POSITION PAPER

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1. Background Material

LITERATURE USED:
• ONL 15-083-T11_Overplanting_PP.docx (Borssele) • Cigre 2018 B1-118 Ampacity calculation method for deeply buried wind farm AC submarine export cables

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 position paper describes how TenneT intends to use dynamic DC cable rating to make optimal use of the DC cable.

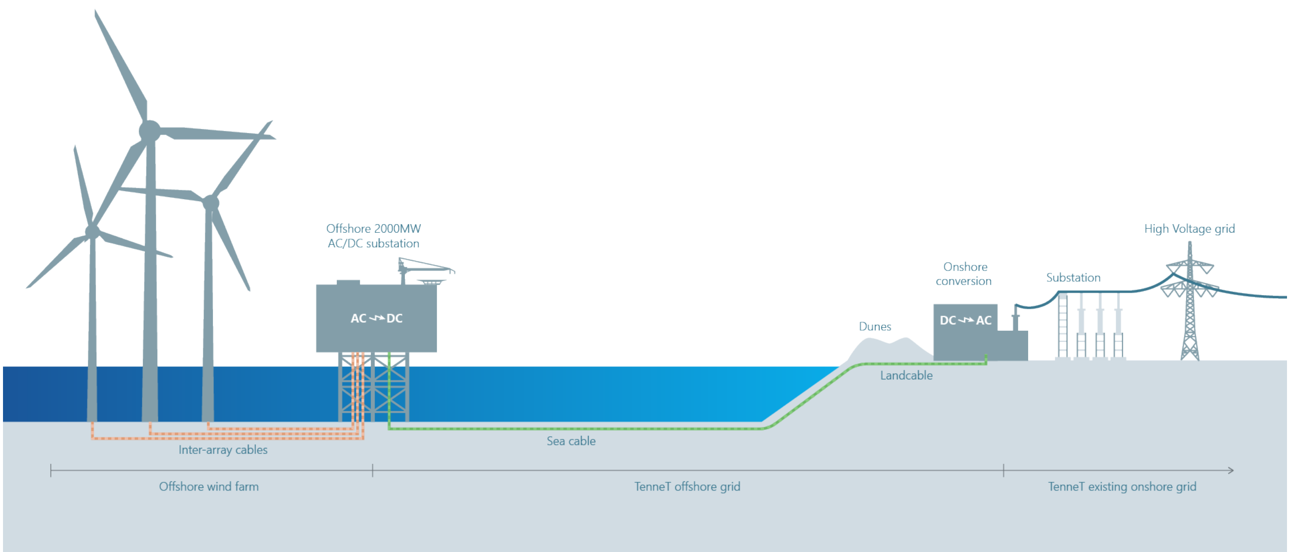

Figure 1 - HVDC grid connection concept

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In addition to Figure 3, a multi-terminal HVDC system may also be installed between the IJmuiden Ver grid connection system and the United Kingdom (a so called "Windconnector"). With this system the grid design combines an HVDC offshore wind connection point with a HVDC interconnector and can as such have an effect on the cable rating.

TenneT intends to give the design responsibility to the cable contractor and therefore the cable system design is based on an ampacity requirement. This paper describes the position of TenneT with respect to the most important design requirements that impacts the ampacity of the HVDC cable system. These design drivers requires answers to the following questions:

- Shall current rating be based on static or dynamic load profiles?
- What is the impact of overplanting on the cable design?
- What is the impact of the Windconnector on the cable design?

3. Maximum or average load profiles, static or dynamic calculation approach

2000 MW on 525 kV DC voltage level corresponds with 1905 A current rating[1]. However, due to the dynamic wind profile the electrical current will not be 1905 A continuously. Studies by BLIX show a yearly average electrical load factor[2] of 0.517.

Choosing a current rating based on continuous maximum loading may lead to an overdimensioned cable system for some sections, but design calculations based on average load may lead to hotspots, in particular during high wind speeds over a longer period in time. Historic wind data shows that high wind speeds and thus maximum loading can occur for more than 240 consecutive hours. This can become critical, especially when using a load factor for current rating in the sections with short thermal time constants which can heat up fast (e.g. J-tube, low soil coverage). Moreover, the load factor may change over time due to meteorological changes or new types of wind turbines with a higher efficiency.

