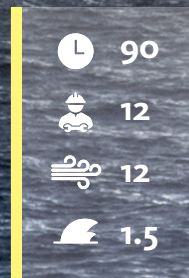
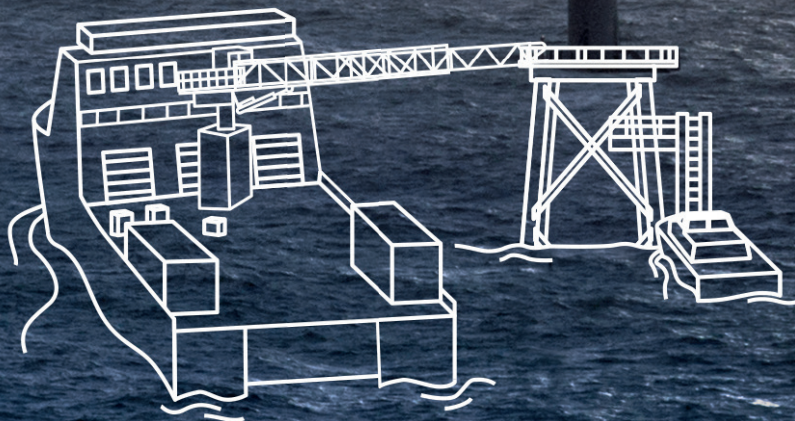


# Offshore Wind Access 2017

G. Katsouris  
L.B. Savenije

December 2016  
ECN-E-16-013



⌚ Response Time [minutes]

👤 Technician Capacity

🌬️ Maximum Wind Speed [m/s]

🌊 Maximum Wave Height [m]



Although the information contained in this report is derived from reliable sources and reasonable care has been taken in the compiling of this report, ECN cannot be held responsible by the user for any errors, inaccuracies and/or omissions contained therein, regardless of the cause, nor can ECN be held responsible for any damages that may result therefrom. Any use that is made of the information contained in this report and decisions made by the user on the basis of this information are for the account and risk of the user. In no event shall ECN, its managers, directors and/or employees have any liability for indirect, non-material or consequential damages, including loss of profit or revenue and loss of contracts or orders.

# Contents

|                                        |           |
|----------------------------------------|-----------|
| <b>Summary</b>                         | <b>5</b>  |
| <b>1 Introduction</b>                  | <b>7</b>  |
| 1.1 Offshore wind O&M background       | 7         |
| 1.2 Objective and report outline       | 10        |
| <b>2 Access systems overview</b>       | <b>11</b> |
| 2.1 Access to the boat landing         | 12        |
| 2.2 Access to the platform             | 17        |
| 2.3 Access to the helideck             | 24        |
| <b>3 O&amp;M modelling</b>             | <b>25</b> |
| 3.1 Approach                           | 25        |
| 3.2 ECN O&M Access                     | 26        |
| 3.3 Case study                         | 26        |
| <b>4 Conclusions &amp; future work</b> | <b>31</b> |
| 4.1 Conclusions                        | 31        |
| 4.2 Future work                        | 32        |
| <b>Bibliography</b>                    | <b>33</b> |





# Summary

Offshore wind farms in Europe are constantly moving further from shore in order to capture the favourable wind conditions. However, challenges regarding their installation, Operation and Maintenance (O&M) become more prominent. Specifically, O&M costs contribute significantly (20-30%) to the Levelized Cost of Energy (LCOE) over the lifetime of an offshore wind farm. One of the main reasons is the low accessibility to the wind farm which increases the downtime and the revenue losses due to loss of energy production, especially for far-offshore wind farms. The latter has driven the research on innovative access systems which promise average yearly accessibility of 90%.

In this report, an overview of the current and under-development access systems is presented as the first effort for including all available access systems for offshore wind in one document and ECN intends to update it every year. Based on the point of access, three categories are identified: i) Access to the boat landing, ii) Access to the platform of the transition piece and iii) Access to the helideck on top of the nacelle. Besides the conventional method of access to the boat landing through Crew Transfer Vessels (CTVs), motion compensated gangways on the deck of Service Operation Vessels (SOVs) have entered the market during the last decade, moving the maintenance base offshore. The analysis shows the growth of this market in alignment with the needs for more efficient and safer transfer of technicians and cargo to offshore wind turbines.

In order to assess the impact of selecting a particular access system, the importance of modelling the O&M activities in offshore wind farms is outlined. By doing so, design drivers can be identified, business cases of new systems can be established and optimal decisions can be made both for defining the O&M strategy and choosing the access system. This analysis is possible through ECN's in-house developed tool "ECN O&M Access", an operation and maintenance cost estimator specifically developed for designers and developers of maintenance vessels and access systems for the offshore wind industry. In this work, a reference wind farm is chosen for which harbour and offshore based O&M strategies are compared. The access systems that are considered include CTVs, CTVs combined with helicopter and SOV including motion compensated gangway. The results of this study show that wind farm availability varies between 94% to 96% and suggests harbour based strategy as the optimal in terms of O&M Cost of Energy (COE) minimization considering the relatively small distance from shore.

Last, the findings of this work are concluded. The market overview of the access systems shows that the relative short distance from shore of the existing offshore wind farms has driven the extensive use of CTVs but as offshore wind farms move further from shore, more SOVs are being deployed, helicopters become the norm and new designs for motion compensated gangways are being introduced. In the context of future work on O&M logistic concept and access system selection, ECN is improving its O&M simulation capabilities to account for all relevant environmental conditions by combining ECN's modelling expertise with vessel hydrodynamic calculations performed by MARIN and the study about the effect on technician performance performed by TNO.

**Keywords:** offshore wind, operation and maintenance, accessibility, crew transfer vessels, service operation vessels, motion compensated gangways, ECN O&M Access

# 1

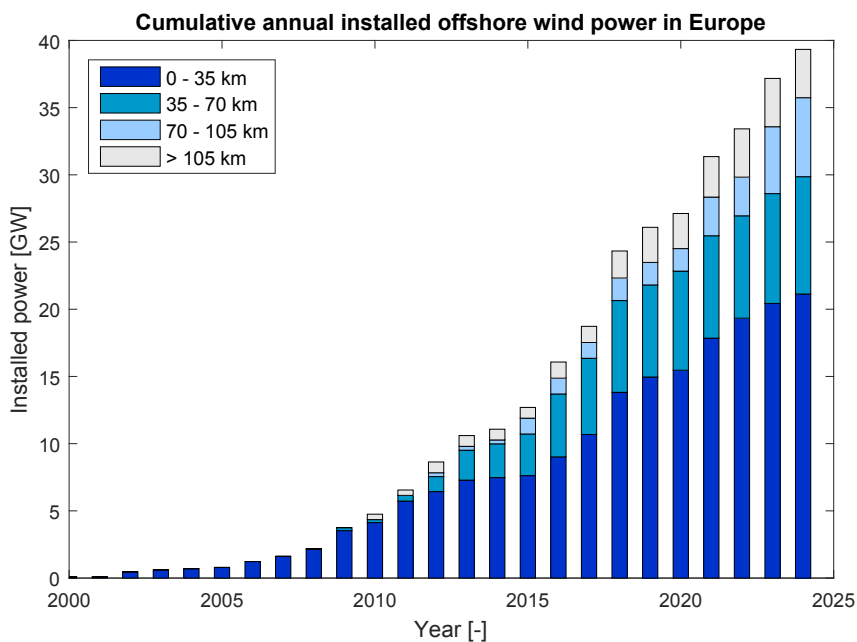
## Introduction

Chapter 1 pinpoints the importance of offshore wind access, explains the motivation behind this work and provides the structure of this report.

### 1.1 Offshore wind O&M background

Offshore wind energy has grown rapidly over the past decade and it is constantly moving further offshore into deeper waters. Figure 1 presents the currently (end of 2016) installed power in Europe and the projections until 2025 based on the under-construction, planned and consented offshore wind farms.

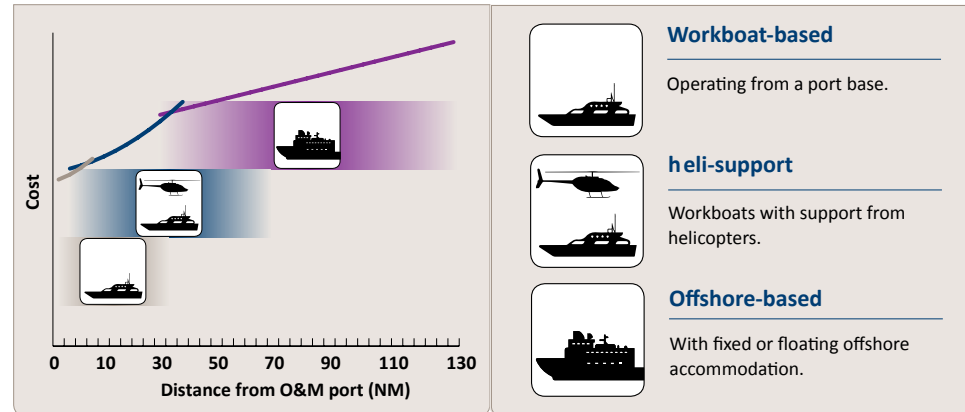
**Figure 1:** Cumulative annual installed power in Europe from 2000 until 2025 (expected) [1].





