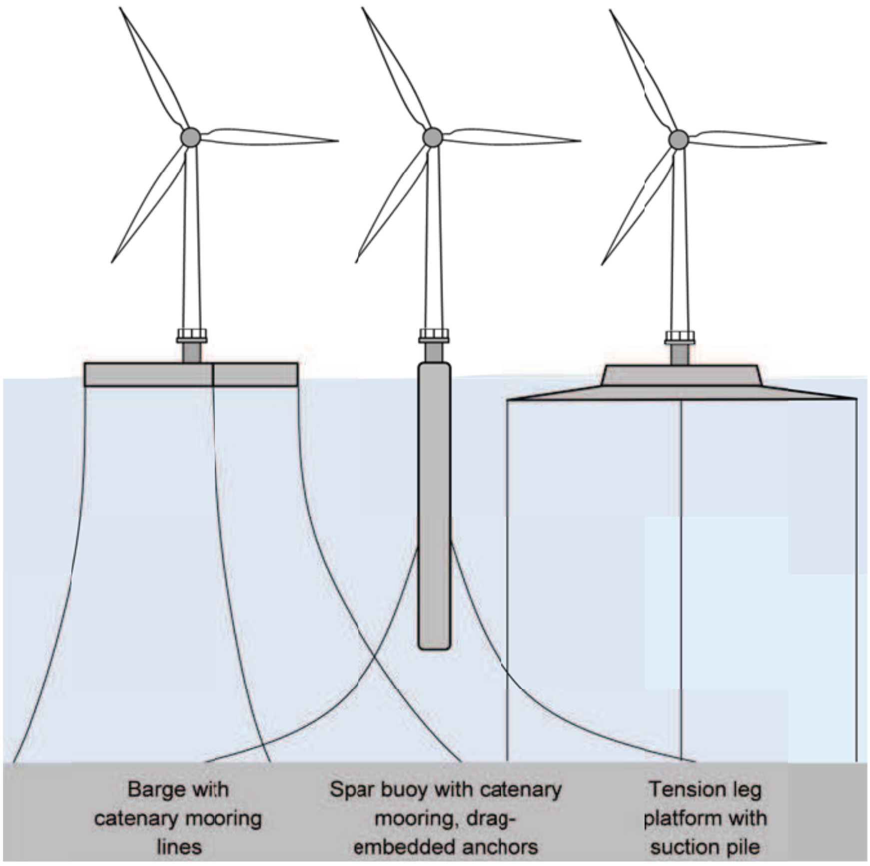

Fig. 6. Floating foundations of offshore wind power turbines

The spar buoys are designed for deeper waters of up to 300 meters. It incorporates an elongated cylindrical tank with a high aspect ratio, which holds ballast at the tank bottom. The ballast helps

to lower the center of gravity of the tank and make it more stable. In addition, the spar buoy is moored to the ocean bed with either taut or catenary lines to provide further stability.
The tension leg platforms are examples of semi-submersibles, which are installed below the zone of major wave action so that they are essentially anchored in still water. They achieve stability through the use of vertical mooring lines that are attached to tank legs and tensional by the reverse buoyancy of the tank. Only a slender member breaks the surface, which also reduces the wave loads.

4. Vessels and crafts servicing offshore wind power systems

Manufactured components of offshore wind farms need to be transported, installed, and maintained. At present, only a limited capacity of dedicated units is available on the market, resulting in the development and construction of new ones. Ships and offshore structures, such as offshore wind farm construction vessels and service crafts, could be purpose build or converted. These designs might deviate from existing ship types currently employed in the offshore oil and gas industry, such as Mobile Offshore Drilling Units (MODU) and Offshore Supply Vessels (OSV). Availability of offshore vessels and platforms is a prerequisite for the timely achieving of EU targets regarding the renewable energy. Only a minority of ships serving the construction and maintenance of offshore wind farms are purpose built. Among the existing service vessels some are only marginally converted or adapted to perform their new function in a very demanding environment.
Offshore wind farm units designed for transporting, installation and maintenance offshore turbines and their units can be two main types (Fig. 7):

- offshore wind farm construction vessels (OWFCV),
- offshore wind farm service crafts (OWSSC).

This terminology is accordance with practice used at IMO forum, what was presented by Germany delegation during 56 session of Design and Equipment Subcommittee of IMO [10].