TenneT proposes to follow the approach of the Net op Zee AC cable designs. This is an optimised approach using both static and dynamic calculation methods as described below:

1. The cable system will be designed based on a continuous maximum load profile for sections with short thermal constants (which can heat up fast);
2. For the section with a (initial or future) soil coverage of more than 5 m, a dynamic load profile shall be taken into account for current rating. This option is suitable for the sections with longer thermal time constants, which heat up slow (e.g. in deeper parts of HDD's, deep installation in sand dunes, etc.). The dynamic current rating is based on the following principle:
   - Pre-load condition of the cable shall be a partial steady-state average load[3] (f_{Load} *full load current) (full load is in this case 2000 MW) for 87.600 hours (10 years equivalent) to reach a somehow steady state temperature;

[1] Excluding harmonic contribution, which is to be assessed.
[2] The load factor (f_{Load}) depends on actual wind data, park layout and turbine power curves
[3] Average load as assessed for IJmuiden Ver is 0.517

- From t=0, a continuous load condition shall be used at full load current;
- The time shall be calculated between t=0 and the time that the conductor temperature reaches the maximum allowed temperature (in the example 70 °C). The time that the conductor temperature reaches the maximum conductor temperature shall be at least a certain period (in the example 4380 hours – half a year)[4]. TenneT intends to use a load factor between 0.5 and 0.6 and a time frame of half a year.

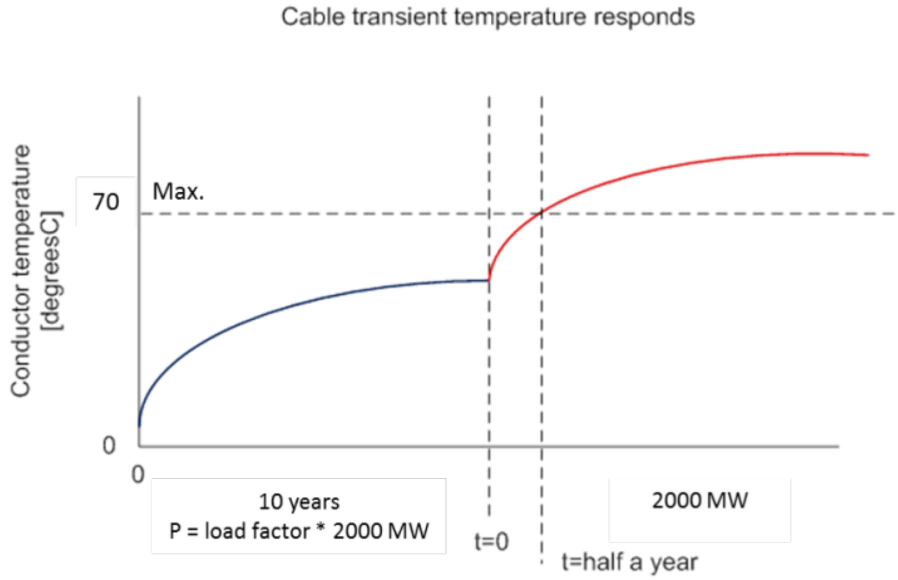

Figure 1: 2-step method for cable rating

Within the Borssele and Hollandse Kust (zuid) offshore grid projects this approach has resulted in cost saving optimisations in the cable designs. By choosing the right parameters the two-step method is considered to have enough margin to cope with changes in the future. More in depth information is given in the Cigré paper B1-118.

4. Base case cable design

There are uncertainties about the soil conditions that will be encountered. For both IJmuiden Ver Alpha and Beta, the majority of the cable route length will be in the offshore sand wave area. Experiences with earlier projects in the North Sea show that the required burial depths in the nearshore can be significant (areas up to 6 or 10 meters due to sea bed morphology). The thermal resistivity can also vary in this area. In the offshore sections the thermal resistivity is more stable and relatively lower compared to nearshore. Soil cover may vary here between 1,5 m and 10 m, because of sand waves.

