Overview topics Consultation Process 2 GW HVDC Grid Connection System

STAKEHOLDER CONSULTATION PROCESS OFFSHORE GRID NL	
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List of abbreviations

DBS	Dynamic Braking System
EAC	Economic Affairs and Climate (Ministry of)
EHV	Extra High Voltage
FEED	Front End Engineering Design
FRT	Fault Ride Through
GCP	Grid Connection Point
GCS	Grid Connection Concept
GIS	Gas Insulated Switchgear
HV	High Voltage
HVAC	High Voltage Alternating Current ("wisselstroom")
HVDC	High Voltage Direct Current ("gelijkstroom")
LCoE	Levelised Cost of Energy
MIVSP	Maritiem Informatievoorziening Service Punt
OWF	Offshore Wind Farm (developer)
PCC	Point of common coupling
PPM	Power Park Module
RWS	Rijkswaterstaat
TOV	Temporary Overvoltages
WTG	Wind Turbine Generator

Introduction

For the roadmap offshore wind 2030 ([1]), TenneT is tasked with the connection of several offshore wind farms up to 2030. The wind farm zones 'Hollandse Kust West' and 'Ten Noorden van de Waddeneilanden' will be connected with TenneT's previously established and consulted standardized 700 MW grid connection concept. For the wind farm zone IJmuiden Ver, due to its large size and large distance to shore, a new grid connection concept has been established.

TenneT has presented its advice for the offshore grid connection system to the Ministry of Economic Affairs and Climate (EAC). Based on this advice and the subsequent validation executed by Blix consultancy in assignment of the Ministry, the Minister of EAC decided on a grid connection concept (GCS) for IJmuiden Ver which is displayed in Figure 1. Wind turbines are connected through 66 kV “inter-array” cables (in orange) to an offshore 2000 MW AC/DC substation. The substation will be based on HVDC technology. Using 2 GW high voltage (525 kV) export cables (in green) the electricity is transported to shore where the DC is converted back to AC again.

TenneT will be responsible for the offshore grid, from the onshore substation up to and including, the offshore substation and intends to develop a new standard both connections to IJmuiden Ver and potential future far shore wind farms. To ensure this new standard has an optimal design from a system perspective TenneT has initiated a consultation process with relevant stakeholders on all relevant interfaces with offshore wind farm developers (OWFs). By involving stakeholders early on in the process TenneT aims to create maximum consensus and transparency on design choices that have an impact beyond the scope of TenneT. This holistic design approach will ensure the system has a maximum benefit to society: Efficient from a levelised cost of energy (LCoE) perspective, while remaining effective for potential future connectees.

This concluding report describes the consultation process and it contains the end result: a summary of the consulted design options and the final positions on these topics. The final position papers per topic, which include a more in-depth description and substantiation of the positions, are included in the Appendix. This report can be used as a reference work of the consultation process. To facilitate readers a summary of the position papers has been added per topic. These summaries are meant to aid in understanding the background of the positions but have not been aligned in the consultation process. The final positions for each topic stem directly from the position papers which have been established in collaboration with all participating stakeholders.

[1] Minister van Economische Zaken & Klimaat, Routekaart windenergie op zee 2030, 27 maart 2018

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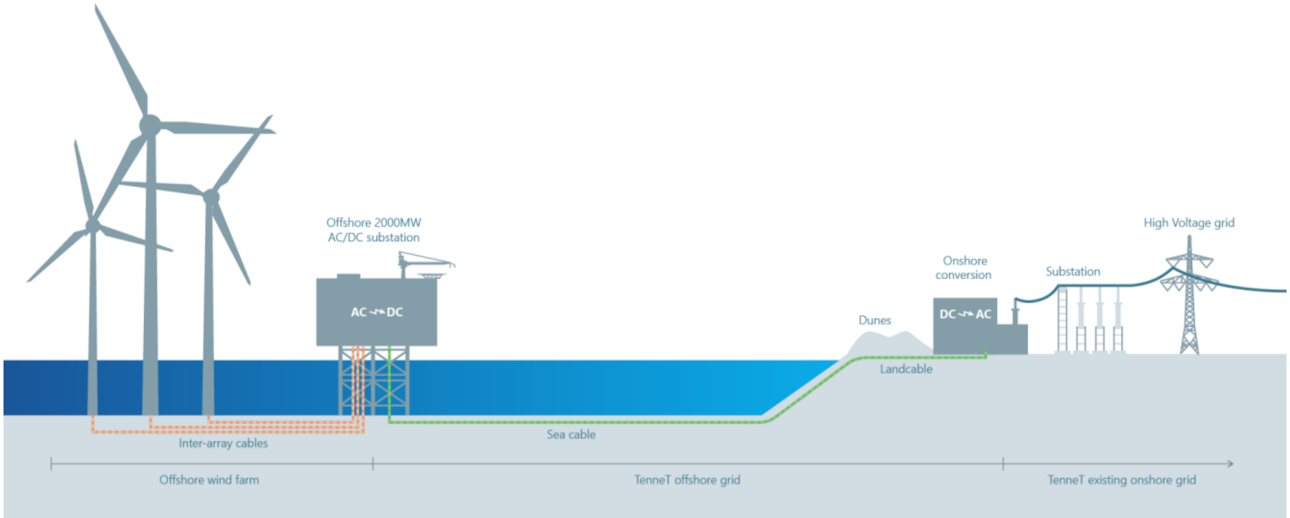

Figure 1 - HVDC grid connection concept

Process description

The overall goal of the stakeholder consultation process is to ensure optimization of the offshore grid connection system via an aligned and transparent process with the relevant stakeholders.

Relevant stakeholders are defined as OWF developers (possibly including leading suppliers) that may have a future role as connected party to TenneT's offshore grid, governmental agencies such as the Ministry of EAC and Germany's BSH (Federal Maritime and Hydrographic Agency), and branch organisations such as NWEA (Nederlandse WindEnergie Associatie) representing offshore wind organisations.

The consultation process consists of:

1. **Topics**
   The key design options identified by TenneT and the stakeholders for consultation, are referred to as "topics". These topics can be divided into two work streams: technical (topic numbers starting with an "T") and interface management (topic numbers starting with an "I").
2. **Position papers**
   Papers that describe the topics and the different variants that are possible for that topic. In addition, the position papers explain TenneT's position with regard to these topics with clear and transparent substantiation. For most topics the final position papers are the result of multiple iterations of receiving feedback from the stakeholders (or new insights by TenneT) and updating the paper.
3. **LCoE analysis**
   For some specific topics the Levelized Cost of Energy (LCoE) have been calculated to determine the impact of different design options on the project costs for TenneT, the OWF developer and overall for the society. For this assignment, TenneT's validated LCoE model was updated with specifications of wind farm zone IJmuiden Ver, based on input from MinEACP for the site layout. The cost estimates of the future grid connection system have been provided by TenneT and the assumptions regarding the parameters of a potential future wind farm are based on input from the OWF developers involved in this consultation process and the expert view of BLIX Consultancy.
4. **Online portal**
   All relevant information for the consultation process is published via an online portal:

   - The topics are addressed via individual web pages, with a brief description of the topic and providing the different versions of the position papers and supporting documents.
   - The discussion tool per topic offers the possibility to exchange feedback about the content of the position papers between TenneT and the stakeholders.
   - A calendar keeps the stakeholders informed of the timelines of the process and the event registration tool offers them the opportunity to register for the expert sessions.
   - Minutes were made available on the portal after each expert session.

