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In case you wish to contact ECN part of TNO regarding the content of this report, please send an email to: windenergy@tno.nl.

[1] ECN, the organisation which published the previous two editions has become a part of TNO since April of 2018.

Summary

Offshore wind farms in Europe are moving further from shore in order to capture more favourable wind conditions. However, this creates additional challenges regarding their Operations & Maintenance (O&M). O&M costs contribute significantly (20-30%) to the Levelised Cost of Energy (LCOE) over the lifetime of an offshore wind farm. One of the main reasons is the relatively low accessibility to the wind farm, which increases the downtime and therefore lost energy production, especially for far-offshore wind farms. This has driven the research into innovative access systems which promise average annual accessibility of 90%.

In this third edition, an updated overview is presented of commercially available and demonstrated access systems for offshore wind farms. Three categories of access system are identified, based on the point of access: i) access to the boat landing, ii) access to the platform of the transition piece, and iii) access to the helicopter hoisting platform on top of the nacelle. Besides the conventional method of access to the boat landing through Crew Transfer Vessels (CTVs), motion compensated gangways mounted on the deck of Walk-to-Work (W2W) Vessels or dedicated Service Operation Vessels (SOVs) have entered the market during the last decade, which moves the maintenance base offshore. The analysis in this report shows that the growth of this market is in alignment with the needs for more efficient and safer transfer of technicians and cargo. In addition, while the relatively close-to-shore locations of current offshore wind farms has driven the extensive use of CTVs, more SOVs are being deployed as wind farms move further from shore, and new designs for motion compensated gangways and cranes (for SOVs) are being introduced. Furthermore, the following trends are discovered:

- The motion compensated gangway for CTVs are not well adopted by the industry.
- Within the category of CTVs, the market share of SWATH vessels (a type of CTV with improved seakeeping performance) is increasing.

- In addition to the wind farm installation and (short-term) maintenance campaign, a rising number of dedicated SOVs are entering the offshore wind industry for (long-term contract) daily operation and maintenance (O&M).

It is important to model offshore wind farm Installation / O&M activities to fully assess the impacts of a particular access solution. 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 Installation / O&M strategy and choosing between different access solutions. ECN (now part of TNO) has been constantly developing software tools (e.g. ECN Install, ECN O&M Calculator) to make such analysis, and will constantly upgrade these tools to improve the fidelity and user-friendliness.

Contents

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 capacity of all seabed-fixed offshore wind farms in Europe by the end of 2018, based on those wind farms which are commissioned (online), under construction, consented and application-submitted.

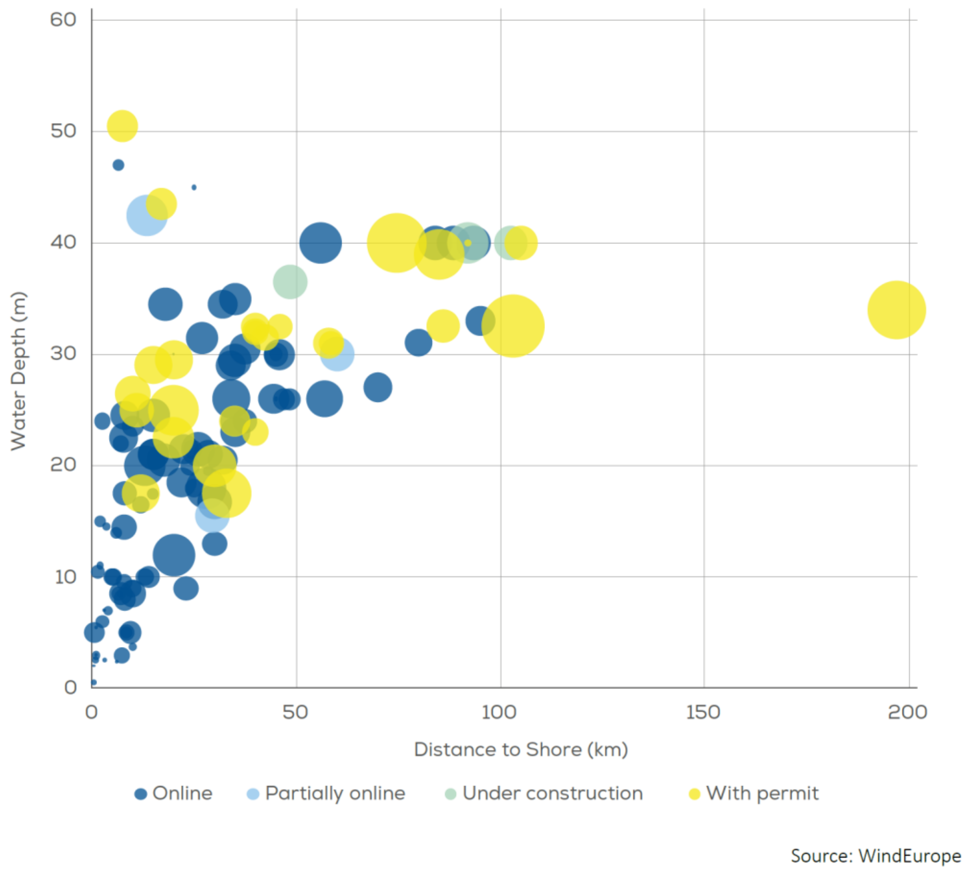

Figure 1 Average water depth and distance to shore of seabed--fixed offshore wind farms, organised by development status. The size of the bubble indicates the overall capacity of the site [2].

As Figure 1 indicates, most of the existing wind farms (those that are already online) in Europe are located near-shore (<70 km), while a large capacity of new offshore wind farms (those being constructed and planned) will be located far-offshore (>70 km). Despite the favourable wind conditions, increasing distance from port leads to higher O&M costs. In an attempt to reduce these costs, new strategies for logistics are being developed using offshore-based accommodation and innovative access gangways. The distance to port has a large influence on the most suitable strategy, as can be seen in Figure 2.

For near-shore wind farms, work-boats (medium sized CTVs) are most commonly used for daily mobilisation from the port base. The further offshore the wind farm is, the more the travelling time increases, which can significantly reduce the working time available on a turbine. Besides, long trips with CTVs in less favourable weather conditions can cause sea-sickness to the technicians onboard, especially when CTVs travel at high speed. In general, it is preferred to limit the transit time between the port and wind farm to less than one and a half hours, if work-boats are used to transfer technicians. Far-offshore wind farms therefore require an offshore base for accommodating the technicians and potentially spare parts. Helicopters can also support O&M activities when the use of work-boats leads to too short a working period, or when conditions are too rough for access onto the turbine. The most commonly used offshore O&M base is the Service Operation Vessel (SOV) or Walk-to-Work (W2W) vessel. These Dynamic Positioning (DP) vessels are typically longer than 50 m and can accommodate up to 75 technicians and small-sized spare parts. Several of them can facilitate landing of a helicopter.

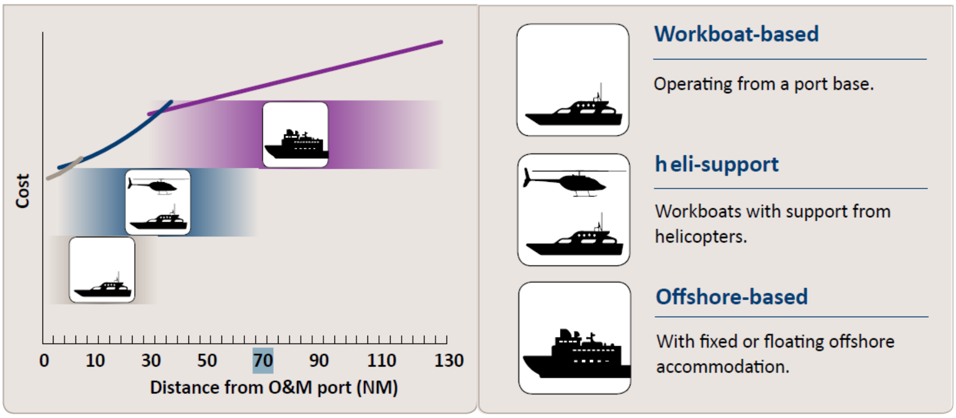

Figure 2 O&M logistics strategy as function of distance from port [3].

Overall, the goal for selecting the O&M logistics strategy is to achieve the most optimal trade-off between the overall O&M costs and the availability of the wind farm. Typically for offshore wind farms, availability of 95% is targeted to achieve this trade-off. The limitations on achieving higher reliability of components have turned attention towards optimizing the maintenance strategies including the access methods to the offshore sites. The latter is described with the term *accessibility*, meaning the percentage of time that an offshore wind farm can be approached and accessed by technicians; and is a key element for the economic viability of a project and the source of high uncertainties.