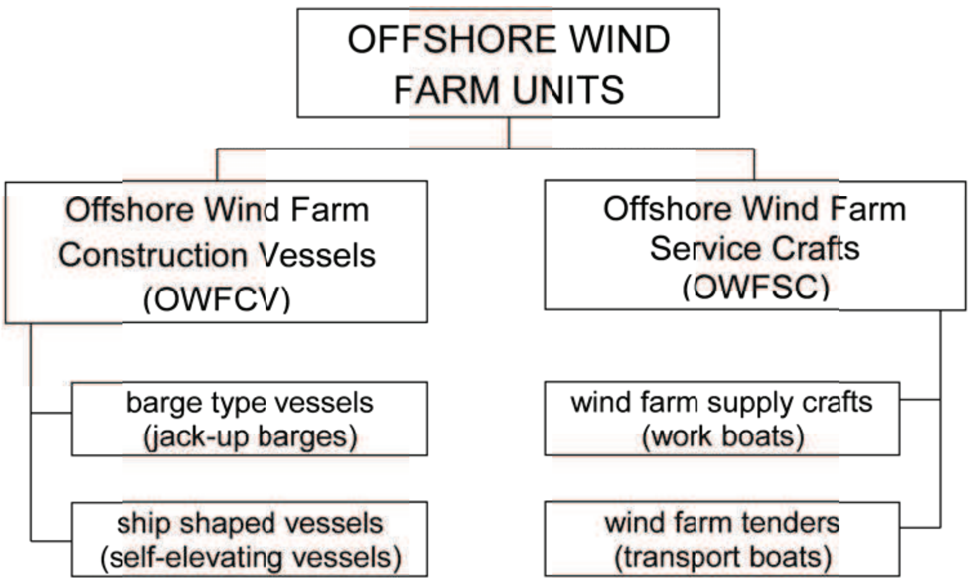

Fig. 7. Types of offshore wind farm units

Offshore Wind Farm Construction Vessels (OWFCV) are designed to carry out foundation work, tower and turbine installation as well as maintenance work during the operation phase. They can be either barge type or ship shaped and can be both self-propelled or without propulsion.

Fig. 8. Jack-up barge for installation of offshore wind farm

The jack-up barges are floating units that are capable elevating themselves at the construction site on their jack up legs (Fig. 8). They are not self-propelled units and they must be towed to the construction site. The service speed of the barges is dependent on the tug's power (a speed of 5 knots can be assumed). Jack-up barges do not have Dynamic Positioning Systems (DPS) that allows a unit to automatically maintain its position through the coordinated control of thrusters. Jack-up barge cargo capacity ranges from 900 to 2000 tons in terms of weight. Their operational water depth (max) is in the range of 18 to 50 meters and leg lengths are 40 to 82 meters whereas their jacking speed is generally in range of 0.15 to 0.8 meters/minutes.

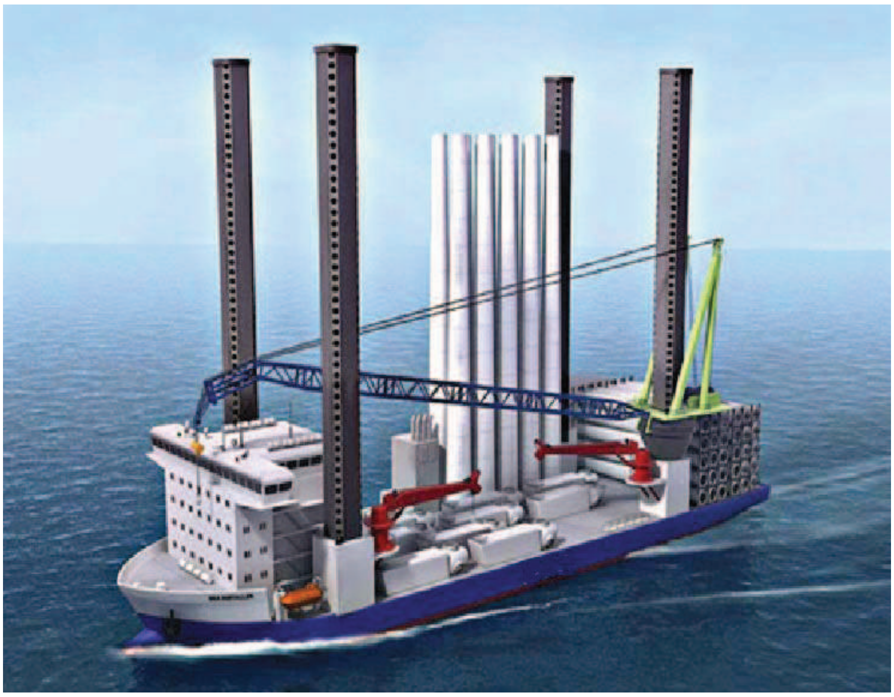

Fig. 9. Ship shaped vessel for transportation and installation of offshore wind farm