5. **Expert sessions**
   TenneT organized live meetings with a duration of 1 or 2 days for the stakeholders where the topics were discussed via the position papers and the feedback that was received via the portal. All 20 topics have once or more been discussed during these four expert sessions.
6. **Steering committee meetings**
   After reaching consensus with the stakeholders on the position of TenneT for each topic, these topics were brought up for approval in the steering committee, consisting of TenneT, BLIX Consultancy and the Ministry of EACP.

Figure 2 gives a schematic overview of the consultation process.

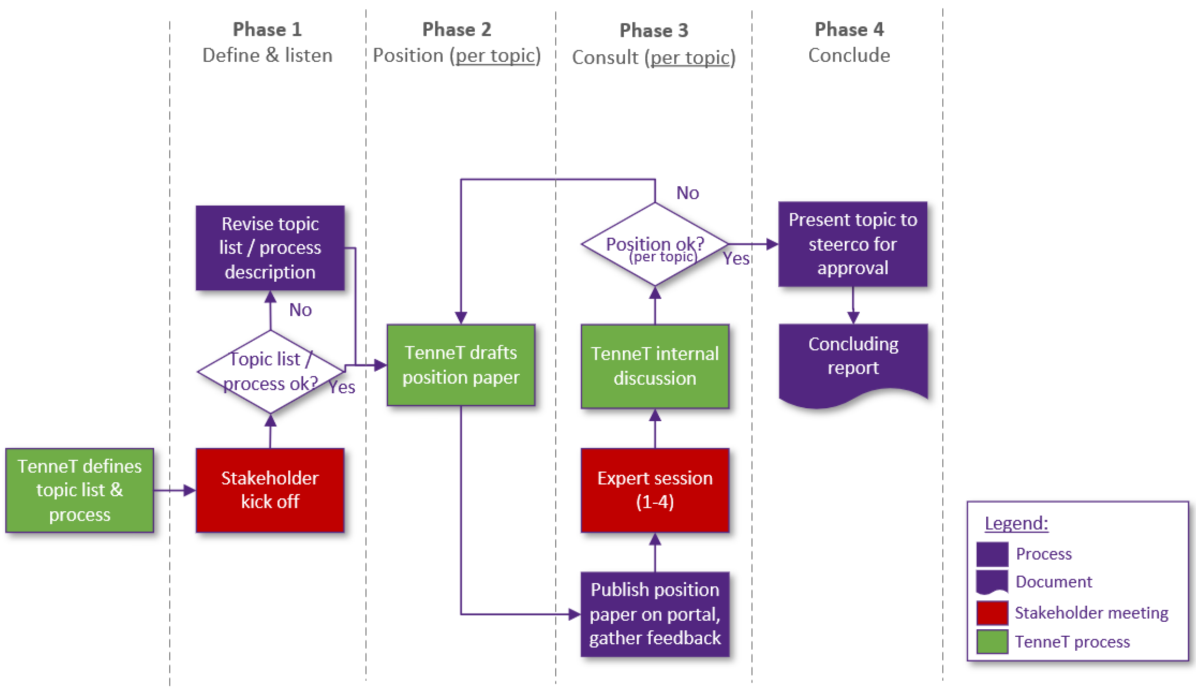

Figure 2 – Schematic overview of the consultation process

1. T01 - HVDC Grid Design and Reliability & Availability

1.1 Summary

In an earlier process TenneT has developed and assessed various Grid Connection Systems (GCS). The seven most promising alternatives are based on three principal choices. The choice between HVAC or HVDC technology, the choice between an island or platform based solution for the offshore substation and the capacity of the grid connection.

Based on extensive technology and Levelized Cost of Energy (LCoE) analyses, TenneT has advised the Ministry of EAC to select a 2 x 2 GW 525 kV HVDC grid connection, located on a platform. The Ministry of EAC has validated TenneT's advice and gave its final decision on the grid connection concept[2] to be realized in wind area IJmuiden Ver. These main design choices are firm and were not up for consultation.

This report describes several key design choices within this previously established framework for the IJmuiden Ver GCS. These choices relate to the setup of high voltage equipment on the offshore platform, such as the converter and transformers, and can be considered as the fundamental base from which other topics are derived. These fundamental choices are listed below.

- A Direct-Link connection will be used, meaning the inter-array cables will be connected directly to TenneT's platform. This eliminates the need for an intermediate AC collection platform, and is a more cost-effective solution in terms of LCoE.
- For the topology a bipole with dedicated metallic return will be used. The choice for a bipole with metallic return is a weigh-off between additional Capex and a higher availability of the system compared to the monopile topology. This higher availability is due to the fact that in the event of a pole outage 50% of the transmission capacity can be retained, which results in a net LCoE reduction for the system.
- For the onshore converter stations six single-phase units per station will be used. The technical feasibility of manufacturing alternatives (three-phase transformers) of that power range becomes very challenging and introduces significant transportation limitations. Therefore, there is a strong preference to use single-phase transformers for the onshore convertor stations.
- For the offshore transformer arrangement TenneT has a preference for using four three-phase two-winding units per platform. However, the most cost effective solution will be determined during the platform FEED (front-end-engineering design).
- A cross-coupling arrangement will be installed between the offshore convertor poles, resulting in a higher availability of the system without the need for additional investments.
- The cable laying configuration and subsequent availabilities will be discussed in a different position paper.

[2] Minister van Economische Zaken & Klimaat, Voortgang uitvoering routekaart windenergie op zee 2030, 5 april 2019

1.2 Summary of discussions

An overview was presented by TenneT on the grid design choices, funnelling down from the choice between AC and DC, to single line diagrams. Moreover the rationale and calculations behind the losses & availabilities were provided. The design choices for a monopole vs bipole converter and for a dedicated metallic return (DMR) or no DMR are substantiated with LCoE calculations.

Due to many questions on availability and cable laying configurations it was decided to create a dedicated topic for this (topic T16). Additionally, some questions were raised about the use of XLPE cables since they are not market ready at this point in time. A paragraph was added to the position paper indicating the process to market readiness of XLPE cables and including a fall-back scenario to Mass Impregnated (MI) cables; a type of cable that is already proven at 525kV (a.o. NordLink cable).

This position paper was discussed in two sessions and subsequently amended based on the input before being approved.

1.3 Final position

TenneT will apply the *Direct Link* solution for the grid connection system of IJmuiden Ver.

TenneT will apply the *"bipole with dedicated metallic return"* topology as the basis of design for the grid connection system.

TenneT will apply the *"six single-phase units per station (2 GW), each rated at 350 MVA, one spare per station"* option for the onshore transformer arrangement.

TenneT will apply the *"four three-phase two-winding units per station (2 GW), each rated at 550 MVA, no spares"* option for the offshore transformer arrangement.

TenneT will apply a cross-coupling arrangement possibility between the offshore converter poles.

2. T02 - HVDC grid code

2.1 Summary

This position paper describes how TenneT deals with the implementation of the HVDC grid code.

The European Commission has issued a regulation establishing a network code for the requirements for the grid connection of high voltage direct current (HVDC) systems and direct current-connected power park modules. This regulation is mandatory for all countries in the European Union. Currently, it is being implemented in the Dutch law.