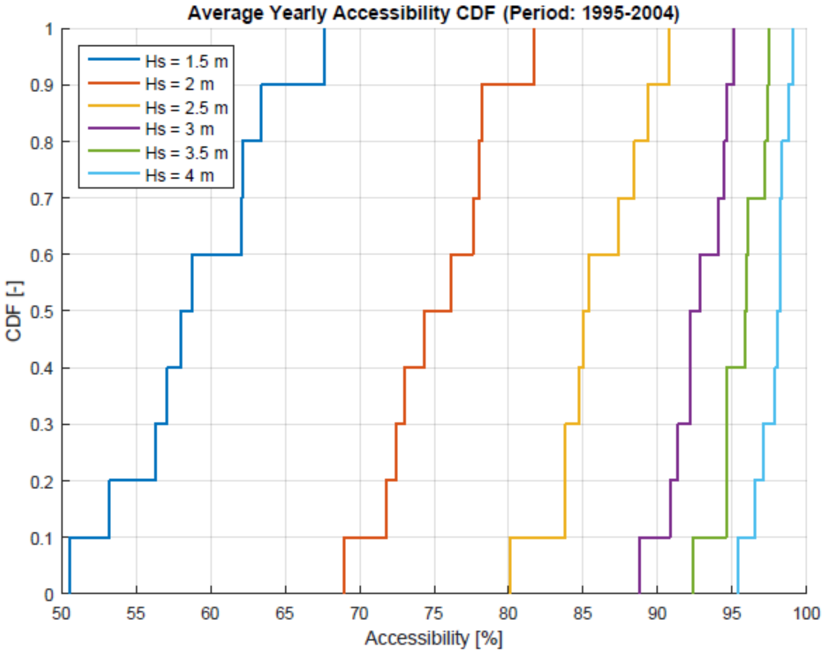

Figure 3 Average yearly accessibility CDF for various max. allowable wave heights (H_S) for the period from 1995 to 2004 at K13 location.

Results of studies [4] reveal that accessibility of at least 80% of the time is necessary 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. Wave conditions are generally described by three parameters: the significant wave height (H_S), the mean zero-crossing wave period (T_Z), and the wave direction. However, limiting wave states have traditionally been described only with significant wave height. For a given access method, this practically means that accessibility can be approximated by the probability of wave height occurrence less than the related limiting significant wave height. Figure 3 shows the Cumulative Distribution Function (CDF) of the average annual accessibility to a location close to North Sea oil platform K13, 100km from the Dutch coast, depending on the limiting significant wave height.

As an example, looking at the (red) 2m Hs line which would be relevant for an access system with that limiting wave height, 50% of years (0.5 on the vertical axis) have 75% of the time accessible. According to Figure 3, for an access system operating up to sea states of $H_S = 1.5$m, the expected average annual accessibility ranges from 51% to 68%. Increasing the limit sea state to 2.0 m increases the annual accessibility by 20% whereas a more advanced access system (max $H_S =$ 2.5m) would offer at least 80% annual accessibility.

Besides average annual accessibility, the monthly accessibility is also of importance since it indicates the seasonal effect. Figure 4 presents the monthly accessibility for a different North Sea location as an average (median) scenario, through the choice of the year 1999.

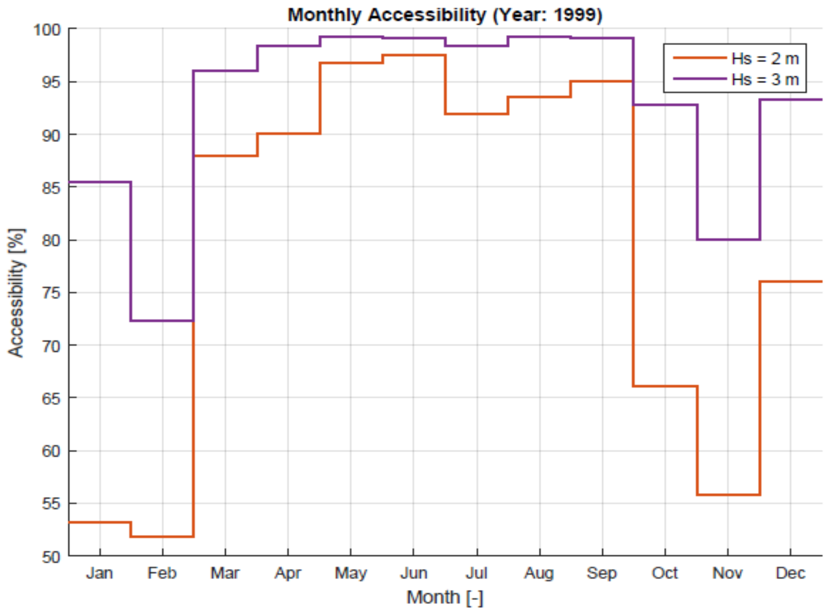

Figure 4 Monthly accessibility for max. allowable H_S of 2.0m and 3.0m for a single year at the North Sea.

In this case, two maximum allowable significant wave heights were used (H_S of 2.0 and 3.0m) for clarity reasons. As expected, the major difference between the two significant wave height limits is during the winter months, where the accessibility drops by 20-30% for an access system operating up to 2.0m H_S. This leads to an overall annual accessibility of 74% and 92% for H_S of 2.0 and 3.0m respectively.

1.2 Access systems overview

There are essentially three ways 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 /hoisting platform, 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 [5], TP platform [6] and helideck/hoisting platform [7] (from left to right).

While presenting this report, it should be noted that the most important characteristic of an access system is the accessibility it can provide. This is usually defined by the significant wave height (H_S) which is the dominant statistical measure commonly used in the industry. However, the accessibility that an access system can provide in reality is dependent on a combination of factors: not only the motion compensating capabilities of the access system, but also the size and hull design of the vessel on which it is mounted, the location of the access system on the vessel, the manoeuvring capacity of the DP system, the vessel's power-management system and the captain who is manoeuvring the vessel. Therefore, the accessibility provided by an access system cannot be accurately captured by just one environmental parameter. Besides all relevant environmental conditions (wind speed and direction; wave height, direction and period both for swell and wind-waves; current speed and direction), other aspects such as the vessel characteristics should also be taken into account when defining the accessibility such a system could deliver. There is not yet a standard method to define the accessibility that allows one to compare access systems between each other, therefore the accessibility figures mentioned in this report are based on data provided by the manufacturers or designers.

1.3 Objective and report outline

As 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 existing and future access systems for offshore wind with their specifications.

However, only systems that have either been demonstrated at a prototype level, or are commercially available in the current market will be discussed. To make the distinction between the different systems, the technology readiness level (TRL 1-9) is used, with definitions from EU Horizon 2020 [48]. Relevant here are TRL 7 and TRL 9:

TRL 7: System prototype demonstration in operational environment

TRL 9: Actual system proven in operational environment

For the demonstrated systems TRL 7 applies, while for the commercially available systems the highest level of TRL 9 is used. Conceptual designs are therefore not included in this report. Note however that this excludes systems that are currently being built (EagleAccess or Horizon V5 by TTS). It is expected that these systems will feature in the next edition of this report.

The report is organized as follows: Chapter 1 introduced the background of this report and gave an overview of offshore wind access systems. Chapter 2 and Chapter 3 presents the vessels and equipment that provide access to the wind turbine boat landing and wind turbine TP platform, respectively. Chapter 4 describes the method to access the wind turbine from the hoisting platform on the nacelle, which is at this moment by helicopters. Finally, Chapter 5 provides the conclusions and future work.

1.4 Changes with respect to the 2018 Offshore Wind Access Report

In this edition, the following changes are made with respect to the previous edition:

- The information, values, and statistics in the previous edition have been updated based on the latest knowledge and updates from the access systems market.
- Based on the development status, the access systems have been categorised into “commercially available” and “demonstrated systems (prototyped)”.
- A dedicated section about Walk-to-Work vessels and SOVs is added, including a table showing all the European wind farms which are / will be serviced by SOVs for the daily O&M (data available December 2018).

2 Access to the boat landing

The most commonly used way of accessing offshore wind turbines is through the boat landing, which is mounted in the splash zone of the wind turbine foundation. The reason for its popularity is that it is the most cost-effective and it is 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 an evolution in CTVs and access 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 in bad weather conditions.

2.1 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 wind turbine boat landing to eliminate vessel's translations, commonly known as the “bump and jump" method. CTVs typically carry 12 technicians and cargo such as small spare parts and equipment. Deck cargo is generally lifted from the deck to the platform of the Transition Piece by using the platform davit crane or built-in nacelle crane. Currently, more than 400 CTVs transfer technicians to offshore wind farms. The types of CTVs according to their hull shape include:

1. **Mono-hull**
   The first CTVs that were used in offshore wind farms were mono-hull vessels modified from an existing pool of multi-purpose vessels, which were in use as pilot and merchant marine supportive crew tender boats. Their main advantages are their low cost and scalability. On the other hand, mono-hull CTVs can only operate safely[2] up to sea states of significant wave height of 1-1.2 m due to their low stability while transferring offshore technicians onto the monopile.