Ship shaped vessels are self-propelled units that are specially designed in line with the industry demands. These purpose-built self-propelled transportation and installation vessels have jack up legs and cranes with big lifting capacities. Their maximum operational water depth ranges between

24 meters and 45 meters while the leg lengths are varying from 32 meters to 85 meters.
The service speed of the ship shaped vessels is in the range of 7.8 to 12.5 knots and the jacking speed is in the range of 0.35 to 0.8 meters/minute.
Ship shaped vessels have Dynamic Positioning Systems which enables them to stay constant at a certain point to be able to land their legs on the exact locations precisely.
The self-propelled vessels with dynamic-positioning system can easily cost 3-5 times as much as juck-up barges with the same crane capacity and jacking system [11]. A self-propelled vessel can achieve higher transit speeds than a towed barge and can work independently (without tug boats).
Offshore Wind Farm Service Crafts (OWFSC) are designed with the versatility to allow them to provide offshore support on offshore wind farms, for survey work, for remotely operated vehicles (ROV) and dive support. They can be used to transport service personnel, parts and tools offshore on the wind farm. Internally they have some places for seating or accommodation of service crew. Externally they have sufficient working deck aft and they can be fitted with a customized bow section designed for safe personnel transfer.

5. Take-off systems of vessels servicing offshore wind farms

Power plants of Offshore Wind Farm Construction Vessels can provide energy for various purposes, mainly for:
– jacking units out of the water,
– working of cranes,
– propulsion and dynamic-positioning of the vessel.

Diesel engines compose the majority of power sources on OWFCVs. They drive large electric generators, which produce electricity that is sent through cables to electric switch and control gear.
The primary machinery requirements for OWFCVs are the jacking system and the crane. Since they do not operate simultaneously, a single power plant can be used to power both systems. Cranes capable of lifting turbine components require as much as a few thousands kilowatts of power supply. This amount of power should suffice for a jacking system that meets lifting capacity and jacking speed requirements for a vessel carrying three to four complete sets of turbine components. Heavier vessels with larger jacking system requirements will require more installed power.
The self-propelled vessels will require a separate plant providing approximately 20000 kW of power to the propulsion system, which can also be used to power a dynamic-positioning system. This power plant could also power the crane, but is unlikely to suffice for simultaneous operation of the DP system and the jacking system.
Depending on whether condition, OWFCVs can perform the necessary steps to jack up within approximately eight hours. The jacking process is the following:
– position the vessel at a target location,
– lower the legs,
– elevate the hull out of the water,
– pre-load the legs.

The purpose of pre-loading is to prove the soil’s load-bearing capability. This can be achieved by pumping sea water ballast into the vessel hull or by selectively raising one leg at a time (on vessel with four or more legs) in order to transfer load to the lowered legs. To achieve even heel and trim prior to jacking operations, the OWFCVs require a relatively robust ballasting system.
OWFCVs are trending toward four-leg configurations of the jacking system. The oil and gas industry typically uses three-leg jack-ups. The reason for using four legs is to reduce the time required to pre-load the legs (i.e., test the soil). A three-legged rig requires sea water ballasting to achieve pre-load. With four legs, pre-loading can be achieved by lifting one leg at a time, thereby transferring loads to the other legs. A fourth leg also provides redundancy in the event of a single-leg failure. Nevertheless, there are six-leg configurations of the jacking system what decrease of its

power supply per leg. Leg profile cross-section can be tubular, rectangular or lattice. As a rule, the jack-up legs are to be fitted with spud cans. They consist of a plate or dish designed to spread the load and prevent over penetration of the leg into the sea bed. Spuds are circular, square or polygonal, and are usually small.

A continuous hydraulic jacking system or a rack and pinion system can be applied for vessel elevating. A jack-house contains and protects the jacking system. In the four jack houses, on two elevations, a set of hydraulic or electric sea fastening devices should be installed. These devices consist of plates and a hydraulic or electric device to fix the legs during transport.

Lifting out of the water induced larger loads on the legs, which in turn required the size to be increased. The increased leg size had a knock on effect, the winches had to be enlarged and the number of reeving's increased m order to achieve the required lifting capacity. The increased size of each of the components amplified the associated costs.

Currently the installation of offshore wind farms involves using heavy lift cranes. They should be best suited for transporting and handling the foundations for the latest generation of up to 6 MW offshore wind turbines, as well as the turbine towers, nacelles, rotors and blades. As a rule, cranes are operated in the elevated position, however there are OWFCVs specially designed for crane operations in the floating condition. The lifting performance in floating condition is established by means of ballasting. The heavy lift cranes should fulfill the following requirements:

- maximum weight to be lifted ('pick weights'),
- maximum height above sea surface,
- needed spatial clearance for objects being lifted.

