POSITION PAPER

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1. Background Material

LITERATURE USED:

- [1] TenneT Position Paper T01 – HVDC Grid Design and Reliability & Availability
- [2] *"Overvoltage Phenomena in Offshore Wind Farms Following Blocking of the HVDC Converter"*. I. Erlich, B. Paz, University of Duisburg-Essen; M. Koochack Zadeh, S. Vogt, C. Buchhagen, C. Rauscher, A. Menze, J. Jung, TenneT Offshore GmbH.
- [3] *"New Control of Wind Turbines Ensuring Stable and Secure Operation Following Islanding of Wind Farms"*. I. Erlich, University of Duisburg-Essen; M. Koochack Zadeh, S. Vogt, C. Buchhagen, C. Rauscher, A. Menze, J. Jung, TenneT Offshore GmbH.

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.

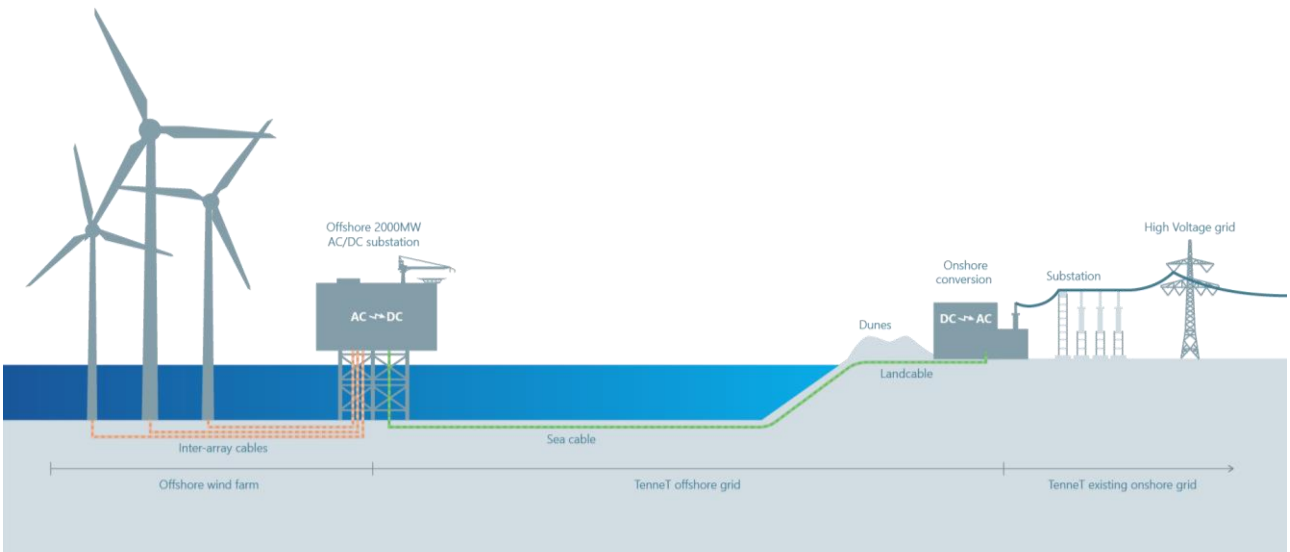

Figure 1 - HVDC grid connection concept

This paper describes how TenneT, as the offshore grid connection owner, proposes to deal with the load rejection occurring in the offshore grid.

3. Technical Background

In an HVDC based offshore grid connection system, the offshore HVDC converters operate as the grid forming unit (controlling the AC voltage magnitude and the frequency) of the offshore AC grid, whereas the wind turbine generators (WTGs) operate as the grid following units. Furthermore, regardless of the HVDC topology, 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. The definitions of the states of the converter are given below:

- **Blocked converter**: The control system sends "turn-off" commands to the main fully controllable switches (e.g. IGBTs) of the valve submodules. In practical terms, a half-bridge modular multilevel converter (HB-MMC) behaves as a six pulse diode rectifier when it is blocked.
- **AC isolated (tripped) converter**: The AC circuit breakers that connect the converter transformers to the relevant AC system are opened. It should be noted that the interval between issuing a trip signal to the circuit breakers and the actual time that the AC isolation is achieved might reach up to 60 – 100 ms.
- **DC isolated converter**: The DC disconnectors that connect the converter to the DC cables are opened. The DC disconnectors can only be opened when the DC current is zero.