2. **Catamaran**
   The majority of CTVs nowadays are aluminium catamarans. The main reasons behind their extensive usage are the high speeds that they can achieve and the good seakeeping behaviour in medium sea conditions as well as their improved stability when pushing against the boat landing of a wind turbine for offshore technician transfer. Their disadvantage compared to mono-hull vessels is their relative higher cost. Catamaran CTVs can operate satisfactorily at significant wave heights up to 1.2-1.5 m.

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[2] This limit is set by the operational phase when the vessel is transferring technicians to/from the wind turbine boat landing. During transit (travelling) phase, the vessel can generally travel with higher significant wave height. The same implication applies to all types of vessel in this report.

Figure 6 Monohull [8], Catamaran [9] and Trimaran [10] CTVs (from left to right).

3 Trimaran

In an effort to improve seakeeping behaviour of catamarans, trimaran CTVs have recently entered the market. Transfer of technicians is possible up to sea states of 1.5-1.7 m H_S.

Figure 7 SWATH [11], SES [12] and TRI SWATH [13] CTVs (from left to right).

4 Small Waterplane Area Twin Hull (SWATH)

The market share of SWATH CTVs is constantly increasing, especially in the field of wind farm installation and commissioning. SWATHs are catamaran-like vessels, which achieve greater stability by minimizing the hull cross section area at the sea's surface. Their disadvantage is higher cost and lower speed compared to catamarans. Their design allows comfort during sailing and safe access at significant wave heights of 1.7-2.0 m.

5 Surface Effect Ship

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 behaviour. This however comes with the disadvantage of design complexity and higher costs. Overall, SES can operate at maximum sea states of 2.0 m H_S during transfer phase. Note that only a very limited number of these types of vessels have been built.

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 exactly represent the CTVs displayed in Figures 6 and 7.

Table 1 Typical characteristics of CTV types

	Mono- hull	Catamaran	Trimaran	SWATH	SES
Length [m]	12 - 25	15 - 27	19 - 27	20 - 34	26 - 28
Top Transit Speed [knots]	15 - 25	18 - 27	18 - 22	18 - 23	35 - 39
Passengers [-]	12	12	12	12/24	12/24
Cargo [tons]	5 - 10	10 - 15	1 - 5	2 - 10	3 - 5
Hs (limit) [m]	1 - 1.2	1.2 - 1.5	1.5 – 1.7	1.7 - 2	1.8 – 2.2

2.2 Systems that enhance access to the boat landing

The demand for high availability has pushed the development of systems that can be fitted to enhance accessibility and overall safety. These systems can either be mounted on the vessel foredeck to compensate motions, or on the turbine structure. Both methods improve access to the turbine 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).

In this section only three commercially available systems have been identified. There are several additional systems existing on the market, which have been excluded (Houlder's TAS) because they are currently not actively deployed.

2.2.1 Overview of technical parameters

An overview of systems that enhance the performance of CTVs is presented in Table 2, stating their relevant technical parameters.

Table 2: Main data of commercially available systems that enhance the access to the boat landing

	Ampelmann L-Type	Maxccess T-Series	Uptime		
			8 m	12 m	15 m
Minimum length gangway [m]	5	N/A	8	12	15
Maximum length gangway [m]	11	N/A	13	18	21
Maximum working angle +/- [deg.]	±15	±15	±30	±30	±30
Height from deck [m]	2	1.2	Custom	Custom	Custom
Vertical reach [m]	4	N/A	-	-	-
Gangway width [m]	0.55	0.6	0.8	0.8	0.8
System weight [ton]	8	1.9	1.5	2.5	3.5
Footprint on vessel [m^2]	2.2 m x 5.7 m	8 m^2	5 m^2	5 m^2	5 m^2
Limiting wave condition Hs [m]	2	2.5	2	2.5	-
Vessel length [m]	30+	<26	>15	>20	>25
Mobilization time [hr]	8	24	12	12	12
Deployment time [s]	60	60	24	24	24
Maximum connection time [hr]	-	12 h	No limit	No limit	No limit
Power consumption [kW]	22	25	25	25	25
Maximum load [kg]	150	350	400	500	500
Maximum load per area [kg/m^2]	-	-	200	200	200
Redundancy	-	Maintain grip	Fully redundant	Fully redundant	Fully redundant
Ride through failure [s]	30	-	Unlimited	Unlimited	Unlimited
Number of systems built [-]	8	4	10	5	5
Number of transfers [-]	> 200,000	> 30,000	~10,000	~10,000	-

Notes:
1. Only systems for which technical details were either publicly available or were shared by the developers are included in the table. A blank cell indicates that the data were not made available.
2. The table provides an overview of commercially available and demonstrated systems that enhance the access to the boat landing, but a direct comparison between them should not be made since the numbers included are highly dependent on individual assumptions.
3. The values given for limiting wave conditions (significant wave height, or Hs) are provided by the associated companies and no investigation has been performed by TNO and no warranty is given as to their accuracy. It should be emphasised that the vessel size, hull design, location of the access system on the vessel, manoeuvring capacity of the DP system and the captain who is driving the vessel through the motions of the sea, all have a significant impact on the accessibility, which cannot be accurately captured by just one (or a few) environmental parameter(s).

2.2.2 Commercially available systems

Ampelmann L-Type

Ampelmann L-type is the smallest Ampelmann system, suitable for fast crew vessels without Dynamic Positioning (DP), though specified for vessels with a minimal length of 30 m. It is a plug and play system allowing fast mobilization. Active compensation is used during landing and passive compensation during transfer.

Figure 8 Ampelmann L-Type [14].

MOBIMAR Gripper

The Gripper is only in use on the vessels that are built by Mobimar, a company based in Finland specialized in design of work-boats. This mooring system is stated to enable in open-sea conditions 20% - 30% more operational days per year, while allowing technician and spare part transfers to the turbine up to 2.5 m significant wave height.

Figure 9 MOBIMAR Gripper [15].

MaXccess T-Series

MaXccess T-Series by Osbit is a passive motion compensated gangway which clamps onto one of the vertical tubular spars of the boat landing and allows the vessel to roll, pitch and yaw freely, while preventing vertical and horizontal bow motion. There are two versions of this system (T12 and T18), for which the clamping capacity is 12 and 18 tonnes respectively. Currently two T-Series systems are operating globally. One operates at Fukushima for Marubeni, which has been in service for around 5 years. The other operates in China for SPIC at the Binhai offshore wind farm, which entered service in 2018.

Figure 10 MaXccess T-series [16].

Uptime Gangway 8 m – 12 m – 15 m

Uptime's small gangways are telescopic motion compensated gangways suitable for a variety of vessels, with or without DP. This gangway can be connected to a griper that holds the gangway in position with the boat landing, or by rollers that can be landed on any flat surface. In the latter case the gangway is actively motion compensated. The three systems together have provided more than twenty thousand transfers at sea.

Figure 11 Uptime Gangway 8 m – 12 m – 15 m [17].

3 Access to the Transition Piece (TP) platform

The restricted accessibility that CTVs can provide, the impact of safety-related risks and the effect on humans due to motion-induced fatigue are causing new solutions to be considered, which provide safer and more comfortable access directly to the TP platform at elevation from the sea level of approximately 15m - 20m. As wind farms move further offshore, accommodation near the offshore wind farm becomes more cost-efficient. For this reason, Walk-to-Work (W2W) solutions have been developed, which refer to a Dynamic Position vessel (mostly called support vessel or accommodation vessel), usually longer than 60m, with a motion compensated gangway to eliminate relative motions between vessel and wind turbine.

Figure 12 Walk-to-Work vessels Vroon VOS Start [18] and Bibby Wavemaster [19].

3.1 Service Operation Vessel / Walk-to-Work Vessel

In the offshore wind industry, Walk-to-Work vessels are usually also referred to as Service Operation Vessels (SOVs). At the moment, the majority of the SOVs used in the offshore wind sector are retro-fitted vessels from the oil & gas industry, with permanently or temporarily-installed motion compensated gangways. SOVs are mostly employed in the installation phase of offshore wind farms, especially during cable installation and wind turbine commissioning. SOVs are now also increasingly used for the scheduled maintenance campaign of wind farms and substations. Since 2015, SOVs that are specifically designed for both installation and daily O&M of offshore wind farms have come to the market. Compared with the retro-fitted SOVs, these purpose-designed SOVs generally have better performance in terms of transferring technicians and cargo, because those vessels are designed in an integral manner with the motion compensated gangways onboard (and cranes, if any), hence the parameters such as the location of the gangway/crane, the layout of the deck can be optimised during the design.

The are several advantages of using SOVs for the installation and O&M of offshore wind farms:

- SOVs are offshore-based near the wind farm, which saves time bringing technicians to the wind farm and thus increases their effective working time on turbines. According to the working regulations in Europe, offshore-based technicians normally work on a rotation of two weeks. Therefore, the SOVs used for the wind farm daily operation follow the same working pattern. Every two weeks the SOV travels back to port for crew change, reloading cargo storage and bunkering, which generally takes a day. During this change of shift, the trips between the wind farm and port are normally made in the night, hence the working time of technicians is not reduced.