As Figure 1 indicates, offshore wind power in Europe is expected to reach 40GW by 2025 with 30GW coming from near-shore (< 70km) and 10GW from far-offshore (> 70km) wind farms. Despite the favorable wind conditions, increasing distance from port leads to higher O&M costs and determines the most suitable strategy as it can be seen in Figure 2.

**Figure 2:** O&M strategy as function of distance from port [2].

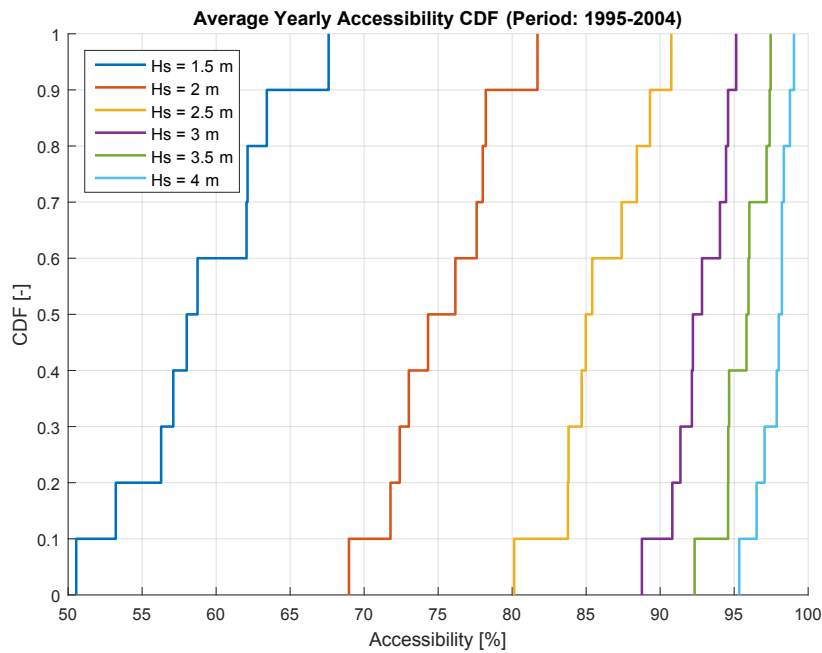


Specifically, for near-shore wind farms, workboats (medium sized CTVs) are usually launched from the port base whereas helicopters can support the O&M activities in case harsher weather conditions require that. Far-offshore wind farms require an offshore base for accommodating the technicians and possibly spare parts since the travelling time from the port significantly increases and thus, the effective working time offshore is limited. The most commonly used offshore O&M base is the Service Operation Vessel (SOV) or Walk to Work vessel. These Dynamic Positioning (DP) vessels are typically longer than 50m and they can accommodate up to 60 technicians and spare parts.

Overall, the goal for choosing the most suitable maintenance strategy is to achieve the optimal trade-off between the O&M costs and the availability of the wind farm. Typically for offshore wind farms, availability of 95% is realised as the most efficient in terms of cost minimization. The limitations on achieving higher reliability of components have turned the attention towards optimizing the maintenance strategies including the access methods to the offshore sites. What is described with the term Accessibility, meaning the percentage of time that an offshore wind farm can be approached and accessed by technicians, is a key element for the economic viability of a project and the source of high uncertainties.

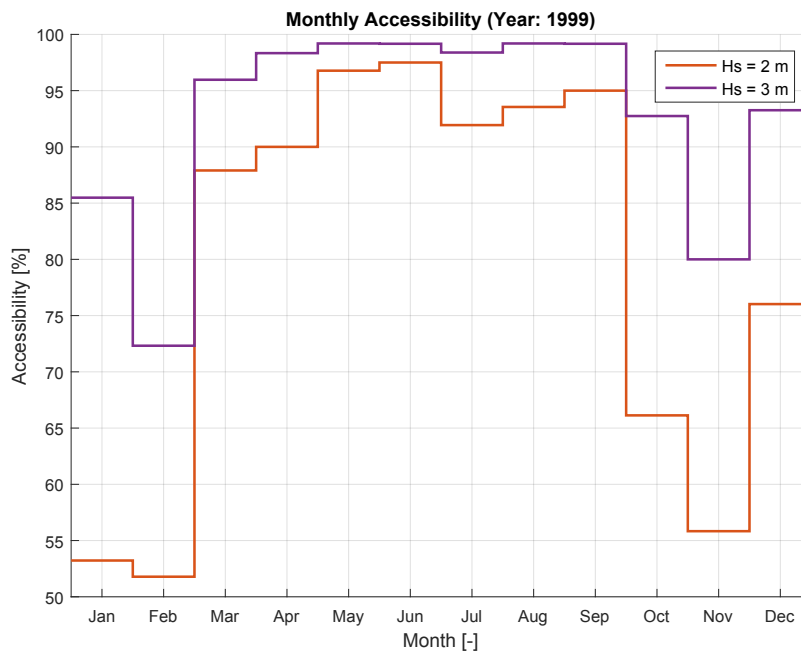
Results of studies [3] reveal that accessibility of at least 80% of the time is necessary in order to achieve wind farm availability of over 90%. It should be noted that the calculations regarding the accessibility for ship-based access are based on the maximum allowable wave conditions during personnel transfer. Successively, wave conditions are generally described by two parameters: the significant wave height ( $H_s$ ) and the mean zero-crossing wave period ( $T_z$ ). However, the limit wave states are usually described only by using the significant wave height. This practically means that for a given access method the accessibility is equal to the probability of sea states up to the related limiting significant wave height. Figure 3 shows the Cumulative Distribution Function (CDF) of the average yearly accessibility to a location close to K13, 100km away from the Dutch coast, depending on the limiting significant wave height. In other words, each line in Figure 3 indicates the range of the expected yearly accessibility per maximum allowable significant wave height.

**Figure 3:** Average yearly accessibility CDF for various max. allowable  $H_s$  for the period from 1995 to 2004 at K13 location.



According to Figure 3, for an access system operating up to sea states of  $H_s = 1.5m$ , the expected average yearly accessibility ranges from 51% to 68%. Increasing the limit sea state to  $2.0m$  increases the yearly accessibility by 20% whereas a more advanced access system (max  $H_s = 2.5m$ ) would offer at least 80% yearly accessibility. Besides average yearly accessibility, the monthly accessibility is also of importance since it indicates the seasonal effect. Figure 4 presents the monthly accessibility at K13 location for year 1999.

**Figure 4:** Monthly accessibility for max. allowable  $H_s$  of  $2.0m$  and  $3.0m$  for year 1999 at K13 location.



Year 1999 was chosen since it corresponds to  $CDF = 0.5$  in Figure 3, basically representing the  $P50$  weather scenario which is particularly useful when describing weather downtime. In this case, two maximum allowable significant wave heights were used ( $H_s$  of 2.0 and 3.0m) for clarity reasons. As it is expected, the major differentiation between the two significant wave height limits is identified during the winter months where the accessibility drops by 20 – 30% for an access system operating up to  $H_s$  of 2.0m. This leads to an overall yearly accessibility of 74% and 92% for  $H_s$  of 2.0 and 3.0m respectively, during year 1999 according to Figure 3 (see  $CDF = 0.5$ ).

## 1.2 Objective and report outline

As it was already highlighted in the previous section, accessibility is crucial for offshore wind farms. Enlarging the operating weather windows for accessing far offshore sites is a key driver for cost reductions in offshore wind. Hence, the market for access systems has evolved rapidly and every year new systems are being introduced. This work intends to:

- Present the state-of-the-art access systems for offshore wind
- Identify their key parameters
- Show the importance of O&M modelling
- Provide recommendations for future developments.

The report is organized as follows: Chapter 2 gives an overview of offshore wind access systems, both existing and under-development, Chapter 3 explains the framework for assessing their impact through ECN O&M Access tool and Chapter 4 provides the conclusions and future work.

# 2

## Access systems overview

The importance of offshore wind access in terms of O&M aspects was outlined in Chapter 1. This is also supported by the fact that offshore wind access industry is evolving rapidly. In this Chapter, an overview of existing and under-development offshore wind access systems (start 2017) is presented. It should be noted that the information presented is partly based on publicly available information and was partly provided by access system developers.

There are basically three routes to access an offshore wind turbine: **1) The boat landing** at sea level, from where technicians climb the ladder(s) to reach the platform, **2) The platform**, located on top of the Transition Piece (TP) where technicians can enter directly into the turbine tower and **3) The helideck**, which provides direct access to the nacelle. Figure 5 shows one example for each access method. In the following Sections, the access systems presented are categorized based on their landing/access point.

