From existing units to dedicated units for the offshore wind farm installation

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Summary
This paper discusses the development of offshore Wind Turbine Installations units. Following an overview of the offshore wind turbine potentials as an emerging market especially in Europe and the different wind turbines, this paper will concentrate on the different designs being used in the industry. Requirements are set and the different applications will be discussed.
Although at present existing jack-ups are being modified for the installation of wind turbines, we foresee that quite a number of new build units will be required in European waters to achieve the objective of 35,000 MW installed by 2020. In addition to the installation units, a number of dedicated Inspection, Maintenance and Repair (IRM) units will also be required.

Introduction
The development of offshore wind farms is an emerging market, especially in Western Europe, with many initiatives by several governments supporting this part of the renewable energy sector. Market prospects are booming with installed offshore power in Europe standing at over 2,000 MW in 2009, this is expected to grow steadily towards 30,000 – 35,000 MW in 2020. New developments are also planned for the USA and China.
With increasing demand for offshore wind farms, these wind farms need to be manufactured, installed, commissioned 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.
This paper will discuss the development of offshore wind farms, in short: the installation methods and today's installation equipment. Some conclusions will be drawn for the future in terms of greater water depth and maintenance requirements.

Offshore wind farms

Typically, offshore wind farms are developed in a grid of approx.100 units. The power capacity of the individual wind turbine ranges between 2 and 5 MW, with two main manufacturers producing 3.6 MW units and three manufacturers with 5 MW turbines. The rotor diameters vary between 85 and 125 m. Turbine weights (nacelle and rotor) are in the range of 200 – 450 tons, whereby the nacelle is at an elevation of 70 – 90 m above sea level. See figure 1.

The design criteria for the crane are set by the maximum weight to be lifted and in addition the outreach in vertical and horizontal direction, thus the 450 ton at a height of 90 m above sealevel.

The second aspect are the foundations of the wind turbines. Several foundation types have been developed for the present water depth of up to about 45 m, e.g. monopiles, suction pile foundation, tripod foundations with piles or small standard jacket structures. The choice of the most suitable foundation will depend on water depth, soil conditions and overturning moment caused by the wind turbine forces. The foundations structures must be installed in a true vertical plane with very small tolerance, providing a challenge to the installation contractor. See figure 2.

Thirdly, the transition piece between the foundation and the tower offers an opportunity to adjust any of the required tolerances. The transition piece is also equipped with platforms and boat landings as a point of entrance to the Wind Turbine Units. These three elements are recognized in all offshore wind turbines.

Each individual wind turbine will be linked through a central transformer platform with a high voltage direct current transmission to the shore connection. The individual cables running between the turbines and the central platform and the connection to shore are to be installed with dedicated equipment. See figure 3.

In Europe there are various different incentive systems encouraging offshore wind energy. The tariff payable to supplied energy is the central component. The combined maximum tariff paid varies in the different European countries in the range between 7 – 15 eurocents per KWh. Based on this tariff the energy company must take care of investment, installation, operation and maintenance. As about 10% of the total investment can be spent on installation of the Wind Turbines, the pressure is on the installation contractor to provide cost effective installation solutions. The challenge for the industry is to develop efficient installation equipment and a proper logistic system and stay within these budget figures.

Installation methods for offshore wind farms

The installation can be split into different phases, i.e. installation of the foundations, installation of the transition piece, installation of the tower, installation of the nacelle and installation of the rotor and the blades, in one piece or several pieces.

The installation of the foundation structures is generally carried out by crane vessels or heavy lift units. One of the reasons for installing foundations with crane vessels is because their size and weight are above the capacity and capability of existing wind turbine installation units.

At this moment the Stanislav Yudin is installing the foundations for the Greater Gabbard wind farm. The Svanen has been used for the Egmond Amalia field, while the Rambiz is being used for the Thornton Bank wind farm.

The installation of transition piece, tower, nacelle and rotor is performed using wind turbine installation vessels or jack-ups. These elements will be translated into design requirements for the installation units. An example of a retrofit for lifting operations is shown in figure 5.

The critical weight and reach requirements for lifting the nacelle and rotor and blades are:

- lifting weight of max. 450 tons for a 5 MW turbine
- lifting reach of up to 90 m above sea level.

Existing units presently active in the wind turbine installation market

In an upcoming market it is common to see existing equipment or conversions being used for installation activities. The wind turbine installation market will be no different in that perspective.

Today a contractor such as A2SEA operates a couple of converted vessels and general purpose jack-ups. Other contractors are using standard jack-ups, like the Buzzard, Pauline and Vagant. See figure 6 and 7.