- Since the technicians on SOVs are offshore-based, they can have a staggered working pattern, meaning that the working shift of technicians can start only when they are being transferred to the wind turbine. In general, the SOVs employed for wind farm O&M need to transfer multiple teams of technicians to different turbines in one day. Due to the staggered working pattern, the working time of technicians to be transferred later in a day is not reduced while the vessel is travelling or transferring earlier teams. This also increases the effective working time of technicians compared to the shore-based access strategy, where the working shift of all the technicians start at the same time when they are going to the wind farm from the port.

- The enhanced accessibility of SOVs results in longer weather windows for installation, commissioning or maintenance activities. This is the main reason why SOVs are widely used during installation (commissioning phase) of the wind farm, even when the wind farms are close to shore. The motion compensated gangway on SOVs can provide much easier and safer transfer of technicians and cargo to the wind turbine, compared to the access by boat landing. In order to further improve the efficiency and safety during transfer, many new SOVs are adopting a “step-less” approach, which means that technicians do not need to step up (or down) during the entire transfer process from the cargo deck / accommodation to the wind turbine TP platform. The step-less approach also allows for transfer of small size cargo (<200 kg) with trolleys/pallets, instead of being carried by technicians. In general, the step-less approach is achieved with the help of the integrated lift in the SOV and the motion compensated gangway.

- The better seakeeping behaviour of SOVs compared to CTVs causes less motion-induced fatigue to technicians, which has a positive effect on the performance of technicians.

On the other hand, SOVs also have some disadvantages:

- SOVs are much more expensive than CTVs. The day rate of an SOV is approximately 8 – 10 times that of a CTV. This is the main reason why most of the near-shore wind farms are still operated with CTVs. During the installation phase of wind farm, technicians can work on two shifts (day shift and night shift), hence the high costs of SOV can be “halved” by using it twice as efficiently. However, this is not the case for the O&M phase, during which technicians normally work only on the day shift.

- The transit speed of SOV in the wind farm is very slow (10 – 12 knots), especially when sailing on Dynamic Positioning mode. In a large wind farm, an SOV may take a very long time travelling between turbines that are far away from each other. To solve this problem, and meet safety requirements, some of the SOVs are equipped with daughter craft (usually fast cruising boats of 7-15 m). However, the daughter craft can only operate in very good weathers, preferably when the significant wave height is under 1.2 m.

As more and more wind farms in Europe are located far-offshore and have larger capacity, the rise of specifically-designed SOVs for daily O&M has been noted as a trend. Up until the end of 2018, it is known that the European offshore wind farms summarised in Table 3 are / will be serviced by SOV for the O&M phase.

Table 3 The European offshore wind farms which are / will be serviced by SOV for O&M (knowledge by the end of 2018)

Wind Farm	Country	Distance to Port	No. of Turbines	Year (to be) Commissioned	SOV for O&M	Motion compensated gangway on SOV
BARD Offshore 1	DE	110 km	80	2013	Acta Auriga	SMST TAB - L
EnBW Baltic 2	DE	60 km	80	2015	Esvagt Froude	Ampelmann A-type
Butendiek	DE	40 km	80	2015	Esvagt Faraday	Ampelmann A-type
Gemini	NL	75 km	150	2016	Windea La Cour	Uptime 23.4m
Belwind 1 Nobelwind	BE BE	45 km 45 km	55 50	2010 2017	Esvagt Mercator	None[3]
Veja Mate	DE	110 km	67	2017	Acergy Viking[4]	Uptime 23.4m
DanTysk Sandbank	DE DE	75 km 100 km	80 72	2015 2017	Windea Leibniz	Uptime 23.4m
Dudgeon	UK	45 km	67	2017	Esvagt Njord	Uptime 23.4m
Race Bank	UK	40 km	91	2018	Edda Passat	Uptime 23.4m
Borkum Riffgrund 1 Borkum Riffgrund 2 Gode Wind 1 & 2	DE DE DE	60 km 60 km 55 km	78 56 97	2015 2019 2017	Wind of Change	Uptime 23.4m
Merkur	DE	60 km	66	2019	A new SOV of Windea (to be named)	Uptime 30m
Arkona	DE	45 km	60	2019	VOS Stone	Ampelmann A400
Hohe See and Albatros	DE	110 km	87	2019	Bibby WaveMaster Horizon	SMST
DeBu	DE	110 km	33	2019/2020	A new SOV of Esvagt (to be named)	SMST
Hornsea 1	UK	120 km	174	2020	Edda Mistral	Uptime 23.4m
Hornsea 2	UK	110 km	165	2021	Wind of Hope	TTS Horizon V5
Borssele 3 & 4	NL	50 km	77	2021	A new SOV of Esvagt (to be named)	Not yet known
Triton Knoll	UK	50 km	90	2021	A new SOV of Esvagt (to be named)	Not yet known
Moray East	UK	70 km	100	2021	A new SOV of Esvagt (to be named)	Not yet known

It should be noted that Table 3 does not cover all the existing and to-be-built SOVs in the offshore wind sector, as some SOVs (e.g. Bibby WaveMaster 1, VOS Start, Acta Orion) are currently on other duties than servicing the O&M of offshore wind farms.

[3] Esvagt Mercator is not equipped with motion compensated gangway. Instead, it uses daughter craft onboard to transfer technicians.
[4] Will be replaced by a new SOV

3.2 Motion compensated systems for transfer of personnel

There are two modes of motion compensation: active and passive. Active motion compensation uses sensors and control systems to eliminate relative motions. Passive compensation is achieved by a mechanical connection which adjusts itself passively. Offshore wind access through motion compensated gangways is a relatively new market and new systems are constantly being developed. Effort has been made to include most of them in this publication. Besides motion compensated gangways, there are also other systems that can be installed on vessels and transfer technicians to the TP platform.

The majority of the systems providing direct access to the TP's work platform for personnel are active motion compensated gangways. Increasing numbers of them also provide lifting capacity for larger cargo, in most cases up to 1000 kg.
There are also some motion compensated cranes that are additionally capable to transfer personnel through some sort of basket. In this section, an overview of commercially available and prototyped motion compensated systems that transfer personnel to TP's work platforms is presented. The relevant technical characteristics are summarised in section 3.2.1, after which these systems are categorised and presented respectively in section 3.2.2 (for commercially available systems), section 3.2.3 (for demonstrated systems which are not yet deployed) and section 3.2.4 (alternative ways of personnel transfer).

3.2.1 Overview of characteristics

An overview of the relevant technical characteristics is given in the tables below.

Table 4: Main data of commercially available and demonstrated motion compensated access systems that provide access directly to the TP platform.

	Ampelmann			Barge Master		KENZ	
	A-Type	E-Type	N-Type	Basic	Adjustable	EH 15-25/1800	EH 16-26/1800
Min. length gangway [m]	16	21	23	14.9	14.9	14.6	17.1
Max. length gangway [m]	25	30	32	25.1	25.1	24.6	27.1
Max. work. angle +/- [deg.]	±17	±17	±15	±18	±18	±15	±18
Height from deck [m]	5.4	9.5	12	Any Req.	Any Req.	custom	custom
Vertical reach [m]	12	14.9	15	12.4	24.4	13	19
Gangway width [m]	0.55/1.2	0.55	0.8	0.9	0.9	0.8	1.2
System weight [ton]	39	105	225	28	86	32.1	49.3
Footprint on vessel [m^2]	41.8 m^2	95	11 m x 11 m	Ø 1.9 m	3.3 m x 3.3 m	40 m^2	12 m^2
Limiting wave condition Hs [m]	3 (3.5 for A^{EP})	4.5	3.5	3.5+	3.5+	1.5	3+
Vessel length [m]	55+	70+	70+	-	-	88	83.7
Mobilization time [hr]	12	48	60	48	168	48	48
Deployment time [s]	60	60	120	32	60	120	120
Max. connection time [hr]	-	-	-	No limit	No limit	No limit	No limit
Power consumption [kW]	2 x 200	2 x 400	2 x 450	2 x 200	2 x 200	200	260
Max. load [kg]	300/600	1000	450	2000	2000	300	500/1000
Max. load per area [kg/m^2]	-	-	-	-	-	200	400
Redundancy	fully redundant	fully redundant	fully redundant	fully redundant	fully redundant	-	fully redundant
Ride through failure [s]	60	60	60	Until end of operation	Until end of operation	Until end of operation	Until end of operation
Number of systems built [-]	>40	>15	1	3 built, 2 under construction	1 built, 2 under construction	2	1
Number of transfers [-]	>3,000,000	>1,500,000	>20,000	~25,000	~25,000	>20,000	>10,000

Notes:
1. Only systems for which technical details were either publicly available or were shared by the developers are included in the table. A blank cell indicates that the data was not made available.
2. The table provides an overview of commercially available and demonstrated motion compensated access systems, but a direct comparison between them should not be made since the numbers included are highly dependent on individual assumptions.
3. The values given for limiting wave conditions (significant wave height, or Hs) are provided by the associated companies and no investigation has been performed by TNO and no warranty is given as to their accuracy. It should be emphasised that the vessel size, hull design, location of the access system on the vessel, manoeuvring capacity of the DP system and the captain who is driving the vessel through the motions of the sea, all have a significant impact on the accessibility, which cannot be accurately captured by just one (or a few) environmental parameter(s).