**Figure 5:** Access to the boat landing [4], platform [5] and helideck [6] (from left to right).



Before presenting the overview of access systems, it should be noted that the accessibility they can provide is the measure that is mostly used to characterize them. Especially for ship-based access, significant wave height ( $H_s$ ) is the statistical measure that has been widely used to define accessibility. For direct access through CTVs, defining accessibility based only on  $H_s$ , it is a generally accepted assumption, even simplistic. On the other hand, for access through systems that are mounted on top of CTVs or SOVs such as motion compensated gangways, the interaction of the system with the vessel is utterly important. Besides all relevant environmental conditions (wind speed and direction; wave height, direction and period both for swell and wind-waves; current speed and direction), vessel

design and size and location of the system on the vessel should also be taken into account when defining the accessibility such system can provide. Since the underlying assumptions for defining accessibility based on  $H_s$  can vary between individual access system providers, references that relate accessibility with  $H_s$  for systems mounted on vessels are not included in this report, even if available.

Moreover, ECN proposes a framework for assessing accessibility in collaboration with MARIN and TNO under the Offshore Maintenance Joint Industry Project (OM JIP). In this project, vessel motions are calculated for a variety of designs for CTVs and SOVs (MARIN), the effect of vessel motions on technician performance is studied (TNO) and these are coupled in ECN's O&M modelling tool. The results can form a common way for assessing accessibility which considers all relevant environmental conditions and ship-access system interaction especially for the case of SOVs.

## 2.1 Access to the boat landing

The most commonly used way of accessing offshore wind turbines is through the boat landing, on the foundation of the wind turbine. The reason for its popularity is that it is a cost-effective and a fast solution, especially for near-shore wind farms. Originally, small boats were used by the industry. The increasing volume of the offshore wind industry alongside with the increased knowledge have brought about an evolution in CTVs and support systems on these CTVs: faster transit to and from the port, enhanced comfort, higher safety standards especially during the actual transfers, better trained crews, larger deck space on the front deck for cargo and last but not least: improved accessibility.

### Crew Transfer Vessels (CTVs)

There is a wide range of specialized CTVs that provide fast access to offshore wind farms, located usually in close proximity to a port base. Personnel transfer is accomplished by creating frictional contact between the vessel's specially shaped bow with fender and the foundation in order to eliminate vessel's translations, commonly known as the "bump and jump" method. CTVs carry typically 12 technicians and cargo such as small spare parts and equipment. Deck cargo is lifted from the deck to the platform of the TP by using the built-in davit crane or nacelle crane. Currently, more than 400 CTVs transfer technicians to offshore wind farms. The types of CTVs according to their hull shape include:

#### 1. Monohull

The first CTVs that were used in offshore wind farms were monohull vessels modified from an existing pool of multi-purpose vessels. Their main advantages are their low cost and scalability. On the other hand, monohull CTVs can typically operate safely up to sea states of significant wave height of  $1.2 - 1.5m$ .

#### 2. Catamaran

The majority of CTVs nowadays are aluminum catamarans. The main reasons behind their extensive usage are the high speeds that they can achieve and the good sea-keeping behavior in medium sea conditions. Their disadvantage compared to monohull vessels is their relative higher cost. Catamaran CTVs can operate satisfactorily at significant wave heights up to  $1.5 - 2m$ .



### 3. Trimaran

In an effort to reduce fuel consumption and improve seakeeping behavior of catamarans, trimaran CTVs have recently entered the market. After employing a gripper system in the bow, transfer of technicians is possible up to sea states of  $H_s$  of 2.5m.

**Figure 6:** Monohull [7], Catamaran [8] and Trimaran [9] CTVs (from left to right).



### 4. Small Waterplane Area Twin Hull (SWATH)

The market share of SWATH CTVs is constantly increasing. SWATHs are catamaran-like vessels, which achieve greater stability by minimizing the hull cross section area at the sea's surface. Their design allows comfort during sailing and safe access at significant wave heights of 2.0 – 2.5m. Their disadvantage is higher cost and lower speed compared to catamarans.

### 5. Surface Effect Ship (SES)

The technology of SES has also been adopted for CTVs. The hull shape of SES CTVs is similar to catamarans but most of the vessel's weight is lifted by an air cushion, which provides high stability leading to high speeds, less fuel consumption and good seakeeping behavior. However this comes with the disadvantage of design complexity and higher costs. Overall, maximum operable sea states vary from 2.0 to 2.5m  $H_s$ .

**Figure 7:** SWATH [10] and SES [11] CTVs (from left to right).



Table 1 shows an overview of typical values of the characteristics of the aforementioned CTV types. It should be noted that the values do not essentially represent the CTVs displayed in Figures 6 and 7.

**Table 1:** Main characteristics of CTV types.

|                     | Monohull | Catamaran | Trimaran | SWATH | SES |
|---------------------|----------|-----------|----------|-------|-----|
| Length [m]          | 21       | 20        | 18       | 20    | 28  |
| Speed (max) [knots] | 23       | 25        | 20       | 23    | 33  |
| Passengers [-]      | 12       | 12        | 12       | 12    | 12  |
| Cargo [tons]        | 5        | 10        | 1        | 2     | 4   |
| $H_s$ (max) [m]     | 1.5      | 2         | 2.5      | 2.5   | 2.5 |

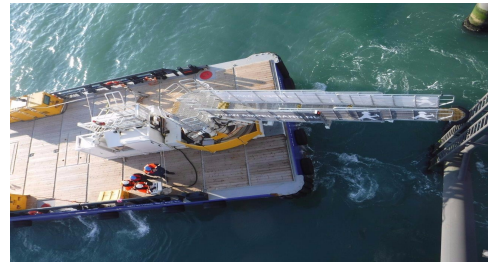
## Systems that enhance access through CTVs

The cost advantage of CTVs has driven the development of systems that can enhance their accessibility and overall safety. These systems can either be mounted on their foredeck compensating vessel's motions or on the turbine's structure, both assisting access to the turbine's ladder. The requirements for the vessel characteristics (e.g. length) and the boat landing vary for each system as well as the compensation method (active or passive). Most of the aforementioned devices are gangways but there are also other concepts, as presented below.

### Ampelmann L-Type

Ampelmann L-type is the smallest Ampelmann system, suitable for fast crew vessels without Dynamic Positioning (DP). It is a plug and play system allowing fast mobilization. Active compensation is used during landing and passive compensation during transferring [12].

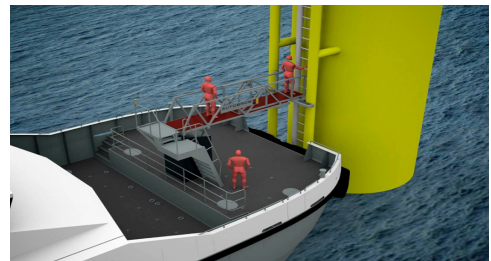
Figure 8: Ampelmann L-Type.



### Autobrow

The Autobrow System has been developed by Otso Ltd from a concept designed by Ad Hoc Marine Designs. Autobrow is a motion compensated gangway system, suitable for CTVs, actively eliminating the effect of heave and pitch while passively reducing roll. Its design is focused on light weight, reliability and low cost.

Figure 9: Autobrow [13].



### Houlder - Turbine Access System (TAS)

Houlder's TAS is a motion compensated gangway which reduces the vertical movements by using a damped roller system. It can be fitted in small CTVs without DP, hence contact between the boat landing and the CTV's fender is required. Once connected, it automatically compensates for relative motions to allow continual transfer of personnel. The total working load is 350kg.

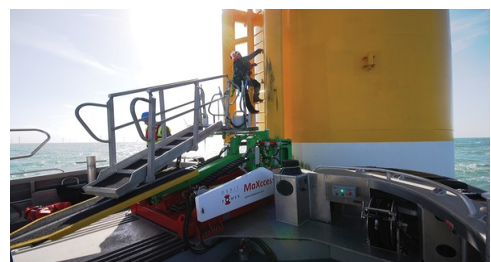
Figure 10: Houlder's TAS [14].



### MaXccess T-Series

MaXccess T-Series by Osbit Power is a passive motion compensated gangway which clamps onto either of the vertical tubular spars of the boat landing and allows the vessel to roll, pitch and yaw freely, while preventing vertical and horizontal

Figure 11: MaXccess T-Series [15].



bow motion. There are two versions of the said system (T12 and T18), for which the clamping capacity is 12 and 18 tonnes respectively.

### MOMAC - MOTS 500 and MOTS 1000/G

MOTS 500 is a robotic-based transfer arm actively compensating vessel's motions in all directions. It can be installed in small vessels without DP and requires contact of the vessel with the boat landing. On the other hand, MOTS 1000/G is an active motion compensated gangway requiring a DP vessel.

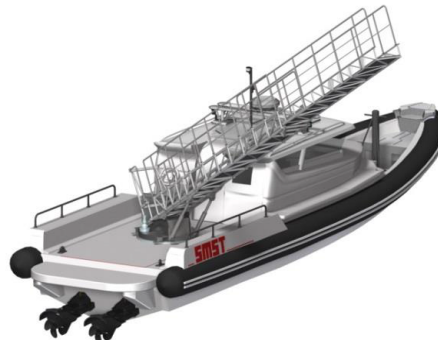
Figure 12: MOTS 500 and MOTS 1000/G [16].