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

[4] Half a year is based on studies on typical wind data and need to be reassessed for IJmuiden Ver

5. Overplanting

The term overplanting is used to describe the strategy to install more wind power capacity (turbines) than the available transport capacity. This strategy increases the average load factor of the windfarm which results in additional renewable energy production and a more optimal use of space and grid connection system.

Overplanting is different in HVAC and HVDC grid connections. In a HVDC grid connection the maximum transport capacity is defined by the dimensioning of the HVDC converters. For the converter there is no difference between a dynamic and continuous rating. The converter is designed for maximum 2000 MW, therefore in case of overplanting the higher power output will be capped to 2000 MW and the cable load will not exceed 1905 A in any case.

In the HVAC grid connections the bottleneck is defined by dynamic rating of the export cable (700 MW continuous, >700 MW temperature dependent) and the platform (760 MW continuous). The HVAC grid connections have a guaranteed (continuous) connection capacity of 700 MW and a dynamic, temperature dependent, connection capacity of 760 MW.

The below figure shows the effect of overplanting for the IJmuiden Ver wind area. By allowing 20% overplanting the power-duration curve shifts to the right and on average more power will be produced.

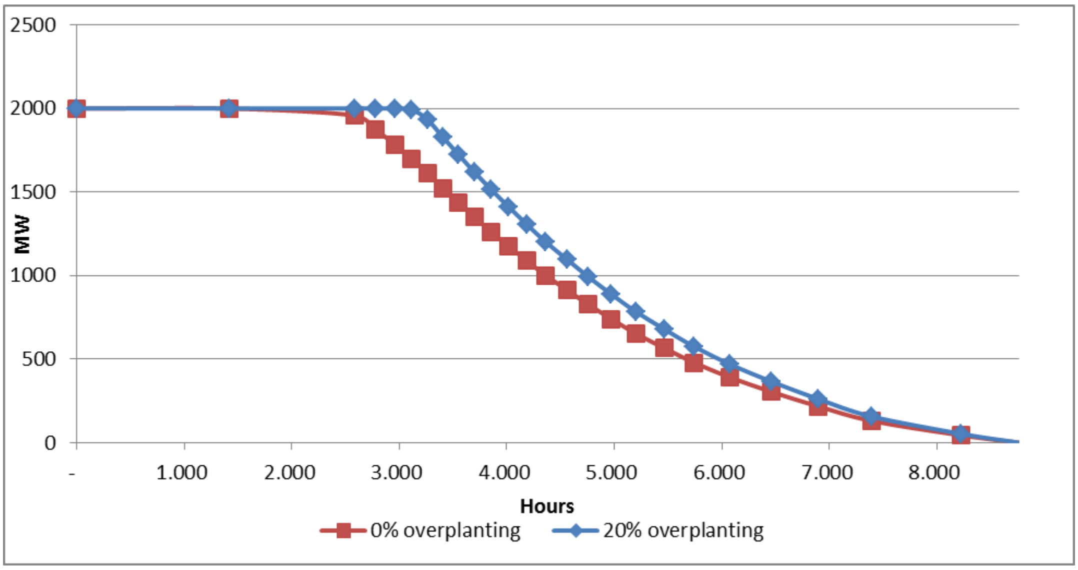

Figure 2: Effect of 20% overplanting on the power-duration curve

The effects of overplanting on the capacity factor of the offshore grid transmission capacity and amount of energy produced can be found in the table below