The articles in the HVDC network code that apply to the offshore AC grid and associated equipment are outlined in the position paper. TenneT has to implement the requirements as given in the Dutch "netcode elektriciteit" and will adhere to modifications to the grid code.

In the position, TenneT indicates to implement the requirements as given in the Dutch "netcode elektriciteit" and to follow the latest draft version of the proposed new "netcode elektriciteit", in order to be prepared to implement the new netcode once it is accepted and published.

2.2 Summary of discussions

Some questions were raised on the process for establishing the new HVDC Grid code, how to provide feedback on this process (which is part of the regular Dutch code change procedures with the regulator (ACM)) and if the German HVDC Grid code would be used as a basis. There was a heavy reliance on the German code but the grid codes from other countries such as France and Belgium were also used as a reference on every article, in the end the best articles were picked.

This position paper was discussed in one session before being approved.

2.3 Final position

TenneT has to implement the requirements as given in the Dutch "netcode elektriciteit". The current prevailing netcode is not incorporating the specific requirements for HVDC converters and DC connected wind park modules.

TenneT follows in this respect the latest draft version of the proposed new "netcode elektriciteit", in order to be prepared to implement the new netcode once it is accepted and published.

3. T03 - Reactive Power Strategy

3.1 Summary

In an AC power system reactive power is created by the voltage and current waveforms that are not perfectly aligned. In contrary to "active power", reactive power can be described as the power component which cannot do useful work with the load, therefore it requires compensation.

This position paper describes the distinction in support duties, for the reactive power compensation, by the offshore HVDC platform (TenneT) and the offshore wind farm. TenneT intends to make the wind farms responsible for achieving zero reactive power exchange at the Point of Common Coupling (PCC) they are connected to, for which the reactive power capabilities of the wind turbines can be used. This strategy allows windfarm operators to optimize their assets and operations, through coordination between the individual strings, without extra costs for TenneT. This is in line with the Dutch "netcode elektriciteit" and ensures the lowest societal costs.

When there is no wind production and the wind turbines remain connected to the grid, the active power losses of the offshore grid are supplied by the HVDC system. Although the WTGs may still be able to provide reactive power, from a loss perspective, this may not be the optimum solution in terms of the LCoE. As a result, the HVDC converters compensate the offshore reactive power up to 10% of the agreed active power connection capacity at the PCCs.

3.2 Summary of discussions

OWF developers would like to know what happens when turbines are not able to supply reactive power due to the unavailability of wind. This scenario was added to the position paper. Furthermore questions were raised on who needs to supply dynamic voltage control. TenneT will supply dynamic voltage control, this was added to the position paper.

This position paper was discussed in two sessions and subsequently amended based on the input before being approved.

3.3 Final position

TenneT intends to reserve reactive power compensation capability for the offshore grid using only the inherent capabilities of the converters.

TenneT does not intend to install any additional equipment on the offshore grid or to allow Power Park Modules (PPMs) to install their own equipment on the platform for the reactive power compensation purposes.

TenneT intends to select the *"Zero Reactive Power Exchange at the PCCs"* option for the offshore reactive power strategy.

TenneT intends to allow reactive power exchange up to 10% (between -0.1 p.u. and 0.1 p.u.) of the agreed connection capacity with regards to the active power, at the PCCs during no wind production.

TenneT intends to exercise only the "Reactive power control mode" functionality by the wind farms.

4. T04 – Harmonics

4.1 Summary

The feed-in of multiple inter-array cables into the offshore grid connection can lead to harmonic distortions in the network. These distortions can damage the high voltage equipment and must therefore be mitigated. This paper describes how TenneT proposes to deal with the harmonics on the offshore grid.

Harmonic emission limits, such as the planning limits, will be equally distributed between the grid connection system (TenneT) and the offshore wind farm. This means that half of the planning limits of the total harmonic distortion, which are limited by the international standards (IEC TR 610003-6), will be allocated to the HVDC converter pole unit and the other half to the offshore wind farms. Planning limits are used in the design of the network to determine how to connect new loads. These limits are lower than the compatibility limits due to design uncertainties.

Harmonic compliance is determined at the 66 kV busbar (i.e. Point of Common Coupling) instead of the grid connection point. This allows the offshore wind farm to neutralise harmonic distortions over multiple connections. Since more than one wind farm could be connected to the busbar it is required to exchange data to enable proper harmonic calculations.

The paper further describes the roles and responsibilities of TenneT as well as the offshore wind farm regarding the procedure, data exchange, studies to be performed and the mitigation methods. In short, good cooperation is necessary among all parties, while TenneT remains responsible for the correct operation of the system. These items are listed explicitly in the position. Equations and definitions are also provided in the position paper.

4.2 Summary of discussions

In the first version of the position paper the harmonic distortion limits were set on the GCP. This makes the measurement and enforcement of harmonic limitations easier but does not allow the offshore wind farm to neutralise harmonic distortion over multiple connections. OWF developers indicated this is not preferable, therefore it was decided to move the harmonic limits to the busbar (PCC). This can potentially create an interface between windfarms which will require data exchange between OWF developers during project execution. There was some discussion on how this could be arranged. TenneT clarified that a detailed framework will be developed in the coming years that will describe which exact data needs to be exchanged, their format, timeline, etc. Consultation with OWF developers will become necessary for this task.

Questions were raised on clarifying the differentiation between the treatment of steady state and transient harmonics, and on the requirements of the connectees. Both have been added to the final position paper.

This position paper was discussed in two sessions and subsequently amended based on the input before being approved.

4.3 Final position

TenneT specifies the total harmonic distortion, the harmonic emission levels per harmonic order (EUhi) and per 66 kV busbar (i.e. PCC) for the OWF for steady-state operating conditions.

The different OWFs shall exchange data (grid layout, impedances, etc,) to enable proper harmonic calculations. A detailed compliance procedure about harmonics will be prepared by TenneT in the coming years (prior to tender stage), where OWF developers will be further involved. TenneT is responsible to safeguard this procedure during the execution phase.

Harmonic studies will be performed by the OWF as part of the grid compliance procedure. Harmonic measurements will be made during system commissioning as part of the operational preparedness activities.

In case of background amplification problems at the offshore PCCs, a joint analysis between TenneT and the OWF will be conducted to determine the most cost efficient mitigation actions.

TenneT will require harmonic damping controlling functions as part of the control and protection (C&P) system of the offshore HVDC station to effectively mitigate resonance problems during steady-state but also transient operating conditions.

Studies will be performed by both TenneT and OWF to analyse the offshore harmonic stability. TenneT remains responsible to prove that the overall offshore system operates correctly under all specified contingencies and operating conditions.

5. T05 – Load Rejection

5.1 Summary

In an HVDC based offshore grid connection system, the offshore HVDC converters operate as the grid forming unit of the offshore AC grid, whereas the wind turbine generators (WTGs) operate as the grid following units. In addition, a WTG is connected to only one HVDC converter at a time.

This means that in the event of a block and/or trip of the offshore HVDC converter, the WTGs connected to that converter may experience a load rejection that causes temporary overvoltages at the offshore AC grid.