Table 5: Main data of commercially available and demonstrated motion compensated access systems that provide access directly to the TP platform.

	Lift2Work	Osbit - Maxxcess		Royal IHC	Safeway Seagull
		AM-Series	P-Series	AMC-38	
Min. length gangway [m]	12	-	Various	26	18
Max. length gangway [m]	24	18, 25, 35	10, 18, 24, 32, 35, 58	38	28-30
Max. work. angle +/- [deg.]	N/A	±25	±30	+25/-20	±15
Height from deck [m]	20	custom	custom	custom	6-16
Vertical reach [m]	24	custom	custom	-	17
Gangway width [m]	2.4	1.2	1.2 - 2	1.2	1
System weight [ton]	10 – 15	-	-	-	90
Footprint on vessel [m^2]	8.8 m^2	9 m^2	9 m^2	3 m x 3 m	30 m^2
Limiting wave condition Hs [m]	2.5 – 4	3	4.5	4	3.5
Vessel length [m]	40+	any	any	>80	>60
Mobilization time [h]	8	24	24	-	24
Deployment time [s]	60	60	60	60	60
Max. connection time	-	several	several weeks	no limit	no limit
Power consumption [kW]	2 x 76	varies	varies	2x140	75-85
Max. load [kg]	1000/2500	500	500	1000	1,000
Max. load per area [kg/m^2]	-	-	-	-	400
Redundancy	fully redundant	multiple	-	fully redundant	according to B.V. class
Ride through failure [s]	-	-	-	fail-safe	-
Number of systems built [-]	1	0	12	1	3 built, 6 under construction
Number of transfers [-]	0	0	100,000	>1,000	>5000

Notes:
1. Only systems for which technical details were either publicly available or were shared by the developers are included in the table. A blank cell indicates that the data was not made available.
2. The table provides an overview of commercially available and demonstrated motion compensated access systems, but a direct comparison between them should not be made since the numbers included are highly dependent on individual assumptions.
3. The values given for limiting wave conditions (significant wave height, or Hs) are provided by the associated companies and no investigation has been performed by TNO and no warranty is given as to their accuracy. It should be emphasised that the vessel size, hull design, location of the access system on the vessel, manoeuvring capacity of the DP system and the captain who is driving the vessel through the motions of the sea, all have a significant impact on the accessibility, which cannot be accurately captured by just one (or a few) environmental parameter(s).

Table 6: Main data of commercially available and demonstrated motion compensated access systems that provide access directly to the TP platform.

	SMST			Uptime		Uptime		Z-bridge
	TAB M	TAB L	TAB XL	23.4 m	26 m	30 m	45 m	
Min. length gangway [m]	13	15	28 – 38	23.4	26	20	31	15
Max. length gangway [m]	21	25	43 - 58	31.4	34	30	45	24
Max. work. angle +/- [deg.]	+25/-20	+25/-20	+27/-23	+15/-10	+15/-10	±25	+20/-15	±15
Height from deck [m]	Up to 30	Up to 30	Variable	custom	custom	custom	custom	13
Vertical reach [m]	16	19	46	-	-	-	-	12.5
Gangway width [m]	0.6	0.9 – 1.2	1.5	1.2	1.2	1.2	2	1.2
System weight [ton]	-	-	-	27	45	15	40	50
Footprint on vessel [m^2]	20 ft container	3 m x 3 m	Ø 3.2 m	10 m^2	10 m^2	10 m^2	10 m^2	15 m^2
Limiting wave condition Hs [m]	2.5 – 3.5	3 – 4	>4	3.5	3.5	4.5	>4.5	4
Vessel length [m]	SOV	SOV, CSV	SOV	>50	>50	>50	>80	>50
Mobilization time [h]	24	-	-	40	40	40	100	36
Deployment time [s]	150	150	-	60	60	60	200	60
Max. connection time	-	-	-	no limit	no limit	no limit	no limit	no limit
Power consumption [kW]	55	100	86	128	128	150	150	50
Max. load [kg]	300	1,000	10,000	1,000	1,000	1,000	18,000	1,000
Max. load per area [kg/m^2]	-	-	400	200	200	200	200	-
Redundancy	fully redundant	fully redundant	fully redundant	fully redundant	fully redundant	fully redundant	fully redundant	fully redundant
Ride through failure [s]	fail-safe	fail-safe	fail-safe	unlimited	unlimited	unlimited	unlimited	-
Number of systems built [-]	7 built, 3 under construction	4 built, 4 under construction	5	27	4	0	82	1
Number of transfers [-]	-	-	-	~1,000,000	-	-	~1,000,000	>600

Notes:

1. Only systems for which technical details were either publicly available or were shared by the developers are included in the table. A blank cell indicates that the data was not made available.
2. The table provides an overview of commercially available and demonstrated motion compensated access systems, but a direct comparison between them should not be made since the numbers included are highly dependent on individual assumptions.
3. The values given for limiting wave conditions (significant wave height, or Hs) are provided by the associated companies and no investigation has been performed by TNO and no warranty is given as to their accuracy. It should be emphasised that the vessel size, hull design, location of the access system on the vessel, manoeuvring capacity of the DP system and the captain who is driving the vessel through the motions of the sea, all have a significant impact on the accessibility, which cannot be accurately captured by just one (or a few) environmental parameter(s).

3.2.2 *Commercially available motion compensated systems for transfer of personnel*

This section lists the systems that are currently available on the market (TRL 9). These also include systems which have not been installed but are a variant of an installed system.

Ampelmann A-Type

Inspired by the Stewart platform, the Ampelmann system eliminates any relative motion by taking real time measurements of the ship's motions and then compensates the motions by using six hydraulic cylinders. The first concept was A-Type. Ampelmann A-Type series has four models: A^{EP}, A, A100 and A400. They are different in size and maximum operational sea states. In addition, Ampelmann A^{EP} and A can only transfer personnel, while A100 and A400 are also suitable for transferring small-sized cargo (up to 100kg and 400kg, respectively). All critical components are installed redundantly to ensure constant and safe operation. The A-type is in production since 2008.

Figure 13 Ampelmann A-Type (courtesy of Ampelmann)

Ampelmann E-Type

The Ampelmann E-type is based on the same technology as the A-type, although it is 1.5 times larger. Because of its increased size, the system is capable of compensating higher sea states. Ampelmann E-Type series has four models: E, E100, E1000 and E8000. They are different in size and maximum operational sea states. In addition, Ampelmann E can only transfer personnel, while E100, E1000 and E8000 are suitable for transferring both personnel and cargo. As indicated by their names, E1000 and E8000 are capable of lifting up to 1000kg and 8000kg cargo, respectively. The transformation from the gangway to crane configuration (and vice versa) takes less than one minute.

Figure 14 Ampelmann E-Type (courtesy of Ampelmann) [20].

Ampelmann N-Type

Ampelmann's latest product, the N-type, has been designed for operation in extreme cold regions with temperatures down to -40 ºC, ice and snow. The N-type improves safety and efficiency of operation through active motion compensation fully controlled from the vessel and flexibility in platform landing locations and directions.

Figure 15 Ampelmann N-Type [23]

Barge Master Motion Compensated Gangway

Barge Master's gangway was introduced in 2015. The gangway can be installed as a basic system mounted directly on the deck of a vessel on a fixed pedestal of any height. The gangway can also be equipped with an adjustable pedestal with integrated elevator to facilitate variations in landing height or tidal range. The system can additionally be used for trolley transfer for 800 kg cargo and be fitted with a module that can provide a hoisting capacity up to 2000 kg.

Figure 16 Barge Master basic [24] and extended [25] gangway.

Kenz Cranes EH-15-25/1800

The Kenz Figee Group has built two types of 3D active motion compensated gangways. The first systems (EH-15-25/1800) were developed for the POSH Endeavour and the POSH Enterprise. During approach the gangway is actively motion compensated. After connection and during personnel transfer, the system is set to passive compensation.

Figure 17 Kenz EH-15-25/1800 gangway (courtesy of Kenz).

Kenz Cranes EH-16-26/1800

The second gangway system (EH 16-26/1800) is currently being installed on the Notus Express for service in Hornsea 1 wind farm. It is equipped with active motion compensation. To access offshore wind turbines, the gangway is equipped with a bumper docking system. The gangway is also provided with a hook attachment using the same 3D motion compensation system to safely hoist equipment to the platform [26].