### SMST Telescopic Access Bridge (TAB)

The small SMST TAB can be mounted on fast offshore crafts and CTVs. The length can vary from 7m to 24m while the low weight ensures low power consumption. Vessel motions can be compensated actively or passively dependent on the application.

Figure 13: SMST Small TAB [17].



### Uptime Gangway 8m - 12m - 15m

Uptime's small gangways are telescopic, passive motion compensated gangways suitable for a variety of vessels, with or without DP.

Figure 14: Uptime Gangway 8m - 12m - 15m [18].



### WaterBridge

WaterBridge, designed by the Engineering Business (later acquired by IHC) consists of an inflatable structure which creates a temporary bridge between the vessel and the turbine structure. Once deployed, the WaterBridge minimises the effect of relative motions between the support vessel and the structure at the transfer point allowing safe access for technicians.

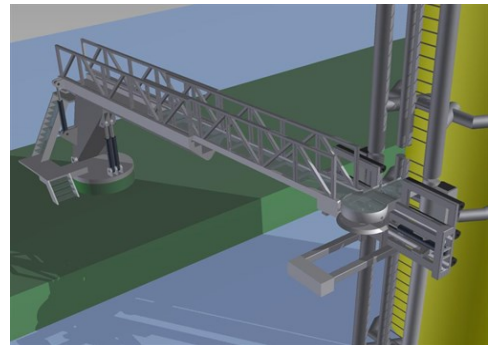
Figure 15: WaterBridge [19].



### Wind-Bridge

Wind Bridge by Knut Hansen is a pneumatic-based boarding bridge for access to boat landings on offshore wind turbines from a service vessel featuring an impact absorbing boarding system and dynamic heave compensation. After contact is made, an automated retention clamp system is activated forming a safe access. The advantage of this system is that it can hook on to a standard boat landing regardless of the direction of the waves, current and wind.

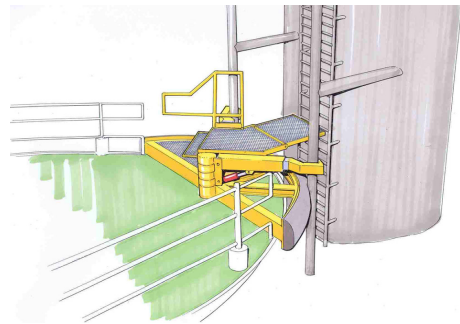
Figure 16: The Wind-Bridge [20].



### Z-Catch

Zcatch by Ztechnologies is a hydraulic clamping system that can be mounted on the deck of CTVs. It consists of 2 hydraulic arms which can rotate around a vertical axis. At their front-end a hydraulic clamp is mounted which can be swung around the vertical steel bars of the boat landing. The constant tension system guarantees a constant clamping-force while it still allows the pitch and heave movement of the vessel.

Figure 17: Zcatch [21].



### Sliding Ladder (SLILAD) and Z-Step

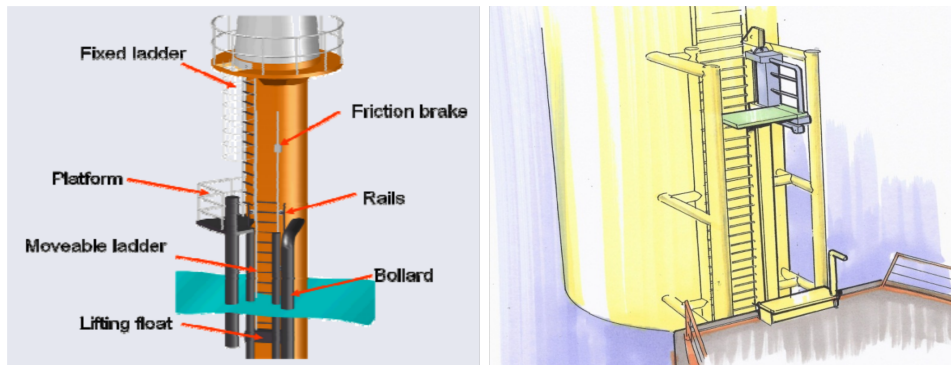
Besides systems mounted on the deck of CTVs, there are systems that can be installed on the TP in order to assist personnel transfer. SLILAD developed by MOMAC is a sliding ladder which eliminates the relative motions between vessel to ladder and ladder to platform during access operations. Initially, the vessel movements are compensated through a locked connection element. Hence, the ladder is fixed to the vessel providing safe transfer. After stepping to the ladder, it becomes fixed to the offshore structure, allowing safe access to the platform.

Zstep by Ztechnologies is a step up platform which compensates the movement of the



vessel during access and egress of the turbine foundation ladder. During the moment of stepping over, the Zstep platform moves simultaneously with the vessel bow. This results in a smooth step over from the vessel to the offshore ladder and vice versa.

**Figure 18:** SLILAD [22] and Zstep [23].



## 2.2 Access to the platform

The limited accessibility CTVs can provide and the safety implications that are imposed have turned the attention to solutions that provide fast and safe access directly to the TP platform at elevation from the mean sea level of approximately 15 – 20m. Considering also the fact that wind farms move further offshore, offshore accommodation is also highly desirable. This is the reason why Walk to Work (W2W) solutions have been developed, also known as SOVs which include a DP2 vessel usually longer than 60m with a motion compensated gangway to eliminate relative motions between vessel and wind turbine.

**Figure 19:** Walk to Work vessels Esvagt Faraday [24] and Damen [25].



In terms of motion compensation, there are two modes: active and passive. Active motion compensation uses sensors and control systems to eliminate relative motions. Passive compensation is achieved by a mechanical linkage which adjusts itself passively. Offshore wind access through motion compensated gangways is a relatively new market and new systems are constantly being developed. However, effort has been made to include most of them in this publication. Besides motion compensated gangways, there are other systems that can be installed on vessels and transfer technicians to the TP platform. Last, systems that can be located on the wind turbine structure that provide direct access from the vessel to the TP platform are also presented.

## Motion compensated gangways

Most of the motion compensated gangways focus on personnel transfer either to the TP's work platform or to the intermediate platform. Moreover, some of them can also be used in their standard version or after certain upgrades for carrying small cargo (in most cases up to  $1000kg$ ). This covers 92% of all O&M activities in offshore wind farms [26]. The other activities include the replacement of heavy components and lifting of these heavier parts is usually carried out by the internal crane of the wind turbine and in some cases the built-in crane of a jack-up vessel or barge.

### Ampelmann A- and E-Type

One of the market leaders of motion compensated access systems is Ampelmann. Inspired by the Stewart platform, Ampelmann eliminates any relative motion by taking real time measurements of the ship's motions and then compensates them by using 6 hydraulic cylinders. Active motion compensation reduces the residual motion compared to passive compensation. The first concept was A-Type and later, Ampelmann E-Type was introduced. Both are stand-alone systems and they are suitable for transferring people and cargo. All critical components are equipped redundantly. The largest E-Type, E8000, is capable of transferring cargo up to  $8000kg$  and personnel [12].

**Figure 20:** Ampelmann A-Type and E-Type (courtesy of Ampelmann).



### Barge Master 3.0 and 4.5 gangways

Barge Master's motion compensated gangways were introduced in 2015. The difference between these two is a motion compensated pedestal which increases workability. Barge Master's gangway has a modular design and functionality can be extended with a height adjustable tower for instance (Figure 21). Besides personnel, cargo can be transferred by a cargo basket (max  $150kg$ ), a pallet trolley (max  $500kg$ ) and a lifting winch (max  $1000kg$ ).

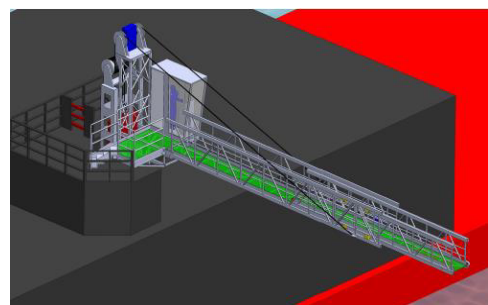
**Figure 21:** Barge Master Gangway [27].



### Crew Access Bridge (CRAB)

CRAB by W3G Marine is a new design for a motion compensated gangway, fully electric, aiming for low weight and small footprint on the deck of the vessel. CRAB uses

**Figure 22:** Crew Access Bridge [28].



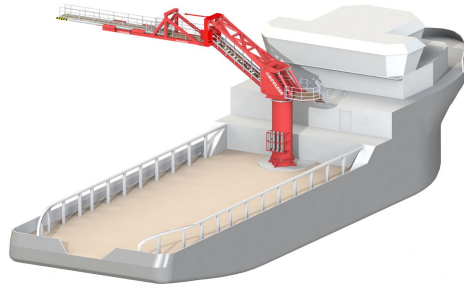


a counterweight supported by two wires and the system supports slewing, luffing and telescoping.

### Houlder Personnel Transfer System (PTS)

Houlder's PTS utilises an adjustable stair structure to allow a large vertical envelope while keeping the gangway relatively horizontal for improved safety. Once connected, the system automatically compensates for relative motions between the vessel and the structure to allow continuous transfer of personnel. The total working load is  $350kg$ .