During the interval between blocking and tripping (characterized by the circuit breaker opening time) the converter valves are also subject to these temporary overvoltages. The HVDC system may be designed to withstand such temporary overvoltages with the cost of additional CAPEX.

By setting a maximum admissible voltage at the point of common coupling these investments can be limited. The position paper describes these maximum voltage limits.

5.2 Summary of discussions

Main discussion was on the maximum admissible voltage at the PCC. TenneT consulted the OWF developers on what would be an acceptable value for them. Furthermore a decision was made to wait for the German grid code paper and re-evaluate this position paper in the fourth consultation session. In this session TenneT presented a limit of 1.3 p.u. which was accepted by the OWF developers.

This position paper was discussed in two sessions and subsequently amended based on the input before being approved.

5.3 Final position

TenneT intends to set the maximum admissible voltage at the PCC to 1.3 p.u. such that it does not lead to additional CAPEX increase in the grid connection system. The exact voltage against time profile will be in accordance with the High Voltage Ride Through (HVRT) requirements to be defined in the Grid Code.

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6. T06 – OWF Modelling for HVDC System Studies

6.1 Summary

TenneT must provide relevant data with regard to the specific design of the offshore wind farm (e.g. wind farm grid configuration, type of wind turbine generator, inter-array cable parameters) to the HVDC vendor(s) such that the HVDC vendor can perform various simulation studies during the engineering, verification and validation phases of the project.

This information will not be available at an early stage and final data can only be provided after an offshore wind tender winner has been appointed. In this position paper, TenneT proposes an indicative planning based on an iterative approach to narrow the envelope of the offshore wind farm (OWF) data. This gives TenneT and the HVDC vendor the clarity to properly design the HVDC equipment, whilst providing the wind farm developers with the necessary design freedom.

6.2 Summary of discussions

OWF developers indicated that the planning as presented in the first paper was too high over and required more detail of which data was required when. Furthermore there was an open discussion on how to deal with the requirement of data before the windfarm tenders are finalized. OWF developers argue that they will not be able to provide all information on the day they win the tender, since WTGs choice and site layout are not necessarily fixed by then. In subsequent versions of the position paper TenneT further substantiated the schedule and suggested the use of two consultation rounds with the OWF developers. The first would be a high level in 2022 (before the tenders close) on an envelope with outer boundaries of OWF characteristics which can be used in the engineering phase of the HVDC system at that time. The second in 2025 on detailed engineering when the tender winners are known. This suggestion was accepted by the OWF developers.

This position paper was discussed in three sessions and subsequently amended based on the input before being approved.

6.3 Final position

TenneT will not require detailed OWF data to be made available for the studies to be performed during the development phase.

TenneT will require an envelope of the OWF data to be made available for the studies to be performed during the detailed engineering phase.

TenneT will require the detailed OWF data to be made available for the off-site commissioning tests of the HVDC system commences.

TenneT will require the OWF data to be maintained and updated actively during the on-site commissioning tests.

TenneT will add this topic to a list with topics that will require consultation after this round.

It must be highlighted that due to the very recent publication of the "HVDC Compliance Verification" policy by Netbeheer Nederland, there may be contradictory descriptions between this position paper and the compliance policy. In that case, the "HVDC Compliance Verification" policy shall of course prevail in the relevant parts.

7. T07 – Voltage level and frequency

7.1 Summary

This position paper describes the position of TenneT with regard to the voltage level and frequency of the offshore grid. The voltage level is an important parameter determining amongst others the amount of wind turbines that can be connected to a single cable string and the distance it can cover.

In the previous consultation with offshore wind farm developers in 2015, the voltage level for the AC windfarm zones was set at 66 kV (coming from the common practice 33kV at that time). TenneT sees no benefit in studying a higher voltage level (e.g. 110 kV) within the time frame of IJmuiden Ver, because the predicted rated power of the wind turbines (less than 20 MW) does not justify this.

Similarly, TenneT intends to apply 50 Hz as nominal frequency for the operation of the offshore AC grid, which is currently the standard for offshore wind farm connections. In this way, optimal use is made of the available knowledge in Europe (50 Hz is standard practice) and the possibility of connecting potential consumers (current and new oil and gas platforms) directly to the offshore grid in the future.

7.2 Summary of discussions

TenneT indicated in the first position paper that 66 kV and 50 Hz would be used as the standard design starting points. Both the frequency and voltage were briefly discussed before being endorsed by the OWF developers. According to OWF developers it is not likely that wind turbine capacities of 20MW (or even higher) will be deployed for the IJmuiden Ver timeframe or soon thereafter and the OWF developers support to maintain the inter-array voltage level at 66kV.

This position paper was discussed in one session before being approved.

7.3 Final position

TenneT intends to apply 66 kV as nominal voltage for connecting directly to the offshore HVDC platforms and operating of all the offshore inter-array cable systems of the OWF's for IJmuiden Ver.

TenneT intends to apply 50 Hz as nominal frequency for the operation of the offshore AC grid.

8. T08 – Point of Common Coupling and Grid Connection Point

8.1 Summary

TenneT is responsible for the realization and the operation of the offshore electricity grid which requires the definition of a Grid Connection Point and a Point of Common Coupling between TenneT and the offshore wind farm, in this case referred to as a Power Park Module (PPM).

These definitions are used in several other position papers to describe the interface between TenneT and the offshore wind farm.

The Grid Connection Point (GCP) is defined as the point at which a PPM is connected to the HVDC system and for which the requirements of the grid code have to be fulfilled by PPM.

The Point of Common Coupling (PCC) is defined as the location (busbar) at the HVDC converter platform, which enables the connection of different generator blocks, neighbouring grids, auxiliary systems or other equipment of the HVDC converter platform and for which the requirements of the grid code have to be fulfilled by the remote end HVDC converter station.

8.2 Summary of discussions

The position paper indicates where the GCP and PCC are located. OWF developers requested TenneT to remove the PCC for the export cable as this leads to ambiguity of the diagram.

This position paper was discussed in one session and approved with the change as mentioned above.

8.3 Final position

The Grid Connection Point (GCP) for the offshore Power Park Module (PPM) is specified right after the cable termination of the inter-array cables and before the switchgear on the HVDC platform of TenneT.

The Point of Common Coupling (PCC) is specified at the 66 kV AC bus of the HVDC platform of TenneT.

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9. T09 - Control & Protection design 66 kV

9.1 Summary

This position paper elaborates on the detailed aspects for the area of common interest between TenneT and the offshore wind farm: the 66 kV switchyard of the converter platform.

TenneT will be responsible for the protection equipment of the offshore wind farm inter-array cable strings on the platform and will design, install, operate and maintain the protection system. This has advantages in terms of installation and maintenance activities that can now be performed by TenneT personnel only. The protection system and its settings will be aligned with the offshore wind farm.

9.2 Summary of discussions

OWF developers made some editorial remarks on the position paper which were adopted by TenneT.

This position paper was discussed in one session and approved with the remarks as mentioned above.

9.3 Final position

TenneT proposes a standardised approach for the detailed representation of the 66 kV switchyard on the converter platforms.

TenneT will standardise the operation of the 66 kV bays for the offshore platform, similar to the current practice in the Netherlands for the operation of switchgear onshore (and offshore) for the connected parties, where the switchgear installation with connections to the OWF is fully operated by TenneT, as the owner of the switchgear.