Moreover, they should be large enough to lift anywhere on the vessel deck, this negates any requirements for skidding large sensitive equipment. The weight of the crane should be kept as small as possible to reduce unnecessary loads on the stabilization legs. As a rule the heavy lift cranes are fully integrated into the vessel hull. The heavy lift cranes can be hydraulic or electric driven. The crane requirements for installation of 3,6 MW and 5 MW offshore turbines and monopole foundations are presented in Table 1.

Table 1. Crane requirements for turbines and associated monopile foundations

Parameters	**Siemens 3.6 MW**	**REPower 5 MW**	**Monopiles**
Maximum pick weight	138 tons	320 tons	200-500 tons
Maximum pick height	80 meters	85-90 meters	less than 30 meters

Existing OWFCVs can operate their cranes in up to 18 knots wind speed at the deck level (approximately 25 knots at the crane tip) and can jack-up and down in seas as high as 1.5 to 3 meters (significant wave height).

In a case of OWFCVs, their power plants supply of energy necessary for propulsion and steering. They can be fitted with several azimuth thrusters for propulsion, maneuvering and dynamic positioning and few bow thrusters for maneuvering and dynamic positioning. As a rule, diesel electric propulsion is used for vessel's propelling. Electric power is generated by several diesel driven generators. The vessel with a clean hull, sailing on even keel in deep water with sea state not exceeding 2 and wind force not exceeding 2°B can achieve the speed up to 12 knots. The azimuth and tunnel thrusters have fixed pitch subject to dynamic positioning (DP) analysis.

OWFCVs are equipped with a dynamic positioning system. All wiring, arrangement and components are suitable for DP operation. The dynamic positioning system can operate as a minimum in the following modes:

- standby mode: the vessel's position is not actively controlled by the DP system,
- manual mode: the vessel's position can be controlled by the operator,
- auto mode: the system keeps the vessel at the given position and heading with high accuracy; the position is measured by the use of the position reference systems,
- mixed manual auto mode: the operator may select a combination of manual and automatic positioning, and can control one or more of the three axes (surge, sway and yaw) manually as

in the manual mode, while the remaining are controlled automatically by the system as in auto mode,

- auto track mode: the vessel is able to follow a predefined track of way-points,
- anchor control mode,
- auto pilot mode allowing the DP system to control the vessel heading,
- jacking mode.

The DP system can use the following systems as position reference:

- DGPS different satellite systems, which should be capable to read GPS and Glonass signals at the same time, as well the Galileo signal in the future,
- external DGPS input from mobile, mission based equipment,
- external reference systems (laser or radar based).

The DP system must be based on a mathematical model and control all thrusters in thrust and direction. Moreover, it should control the vessel thrusters in most optimum way, utilizing mathematical modeling of vessel behavior in order to provide the required positioning accuracy and reliability for the various modes of operation.

According to the technical specification of the offshore wind farm construction vessel VIDAR [12], electric power is generated by six diesel driven generators with rated power approximately 4000 kW and one 700 kW emergency generator. Diesel electric propulsion is used for vessel propelling and dynamic positioning by means of four azimuth thruster motors and three tunnel thruster motors with rated power 2 600 kW and 2 500 kW respectively.

The VIDAR power plant provides 20 000 kW total power, what guarantees the following operating parameters:

- service speed 10,2 knots with minimum three aft azimuth thrusters working at 85% power,
- lifting force 24 000 ton with lifting speed up to 1 m/min,

The VIDAR main features will be a 1 200 ton crane, a loading capacity of up to 6 500 tons, and the ability to work in water depths of up to 50 meters. These properties will make the VIDAR one of the most powerful lifting vessels in Northern Europe.

6. Conclusion

Wind power is one of the most important and promising forms of renewable energy being developed. The increasing demand to produce renewable energy from the offshore wind power forces developing the various structural designs of offshore units. Manufactured components of offshore wind farms need to be transported, installed, and maintained. These tasks are realized by ships and offshore structures, such as offshore wind farm construction vessels and service crafts. Their more and more complicated power plants have to provide energy for various purposes, mainly for: jacking units out of the water, working of cranes and, propulsion and dynamic-positioning of the vessel. Therefore their operation and maintenance requires preparing the appropriate qualified personnel. Such personnel should be educated and trained at faculties of technical and maritime universities, where offshore units are subjects of their interest.

Acknowledgment

The author is a chairperson of Polish department for Subcommittee of Ship and Equipment Design of International Maritime Organization from 1996.

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