POSITION PAPER

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# Table of Contents

## 1. Background Material

**LITERATURE USED:**


- [1] *"Control solutions for blackstart capability and islanding operation of offshore wind power plants"*. A. Jain, K. Dash, O. Goksu, at DTU wind energy.
- [2] BS-SO-TRS_15-001_Productinformatie_herstelvoorziening, https://www.tennet.eu/electricity-market/ancillary-services/black-start-facility-documents/


## 2. Scope and Considerations

For the roadmap offshore wind 2030 (routekaart windenergie op zee 2030) 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. Due to its size and distance to shore, a new grid connection concept has been established for the wind farm zone IJmuiden Ver. The figure below shows a schematic cross-section of this new grid connection concept. Wind turbines are connected through 66 kV "inter-array" cables (in orange) to an offshore (HVDC) converter station. Using 2 GW high voltage (525 kV) export cables (in green) the electricity is transported to shore. TenneT will be responsible for the offshore grid, from the onshore substation up to and including, the offshore substation. TenneT intends to create a new standard HVDC grid connection concept for both connections to IJmuiden Ver and potential future far shore wind farms.

This paper describes how TenneT, as the offshore grid connection owner, proposes to deal with the possibility of assigning grid forming duties to the offshore WTGs.

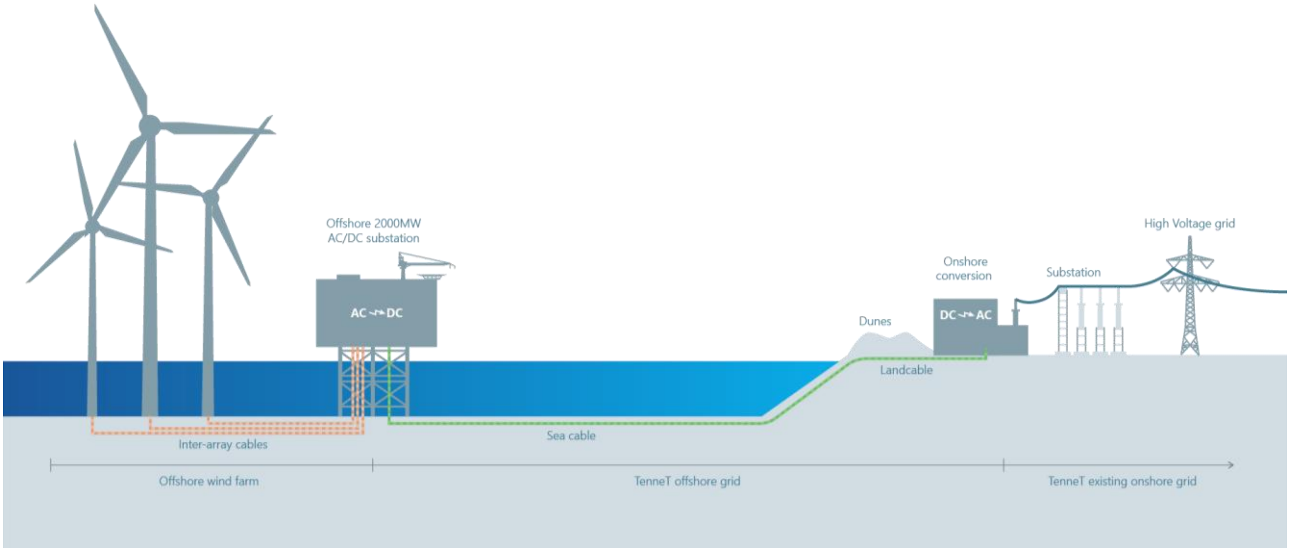


**Figure 1 - HVDC grid connection concept**

# 3. Current Situation

In the Netherlands, all the blackstart units for grid restoration purposes are located onshore. For further information, reference can be made to "BS-SO-TRS_15-001_Productinformatie_herstelvoorziening" [2]. This is a TenneT document that outlines the main operational duties for the blackstart units in the Netherlands.