Figure 23: Houlder PTS [29].



### Kenz Cranes Offshore Gangways

Kenz Cranes can provide several types of 3 motion active compensated gangways (e.g. small  $15 - 25m$  and large  $30 - 45m$ ). Slewing motions are performed by means of a slewing bearing activated by two slewing gears, single stage telescopic motion by means of a winch that pulls the telescopic gangway back and forth and luffing motions by means of two hydraulic cylinders. For accessing offshore wind turbines, the gangway is equipped with a bumper docking system. The gangway is also provided with a hook attachment and uses the same 3D motion compensation system to safely hoist and lower equipment to the platform [30].

Figure 24: Kenz Cranes gangway (courtesy of Kenz).



### MacGregor gangway

MacGregor's experience in compensated cranes gave rise to the development of an active heave compensated gangway which features three compensating motions (slew, luffing, telescoping) in its standard model. However, pedestal's roll, pitch and telescoping can be actively compensated through certain upgrades.

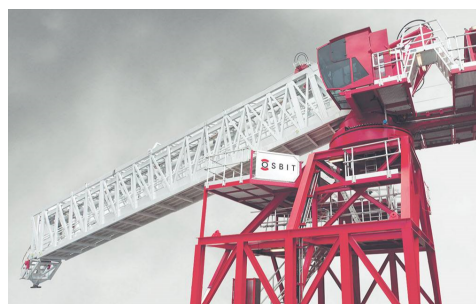
Figure 25: MacGregor gangway [31].



### MaXccess AM- and P-Series

Osbit Power's telescopic access gangways include an active motion (AM-Series) and a passive motion (P-Series) compensated telescopic gangway. MaXccess P-Series is suitable for a variety of vessels and it can be longer than  $50m$  whereas AM-Series is

Figure 26: Maxccess gangway [15].



suitable for medium-sized DP vessels and the maximum length is typically 25m.

### Seagull

Seagull motion compensated gangway by Safeway was introduced in the market in 2015. One of the attributes of this system is its modular design and the height adjustment which can ensure horizontal access even in relatively high landing points.

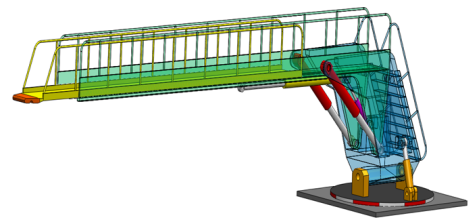
Figure 27: Seagull gangway [32].



### SeaQualizer

SeaQualizer is a design for an offshore access bridge with a balanced heave compensation system, aiming for low cost and reliable operations. This is accomplished by balancing two of the most energy consuming movements of motion compensation for waves (heave and pitch or roll) by a hydro-pneumatic system. The remaining forces required to compensate for the wave motions in all six degrees of freedom are actuated by conventional actuators.

Figure 28: SeaQualizer gangway.



### SMST TAB M and L

SMST's medium and large telescopic access bridges range from 7m to 32m. Because of the modular design, they can be installed on different types of vessels. Height adjustment is also possible by using a pedestal. Vessel motions are compensated by controlling the luffing, slewing and telescoping motions of the system. The bridges can be actively and passively controlled both during landing and transfer operations.

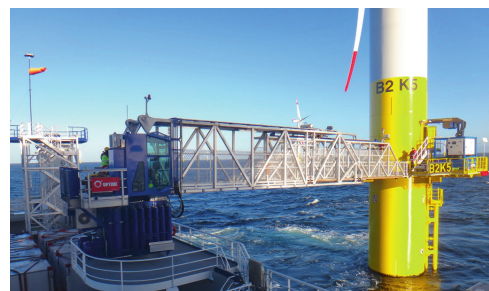
Figure 29: SMST M series TAB [33].



### Uptime Gangway 23.4m and 26m

Uptime's large active motion compensated gangways (either 23.4m or 26m) have been introduced in the market since 2013 and they have an extensive track record. They are suitable for long operations due to the passive connection to the fixed structure after reaching the landing point.

Figure 30: Uptime 23.4m Gangway [18].



## Zbridge

Zbridge by ZTechnologies is a newly built motion compensated gangway system for transferring personnel and cargo (max. 1000kg).

**Figure 31:** Zbridge [34].



All of the aforementioned motion compensated gangways aim to eliminate the relative motions between the vessel and the offshore structure providing safe access for personnel. However, their technical characteristics can differ significantly. Table 2 presents an overview of their most relevant technical characteristics.

**Table 2:** Overview of motion compensated gangways.

|                                         | Ampelmann |        | Barge Master |           | Crab  | PTS   | Kenz      | Seagull | SMST      |         | Uptime |       | Zbridge |
|-----------------------------------------|-----------|--------|--------------|-----------|-------|-------|-----------|---------|-----------|---------|--------|-------|---------|
|                                         | A-Type    | E-Type | 3.0 M   L    | 4.5 M   L |       |       |           |         | TAB M     | TAB L   | 23.4   | 26    |         |
| Min. length gangway [m]                 | 18        | 18     | 15 17        | 15 17     | 14    | 16    | 16.2–30   | 18      | 7 – 16    | 16 – 25 | 15.4   | 18    | 15      |
| Max. length gangway [m]                 | 25        | 25     | 25 28        | 25 28     | 20    | 23    | 26.2–45   | 28      | 11 – 24   | 24 – 40 | 23.4   | 26    | 24      |
| Max. work. angle +/- [deg.]             | 17/17     | 17/17  | 18/18        | 18/18     | 17/17 | 24/18 | 20/20     | 15/15   | 25 – 20   | 27 – 23 | 18/13  | 18/13 | 15/15   |
| Gangway width [m]                       | 0.6       | 0.6    | 0.9          | 0.9       | 0.8   | -     | 0.8 – 1.2 | 1.1     | 0.6 – 0.9 | 1.2     | 1.2    | 1.2   | 1.2     |
| System weight [ton]                     | 39        | 100    | 25           | 113       | < 20  | 25    | -         | 75      | -         | -       | 27     | 37    | 40      |
| Footprint on vessel [m <sup>2</sup> ]   | 46        | 80     | 2.5          | 15        | 16    | -     | -         | 30      | -         | -       | -      | -     | 30      |
| Vessel length [m]                       | -         | -      | -            | -         | -     | -     | -         | -       | -         | -       | -      | -     | > 70    |
| Mobilization time [hr]                  | 8         | 12     | 24           | 48        | 24    | -     | -         | 24      | < 24      | -       | -      | -     | 72      |
| Deployment time [s]                     | -         | -      | 30           | 120       | 60    | -     | -         | -       | -         | -       | 15     | 15    | 15      |
| Max. connection time [hr]               | -         | -      | -            | -         | -     | -     | -         | -       | -         | > 72    | -      | -     | -       |
| Max. power requirement [kW]             | -         | -      | 200          | 700       | -     | -     | -         | 300     | -         | -       | -      | -     | 200     |
| Max. load [kg]                          | -         | -      | 1000         | 1000      | 300   | 350   | 500       | 400     | 1000      | -       | 1000   | 1000  | 1000    |
| Max. load per area [kg/m <sup>2</sup> ] | -         | -      | 400          | 400       | -     | -     | -         | -       | -         | 400     | 400    | 400   | 1000    |
| Systems built [-]                       | > 50      |        | -            | -         | -     | -     | 4         | 1       | 6         | -       | 25     |       | 1       |

**Notes**

1. Only motion compensated gangways for which technical details were either publicly available or were shared by the developers are included in the Table (December 2016).
2. The Table provides an overview of existing and under-development motion compensated gangways and a direct comparison between them should not be made since the figures included are highly dependent on individual assumptions.
3. References to maximum sea state ( $H_s$ ) for which a motion compensated gangway can eliminate vessel motions have been excluded from the Table since it depends on the vessel design and size, location of the system on the vessel and other environmental conditions including wind speed, wave direction and period etc.

## Other systems

Besides motion compensated gangways, there are systems positioned either at the vessel or at the wind turbine structure which can provide direct access to the TP work platform.

### FrogXT

FrogXT by Reflex Marine is a buoyant personnel transfer capsule which is transported using a standard deck crane on a larger vessel. It can transfer up to nine technicians with light equipment and tools. The success of this system in the oil and gas industry has led Reflex Marine to propose a smaller capsule that can be easily stowed on a workboat, combined with a specially-built davit crane on the TP.

Figure 32: FrogXT [35].



### Offshore Passenger Transfer System (OPTS)

OPTS by Offco is a fully compensated basket that can be installed in a large variety of vessels. The OPTS has the ability to move freely 360 degrees with an outreach of 24m. The OPTS can also be used for lifting operations up to 2.5 tons with or without motion compensation.