Although the blocking and tripping may be prompted by several scenarios that require protective action, an exhaustive list is not relevant for the content of this position paper. Nevertheless, it is important to distinguish the level of the DC voltage during the events to describe the behaviour of the circuit.

3.1 Blocking/Tripping due to a Low Impedance DC Side Fault

Since the design basis of the IJmuiden Ver project is a full bipole with a dedicated metallic return, the low impedance DC faults are a possibility such as the pole-to-ground faults due to a cable failure. These faults result in a sudden and sustained drop in the DC voltage along with a high short circuit current, which results in an immediate blocking of the converters connected to that pole followed by tripping the relevant AC circuit breakers.

During the interval between the blocking and tripping, the short circuit current flows from the AC side to the DC side via the converter transformer and the diodes of the converter. As far as the offshore grid is concerned, the short circuit current is dictated by the contribution of the windfarms and to a great extent characterized by the Low Voltage Ride Through (LVRT) requirements. Hence there are no temporary overvoltage (TOV) problems during this interval for the low impedance DC faults.

Tripping the AC circuit breakers isolates the HVDC transformers and valves from the offshore grid, making a transition from a short circuit scenario to no-load as far as the windfarms are concerned. The TOVs created due to this transition are therefore relevant not only for the AC circuit breakers of the HVDC system but also the windfarms. Assuming that the AC circuit breakers can withstand the TOVs, the rest of the HVDC equipment is not impacted.

3.2 Blocking/Tripping without a DC Under-voltage

Some events that cause blocking and/or tripping can also happen when the DC voltage is already at the rated value or even higher. The examples include onshore AC faults that with a duration longer than the LVRT requirements, converter valve side faults, DC overvoltages and AC overvoltages.

During the interval between the blocking and tripping, the current flow from AC to DC side occurs only if the AC voltage is higher than the DC voltage. Since the current flow as such would further increase the DC voltage, these events are treated as load-rejection causing TOVs. Until the converter is AC isolated, the valves are also subject to these TOVs. The insulation coordination has to be performed accordingly and as a result of it the number of submodules as well as the amount of the surge arresters may increase linearly with the amount of overvoltage, causing elevated CAPEX costs.

3.3 Characteristics of the TOVs

The offshore AC grid is a lightly damped network which may contain several resonance frequencies mainly originating from the cable capacitances and the leakage inductances of the transformers. When the HVDC converter is blocked, these resonance modes may be excited by the WTG controls as well as the switching actions. Furthermore, as a result of the TOVs the transformers may also saturate leading to additional distortions [2].

The TOVs decay naturally upon disconnecting WTGs from the offshore AC grid.

4. Mitigation Alternatives

4.1 Design to Withstand TOVs

The HVDC system and the windfarms may be designed to withstand such TOVs with the cost of additional CAPEX. The CAPEX increase in the grid connection system relates to the additional converter submodules as well as surge arresters in the offshore platform and the associated platform costs to accommodate them. The CAPEX increase to the windfarm owners may also relate to the additional surge arresters and increased WTG costs.

4.2 Mitigation of TOVs by Improving WTG Controls & Protection

The most common WTG controls are designed in a way that the contribution to the AC voltage is achieved indirectly by injecting or absorbing reactive current. By definition this strategy requires an existing grid, which is no longer satisfied when the offshore HVDC converter is blocked. Hence to actively limit the voltage magnitude, terminal voltages of the WTGs can be controlled more directly as described in [3].

It may also be possible to enhance the overvoltage protection of the windfarms in such a way that blocking and tripping of the WTGs are achieved in a shorter time as well as at a lower voltage threshold. To facilitate this, HVRT requirements imposed on windfarms should be set accordingly. Alternatively, the blocked status of the offshore HVDC converter can be directly communicated to the WTGs via fast communications to trigger instantaneous block and trip of the WTGs.

5. Position TenneT

Above considerations lead TenneT to the following 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.

TenneT intends to finalize the temporary overvoltage (TOV) requirements as part of the ongoing consultation process.