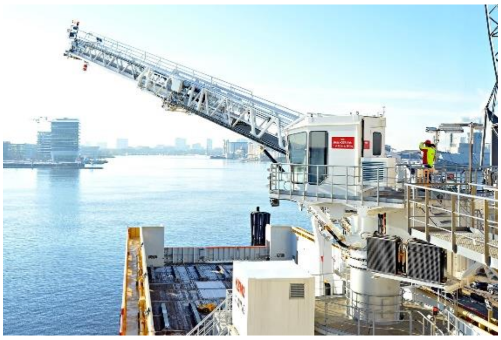

Figure 18 Kenz EH-16-26/1800 gangway (courtesy of Kenz).

Royal IHC AMC-38

Figure 19 Royal IHC AMC-38 Gangway, courtesy of Royal IHC.

Developments within IHC with regards to active motion compensated access systems go back to 2010, and the first system was delivered in 2017. With a length of 38m it is one of the longest active motion compensated gangways on the market. Luffing, slewing and telescoping motions are actively compensated. System control modes allow the gangway to be deployed in a passive mode (with a shock absorber in the landing cone, free floating) or fully active compensated. Royal IHC has also developed a compact gangway system specifically designed for SOVs.

Safeway Seagull

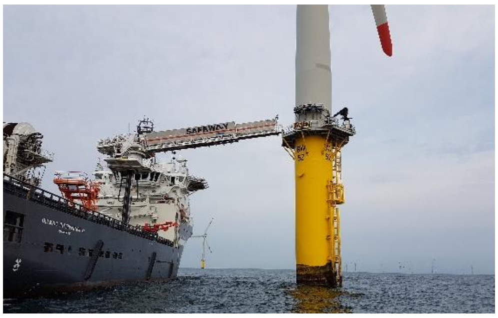

Figure 20 Safeway Seagull gangway [28].

The Safeway Seagull motion compensated gangway by the Van Aalst Group was introduced in the market in 2015. The Safeway Seagull comes with an integrated vertical elevation feature allowing level offshore access at all sites. The fully enclosed bridge is intended to provide the highest safety and comfort under all conditions. Its zero-impact bumper maintains a stationary position without physical connection to any offshore structure. It delivers 1 ton 3D lifting at the gangway tip.

SMST TAB M, L and XL

There are three versions (M, L and XL) of the SMST gangway, Telescopic Access Bridge (TAB), designed for direct access to the platform through larger vessels. The TAB-M, which comes with active motion compensation, has been built and 7 units are available. Due to a modular setup the system can be specifically applied to various landing heights, where container frames are used as stacking modules for higher working heights as shown in the first picture of Figure 21. The TAB-L will normally be offered together with an Access and Cargo tower, including an integrated elevator. The M types are primarily developed for the Walk-to-Work application, whereas the L and XL versions are suitable for the long-term connection between offshore structures and accommodation service vessels and the like. All bridges can be deployed for cargo handling and are available for rent.

Figure 21 SMST TAB: M series, L series and XL series. (courtesy of SMST).

Uptime Gangway

Figure 22 Uptime 23.4m [31].

Figure 23 Uptime 45m [32].

Uptime's large active motion compensated gangways (either 23.4m or 26m) have been on the market since 2013 and they have an extensive track record. The 23.4m version has been produced 27 times and the 26m version four times. They are suitable for long operations due to the passive connection to the fixed structure after reaching the landing point. Besides the active motion compensated gangways, Uptime also delivers larger but passive motion compensated gangways. The 30m version is new and is marketed to be autonomously landed gangway (no operator cabin on the gangway). Furthermore, the 30m version has a crane function with lifting capacity of 4 ton. Currently two 30m gangways are under contract (one for Island Clipper [29] and the other for Windea “Ulstein SX195” [30]) and planned for delivery in 2019/20. The 45m version has been delivered more than 80 times, according to their statistics. This large gangway is more designed for 24/7 connection.

Zbridge

Figure 24 Zbridge (courtesy of Zbridge).

Zbridge by ZTechnologies is a newly built motion compensated gangway system for transferring personnel and cargo (max. 1000kg). Zbridge provides direct access to the main platform through an elevator suitable for a crew of four and/or cargo up to 500 kg. The elevator capacity can be increased from 4 to 8 persons and from 500kg to 1000kg. Due to the height adjustable mechanism the landing height is adjustable from 2.5m up to 23m.

3.2.3 Demonstrated motion compensated systems for transfer of personnel

The previous section listed commercially available systems. This section will show the systems which have been demonstrated at a prototype level (TRL 7) but have not been deployed yet.

MaXccess P- and AM-Series

Osbit, a company based in the UK, is the designer and supplier of the Maxccess systems, which come in two models: a Passive compensated system (P-series) and a system that provides Active Motion (AM-series) compensation. The first one is designed for jack-ups, semi-submersibles and DP moored vessels and typically have a length of up to 50m. The AM-series are designed for mid-sized DP vessels (80-140m) and can bridge a distance of +/- 25m. This type will be designed in cooperation with Seatools, a Dutch subsea technology company.

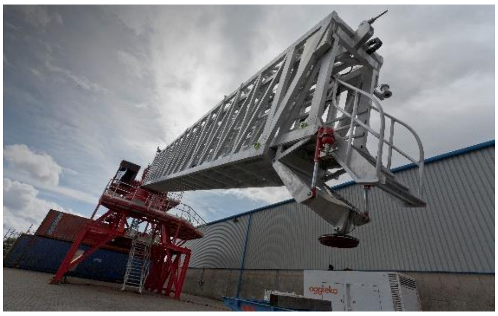

Figure 25 MaXccess P-series [33].

Offshore Passenger Transfer System (OPTS)

OPTS by LIFT2WORK 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. A maximum of 6 persons can be transferred at the same time. Besides transferring personnel, OPTS can also be used as a fully compensated crane with lifting capacity up to 1200 kg. Due to its specific design, the system is considered as one of the few tools which can replace the rope work under the platform, hence it is considered suitable for the decommissioning work in offshore wind farms. The system was built, tested and certified in 2018.

Figure 26 OPTS, courtesy of LIFT2WORK.

3.2.4 Alternative systems for transfer of personnel

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.

Reflex Marine Frog, Wave, Toro

Reflex Marine delivers four different types of personnel carriers with different shapes, names and characteristics for offshore use, as shown in Figure 27. In all cases they are “driven” by an external crane. They provide a shock-proof cabin in which persons can sit or stand, with a protective frame around it. All of them have either buoyancy or floating capacity.

While this method is common in offshore Oil & Gas, it has not been implemented in offshore wind. The main advantage of this system is safety, since according to DNV-GL and Reflex Marine [37] transfers through crane-lifted carriers have a fatality rate per transfer ten times lower than helicopter transfer. Additionally, it has a lower cost than gangway systems. The disadvantage is the requirement for a crane on either the platform or the vessel and the non-continuous transfer of goods or personnel.

Figure 27 Left: FrogXT in operation [38]. Right: Wave-4 (top left), Frog-XT (top right), Frong Range (bottom left) and Toro (bottom right) [39].

3.3 Motion compensated cranes for components between 1 and 20 metric tons

It is equally important to transfer cargo to the offshore structures as personnel. For maintenance purposes, it is mostly required to have tools and parts transported to the wind turbines and to substations (individually, in crates or in small containers). Depending on the weight of the loads, they can be transferred in different ways. The light tools and spare parts can be brought by technicians or helicopters. The davit crane on the transition piece platform can also typically hoist loads up to 1 ton from the vessel. Moreover, as mentioned earlier, some motion compensated gangways are also capable of transferring spare parts (generally below 1 ton). However, as the weight of the loads increases or the height of the platform goes up, transfer of cargo in the offshore environment can become a difficult issue. In this regard, the motion compensated cranes are introduced to the market. They are usually mounted on SOVs and can position the load on the drop zone even while the vessel is moving due to waves and current. Some of them can transfer personnel as well. Although motion compensated cranes are relatively new in the market, it is expected that they will have an increasing role in the future, particularly as individual turbines become larger (hence heavier spare parts). Below, an overview of commercially available and demonstrated motion compensated cranes for components above 1 metric ton are presented. First, the relevant technical characteristics are summarised in Table 7, then the systems are presented in alphabetical order.

Table 7 Main data of commercially available and demonstrated motion compensated cranes for components above 1 ton.