TenneT will standardise the protection equipment of the OWF inter-array cable strings to the TenneT offshore converter platforms. This will be done by implementing a standardised, fully redundant protection system with distance protection as the main protection function for the cable strings.

The protection settings will be aligned with the OWF.

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10. T10- Dynamic DC cable rating

10.1 Summary

The power output of offshore wind farms naturally differs considerably over time. The load profile describes the power output of these windfarms over a year. When designing an export cable for a wind farm, the cable has to be designed to withstand a certain load profile, indicated by the cable rating. This paper describes TenneT's strategy with regard to the export cable rating, which determines for example how much overplanting can be achieved.

Overplanting is different in an HVAC and an HVDC grid connection systems (GCS). In an HVAC system additional capacity can be transmitted through the system for brief periods of time, this can be more than the system was originally designed for. In an HVDC grid connection the maximum transport capacity is limited by the capacity of the HVDC converters. For the IJmuiden Ver GCS, the converter is designed for a maximum load of 2000 MW, therefore, also in case of overplanting the power output will be capped at 2000 MW. However, the load profile of a wind farm with overplanting will be different from a wind farm without overplanting: the load factor will shift and therefore it is more likely that the wind farm will be able to deliver its maximum power more hours per year (see Figure 2 below). This has an effect on the load profile and therefore has to be taken into account when determining the cable rating.

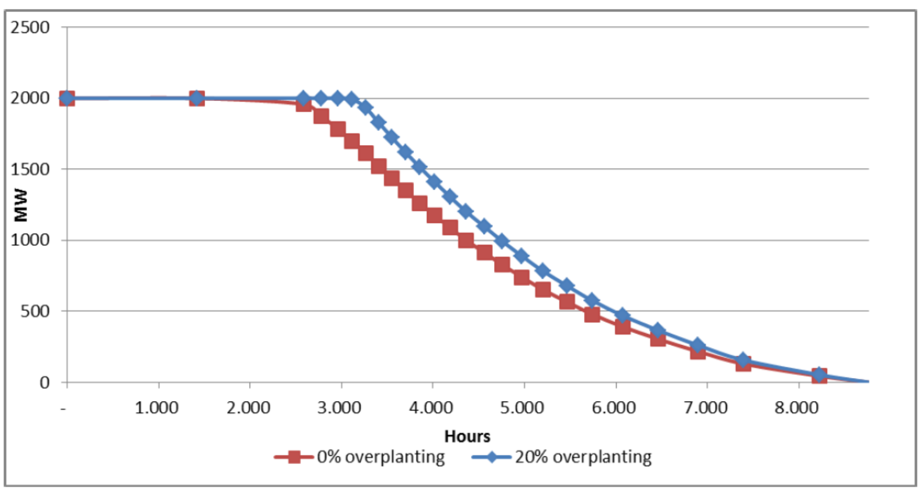

Figure 2 – Illustrative effect of overplanting the load profile of a wind farm

TenneT will design the cable in such a way that an overplanting rate of 0-15% can be achieved in order to give maximum flexibility to the offshore windfarms. Furthermore, there is a possibility that a WindConnector (an interconnection between NL and the UK via an offshore GCS) will be realised for IJmuiden Ver. This would also change the load profile of the cable since some of the cable capacity might be used for interconnection capabilities. It is the aim of TenneT that in case a WindConnector is added to the grid connection system of IJmuiden Ver, the windfarms will not be negatively affected by cable rating constraints.

10.2 Summary of discussions

This topic was first presented in consultation session 1 where TenneT indicated that a hybrid approach would be used as a general approach to cable design to optimize dimensioning of the cable. The expected utilisation of the cable is required for further analysis, it was decided that BLIX will assume a load factor which was shared with developers for confirmation.

Furthermore the amount of overplanting was discussed. The OWF and BLIX experts discuss that 15% overplanting is high, since wake losses will become an issue; 5-10% is considered normal. A cap of 15% overplanting is considered by TenneT in cable design since it is highly unlikely this will limit overplanting capabilities for the wind farm developers.

Some questions were raised on the WindConnector, a bullet has been added to the final position.

This position paper was discussed in two session and subsequently amended based on the input before being approved.

10.3 Final position

Current rating principles

The cable will be designed on the ampacity requirement of 2000 MW.
For cable rating the approach of the Net op Zee AC cable designs will be used. This is an optimised approach using both static and dynamic ampacity calculation methods as described below:

1. The cable system shall be designed based on a continuous load profile of 2000 MW;
2. For sections with a (initial or future) soil coverage of more than 5 m, a dynamic load profile based on a 2-step method shall be taken in to account for current rating (preloading with the applicable load factor followed by 100% load for certain time). TenneT intends to use a load factor between 0,55-0,60 and a time frame of half a year.

Base case cable design

At this moment a combination of 2000 Cu and 2500 Cu Copper conductors (or the Aluminium equivalent 3000 AL, 3500 AL and 4000 AL) is expected as cable design.

Overplanting

TenneT proposes to set the maximum overplanting in the IJmuiden Ver area to 15%.
An overplanting rate between 0-15% gives maximum flexibility to the offshore windfarms to optimize their wind farm lay-out and business case.
Overplanting increases renewable energy production and increases efficient use of the grid connection system. The maximum overplanting has to be confirmed by the Ministry of EAC.

WindConnector

In case of a WindConnector it is the aim of TenneT that the HVDC cable will be designed in such a way that it will not negatively affect the windfarms (no curtailment necessary because of cable rating constraints). TenneT has to estimate the operational requirements for the WindConnector and to what time extent the cable system should be capable to function with 2000 MW transport in the interconnector operation mode.

11. T11 - J-Tubes and number of Bays

11.1 Summary

The J-tubes are used to pull in 66 kV inter-array cables on the platform and are provided to the offshore wind farm developers by TenneT. The number of J-tubes which are allocated to the OWFs is set to a maximum of 28 per 2000 MW connection, based on the capacity of 1250 A per 66 kV GIS bay, the number of 66 kV GIS bays, and the capacity of the wind turbines (12, 15, 17 and 20 MW). The process to reach this number of J-tubes was an optimization between having an effective amount, whilst avoiding building J-tubes that are likely not going to be used. Close consultation led to this balanced number of 28, which should be sufficient for all expected turbine sizes and leaves some room to optimize the layout of the OWF, while limiting the risk of unused assets.

The cables that are pulled into the platform are connected to six bays in each of the four generator blocks (500 MW each). A seventh bay can be made available to the OWF operator in case this is required, although this is not expected. To stimulate the efficient use and building of bays while providing the OWF developer with sufficient degree of design freedom, the costs of the seventh bay will be allocated to the OWF developer.

11.2 Summary of discussions

In the first version of the position paper TenneT proposed to provide 6 bays per 500 MW generator block and 26 J-tubes. OWF developers pleaded for more J-tubes (30 or more) and bays to increase their design freedom whereas TenneT would like to opt for a lean amount to prevent inefficient use of the assets (such as in the Borssele alpha grid connection system). The option to perform a LCoE analysis was discussed but dismissed due to the inability to take into account layout optimization on the OWF side. Furthermore 8 and 10 MW turbines were considered unrealistic for further analyses. The discussion was settled on 28 J-tubes and 6+1 bays. There were some questions on the maximum and minimum capacity of the bays and the seventh bay, this resulted that an additional elaboration was added to the position paper.