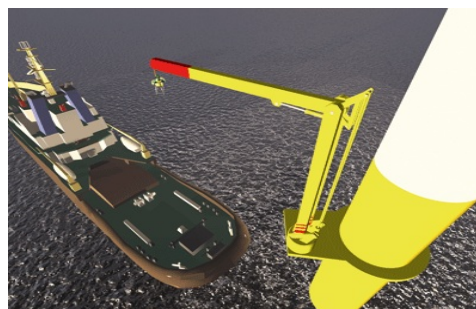
Figure 33: OPTS [36].



### Personnel Transfer System (PTS)

This system is being developed by Personnel Transfer System GmbH. PTS consists of a remote controlled crane installed on each turbine's transition piece platform which lifts one technician from the vessel to the working platform of the structure and vice versa. It is a fully heave compensated system and the limit for safe operation is 500kg and 800kg.

Figure 34: PTS [37].



### Selstair

The Selstair personnel transfer system developed by Viking is a collapsible remote operated staircase that can be lowered either to sea or above sea for personnel transfer to vessel and vice versa. The system is deployed by pure gravity and electrical power is only needed for retrieval.

Figure 35: Selstair [38].





### Wind lift

The Wind lift system, developed by Fassmer, is a height-adjustable platform for access to offshore wind turbines from small vessels. Personnel and equipment are transferred to the platform at vessel-deck level. The platform, which is fitted around the turbine foundation, is then hoisted to the working deck level, avoiding the need for technicians to climb external ladders.

Figure 36: Wind lift [39].



## 2.3 Access to the helideck

Helicopters can offer access to the helideck of offshore wind turbines and substations for wind speeds up to  $20m/s$  [3]. Because of the safety issues regarding helicopter access, ditching requirements have been established which also account for the sea state [40]. Helicopter access requires a hoisting platform built on top of the nacelle which is mostly common nowadays in offshore substations. Besides their advantage in terms of accessibility, helicopters can significantly decrease the travelling time compared to CTVs but they can only carry a small number of technicians (usually 3) and small spare parts and equipment at high hourly rates. All personnel and equipment need to be winched from the helicopter on to the helideck at the nacelle roof, requiring stand-still of the wind turbine.

Figure 37: Offshore wind helicopter access [41].



# 3

## O&M modelling

This Chapter explains the added value of O&M modelling when assessing the impact of various access systems and presents the results of a case study by using ECN O&M Access tool.

### 3.1 Approach

The evaluation of the performance of access systems is usually based on the maximum sea state they can operate safely in, since this is usually the bottleneck while accessing offshore wind turbines. This form of evaluation is rather simplistic and it can only provide average accessibility values depending on the location and the time period within a year. In order to accurately examine the added value of an access system during offshore wind O&M activities, a realistic O&M scenario needs to be developed where the access system is integrated as part of the available resources. Some of the parameters and interactions that influence O&M and should be taken into account include:

- Component failure rates of wind turbines and Balance of Plant (BoP)
- Metocean conditions
- Weather operating limits for vessels and equipment
- Availability of access systems
- Availability of other vessels and equipment (e.g. jack-up vessels)
- Availability of spare parts
- Technicians working shift patterns
- Maintenance type (corrective or preventive).

In order to explain the relation of the aforementioned parameters with an access system and starting from the failures of the various parts of an offshore wind farm, these primarily define the operational time that an access system is required. Besides failures, the weather conditions during the time of failures determine whether an access system can be used according to its weather operating limits. However, even if the weather conditions allow the usage of an access system, it is possible that it is already occupied with another maintenance activity. In some cases, where two systems are required for one activity (e.g. access system and jack-up barge), the unavailability of one of the required resources leads to additional downtime. Including also the various shift patterns and the

maximum number of available technicians, downtime due to lack of man-power could be experienced. The same applies for lack of available spare parts, hence the availability and required lead time for spare parts need to be taken into account. Finally, the type of maintenance is crucial since for preventive maintenance, the required resources including access systems are already reserved but in the case of corrective maintenance, additional time may be required to mobilize the access system. All the above pinpoint the complexity of offshore wind O&M activities as well as the necessity for evaluating the effect of various parts of the entire chain such as access systems through a holistic approach.

### 3.2 ECN O&M Access

For the purposes of this work, ECN's in-house developed tool O&M Access is used to investigate the added value of access systems for offshore wind O&M [42]. ECN O&M Access tool is an O&M cost estimator specifically developed for the designers and developers of maintenance vessels and access systems for the offshore wind industry. Through this tool, vessel and access system designers and developers are able to investigate the impact of their systems on the wind farm availability and maintenance costs. Generating cost impact and lost production information of wind farms towards vessel and access system designers ensures that the effect of their design assumptions and the total business case for new developments can be properly evaluated.

### 3.3 Case study

In order to illustrate the framework of O&M modelling, a reference wind farm in the Dutch Exclusive Economic Zone (EEZ) is chosen,  $50\text{km}$  away from shore. The wind farm capacity is  $720\text{MW}$ , comprising of 90  $8.0\text{MW}$  wind turbines. A typical  $8.0\text{MW}$  is selected including its power curve, cost of spares and failure rates. The metocean data used correspond to an offshore location  $10\text{km}$  north of the Borssele Site I centre [43]. Next, the O&M strategies are developed and finally the results are presented. It should be noted that for this case study, the weather operating limits include only thresholds on wind speed and significant wave height. It is intended that this study will be repeated and published after the improvements in the accessibility model of ECN O&M Access tool under OM JIP.

#### O&M strategies

As far as the O&M strategies are concerned and starting with the repairs that are needed for each wind turbine fault or failure, all maintenance activities can be categorized as follows:

- **Remote reset:** Turbine in error, can be reset remotely, no access necessary, only downtime
- **Inspection/repair inside:** Small inspection or repair action inside the turbine, technicians with toolbox, low costs, limited downtime
- **Inspection/repair outside:** Small inspection or repair action outside the turbine (e.g. blade inspection or repair), technicians with toolbox, low costs, limited downtime
- **Small replacement:** Replacement of components which can be hoisted with the turbine crane, medium costs, medium downtime
- **Large replacement:** Replacement of large components which need to be hoisted with a jack-up vessel, high costs, high downtime.

Hence, the decision on the O&M strategy determines how the aforementioned repairs can be carried out including the access systems needed. For example -in the case of harbour based O&M strategy-, a small replacement may require a CTV with sufficient cargo capacity whereas in the case of offshore based strategy, a SOV can perform most of the small replacements. Moreover, all repair activities except remote reset require an access system than can bring technicians on the wind turbine structure. Therefore, there is always a primary access method (e.g. CTV) which is usually the most efficient time- and cost-wise but in most cases, at least one alternative method of access (e.g. helicopter) may be available in order to decrease downtime. Currently, ECN O&M Access tool allows maximum one alternative access method for each repair.

Focusing on the O&M strategies, 3 baseline O&M models are defined by using the ECN O&M Access tool: i) Harbour based O&M performed by CTVs, ii) Harbour based O&M performed by CTVs and supported by helicopter and iii) Offshore based O&M performed by a SOV including a motion compensated gangway for access. As far as SOVs are concerned, it should be mentioned that two daughter crafts can be launched from the SOV as the primary access method for inspection and small repairs. Table 3 corresponds the various repairs with the primary (1st) and alternative (2nd) access methods that are used by each of the O&M strategies.

**Table 3:** O&M strategies – Overview of repair actions and access methods.

|                           | Harbour (CTVs) |     | Harbour (CTVs+heli) |      | Offshore (SOV) |     |
|---------------------------|----------------|-----|---------------------|------|----------------|-----|
|                           | 1st            | 2nd | 1st                 | 2nd  | 1st            | 2nd |
| Remote Reset              | -              | -   | -                   | -    | -              | -   |
| Inspection/Repair Inside  | CTV            | -   | CTV                 | Heli | Craft          | SOV |
| Inspection/Repair Outside | CTV            | -   | CTV                 | Heli | Craft          | SOV |
| Small Replacement         | CTV            | -   | CTV                 | -    | SOV            | -   |
| Large Replacement         | CTV            | -   | CTV                 | -    | SOV            | -   |

For the reference wind farm, all three defined O&M strategies are investigated. For the harbour based strategy, three CTVs are available whereas in the case of helicopter support, two CTVs are used. The offshore based strategy consists of one SOV with a motion compensated gangway and two daughter crafts. Moreover, the weather limiting conditions considered for the access systems include: maximum significant wave height of 1.2m, 1.5m and 3.0m for the daughter crafts, CTVs and SOV respectively and maximum wind speed of 20m/s for helicopter access. Besides the aforementioned O&M specifications, the number of available technicians, the vessels and equipment (e.g. jack-up barges, diving support vessels, cable laying vessels) needed for performing the maintenance and the cost parameters are chosen based on ECN's in-house experience.

## Results

The specified inputs and repair strategies are used during the Monte Carlo simulation of random failures and relative performance indicators are generated (e.g. availability, cost of energy, total O&M costs) as well as specific data regarding downtime and cost breakdowns. Table 4 summarizes the key O&M figures including the time and yield availability of the wind farm, the repair costs and revenue losses during downtime which are summed up to give the total O&M costs and finally the O&M LCOE. It should be noted that these numbers correspond to one year of operation and they are averaged over 500 simulations. As it can be seen in the Table, the effect of various O&M strategies and different means of access is clear to the performance of the wind farm. In general for all three strategies,

the O&M contribution to the overall COE ranging from 1.83 to 2.10 $\text{€}/\text{kWh}$  shows that the upscaling in wind turbine sizes can decrease significantly the O&M costs, compared to the typical values between 2 to 3  $\text{€}/\text{kWh}$ .