A noteworthy difference between the A2SEA vessels and the other equipment is the ability to take several sets of blades and nacelles in one haul, while the others can only carry one at a time.
Here one can pose the question of logistical efficiency during the installation sequence.
The only dedicated new build Wind Turbine Installation Unit (WTI Unit) is the MPI Resolution which entered service in 2003. At the time of starting operations, it was a sophisticated and efficient unit equipped with a 300 ton crane for installation purposes. This WTI Unit was intended to install the complete Offshore Wind Farm, from foundations up to the rotors. However it transpired that the foundations tended to be heavier than the crane capacity. Consequently, GustoMSC designed a pile upending tool to handle the heavier monopiles. Final installation is carried out with the main crane. See figure 4.

Future requirements for offshore wind turbine installation vessels

Based upon the experience gained by the contractors and GustoMSC new trends were recognized and design requirements redefined:

- trend towards going into deeper waters beyond the 40 m requires foundations of tripod or jacket sizes, tending to be over 700 tons in weight,
- trend towards increasing the capacity of the wind turbine power output to 5 MW or over resulted in nacelle weights of 450 tons or over,
- trend towards installing multiple wind turbines in one haul resulted in an increase in available deck space and transit capacity requirements.

Combining these operational trends and requirements, one should consider where to split the operations. At present two types of vessels are being used, i.e. construction vessels with large crane capacity like the Stanislav Yudin and self-propelled DP2 WTI units. The first ones are effective for installation of the foundations where ample crane capacity is available.
The WTI Units are more critical to transit capacity and lightweight as the combined weight is to be jacked-up. Weight considerations are of prime importance for obtaining a cost effective unit.

Design considerations for new build WTI units are:

1. The intended offshore location will define water depth, soil conditions and environmental conditions which are important not only for the design of the wind turbine installation but also for the WTI Unit.
2. Offshore location and shore base will define the sailing time. When offshore wind turbines are to be installed in a rapid sequence, the transit time and transit payload are of importance.
3. Although the new build units are mostly self-propelled and DP, one should consider the question between self-propelled and towed, exchanging CAPEX versus OPEX.
4. Jacking speed and DP power determine the total installed generating power. The jacking speed and elevating weight will define the generating power required for the jacking operations. The environmental conditions in which one decides to operate under full DP control will define the generating power.
5. Deck space must be seen in relation to the variable load of the unit. How many towers, nacelles and rotors would be transported in one haul?
6. The number of legs will have an impact on the total costs of the unit.

Discussion of design considerations and GustoMSC's approach

First of all, intensive discussions have been arranged with the parties involved in the Offshore Wind Turbine market to understand the needs, requirements and wishes. So far, a single conclusion could not be drawn as contractors have their own views about the installation market. Sometimes the time line was of relevance, as for instance the earlier projects with the crane capacities limited to 300 – 500 t hoisting capacity. As the wind turbine manufacturers continued their developments, the sizes start to increase to approx. 5 MW turbines, resulting in greater crane hoisting requirements. Now the contractors' requirements tend to be WTI Units with a crane capacity of 800 tons. The tendency for deeper water will mainly affect the

foundations, which could require crane capacity of 1,200 tons to cover the majority of projects. These cranes can be mounted on pedestals or on top of the jackhouse rotating around the leg.
Operational limitations can be part of the selection process for the unit. To date three different methods are being used for wind turbine installation units, namely vessels using the legs only for stabilizing, jack-up units with wave height restrictions and jack-ups for all-year operations for the intended locations.
The first two types of units are dependent on weather routing / forecasting to start and to discontinue operations. The vessels should be in near-shore locations to avoid storm conditions. The latter units can remain at location is the weather worsens and wait on weather offshore.
Offshore location and shore base distance combined with equipment available have led in two directions: conversions and upgrading new build jack-up units.
The A2SEA vessels have been upgraded by adding legs to existing vessels and outfitting the units with suitable cranes. These units are classed as surface units with stabilizing legs with a crane capacity of 100 tons and are not elevated with the complete hull above sea level. Consequently these vessels have a limited operating workability.
The second approach is the use of recently delivered jack-up platforms to be outfitted for the wind turbine installation market. These jack-ups are a general type of construction unit without thrusters; consequently these units have to be towed to location. The Sea Worker, JB-114. JB-115, Buzzard and Vagant are examples of such a configuration. Although delivered as general construction units, main cranes have been added or upgraded, resulting in lifting capacities up to 300 tons with extended boom length to install the nacelles and rotors.
The self-propelled jack-up unit was initiated by MPI Offshore with the installation vessel Resolution. The company decided on a 6-legged unit which could be elevated completely out of the water and was self-propelled, including DP capability. At the time of building the maximum crane size was defined at 300 tons for all types of operations. GustoMSC assisted MPI in the jack-up technology and the delivery of the double acting jacking systems to improve on the jacking speed.
This unit set the trend, as the majority of new building plans are self-propelled and dynamically positioned. The choice for CAPEX has been made to obtain a higher flexible unit instead of OPEX with non-propelled units. Examples are the Seajacks' Seajacks Leviathan, Bard Engineering's Wind Lift 1 and the 2 new build units for MPI Offshore.