	Ampelmann E8000[5]	Barge Master BM-T40	MacGregor	SMST M	SMST L	TTS COLIBRI
Ability to transfer personnel	Yes	Yes	Yes	Yes	Yes	Yes
Method to transfer personnel	Gangway	Lifting	Lifting	Lifting	Lifting	Personnel Lift Basket
Max. safe working load for cargo	8 ton	at 10m radius: 15 ton (sea state 4)/ 20 ton (sea state 1); at 20m radius: 5 ton (sea state 4) / 8 ton (sea state 1)	5-20 ton	3-5 ton	5-10 ton	1 ton; 3 ton; 7 ton; At H_s = 2.5m
Max. Crane Lifting Height [m]	36	35	27	-	-	40
Max. Radius [m]	28	-	-	25	35	35
Compensation DOF	6	3	3	3	3	3
Limiting wave condition Hs [m]	4	3	4	4.5	4.5	3.5
Wave period limit [s]	-	4-18	-	-	-	4
Max. wind speed [m/s]	-	-	-	25	25	24
Foundation footprint	8.4 m x 9.5 m	4:8 m; 3:7 m; 3:7 m (triangle)	-	Ø 1.8 m / Ø 2.2 m (footprint of knuckle boom crane)	Ø 2.6 m (footprint of knuckle boom crane)	Ø 1.8- Ø3.6 m
Weight [ton]	111	Barge Master: 85; HPU: 34; crane: 35	-	45 (with knuckle boom crane)	84 (with knuckle boom crane)	35-90T

Notes
1. Only systems for which technical details were either publicly available or were shared by the developers are included in the table. A blank cell indicates that the data was not made available.
2. The table provides an overview of commercially available and demonstrated motion compensated cranes, but a direct comparison between them should not be made since the numbers included are highly dependent on individual assumptions.
3. The values given for maximum workable sea state (significant wave height, or *Hs*), wind speed and wave period limit are provided by the associated companies and no investigation has been performed by ECN and no warranty is given as to their accuracy. It should be emphasised that the vessel size, hull design, location of the access system on the vessel, maneuvering capacity of the DP system and the captain who is driving the vessel through the motions of the sea, all have a significant impact on the accessibility, which cannot be accurately captured by just one (or a few) environmental parameter(s).

[5] As a configuration of Ampelmann E-type, the E8000 is primarily recognised as a gangway instead of a crane. However, it is included in this table due to the large lifting capacity and lifting height. The description of Ampelmann E-type motion compensated gangway can be found in the earlier section.

Barge Master BM-T40

The Barge Master BM-T40 is a 3D motion compensated pedestal crane. Instead of compensating the motion of the jib, BM-T40 keeps the entire crane still by actively compensating the motion at the pedestal. Besides the suitability of lifting loads, the T40 is manriding certified for safe personnel transfer. Currently there are two BM-T40 systems in operation, servicing the Shell/NAM platforms (Oil & Gas) onboard Wagenborg's Kroonborg (since 2014) and Kasteelborg (since 2018). [41].

Figure 28 Barge Master BM-T40 [40].

MacGregor 3-axis motion compensation crane

MacGregor's 3-axis motion compensation crane compensates for the pitch and roll movements of the vessel with the hydraulic crane base (pedestal), and actively compensates the heave motion on the winch of the crane. It can also be connected to a personnel basket to transfer technicians The system has been used since 2014.

Figure 29 MacGregor 3-axis motion compensation cranes [42].

SMST 3D motion compensated cranes

SMST offers three sizes of the 3D motion compensated cranes (M, L and XL) [43]. The crane has a modular design which can be new-build and retrofit on the SMST knuckle boom crane of the corresponding size (M, L and XL). Six systems have been installed on vessels: two M-size with capacity of 1 ton on the Service Operation Vessels (SOV) of Østensjø Rederi, two M-size with capacity of 5 ton on the Subsea Support Vessels of Vroon, and two L-size with capacity of 6 ton on the Construction Support Vessels *Acta Auriga* and *Acta Centaurus* of Acta Marine .

Figure 30 SMST 3D motion compensation crane (L) courtesy of SMST.

TTS Colibri

Figure 31 TTS COLIBRI [44].

Ulstein[6] and TTS have collaborated to provide the TTS Colibri series of 3D motion compensated cranes to the offshore industry. The Colibri motion compensation system is a stand-alone add-on device to a standard offshore crane. It can be mounted on the tip of a standard crane as a new-build option or retrofit. In addition, Colibri uses “ground-breaking anti-sway technology" to mitigate wind induced motions acting directly on the load [44]. The cranes come in a range of 3 different sizes: 1 mT, 3 mT and 7 mT. The first system (1 mT version) has been installed on the newbuild offshore wind SOV Wind of Change for Louis Dreyfus Armateurs. A second crane will be delivered to its sister-ship Wind of Hope of LDA in 2021 [45].

[6] Ulstein has decided to withdraw from the handling equipment market and close down Ulstein Equipment. All IPR related to the TTS Colibri crane has been transferred to TTS.

4 Access to the hoisting platform

Helicopters can provide access through the hoisting platform on top of the wind turbine nacelle and through the helideck of the substation for wind speeds up to 20 m/s [46]. Because of the safety issues regarding helicopter access, ditching (safe landing on water during emergency) requirements have been established which also dictate a limiting maximum sea state for helicopter transportation. Helicopters can significantly decrease the travelling time compared to CTVs but they are expensive (typically costing 100 – 200 euros per minute, depending on the size of the helicopter) and can only carry a small number of technicians (usually 3 - 6) and very limited weight of small spare parts and tools (usually less than 100 kg). The time that a helicopter can wait in an offshore wind farm while technicians are at work inside a nacelle is very restricted (typically less than 30 minutes), unless they can land temporarily on a fixed landing platform nearby. In general, the helicopters servicing offshore wind farms do not stay in the wind farm. Therefore, helicopters go back to the heliport after they transfer the technicians and come to wind farm again to pick up technicians once the work is finished. This means a transfer by helicopter requires two round-trips, which doubles the costs.

Figure 32 Offshore wind helicopter access [47].

5 Conclusions & future work

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

5.1 Conclusions

The primary goal of this work is to provide an overview of the commercially available and prototyped access solutions for offshore wind. The comparative study outlines that currently a wide range of CTVs is mainly used for offshore wind activities, providing access up to sea states of H_s of 1.2 to 1.5 m. In addition, several systems that enhance CTVs' performance in terms of accessibility and safety (mostly access gangways) have been developed, but only a limited number of systems are commercially available. In fact, none of these commercially available systems are currently in use on CTVs, except for Mobimar gripper, which is only installed on the vessels that are built by Mobimar. To have an improved accessibility, SWATH vessels are increasingly used, especially for the installation and commissioning of offshore wind farms. Due to the speed and induced sea-sickness to the technicians onboard, access through CTVs is generally relevant for near-shore wind farms closer than 40 km from shore. With much higher speed, SES can service wind farms further offshore, up to approximately 70 km from shore. However, there are currently a very limited number of SES vessels available and in use for the offshore wind sector. Far offshore (more than 70 km), offshore accommodation is more suitable.

The current trend of wind farms being built further offshore opens up a larger potential market for 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 70 km, strategic reasons have already led some service providers and wind farm owners to choose SOVs over CTVs. In recent years, the offshore wind industry has seen a clear rise of SOVs: an increasing number of these vessels have been used for the wind farm installation, commissioning and scheduled (short-term) maintenance campaigns. Moreover, many dedicated offshore wind SOVs with integrated motion compensated gangway are entering the market for the (long-term) daily O&M of offshore wind farms.

Additionally, motion compensated cranes have started to play a more important role in transfer of cargo, and optionally personnel as well. Although they are relatively new in the offshore wind industry, their market is expected to continue growing in the future as the wind farms are becoming further away and the individual turbines are becoming larger and heavier, resulting in larger and heavier parts.

Finally, due to the high costs as well as the low passenger and cargo capacity, helicopters are not seen as the main transport method for offshore wind farms. However, helicopter support can be quite beneficial due to the fast response time and high accessibility. Therefore, it is expected that helicopters will be used primarily for emergency transfers and more for auxiliary access than for regular transportation.

5.2 Future work

The following activities are planned by TNO:

1. We will continue to follow the development of offshore wind access systems in order to update this report on an annual basis.

2. We are continuously upgrading our wind farm logistics modelling and simulation software. With future versions of this report, new case studies may be introduced.

We invite readers to contact us and welcome offers of collaboration to update both this annual report and our O&M modelling. Should you be interested to participate and contribute to the development, please contact us by email at windenergy@tno.nl

6 References

[1] H. P. Stumpf and B. Hu, Offshore Wind Access 2018. *ECN Report, 2018.*

[2] WindEurope. Offshore wind in Europe - Key trends and statistics 2018. https://windeurope.org/about-wind/statistics/offshore/european-offshore-wind-industry-key-trends-statistics-2018/

[3] GL Garrad Hassan. A guide to UK offshore wind operations and maintenance. *Scottish Enterprise and the Crown Estate,* 2013

.

[4] 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

[5] Windcat Workboats BV. http://www.windcatworkboats.com/wp-content/uploads/2014/11/Banner_6.jpg. Accessed 9 October 2018.

[6] Uptime Marine Aluminium Group. Normand Jarl working for Dong Energy. http://www.uptime.no/wp-content/uploads/17991363_944220732348233_5349596880670814827_o-768x576.jpg. Accessed 9 October 2018.