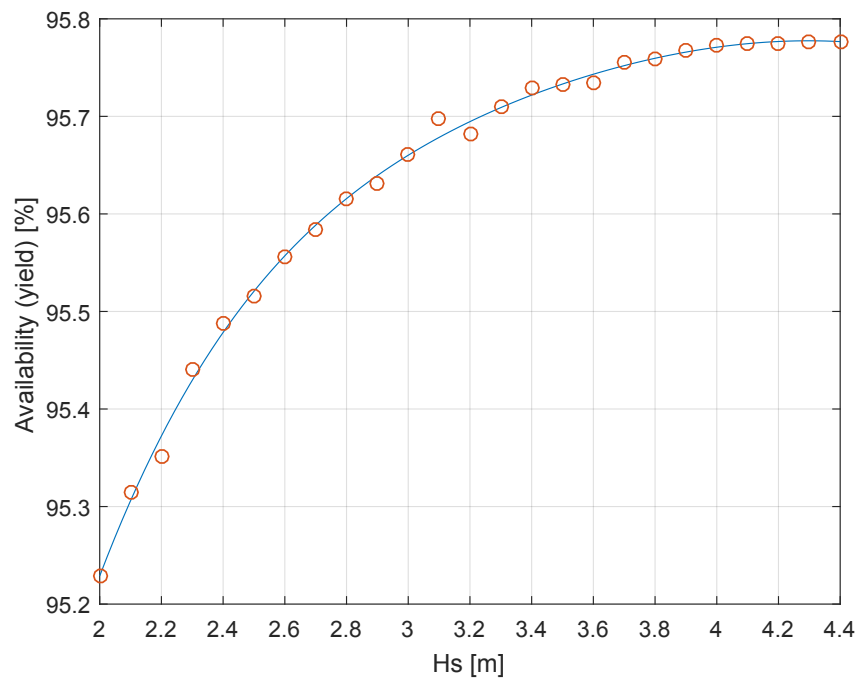
**Table 4:** O&M simulation results.

|                                          | Harbour (CTVs) | Harbour (CTVs+heli) | Offshore (SOV) |
|------------------------------------------|----------------|---------------------|----------------|
| Availability [time/yield %]              | 95.0/94.5      | 95.8/95.6           | 95.9/95.7      |
| Repair costs [ $M\text{€}$ ]             | 59.33          | 59.39               | 68.22          |
| Revenue losses [ $M\text{€}$ ]           | 24.48          | 19.67               | 18.64          |
| Total O&M effort [ $M\text{€}$ ]         | 83.81          | 79.06               | 86.86          |
| Cost of energy [ $\text{€}/\text{kWh}$ ] | 1.85           | 1.83                | 2.10           |

The comparison between the different strategies shows that harbour based strategy supported by helicopter access is the most effective in terms of overall cost. Specifically, replacing a CTV by a helicopter increases the yield availability by 1.1% with a reduction in the revenue losses of 5 $M\text{€}$  per year. Despite the higher costs for employing a helicopter compared to a CTV, repair costs increase only slightly since improved accessibility decreases also the delays for operations that require jack-up vessels such as replacements, leading to higher efficiency in the entire supply chain. Finally, offshore based strategy improves further the availability to 95.7% but it comes with the disadvantage of an expensive SOV.

In order to show the effect of the accessibility on the performance of a wind farm and specifically the availability, Figure 38 shows the results of a sensitivity analysis on the maximum allowable significant wave height for access through a SOV including a motion compensated gangway for the aforementioned reference case.

**Figure 38:** Wind farm availability (yield) versus max. allowable  $H_s$  for offshore based strategy (SOV).





As it can be seen, for the case developed in this work and the corresponding metocean conditions, marginal improvements are expected in the availability of the wind farm after extending the limit beyond  $H_s$  of  $3.0m$  which is currently considered the industry standard for access through motion compensated gangways.

Finally, it should be noted that the results of this study concern specifically the reference wind farm that was chosen including distance from port ( $50km$ ), relevant metocean conditions and other inputs and assumptions. Hence, generic conclusions should not be drawn and for each wind farm, a dedicated model should be developed.



# 4

## Conclusions & future work

This Chapter presents the main conclusions of this publication and provides the scope of the future work.

### 4.1 Conclusions

The primary goal of this work was to provide an overview of the available and under-development access solutions for offshore wind O&M. Moreover, a case study was used to illustrate how ECN O&M Access tool can be used to evaluate the impact of different ways of access on the performance of the wind farm.

The comparative study pinpointed that currently a wide range of CTVs is mainly used for offshore wind O&M, providing access up to sea states of  $H_s$  of  $1.5 - 2m$ . In addition, a number of systems that enhance CTVs' performance in terms of accessibility and safety have entered the market. Access through CTVs is relevant for near-shore wind farms usually closer than  $70km$  from shore and beyond this distance, offshore accommodation is inevitable and the current trend shows the potential of SOVs and motion compensated gangways as the access methods, operating usually up to sea states of  $H_s$  of  $3.0m$ . However, even for distances from shore of less than  $70km$ , strategic reasons have already led some service providers and wind farm owners to choose a SOV instead of CTVs. Moreover, other concepts have been proposed as alternative to motion compensated gangways but they are not yet commercially available. Last, helicopter support can be quite beneficial due to the fast response times and almost unlimited accessibility. Ultimately, logistic concepts that include a variety of access systems (e.g. SOV with daughter crafts supported by helicopter) are required to increase availability to  $96 - 97\%$  for far-offshore wind farms. This will require further innovations of access systems in order to overcome technical challenges and provide these systems at an acceptable cost.

As far as the results of the O&M modelling are concerned, it was made clear that distance from port is crucial for selecting the most suitable O&M strategy. Specifically for the case study developed ( $720MW$  wind farm,  $50km$  away from shore), harbour based strategy supported by helicopter access was to be the most cost-effective option. However, results are based on the model developed in this work and each wind farm needs a separate analysis. In general, accessibility is only one parameter for selecting an access system but a holistic O&M modelling approach is required that is taken into account interactions with

all parts of the O&M supply chain to make a safe conclusion, as the one proposed by ECN O&M Access tool.

## 4.2 Future work

As it was mentioned, ECN will follow the developments of offshore wind access systems and intends to update this report every year.

Moreover, it was made clear through this work that examining the added value of access systems required an integrated approach which takes into account the interactions with other parts of O&M (e.g. crew shift patterns, vessels and equipment). For this reason, “ECN O&M Access” tool was used which simulates offshore wind O&M activities and estimates the costs.

Currently, ECN O&M Access tool restricts the access to offshore wind turbines based on thresholds on the wind speed and significant wave height as defined by the user. However, there are other important parameters such as wave period and direction, currents, tide and swell which also influence accessibility. Moreover, the type of vessels on which an access system as a gangway is installed is crucial for assessing the accessibility. For this reason, ECN is working on a next version of the tool which will include the vessel hydrodynamics, as simulated by MARIN, and hence a more comprehensive approach for defining the access weather operating limits.

In addition, access to offshore wind turbines is mainly related to transfer of technicians. Taking into account the human factor, it is possible that human fatigue and sea sickness can influence the performance of technicians. This means that certain sea states, even if they are suitable for access, can lead to downtime due to poor performance of personnel, an aspect which is currently being investigated by TNO, MARIN and ECN under OM JIP.

Last, reliability of the access system is of great importance. Failures of critical components of the access system can increase the downtime and cause safety implications. For this reason, ECN O&M Access will be upgraded to include reliability aspects of the access systems so the safety, possible risks and downtime due to failures could be quantified.