So far, there has never been grid forming functionality reserved for the WTGs in offshore wind farm applications. This means that for offshore HVDC based transmission systems, they are always energised from the onshore converter station, which requires the presence of a strong onshore grid. Given the single line diagram (SLD) in Figure 2, the essential duties of the power electronics based equipment are described as follows:

- **Onshore converters**: Onshore converters are responsible of controlling the DC voltage magnitude of the HVDC system. This is characterized by the active power exchange of the converter with the onshore AC grid.
- **Offshore converters**: The offshore converter is the offshore grid forming unit, which means that it is responsible for controlling the AC voltage magnitude and frequency of the offshore AC grid by absorbing the active power output of the wind turbines and injecting it to the DC grid as well as exchanging reactive power if necessary. In doing so, the offshore converter relies on the DC bus voltage controlled by the onshore converter.
- **Wind turbine generators**: WTGs produce active power by synchronizing to the offshore grid voltage. They are grid following units, since they rely on the presence of a stiff voltage and frequency.

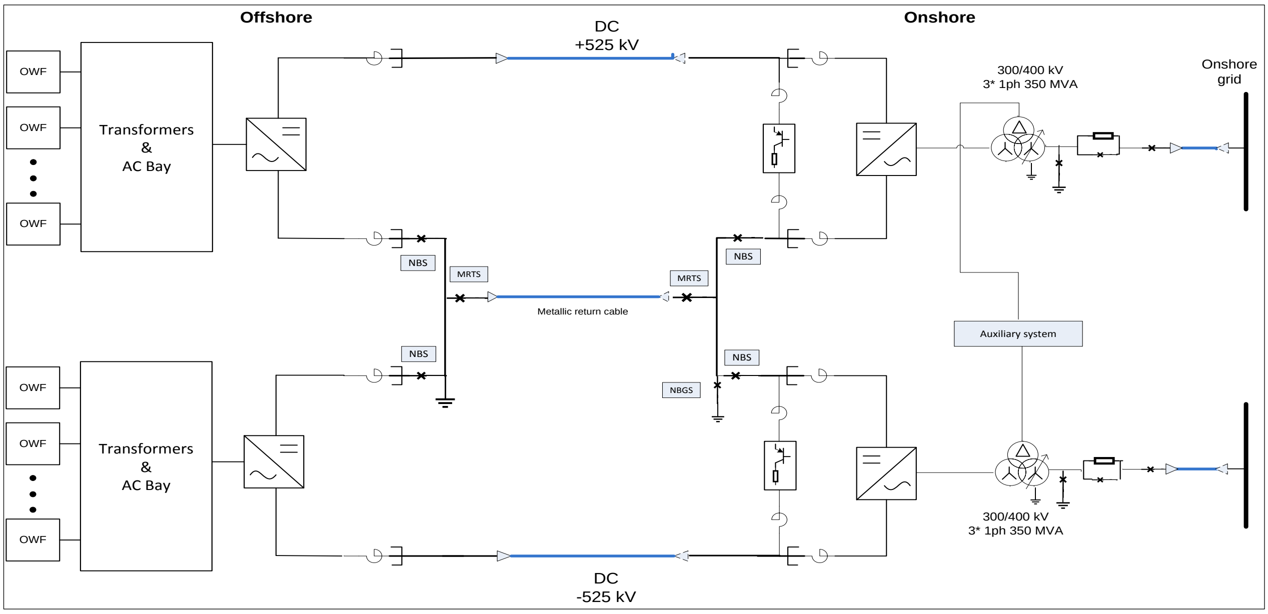


Figure 2: Generic SLD for IJmuiden Ver

The basic operation principle of an HVDC based offshore wind farm grid connection system relies on the balance of generated electrical power and the transmitted electrical power (plus the losses) as there is very limited energy storage capability within the system. The energisation process for an HVDC based offshore transmission system is achieved via the following steps.

- Auxiliary power system supplies the essential loads including the converter control and cooling systems.
- Initially the HVDC transformers are isolated from the grid side.
- The complete DC circuit is formed by connecting both onshore and offshore converters to the DC cables and opening the appropriate earthing switches.
- The pre-insertion resistor (PIR) is connected in series with the onshore transformers.
- The onshore line side circuit breaker is closed. This energizes (passively) the onshore transformers, onshore converter, DC cables and the offshore converter (via its DC side) simultaneously through the PIR.
- The onshore converter de-blocks in the DC voltage control mode.
- The offshore converter de-blocks in the AC grid forming mode.
- The offshore transformer is energized by closing the valve side circuit breaker (if applicable).
- The offshore AC bus (66 kV) is energized by closing the line side circuit breaker.
- The offshore AC cable strings are energized in steps by closing the relevant switchgear.
- The wind turbine connects to the AC cable string in a grid following mode.
- The wind turbine generates active power and injects it to the offshore AC grid. Simultaneously, offshore converter absorbs this power and injects to the DC circuit. Again simultaneously, the onshore converter absorbs active power form the DC circuit and delivers it to the onshore AC grid.