[7] windpoweroffshore.com. Areva has made a framework agreement for helicopter usage spread over different wind farms. https://cached.imagescaler.hbpl.co.uk/resize/scaleWidth/460/cached.offlinehbpl.hbpl.co.uk/news/NOW/areva-20130718034910966.jpg. Accessed 15 October 2018.

[8] KEM Offshore. m/s Elisabeth M. https://cdn.kem-offshore.dk/fleet_images/w2048/Elisabeth/HPIM0336.JPG. Accessed 9 October 2018.

[9] Turbine Transfers Ltd. 25m DNV Class Offshore Support Vessel. http://www.turbinetransfers.co.uk/wp-content/uploads/2014/09/25m_DNV_Class_Offshore_Support_Vessel_03.jpg. Accessed 9 October 2018.

[10] https://i.ytimg.com/vi/IUhUnWSgC7Y/maxresdefault.jpg. Accessed 9 October 2018.

[11] Blubird Marine Systems. SWASH Submerged Single Hull Active Surface Stabilization. http://www.bluebird-electric.net/SWASH_Submerged_Single_Hull_Active_Surface_Stabilization.htm. Accessed 9 October 2018

[12] VED Marine Services. http://www.vedshipping.com/shipping/sale-and-purchase/wp-content/uploads/sites/4/2015/09/HSC-HIGH-SPEED-CATAMARAN-CREW-FERRY-2.jpg. Accessed 12 December 2017

[13] AUSTAL. AUSTAL WIND EXPRESS TRI SWATH 27. https://www.austal.com/sites/default/files/data-sheet/Austal%20Wind%20Express%20TRI%20SWATH%2027%20Cable%20Bay.pdf. Accessed 9 October 2018.

[14] Damen Magazine. OFFSHORE ACCESS: GETTING A CLOSER LOOK AT AMPELMANN. https://magazine.damen.com/wp-content/uploads/2016/11/offshore_wind_support_ship.jpg. Accessed 10 October 2018.

[15] MOBIMAR. SAFE EMBARKATIONS HAVE BECOME REALITY FOR WINDFARM TECHNICIANS. http://www.mobimar.com/application/files/8314/9762/0064/Mobimar-safe-01.jpg. Accessed 10 October 2018.

[16] Osbit Power. Offshore Access. http://www.osbit.com/wp-content/uploads/2016/07/offshore-access-3-1.jpg. Accessed 10 October 2018.

[17] Uptime. Walk to Work solutions. http://www.uptime.no/wp-content/uploads/brochure_UPTIME_A5.pdf. Accessed 10 October 2018.

[18] heavyliftnews.com. VOS Start at work in Irish Sea. http://static.heavyliftnews.com/media/0f/8/a61bb0fbcae476cb867e9fbd5934936adfee25bd32e5d57ea19517172f80e8f0_m.jpg. Accessed 15 October 2018.

[19] Uptime.no. Bibby WaveMaster 1 Hits W2W Milestone at Galloper OWF. http://www.uptime.no/wp-content/uploads/FF86769-1024x731. Accessed 15 October 2018.

[20] Ampelmann. Ampelmann E-8000. https://www.ampelmann.nl/systems/e8000. Accessed 11 October 2018.

[21] offshoreWIND.biz. Ampelmann Cuts Gangway Conversion Time. https://www.offshorewind.biz/2017/10/09/ampelmann-cuts-gangway-conversion-time/. Accessed 11 October 2018.

[22] Ampelmann. Ampelmann O-Type. https://www.ampelmann.nl/assets/uploads/ampelmann-o-type-3.jpg. Accessed 11 October 2018.

[23] Ampelmann. Ampelmann N-type mobilised and ready for operations. https://www.ampelmann.nl/news/ampelmann-n-type-mobilised-and-ready-for-operations. Accessed 11 October 2018.

[24] Barge Master. Motion Compensated Gangway. https:/www.barge-master.com/fileadmin/user_upload/BM-Gangway_spec_sheet_-_motion_compensation_systems.pdf. Accessed 15 October 2018.

[25] Barge Master. Barge Master Gangway. https://www.barge-master.com/fileadmin/_processed_/d/e/csm_0Next-Generation-Gangway-Barge-Master_07a83aa1ad.jpg. Accessed 11 October 2018.

[26] KENZ Cranes. OFFSHORE GANGWAYS. http://www.kenz-figee.com/offshore-gangways. Accessed 11 October 2018.

[27] Van Aalst Marine. Successful 'new technology' debut on offshore access market for SafeWay. http://www.vanaalstmarine.com/sites/default/files/Olympic%20Intervention%204%20-%20Safeway%20-Trianel%20OWF%20Adwen%20Siemens.PNG Accessed 15 October 2018.

[28] Van Aalst Marine. Successful 'new technology' debut on offshore access market for SafeWay. http://www.vanaalstmarine.com/sites/default/files/Olympic%20Intervention%204%20-%20Safeway%20-Trianel%20OWF%20Adwen%20Siemens.PNG Accessed 15 October 2018.

[29] Two new contracts for walk to work gangways. http://www.uptime.no/two-new-contracts-for-walk-to-work-gangways/. Accessed 30 April 2019.

[30] Bernhard Schulte orders 3rd Service Operation Vessel (SOV). https://bs-offshore.com/bernhard-schulte-orders-3rd-service-operation-vessel-sov/. Accessed 30 April 2019.

[31] Uptime. Normand Jarl working for Dong Energy. http://www.uptime.no/wp-content/uploads/17991363_944220732348233_5349596880670814827_o-768x576.jpg. Accessed 11 October 2018.

[32] Uptime. http://www.uptime.no/wp-content/uploads/IMG_7035.jpg. Accessed 11 October 2018.

[33] MaXccess walk to work system supplied for Subsea 7 project. https://www.recognitionpr.co.uk/picturedownload.php?imageID=16243.jpg

[34] Houlder. PERSONNEL TRANSFER SYSTEM - Offshore Walk To Work Access. http://www.houlderltd.com/wp-content/uploads/2015/10/Houlder-Personnel-Transfer-System.pdf. Accessed 11 October 2018.

[35] MacGregor. Three Axis compensated Crane for Wind turbine Services. https://www.macgregor.com/Products-solutions/products/offshore-cranes/gangway-systems/. Accessed 11 October 2018.

[36] Offco. Offshore Passenger Transfer System. http://lift2work.nl/. Accessed 11 October 2018.

[37] Risks of Marine Transfer of Personnel Offshore, DNV-GL and Reflex Marine http://static1.squarespace.com/static/5527c9a8e4b05567006abd2e/t/552bdf19e4b00049ca511ef5/1428938521789/FINAL+DNVGL_Risks+of+marine+transfer+paper.pdf. Accessed 31 January 2019.

[38] Reflex Marine. https://news.reflexmarine.com/21st-international-offshore-crane-and-lifting-conference. Accessed 11 October 2018.

[39] Reflex Marine. https://www.reflexmarine.com/products. Accessed 11 October 2018.

[40] Barge Master. https://www.barge-master.com/fileadmin/_processed_/3/7/csm_Barge-Master-T40-with-platform_fd92161f85.jpg. Accessed 11 October 2018.

[41] Wagenborg orders a second Barge Master 3D motion compensated crane. https://www.heavyliftnews.com/wagenborg-orders-2nd-barge-master-3d-motion-compensated-crane/. Accessed 30 January 2019.

[42] MacGregor. 3-axis motion compensation cranes. https://www.macgregor.com/Products-solutions/products/offshore-and-subsea-load-handling/3-axis-motion-compensation-cranes/. Accessed 11 October 2018.

[43] SMST. 3D Motion Compensated Cranes. https://www.smstequipment.com/offshore-cranes/3d-motion-compensated-cranes/. Accessed 11 October 2018.

[44] Ulstein. TTS AND ULSTEIN TEAM UP FOR 3D MOTION COMPENSATED CRANES. https://ulstein.com/news/2017/tts-and-ulstein-teams-up-for-3d-motion-compensated-cranes. Accessed 11 October 2018.

[45] LDA orders SOV package. https://www.4coffshore.com/news/lda-orders-sov-package-nid10981.html. Accessed 1 April 2019.

[46] G.J.W. Van Bussel and W.A.A.M. Bierbooms. Analysis of different means of transport in the operation and maintenance strategy for the reference DOWEC offshore windfarm. *Proc OW EMES, Naples*, pages 1–12, 2003.

[47] Easy Wind Energy. Sizing Up Wind Energy and Transportation. http://easywindenergy.blogspot.nl/2013/03/sizing-up-wind-energy-and-transportation.html. Accessed 11 October 2018.

[48] Technology Readiness Level in Horizon 2020 Work Programme 2014-2015. https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/anne 49xes/h2020-wp1415-annex-g-trl_en.pdf. Accessed 6 March 2019.

[50] Eagle-Access. http://d2f0ora2gkri0g.cloudfront.net/70/63/706338c4-a017-4f63-abc1-f455aba2d5b9.jpg. Accessed 11 October 2018.