Table 1: Effect of overplanting on the load factor

Overplanting	Capacity factor (w.r.t. transmission capacity[5])	Additional MWh (2x2GW)	Curtailment (w.r.t. installed wind power)
0,00%	51,71%	-	-
1,00%	52,01%	102.560	0,22%
2,00%	52,30%	205.120	0,44%
3,00%	52,59%	307.679	0,65%
4,00%	52,89%	410.239	0,86%
5,00%	53,13%	497.463	1,11%
6,00%	53,35%	573.847	1,38%
7,00%	53,57%	650.231	1,65%
8,00%	53,79%	726.615	1,91%
9,00%	54,01%	802.999	2,17%
10,00%	54,21%	875.169	2,43%
11,00%	54,41%	944.666	2,70%
12,00%	54,61%	1.014.163	2,96%
13,00%	54,81%	1.083.660	3,21%
14,00%	55,01%	1.153.157	3,46%
15,00%	55,20%	1.221.824	3,71%
16,00%	55,38%	1.285.524	3,97%
17,00%	55,56%	1.349.225	4,22%
18,00%	55,75%	1.412.925	4,47%
19,00%	55,93%	1.476.626	4,72%
20,00%	56,11%	1.540.326	4,96%

5.1 Optimal maximum overplanting

The optimal maximum overplanting rate is from a LCoE perspective highly sensitive for small changes in:

- Expected electricity price
- Cost of the windfarm (Euro/MW installed)
- Discount rate (WACC)
- Wake effects
- The technical details of the wind turbine

Nevertheless, a parametric study has shown that the optimal overplanting from a developer perspective is most likely between 0-15%.

[5] Including wake effect, capacity factor without wake effect is estimated at 60% for IJmuiden Ver.

From a societal perspective there is an advantage in overplanting, since it increases renewable energy production and ensures a more optimal use of space. In addition, it reduces the relative cost of the transmission infrastructure.

Increasing the overplanting above 15% is not realistic since it would lead to unrealistic power densities in the IJmuiden Ver area.

As a result of the above factors TenneT proposes to set the maximum overplanting in the IJmuiden Ver area to 15%.The incorporation of 15% overplanting would increase the load factor with 3,5%. This would have no effect on the cable dimensioning (or almost none).

In the end the maximum overplanting value will be set by the Ministry of Economic Affairs and Climate. The value will be included in the site decision ("kavelbesluit") and development framework ("ontwikkelkader").

6. Windconnector

The load profile in case of a Windconnector is different compared to the offshore wind connections. In interconnector operation mode a strong static profile (due to the market driven behaviour) will occur while wind power operation shows a strong dynamic behaviour.

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.

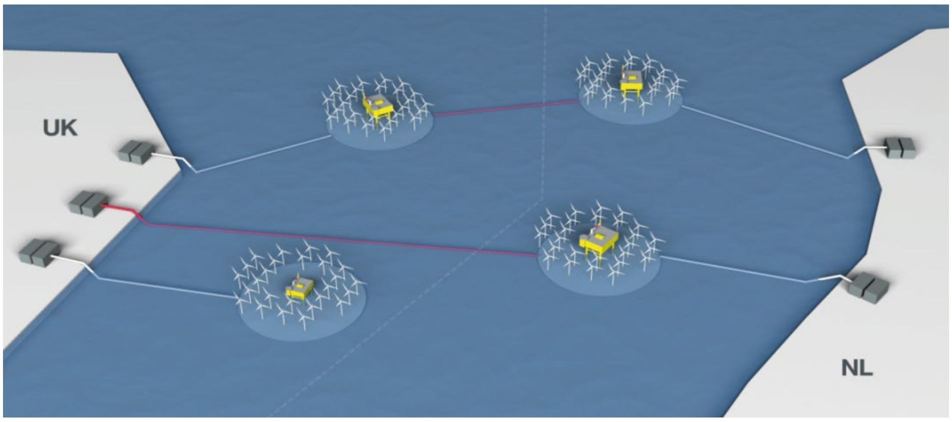

Figure 3: Schematic overview of a "Windconnector" to the United Kingdom

7. Position of TenneT

Above considerations lead TenneT to the following 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[6] and a time frame of half a year.

Base case cable design

At this moment a combination of 2000 Cu and 2500 Cu 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. The value will then have to be included in the site decision ("kavelbesluit") and development framework ("ontwikkelkader").

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.

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[6] The final load factor will be set before the tender of the windfarm (by the Ministry of EAC)