This position paper was discussed in three session and subsequently amended based on the input before being approved.

11.3 Final position

The 2000 MW offshore HVDC converter station shall be equipped with maximum 28 J-tubes for connection of 66 kV inter-array cables.

The number of bays per generator block of 500 MW is set to 6.
A 7th bay can be made available by TenneT, granted that the costs are allocated to the OWF.

The minimum current per 66 kV bay is 625 A.

An inner diameter of 450 mm is considered for the J-tubes.

12. T12 - Technical interfaces and facilities for OWF

12.1 Summary

This position paper describes the proposed technical interfaces and the interface responsibilities between the offshore wind park owners and TenneT. In addition, it defines the foreseen facilities for the OWF which are provided by TenneT, and it describes the responsibilities between TenneT and the OWF.

The following main technical interfaces have been identified:
1. 66 kV cable route starting from the platform 500m safety zone perimeter up to the 66 kV switchgear.
2. 66 kV switchgear at the offshore platform.
3. Telecommunication and fibre optic infrastructure.
4. OWF equipment located on TenneT infrastructure (offshore and onshore).

For each main interface as defined above, sub-interfaces are listed, for which different roles will be assigned to TenneT and the OWF. The definitions of these roles is based on the RASCI system, which stands for responsible (R), accountable (A), supportive (S), consulting (C) or informative (I). The responsibilities for the interfaces will be included in the Realization Agreement between TenneT and the OWF.

Contrary to the current standard for the 700 MW AC platforms, it is deemed not necessary to provide the OWF with a room on the platform to house their equipment. This will reduce the technical and operational interfaces, as well as reduce safety and insurance complexities.

12.2 Summary of discussions

TenneT introduces a list of several technical interfaces and indicates that a RASCI matrix will be used to define the responsibilities on each interface. Furthermore TenneT introduced the concept of not housing OWF equipment on the platform. To determine if this is feasible it was decided that the OWF developers would indicate on the portal which equipment is absolutely necessary on the OSS and can't be moved to onshore room or on the turbines. In the subsequent expert session no insurmountable issues were raised with regards to moving equipment, thereby supporting the position to not house OWF equipment on the platform. The OWF developers requested clarification on the rationale behind the number of fibres and information on the ownership of the metering equipment. This was added to the final version of the position paper.

This position paper was discussed in two sessions and subsequently amended based on the input before being approved.

12.3 Final position

TenneT intends to manage interfaces by involving all stakeholders as early in the project as possible and to define clear roles for each interface.

The interface responsibilities will be incorporated in the Realization Agreement which will be signed between TenneT and the OWF. The interfaces will be further detailed based on the principle responsibilities listed.

TenneT intends to minimize the amount of equipment of the OWF on the platform. As a result no separate OWF room is foreseen and access for OWF during normal operation is not required.

13. T13 - Shared Services (MIVSP) together with RWS

13.1 Summary

Different third parties are in need of data from offshore wind farms. Instead of having each user install their own measuring equipment to collect this data, it is more efficient to have one party gathering relevant data and then distribute it to interested third parties.

For the current 700 MW platforms this service is provided by the Maritiem Informatievoorziening Service Punt (MIVSP) from Rijkswaterstaat (RWS), which makes information from different sensors available to third parties. Similar to the AC platforms, MIVSP will install communication and sensing equipment on the 2 GW DC platforms and will share these services with multiple stakeholders. This paper describes TenneT's position on the number of sensors and interactions with RWS. Additionally, a clarification is provided of the services offered by RWS and how this will be made available to the OWF developers.

13.2 Summary of discussions

Rijkswaterstaat gave a presentation on how MIVSP operates and what it offers to wind farm developers. There were some questions on how to obtain certain information and which information will be made available publicly. Additionally, the list of provided services was incomplete. It was decided that TenneT would provide OWF developers with a list of all provided services.

This position paper was discussed in one session before being approved.

13.3 Final position

TenneT intends to continue the collaboration with RWS MIVSP and to share sensing and communication systems with the offshore windfarms and various stakeholders. This will reduce the number of systems required, eliminating the potential doubling of sensors and therefore lower the LCoE.

In this collaboration RWS MIVSP is responsible to design, install, integrate, transport, test and maintain sensors and communication systems and collect and deliver the data to several stakeholders as a shared service.

An initial list of systems is included in chapter three (of position paper T13). The detailed list of equipment will be developed at a later stage. At least TenneT and RWS intend to share:

- Nautical Sensors
- Meteo and Hydro sensors including LIDAR

Contrary to the 700MW HVAC platforms TenneT does not intend to allow any equipment of the windfarm operator on the platform (this position and supporting rationale is further explained in T12).

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14. T14 – Grid forming functionality OWF

14.1 Summary

In power systems, grid forming functionality is used in case of black-outs to re-stabilize the grid. Theoretically, wind turbine generators (WTGs) could provide this service when there is sufficient wind. However, the grid connection system needs to be adapted to allow wind farms to offer this service.

So far, grid forming functionality has never been reserved for the WTGs in offshore wind farm applications. This means that for offshore HVDC based transmission systems, energization always occurs from the onshore converter station. TenneT is willing to support the plans, if any, of OWF developers for reserving grid forming functionalities in the grid connection system for onshore grid blackstart[3] purposes. During the consultation process the wind farm developers indicated that they do not foresee the need for grid forming functionality. This is partly due to the immaturity of the technology and partly due to the current regulatory requirements that require a high availability of this service, that cannot be reached with an intermittent power source such as wind.

Therefore, the design basis for the Grid Connection System of IJmuiden Ver does not consider the presence of grid forming WTGs in IJmuiden Ver.

14.2 Summary of discussions

TenneT indicated to consider the option for grid forming functionalities in the design for the 2 GW windfarm depending on if this is expedient for the OWF developers. OWF developers indicated that the current market for black-start services has functional demands that do not match with what offshore wind farms can provide. It was decided that TenneT would raise a question on the portal to determine the support from OWF developers for this functionality; "what would be the precise conditions where the OWF are interested to supply this grid-forming functionality?". In the subsequent expert session the consensus was that the technology is still immature and expensive. Moreover, there is no market foreseen, especially since wind turbines generate intermittently, therefore, no developers are looking at this option. Additionally, it was decided to retain the option of re-opening this discussion if there are changes to the market design.

This position paper was discussed in two sessions and subsequently amended based on the input before being approved.

[3] Backstart is the capability to "start" off-grid energization, which is necessary in case of a brown- or black-out to re-energize the grid

14.3 Final position

Currently, the design basis for the Grid Connection System of IJmuiden Ver does not consider the presence of grid forming WTGs in IJmuiden Ver.

TenneT has discussed the possibility of grid forming WTGs with the stakeholders. However there was no interest in this option due to the immaturity of the technology as well as the lack of incentives in the current regulation. Therefore, TenneT will not engineer this option during the basic HVDC design for the Grid Connection System of IJmuiden-Ver.

If the technology or regulation changes before 2021, TenneT will reconsider this position. Hence, TenneT will add this topic to a list of topics that will require consultation after this round.