A jack-up unit is a weight sensitive design as the legs have to carry the weight and to withstand environmental forces. The lightweight and variable loads are to be jacked out of the water. So in the event that one decides to carry quite a few wind turbine elements, the trade off is a larger unit and more expensive jacking and leg systems.
Each operator should balance these two and not only add weight and increase size, as this will escalate building costs and consequently diminish the financial returns.
The present new designs range from 5,500 t up to 21,000 t elevated weight.

Another topic in the industry is the required jacking speed. GustoMSC has several alternatives developed and delivered, being:
- Rack and Pinion systems with a platform lifting speed of 60 m/hr and leg handling speeds of 90 m/hr
- non-continuous hydraulic jacking systems with platform lifting speed of about 12m/hr and leg handling speed of over 40 m/hr
- non-continuous HPE hydraulic jacking systems with platform lifting speed of 24 m/hr and leg handling speed of 60 m/hr
- continuous hydraulic jacking system with platform lifting speed of up to 60m/hr and leg handling speeds up to 100 m/hr.

Here, too, a more complex system and higher jacking speed will result in a more expensive jacking system and more generating power required for jacking.
Another parameter one should consider is the balance between overall hull size, jacking speed and generating power. The present units are all self-propelled with a DP2 notation, which means an overcapacity in power generation and thruster capacity to meet the DP2 notation under the specified weather conditions.

The jacking speed on the other hand will also be translated into the power generation: the higher the speed, the more power is needed.
For the transit condition the installed thruster requirement ranges from 3,000 kW up to 10,000 kW.
Arriving on location, the DP capability will be used in combination with the jacking system which will result in a power requirement in the range of 5,500 KW to 11,500 KW. For the DP2 notation the required power generation to be installed is based on a 4 or 6 engine lay out with a capacity of 6,500 kW to 14,000 KW.
For lifting the platform to the required airgap, the power requirements will depend on the platform weight and jacking speed and can vary between 2,000 KW and 4,500 KW.
Thus the DP2 notation will determine the investment costs for thrusters, power generation and control systems.
In the drilling industry, three-legged units are the standard as these units remain at the same location for quite some time. For installation / construction platforms the general tendency is a four-legged unit, as preloading can be carried out quite quickly by diagonal use of two sets of legs. No need for additional time for taking in ballast water in the case of a 3-legged unit. GustoMSC's preference is a 4-legged unit as the most efficient and cost-efficient unit.

How has GustoMSC translated these design criteria and design considerations into units for the installation of offshore wind turbines?
Based upon the above, GustoMSC has developed the SEA series as non-propelled jack-ups and the NG series as self-propelled units with DP2 capability as WTI Units.
For the SEA series, the SEA2000 class equipped with a 300 ton crane with extended boom length is just on the edge. The units operating in this manner are the Sea Worker, JB-114, JB-115 and Goliath (see figure 9). To enhance these units with additional carrying capacity, the next design in line is the SEA-3250.
For the NG series of WTI units, a range of designs have been developed; these are based on different crane capacities, variable loads and water depth. The units range from the NG-2500X to the NG-10,000. See figure 10.
This range of WTI units can serve the present market requirements in terms of crane capacity, deck load capacity and water depth requirements.

What does the future hold for installation units?
It is our belief that the present range of designs covers the current installation market. The number of units (operational or under construction) is still not in line with the proposed projects or offshore wind farm projects under development. Additional units will probably be required in the near future to meet the demand for installation vessels. Our view is that about 20 new builds will be necessary to fulfill the objective of 35,000 MW installed power by 2020.
At this moment the industry is mainly focusing on the installation market, but with the increasing number of offshore wind farms, the maintenance requirement will also arise. Smaller units should be developed for inspection, maintenance and repair. The crane capacity for these units could be around 100 tons. Variable load requirements are significantly less, around 750 tons, with limited accommodation capacity of approx. 30 persons. The unit in this line could be a NG-2000 or NG-2500 class. Depending on the IRM scenario, a number of dedicated units are to be built.

