MEMORANDUM

TO	Windfarm developers	**DATE**	December 12, 2019
		REFERENCE	AMO-00050
		FROM	TenneT TSO

SUBJECT Overplanting - version: Hollandse Kust (noord)

DECISION ☐

FOR INFORMATION ONLY ■

QUALITY CONTROL		
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Content

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1 Scope and considerations

The *Figure **1*** below shows a schematic cross section of the connection of an offshore wind farm to the onshore electricity grid. Wind turbines are connected through “inter-array” cables (in orange) to the offshore Connection Point (CP) at the offshore substation, from which electricity is transported to shore. TenneT is responsible for the grid connection up to, and including, the offshore substation and will take care for the supply and installation.

The wind park, including the wind turbines and the array cables, up to the offshore CP at the switchgear installation on the offshore substation of TenneT, is to be supplied and installed by the owner of the Power Park Module (PPM).

TenneT intends to standardise the offshore substations as much as possible.

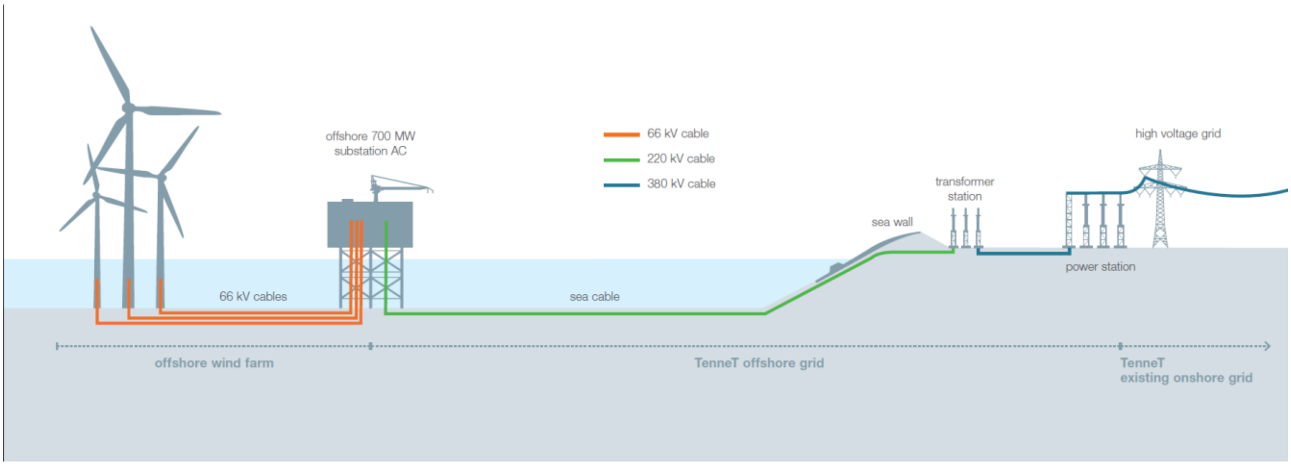

Figure 1 - Schematic of the offshore electrical grid. Source: TenneT

Overplanting

An important aspect in the design of an offshore wind farm, is to optimise the offshore wind farm capacity (type and number of wind turbine generators) to the fixed electrical infrastructure export capacity. This principle is also referred to as overplanting or overbooking since it usually leads to installing a (small) number of extra wind turbine generators compared to the grid connection capacity limit[1]. The "overplanted" power from these extra turbines will result in higher energy yield at lower wind speeds but will lead to a curtailed power at higher wind speeds as depicted in *Figure **2***. Off course, the extra turbines will result in higher CAPEX, which should be balanced by extra revenues from the extra energy yield.