## 4. Grid Forming duties for OWF

As described in section 3, the offshore HVDC converter always operates in a unique sense in which it assumes the duties of grid forming while practically acting as a load to the offshore grid. In the conventional power systems, the grid forming duties are performed by the generators. The shift towards high amounts of renewable energy sources penetration, phase out plans of thermal power plants and the growing share of offshore wind in the national power systems means that ancillary services, such as blackstart capabilities, could be potentially reserved also for OWFs.

TenneT is willing to support the plans, if any, of OWF developers for reserving grid forming functionalities in IJmuiden Ver connections for onshore grid blackstart purposes. However, such plans need to be known well in advance in order to prepare the design of the HVDC transmission system accordingly. Energising the offshore HVDC based transmission system from the offshore side towards the land station is currently not foreseen, unless signalled otherwise from the OWF developers during the consultation process for IJmuiden Ver. It can then be treated as a design option during the engineering development steps of IJmuiden Ver (2019-2021). This will be supported by energisation studies by the HVDC suppliers, that will lead to the final primary layout arrangement on the converter platform and detailed requirements for the OWF regarding the energisation steps. It must also be made clear that the final decision regarding the implementation of grid forming duties for the OWF need to be made before mid of 2022 (according to the current planning), to enable TenneT to capture the right scope of delivery before awarding the relevant contracts for the Grid Connection System for IJmuiden Ver.

The utilisation of grid forming duties from the OWF for blackstarting the onshore grid may be achieved via several ways. It is essential for TenneT to be aware of the detailed energisation plan of the offshore AC grid, in order to engineer the rest of the restoration sequence.

## 5. Blackstart Solution

Following a blackout, the power system restoration strategy requires formation of small electrical islands using blackstart units, such as hydro power plants with storage capability and small gas turbines, to supply the auxiliary power needs of starting larger conventional thermal power plants. The existing HVDC based offshore grid connection systems are not allowed to participate in the early stages of the restoration process due to the concerns regarding the stiffness of the onshore grid. On the other hand, OWFs with grid forming capabilities would not even require the onshore network to be energized let alone being stiff enough. Hence a bottom-up grid restoration strategy initiated by the generators themselves can be achieved by starting and connecting the HVDC directly to a black network.

To achieve blackstart using WTGs with grid forming capabilities, a step-by-step approach inspired by the proposal in [1] is described below:

- **Self-start**: The WT starts itself using an internal power supply for initial energization of its auxiliaries, yaw & pitch mechanisms and starts producing power from the wind.
- **Self-sustain**: The WT operates in a power-curtailed mode for energizing the WT transformer. The power demand of the auxiliary systems is met by the generated wind power. Furthermore, assuming the WT has energy storage capabilities such as a battery system, the excess wind power can be used to charge it up.
- **Charging of the array cable**: A self-sustained WT energizes an array cable. This requires the WT to operate practically like a STATCOM to compensate the reactive power generation of the cable.
- **Parallel operation**: Several WTs should be synchronized possibly by adopting microgrid control strategies. It is also possible that some WTs can be connected in the grid following mode. This process should continue until enough combined generation capacity is achieved to energize the HVDC system as well as to supply the onshore load.
- **Energization of the HVDC system**: The energization process described in section 3 can be performed in a reverse manner:
    - Once the offshore PCC is energized by the WTs, the auxiliary power needs of the offshore converter will be supplied by the generated wind power via a dedicated auxiliary transformer connected to the PCC.
    - Initially the offshore converter should be isolated from the offshore grid side.

- The complete DC circuit should be formed by connecting both onshore and offshore converters to the DC cables and opening the appropriate earthing switches.
- As there is no PIR in the offshore station for energization purposes, one option is to energize the HVDC circuit as well as transformers in a single step. As far as the HVDC equipment is concerned, this is not expected to pose a significant challenge as the total current of the OWF is limited to the rated current. It is also likely to be requested that not all of the wind turbines will be connected prior to energization, in order to further reduce the maximum inrush current. On the other hand, the WTs will probably experience the HVDC energization process as a self-recovering LVRT. Furthermore, the inrush currents of the HVDC transformer may cause significant transients for the WTGs which could require installing PIR in the offshore station. In any case, all these aspects will have to be studied in full detail by both TenneT and the OWF developer. The detailed scope of the energisation studies to be performed by the OWF will be described as part of the connection agreements with OWFs.
- As the voltage builds up in the submodule capacitors of both converters simultaneously, the offshore converter should de-block in the grid following mode and control the DC voltage.
- The onshore converter should de-block in the grid forming mode controlling the onshore AC voltage magnitude and the frequency.
- The onshore AC bus should be energized by closing the line side circuit breaker.