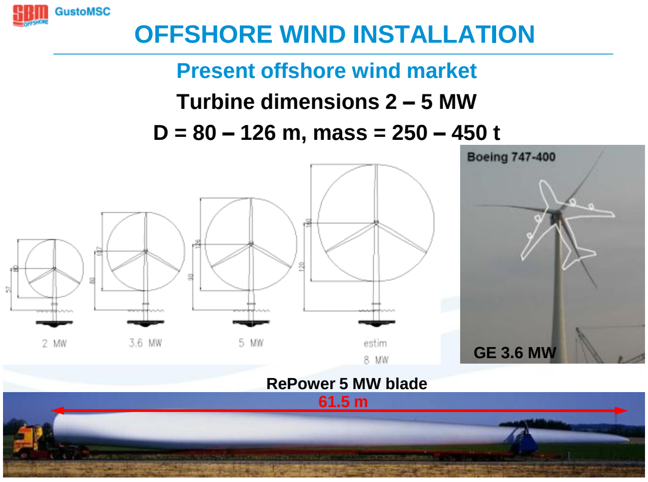


Figure 1

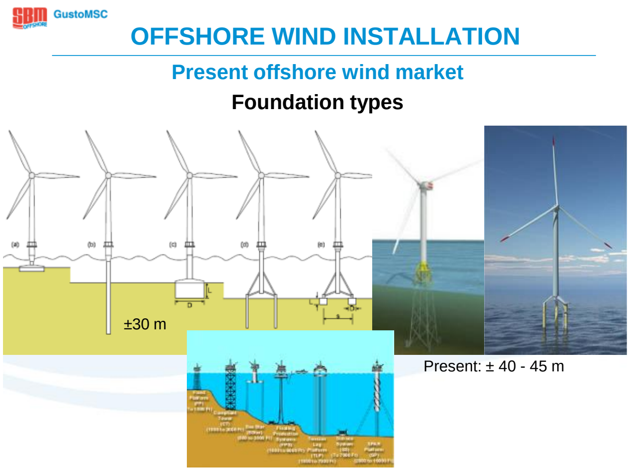


Figure 2

Figure 3: Transmission platform ready for tow out
(courtesy Heerema Fabricators)

Figure 4: Upending tool

Figure 5: Buzzard with Tower Crane

Figure 6: A2SEA equipment

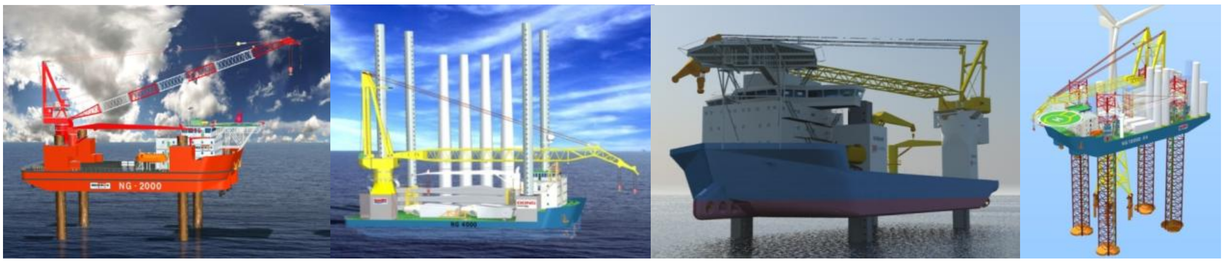
Figure 7: GEOSEA equipment

Figure 8: JB-114 at Alpha Venture

	SEA 800	SEA 900	SEA 2000	SEA 3250
Number	1	1	4	-
Hull (m)	43.5 x 22.5	48 x 23.5	55.5 x 32.2	72 x 40
Leg length (m)	57.5	60 m	73.2	92
Water depth (m)	30	30	40	45
Var. load (t)	1,000	1,100	1,250	2,500

Figure 9: SEA series of Wind Turbine Installation units

	NG600	NG2500	NG5300	NG7500/6
Number	1	2 + 3	1	2
Hull	55 x 18 m	61 x 36 m	93 x 36 m	137 x 40 m
Power gen. set	2 x 560 kW	4 x 1,600 kW	4 x 2,600 kW	6 x 2,250 kW
Crane	Crawler 60 t	300 t @ 25 m	500 t @ 31 m	1,000 t @ 25 m
Water depth	25 m	60 m	45 m	40 m
Var. load	500 t	1,000 t	2,700 t	7,000 t



	NG2000	NG4000	NG7500	NG9000	NG10000-X4
Hull	60 x 34 m	81 x 40 m	95 x 39.6 m	128.9 x 39 m	115 x 50 m
Power gen. set	4 x 1,600 kW	4 x 1,600 kW	4 x 2,500 kW	4 x 4,300 kW	6 x 2,250 kW
Operating w.d.	40 m	40 m	45 m	45 m	65 m
Var. load	950 t	2,750 t	4,000 t	6,100 t	6,500 t
Crane	200 t @ 26 m	800 t @ 24 m	800 t @ 24 m	800 t @ 24 m	1,200 t @ 30 m

Figure 10: NG series of Wind Turbine Installation units