15. T15 – Metering

15.1 Summary

Each inter-array cable string connects a number of turbines of an offshore windfarm to the offshore substation. This paper describes the metering requirements for these strings as proposed by TenneT for all PPMs that are connected to TenneT's offshore substations.

In accordance with the Metering Code art. 1.2.3.8, the connected parties are responsible, together with the offshore platform operator, for assigning one certified metering company.

15.2 Summary of discussions

No remarks were made on this position paper.

This position paper was discussed in one session before being approved.

15.3 Final position

TenneT will facilitate and coordinate the process of selecting a certified metering responsible party, contracted by the connected parties individually. The metering responsible party will be responsible for the installation, commissioning and maintenance of the metering equipment.

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16. T16 – Cable laying configurations and availability

16.1 Summary

This paper describes the different cable laying configurations and their subsequent effect on availability. Four cable laying configurations are considered:

1. Bundled;
2. Unbundled with two metallic returns;
3. Unbundled with one metallic return (plus pole bundled with metallic return and a minus pole laid separate);
4. Unbundled with one metallic return (plus pole bundled with minus pole and a metallic return laid separate).

These options are mutually compared, based on their static magnetic field, spatial footprint, availability and the investment, installation, operation and maintenance costs. To this end, Levelized Cost of Energy (LCoE) calculations are performed to determine the impact of the set of input parameters that correspond to a specific option on the LCoE for TenneT, the OWF developers and generally for society.

The bundled laying configuration (option 1) has the lowest overall LCoE, the smallest spatial footprint and the lowest static magnetic field and is therefore TenneT's preferred option. During the consultation, offshore wind farm developers indicated their preference for an unbundled option (2), because of the higher availability. The overall LCoE (where higher availability of an unbundled option is amongst others weighted against the higher capex and opex of this unbundled option) indicated better results for the bundled option (1). This resulted in the following position.

16.2 Summary of discussions

TenneT presented the potential cable laying configurations and their differences in performance and cost. TenneT indicated a preference for a bundled solution. If technology challenges for the bundled configuration occur, the unbundled configurations will be a fall back solution. OWF developers indicated to have a preference for the solution with the highest availability (i.e. an unbundled solution with two metallic returns). It was decided to perform a LCoE calculation (in which not only the costs, but also the difference in availability is assessed). Since the calculations show that a bundled solution has the lowest LCoE, the stakeholders gave consent to send the updated position paper to the steering committee for final approval.

This position paper was discussed in one session and subsequently amended based on the input before being approved.

16.3 Final position

TenneT will install a bundled cable laying configuration (option 1), if technically feasible. A bundled laying configuration has the best LCoE, the smallest spatial footprint and the lowest static magnetic field.

Unbundled laying configuration with plus and minus bundled together and a separate metallic return (option 4) is seen as the best alternative for option 1. This option scores average on LCoE and has a lower static magnetic field.

TenneT is in the opinion that a higher availability should be achieved by decreasing the cable failure rate (using the risk based burial depth philosophy) instead of unbundle the cable system and adding a second metallic return.

17. T17 – Fault ride through performance

17.1 Summary

Fault ride through (FRT) is the capability of electric generators to stay connected in short periods with system faults and disturbances. It is necessary to prevent a short circuit at HV (High Voltage) or EHV (Extra High Voltage) level causing a widespread loss of generation.

HVDC systems are typically equipped with a dynamic braking system (DBS), an additional converter to dissipate the power of the offshore wind farm for the duration of the disturbance, to fulfil the FRT requirements at the onshore grid connection point. However, this is a costly solution and it comes with an additional investment in the range of 10-20 M€, based on TenneT's experience. In addition, the wind turbines are typically also equipped with a DBS (chopper) to meet the FRT requirements offshore. This DBS is only activated in the event of an offshore fault, as a result of which the wind turbine is unable to supply its active power to the grid.

During the development phase of IJmuiden Ver, TenneT plans to explore alternative and more cost-efficient solutions that offer similar FRT performance. The idea of using the inherent capability of the WTGs to dissipate surplus energy in the event of onshore faults will therefore be studied further.

17.2 Summary of discussions

TenneT wanted to discuss the possible options for FRT-performance. TenneT is investigating innovative solutions and encourages WTG operators to provide additional alternatives. Several stakeholders indicate that the options presented by TenneT rely on fast communication and are not yet technically feasible. More information will be acquired over the next months, so the options can be further discussed with the sector. This discussion will go beyond the scope and duration of the current stakeholder consultation. Therefore, TenneT proposes to create a list with these topics and the proposed way forward. Several stakeholders suggest a three-party discussion before 2021, consisting of WTG manufacturers, OWF developers and TenneT.

This position paper was discussed in one session before being approved.

17.3 Final position

The base case for TenneT is the use of a dynamic braking system (DBS).

TenneT intends to study alternative solutions for the FRT performance of the overall offshore system in case of onshore grid faults. This will include the dissipation of the surplus energy from the WTGs.

In case a proof of concept for a technical alternative with a lower cost (compared to the base case) could be achieved during the development stage of IJmuiden Ver (before 2021), the OWF will be asked to support the onshore FRT behavior of the HVDC system by use of the DBS inside the wind turbines.

TenneT invites the OWF developers to describe their power dissipation solutions in full detail, in order to be properly represented in the simulation work of the development stage of the offshore Grid Connection System.

TenneT will add this topic to a list with topics that will require additional consultation after this consultation process.

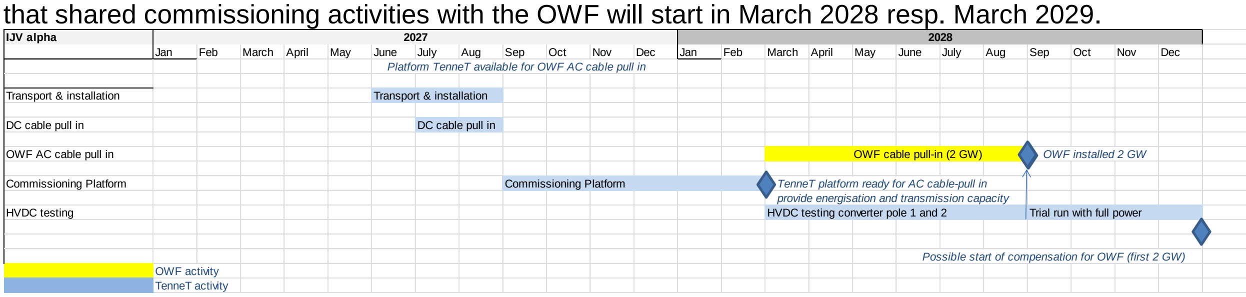
18. I2 – Offshore testing and commissioning with OWF

18.1 Summary

In accordance with the schedule that has been agreed with the Ministry of EAC, the IJmuiden Ver alpha platform is ready for commissioning in Q3 2027 and the IJmuiden Ver beta platform is ready for commissioning in Q1 2029.

For the IJmuiden Ver alpha platform this would imply that the wind farm can only start its commissioning activities in September 2027. As TenneT recognizes wind farm developers' concerns that this is not the preferred time window. Based on developers' requirements, TenneT proposes an alternative schedule in the position paper that allows the OWF to pull in their cable during the good weather season.