- **Restoration of the onshore AC system:** The onshore load will be supplied by the HVDC system. Simultaneously, the offshore converter will absorb active power from the wind turbines to regulate the DC voltage. As the onshore load will increase gradually and possible could fluctuate during the grid restoration process, the coordinated controls of the wind turbines should be robust enough. Also, considering the intermittency of the wind generation, the WTs with energy storage capabilities will be critical to achieve stable operation.

## 5.1 Impact Assessment on the HVDC System

**Auxiliary power requirements:** The offshore converter station does not need any additional auxiliary power equipment for the blackstart operation. In fact, since the offshore grid is formed by the WTGs, there is an increased level of redundancy compared to the normal operation. On the other hand, the onshore converter cannot receive power from the distribution network due to the blackout. Therefore at least an additional set of power supply, in the form of diesel generators, is necessary for the onshore converter station. The associated risks for the modification of the auxiliary power system are negligible.

**Energization requirements:** As discussed in the energization sequence, the existing equipment at the offshore converter station is considered sufficient as far as the stress on the HVDC equipment is considered. However, the HVDC converter transformers may cause significant inrush currents which could endanger the safe operation of the WTGs. Consequently, pre insertion resistors at the 66 kV side could be necessary. Such equipment would affect the size of the platform significantly. In summary, the engineering efforts may be rather extensive which would increase the risks, cost and delivery time.

**Control and protection requirements:** The HVDC controls will need to be adopted for the blackstart operation. In theory, both onshore and offshore converters have the inherent capability to operate in either grid following or grid forming mode. In practice, operating in grid following mode in a network with an extremely low short circuit ratio (could be even less than 1) will be challenging for the offshore converter. Similarly, the grid forming controls will require further tuning for the onshore converter station to ensure stable operation with the other generators. The protection settings should also be revisited to ensure proper coordination during blackstart operation. In summary, the engineering efforts may be rather extensive which would increase the risks, cost and delivery time.

### 5.2 Impact assessment on the OWF

**Energy storage:** The intermittency of the wind power as well as the dynamic performance requirements applied in the WTGs for stable operation of the system may require energy storage elements to be installed in the WTGs or wind farms. In addition to the extra CAPEX that it would bring, the immaturity of such technology integration could pose significant project risks. TenneT will not install such storage facilities on the converter platform.

**Coordinated controls:** The power output of a single WTG is by no means sufficient to assume the grid forming capabilities on its own, hence several WTGs should be controlled in coordination to achieve the end functionality. Given the current practice of stand-alone controls applied directly at the turbine terminals, additional engineering efforts and technology development are necessary.

**Commercial aspects:** To TenneT's knowledge, there are no commercial offerings or communicated plans to make such a technology available within the time frame of IJmuiden Ver.

### 5.3 Opportunities

A bipole HVDC system presents the possibility of grouping the offshore wind turbines based on their grid forming capabilities for optimum utilization of the assets. To be more explicit, one of the poles can be connected mainly to the grid forming wind turbines and perform blackstart as explained in section 5. Coupled at the onshore AC grid, the onshore converter of the other pole can be de-blocked in the grid following mode (controlling the DC voltage) while the offshore converter is operated in the grid forming mode connected to the wind turbines that do not have the grid forming capabilities. It must be noted that proof of such concept has not yet been engineered.

## 6. Position TenneT

Above considerations lead TenneT to the following position:

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

In case the outcome of the consultation process indicates clearly the interest of OWF developers to reserve grid forming capabilities in the WTGs of IJmuiden Ver for onshore network restoration purposes, TenneT will be supportive of this service.

This means that the development of the basic HVDC design for the Grid Connection System of IJmuiden Ver, until Q1 2022, would consider this functionality as an option to the basic design (GCS design to not prevent such functionality). However, it is imperative to have concrete commitment from the interested wind farm developers of IJmuiden Ver well in advance of contract signing. This is because significant additional costs need to be made and making unnecessary investments should be avoided as much as possible.

TenneT invites the stakeholders to propose their solutions in full detail, in order to enable this opportunity in the detailed engineering of the offshore Grid Connection System.