# Bibliography

- [1] 4COffshore. Offshore Wind Farms. <http://www.4coffshore.com/windfarms/>. Accessed 17 November 2016.
- [2] GL Garrad Hassan. A guide to UK offshore wind operations and maintenance. *Scottish Enterprise and the Crown Estate*, 2013.
- [3] GJW Van Bussel and WAAM Bierbooms. Analysis of different means of transport in the operation and maintenance strategy for the reference DOWEC offshore wind farm. *Proc OW EMES, Naples*, pages 1–12, 2003.
- [4] Siemens. Siemens purchases MaXccess system to ensure safe access to offshore wind turbines and reduce the cost of energy. [http://www.siemens.co.uk/pool/news\\_press/press\\_pictures/maxccess-transfer-3.jpg](http://www.siemens.co.uk/pool/news_press/press_pictures/maxccess-transfer-3.jpg). Accessed 17 November 2016.
- [5] The Maritime Exclusive. First Offshore Wind Service Operation Vessels Christened. <http://www.maritime-executive.com/media/images/walk%20to%20work%20ampelmann.jpg>. Accessed 17 November 2016.
- [6] Fiberline Composites. Helihoist platforms. <http://www.fiberline.com/sites/default/files/products-info/20050303-0903.jpg>. Accessed 17 November 2016.
- [7] KEM Offshore. m/s Elisabeth M. [https://cdn.kem-offshore.dk/fleet\\_images/w2048/Elisabeth/HPIM0336.JPG](https://cdn.kem-offshore.dk/fleet_images/w2048/Elisabeth/HPIM0336.JPG). Accessed 17 November 2016.
- [8] Tidal Transit. Workboat Eden Rose. <http://www.tidal-transit.com/assets/images/eden-rose-departs-ssowf-1453724624.jpg>. Accessed 17 November 2016.
- [9] Mobimar. Mobimar 18 Wind. <http://www.mobimar.com/index.php?action=article-getImage&article-imageId=1747&article-type=lightbox>. Accessed 17 November 2016.
- [10] CTruk. CTruk SWATH20. <http://www.ctruk.com/uploads/images/Gallery/Slider/CTruk-CWhisper-SWATH.jpg>. Accessed 17 November 2016.
- [11] ESNA. The Tern SES CTV. ESNA Tern CTV Flyer.
- [12] Ampelmann. Ampelmann Systems. <http://www.ampelmann.nl/systems>. Accessed 17 November 2016.
- [13] OTSO. Autobrow - Innovative offshore access system. Autobrow brochure.
- [14] Houlder. TAS steps up to turbine access challenge. <http://www.houlderltd.com/wp-content/uploads/2014/06/TAS-on-Coastal-Knight.jpg>. Accessed 17 November 2016.
- [15] Osbit Power. Offshore Access. <http://www.osbit.com/equipment/offshore-access/>. Accessed 21 November 2016.



- [16] MOMAC. Momac Offshore Access Systems. <http://www.momac-robotics.de/db/docs/momac-offshore-access-systems-MOTS--500-MOTS-1000EXT-and-MOTS-G-v.2012-11-01.pdf>. Accessed 21 November 2016.
- [17] SMST. Telescopic Access Bridge Specifications.
- [18] Uptime. Walk to Work solutions. [http://www.uptime.no/wp-content/uploads/brochure\\_UPTIME\\_A5.pdf](http://www.uptime.no/wp-content/uploads/brochure_UPTIME_A5.pdf). Accessed 21 November 2016.
- [19] R. Brooks and D. Rodger. The World Offshore Renewable Energy Report 2004-2008. <http://www.ppaenergy.co.uk/web-resources/resources/356866df2d2.pdf>. Accessed 21 November 2016.
- [20] Knud E. Hansen A/S. Exploring New Markets - The Wind-Bridge. <http://www.knudehansen.com/key-services/innovative-design/exploring-new-markets/>. Accessed 21 November 2016.
- [21] ZTechnologies. Zcatch. <http://www.ztechnologies.nl/zcatch.html>. Accessed 21 November 2016.
- [22] MOMAC. MOTS & SLILAD - Improve the safety of turbine personnel transfer. [http://www.momac.de/Offshore/Handout/MOTS\\_SLILAD\\_short\\_information\\_web.pdf](http://www.momac.de/Offshore/Handout/MOTS_SLILAD_short_information_web.pdf). Accessed 21 November 2016.
- [23] ZTechnologies. Zstep. <http://www.ztechnologies.nl/zstep.html>. Accessed 21 November 2016.
- [24] ESVAGT. ESVAGT FARADAY. <http://www.esvagt.com/fleet/wind-service-operations-vessels/esvagt-faraday/>. Accessed 21 November 2016.
- [25] DAMEN. DAMEN W2W OFFSHORE WIND SUPPORT VESSEL 9020. [http://products.damen.com/-/media/Products/Images/Clusters-groups/Offshore-and-Transport/Walk-to-Work-vessel/W2W-9020/Documents/Damen\\_Accommodation\\_Support\\_Vessel\\_9020\\_02\\_2016.pdf](http://products.damen.com/-/media/Products/Images/Clusters-groups/Offshore-and-Transport/Walk-to-Work-vessel/W2W-9020/Documents/Damen_Accommodation_Support_Vessel_9020_02_2016.pdf). Accessed 21 November 2016.
- [26] Salzmann D. C. Ampelmann - the development of an offshore access system. *We@Sea Conference, Den Helder*, 2009.
- [27] Barge Master. VROON AND BARGE MASTER TEAM UP ON NEXT-GENERATION WALK-TO-WORK VESSEL. [http://www.barge-master.com/uploads/pics/Barge\\_Master\\_Gangway\\_on\\_VOS\\_Start.jpg](http://www.barge-master.com/uploads/pics/Barge_Master_Gangway_on_VOS_Start.jpg). Accessed 21 November 2016.
- [28] W3G Marine. Crew Access Bridge - CRAB.
- [29] Houlder. PERSONNEL TRANSFER SYSTEM - Offshore Walk To Work Access. <http://www.houlderltd.com/wp-content/uploads/2015/10/Houlder-Personnel-Transfer-System.pdf>. Accessed 21 November 2016.
- [30] KENZ Cranes. OFFSHORE GANGWAYS. <http://www.kenz-figee.com/offshore-gangways>. Accessed 21 November 2016.
- [31] MacGregor. Three Axis compensated Crane for Wind turbine Services. <http://www.norcove.no/doc/konferanser/2014/Presentasjonar%20SMI%20Bergen/Henriksen%20SMI%20-%20Macgregor%20offshore.pdf>. Accessed 22 November 2016.
- [32] SAFEWAY. SAFEWAY teams up with ASSODIVERS. [http://www.vanaalstmarine.com/sites/default/files/Aethra%20-%20W2W%20Specifications%202016\\_0.pdf](http://www.vanaalstmarine.com/sites/default/files/Aethra%20-%20W2W%20Specifications%202016_0.pdf). Accessed 22 November 2016.
- [33] SMST. Successful first connection by SMST M series Telescopic Access Bridge. [http://www.smst.nl/pageid=16/articleid=398/Successful\\_first\\_connection\\_by\\_SMST\\_M\\_series\\_Telescopic\\_Access\\_Bridge.html](http://www.smst.nl/pageid=16/articleid=398/Successful_first_connection_by_SMST_M_series_Telescopic_Access_Bridge.html). Accessed 22 November 2016.
- [34] ZTechnologies. Zbridge. <http://www.ztechnologies.nl/zbridge.html>. Accessed 21 November 2016.

- cessed 22 November 2016.
- [35] Reflex Marine. Innovative access concept to improve safety in offshore wind energy sector. <http://news.reflexmarine.com/innovative-access-system-for-offshore-wind-energy-sector>. Accessed 22 November 2016.
  - [36] Offco. Offshore Passenger Transfer System. <http://www.offco.nl/products-opts>. Accessed 22 November 2016.
  - [37] PTS GmbH. Personnel Transfer System for Offshore Demands. <http://www.pts-offshore.com/documentation/PTSdocumentation28012008.pdf>. Accessed 22 November 2016.
  - [38] Viking. Selstair by VIKING. <http://www.viking-life.com/en/stair-systems/offshore-evacuation-systems/evacuation-systems-/3483-selstair-viking-selstair-embarkation-system-offshore-one-size>. Accessed 22 November 2016.
  - [39] Fassmer. Windlift. [www.fassmer.de/wind-power/products/offshore-solutions/wind-lifts](http://www.fassmer.de/wind-power/products/offshore-solutions/wind-lifts). Accessed 22 November 2016.
  - [40] DNV GL. Helideck and accommodation facilities on offshore platforms for wind farms. [http://www.tennet.eu/nl/fileadmin/afbeeldingen/grid-projects/Net\\_iop\\_zee/Ronde\\_4/130112\\_NLLD\\_R\\_A\\_public\\_version.pdf](http://www.tennet.eu/nl/fileadmin/afbeeldingen/grid-projects/Net_iop_zee/Ronde_4/130112_NLLD_R_A_public_version.pdf). Accessed 22 November 2016.
  - [41] National Geographic Stock/ Sarah Leen / WWF. A helicopter lowering a technician to maintain the Horns Rev wind farm, Esbjerg, Denmark. [http://blogs.wwf.org.uk/wp-content/uploads/helicopter\\_wind\\_turbines.jpg](http://blogs.wwf.org.uk/wp-content/uploads/helicopter_wind_turbines.jpg). Accessed 22 November 2016.
  - [42] M. Asgarpour and T.S. Obdam. ECN O&M Access V1.0 User Manual. *ECN Report*, 2014.
  - [43] Deltares. Metocean study for the Borssele Wind Farm Zone Site I. <http://offshorewind.rvo.nl/file/view/32962672/metocean-bwfz-time-series-site-i-deltares>. Accessed 22 November 2016.







**ECN**

|                 |                 |
|-----------------|-----------------|
| Westerduinweg 3 | P.O. Box 1      |
| 1755 LE Petten  | 1755 ZG Petten  |
| The Netherlands | The Netherlands |

T +31 88 5154949  
[info@ecn.nl](mailto:info@ecn.nl)  
[www.ecn.nl](http://www.ecn.nl)