The alternative schedule is superior to the original schedule as it reduces risk for the entire system and provides the wind farms with a more favorable window for their installation activities and the potential for early revenues. Therefore, it provides a robust starting point for cooperation between TenneT and offshore windfarm. For IJmuiden Ver alpha and beta this implies that 2 GW is commissioned in a single year and that shared commissioning activities with the OWF will start in March 2028 resp. March 2029.



Graph 1.1 Commissioning Schedule IJmuiden Ver alpha

18.2 Summary of discussions

TenneT presented a proposed schedule for the offshore testing and commissioning period. Due to the nature of HVDC systems, this is a joint effort between the OWF developers and TenneT, since full testing of the HVDC-systems requires infeed from the windfarm. TenneT showed an initial schedule (with 2 separate 1GW wind farms) in which the OWF developers were able to pull-in their cable simultaneously with the commissioning of the platforms. During this period transmission capacity cannot be guaranteed (both the platform HV-system and HVDC-system are not fully commissioned yet). OWF developers indicated this is not preferable since they will not be able to collect early revenues or energise their turbines. In the following expert session a revised schedule (under guidance of NWEA) was proposed which postpones the cable pull-in once the platform is commissioned (this additional milestone is reflected in the graph).

OWFs discussed that a six-month weather window as included in the schedule is short for installing 1 or even 2 GW of turbines. TenneT stated that AC cable pull-in can possibly already start in the year before commissioning (2027 for IJmuiden Ver Alpha and 2028 for IJmuiden Ver Beta) but energizing is not possible yet. Furthermore TenneT and OWFs can assess possibilities together to further optimize the scheme mutually once the tender winner is known.

This position paper was discussed in two session and subsequently amended based on the input before being approved.

18.3 Final position

The offshore wind farm developers and TenneT agree the following definitions to ensure efficient commissioning of the HVDC system:

- *Guaranteed date when TenneT is ready for OWF AC cable pull-in*: As of this date TenneT can energize / commission the OWF (for all 66 kV AC bays) and offer transmission capacity;

- *OWF AC cable pull-in and termination finalized*: Guaranteed date by the OWF developer when their cable pull-in and termination is finalized (2 x 1 GW), thus when the wind farm can provide full power for final HVDC testing. If the OWF is not fully commissioned, this leads to additional costs and delays in the schedule.

- *Testing period*: The testing period will start when the platform is ready for OWF cable pull-in.
    - The wind farm has access to transmission capacity, however, from TenneT's perspective the transportation performance is not yet guaranteed (compensation scheme not applicable);
    - OWF developer and TenneT will bilaterally agree on a detailed schedule to allow HVDC testing throughout this period.

- *Closing of trial operations*: First possible moment to start compensation.

The schedule as indicated in the graph 1.1 of the position paper will be the proposed basis for the future development of the compensation scheme for HVDC systems ("schadevergoedingsregeling" as determined by the Ministry of Economic Affairs and Climate). Any penalties that may apply need to be proportional.

TenneT and the OWF developers may optimize the schedule further after signing the connection realization agreement and transmission agreement (ATO/REA), when agreement between both parties can be reached on the optimization of the schedule. When the wind farm cannot proceed scheduled activities due to limitations of TenneT, then this should be taken into account while evaluating if the OWF has complied with its milestones. Therefore, it is possible to discuss in more detail the period necessary for 2 x 1 GW cable pull-in and the start of the trial run.

19. I3 – Helideck & Access to platform

19.1 Summary

Prior to the consultation process, TenneT has carried out a comprehensive study into the aspects of offshore logistics, access to and egress from its (future) offshore platforms. This includes a full parametric analysis considering all relevant variables such as offshore scope for planned and unplanned maintenance, means of transport, number of crew and distance from (heli)ports. Although the exact location of the IJmuiden Ver platforms is not yet defined, it can be stated that the scope of the IJmuiden Ver platforms falls within the range covered by the referenced study. Based on the study results TenneT has determined a position on the access options to the platform.

- During installation and commissioning the OWF shall be granted access to the platform. TenneT and OWF will intensively cooperate and coordinate the activities during this period. Access can be via boat or helicopter.

- TenneT will not allow access to the platform and helideck during normal operation, so the platforms will not be designed or equipped to serve as logistic hubs for other stakeholders in the area. This is due to the following reasons: TenneT aims to have a clear separation of scope and responsibilities, providing access might require additional investments, and from a safety perspective TenneT aims to minimize hours spent on the platform.

The current trend in offshore wind is moving towards the use of service operation vessels for maintenance purposes. TenneT expects this to be the predominant maintenance strategy by OWF operators, which than also limits or eliminates the need for OWF operators to use the platform helideck.

19.2 Summary of discussions

TenneT indicated that a helideck will be installed on the platform and explained the strategy of limiting third party access to the platform. Since OWF developers will not have an equipment room they will not need access during operation. The fact that access is allowed during installation wasn't entirely clear and has been highlighted by TenneT in an update to the position paper.

This position paper was discussed in one session and subsequently amended based on the input before being approved.

19.3 Final position

TenneT will install a helideck to allow for quick repairs and reduce downtime of the offshore grid connection system.

TenneT will opt for a two-stage crew transfer and accommodation strategy:

1. During the offshore commissioning phase of the platforms as well as during the first period of operation either temporary living quarters will be installed on the platform, or a jack-up barge placed next to it.
2. When both platforms are fully operational and tuned for long-time unmanned operation the living quarters or jack-up barge will be removed.

TenneT will not allow access to the platform and helideck during normal operation, so the platforms will not be designed or equipped to serve as logistic hubs for other stakeholders in the area.

20. I4 – Nature inclusive design

20.1 Summary

It has become more and more clear that ecological aspects are a limiting factor for the continued increase of offshore wind. This has driven the idea of using the offshore grid infrastructure to realise opportunities to increase nature diversity and to achieve additional societal benefits. This paper describes several ecology-friendly measures which can be integrated in the offshore grid design as a basic condition (e.g. Nature Inclusive Design options) such as: a bird deck, fish hotel and a platform safety zone.

As many parties are currently pioneering on Nature Inclusive Design (NID), in this paper, TenneT proposes a way to cooperate with the OWF developers on this topic.

20.2 Summary of discussions

OWF developers requested a schedule concerning NID. TenneT will liaise with the winner of the OWF tender to determine a joint approach for NID in the vicinity of the platform and within the wind area.

This position paper was discussed in one session before being approved.

20.3 Final position

TenneT has to follow the legal requirements as given in the Dutch legislation, Development framework and Codes. The current documents do not yet incorporate specific requirements regarding Nature Inclusive Design. However, as discussions with stakeholders during sessions for the Offshore Wind Roadmap 2030 showed, there is broad support for such measures in order to benefit from new opportunities created by offshore wind areas. TenneT has initiated Nature Inclusive Design measures for the 700 MW AC grid concept and with this paper proposes a similar approach for the 2 GW HVDC grid concept. This implies TenneT will investigate feasibility of NID measures like a bird deck, fish hotel and adding hard substrate in the safety zone around the platform from an ecological, technical and project perspective.

As many parties are currently pioneering in this field, combining efforts where possible seems the rational thing to do. TenneT strongly prefers to perform common investigation with the OWF developer(s) in the wind area to assure design, realisation and monitoring of NID measures in the whole wind area (including the offshore grid) are aligned by these parties prior to implementation and the maximum nature enhancing effect can be achieved.