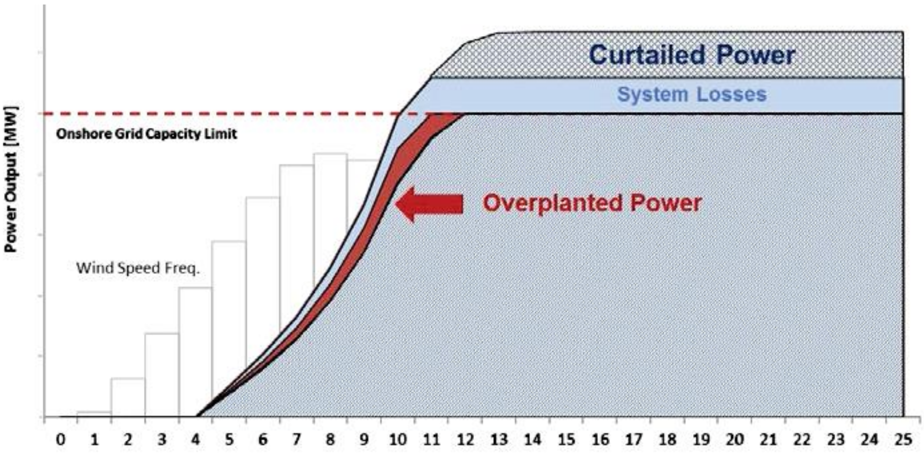

Figure 2 - Principal of Capacity Optimisation. Source: Global Offshore Wind Conference 2014.

To be able to further optimise the PPM lay-out (location, type and number of wind turbine generators), it is necessary for the PPM owner not only to know to what to extent the grid connection may be continuously loaded (e.g. the grid capacity limit) but also to what extent the grid connection may be (temporary) loaded above this capacity limit. In this way, the curtailed power is reduced and the energy yield is increased further. As the possibility for the PPM to temporary overload the grid connection will further reduce LCOE, TenneT will allow this temporary overloading to a certain extent.

This paper describes the position of TenneT with respect to the extent to which the offshore grid specific for Hollandse Kust (noord) may be loaded more than the rated power at CP and under which conditions. The limiting factor in the offshore grid are the 220 kV export cables from the offshore substation up to the land station including the beach landing and an on-shore route of ~3 km.

Also a new 380 kV connection will be built to connect the land station to the TenneT grid. This 380 kV connection will however be designed for higher power ratings and therefore this connection will not limit the power output of the Hollandse Kust (noord) offshore PPM.

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[1] Money does grow on turbines – Overplanting Offshore Windfarms, Andrew Henderson a.o., Global Offshore Wind Conference 2014

2 Active power transfer through the TenneT offshore grid

The offshore grid design will be based on the parameters as listed in *Table* ***1***.

Table 1 - TenneT NL offshore grid parameters

Grid parameter	Value
Grid capacity per PPM at offshore CP:	350 MW
Number of PPM per offshore platform:	2
Reactive power exchange at CP under normal conditions:	Max +/- 0,1 p.u. (+/- 35 Mvar)
Nominal voltage level (220 kV part) onshore / offshore:	225 / 230kV +/- 1%

To determine if more than 700 MW (2 * 350 MW) of active power (P) can be transferred through the offshore grid, TenneT makes an assessment of the capability of the 220 kV export cables (paragraph 2.2) based on the parameters shown above. If there is additional capacity found in the design which allows the 220 kV export cables to transfer more than 700 MW of active power, TenneT will assure that other grid components will also be capable to transfer this extra power. The absolute maximum of transferred active power will in all cases be limited to 760 MW (2 * 380 MW).

With respect to the overloading of the grid connection system, the 380 MW shall be seen as an absolute maximum as other grid components such as the main transformers have much shorter thermal time constants.

According to RfG, PPMs will be required to contribute to the primary voltage regulation with more reactive power than shown in *Table* ***1***. It is assumed that these circumstances (Q > 35 Mvar or Q < -35 Mvar) will be limited in time and therefore will not significantly influence the thermal loading of the cables.

2.1 Simulation method

The duration in hours that a load of 760 MW can be transferred through one of the export cables systems (two 220 kV circuits with 380 MW per circuit) before curtailing of output power of the wind park will take place (referred to in this paper as dynamic ampacity) is dependent on the following factors:

1. Temperature of the cable before the 760 MW limit is reached. This temperature is again dependent on the loading history of the cable in the previous days or even months. This again is directly related to the wind speed;
2. The method of curtailing[2];
3. Final soil resistivity values over the complete cable route;
4. Final design of the cable system;
5. Voltage level of the system.

A clear and binding answer on the question of duration before curtailing will occur can't be given due to e.g. soil resistivity which will only be determined on a limited set of samples and the power output of the wind farms. Only when a wind farm is in operation, the actual temperature response will be known by the actual cable conductor temperature measurements (see chapter 2.3).

Currently, soil resistivity measurement results along the export cable route of HKN (which are part of the geotechnical survey) are available to TenneT. With a preliminary cable design which has been made based on the survey results, dynamic ampacity calculations are made for the worst case location(s) on the cable route (hot spot) as further explained in the paragraphs below based on one preloading conditions and a full load condition of 380 MW per PPM.

The chosen preloading condition of 67% reflects an average loading of the cable which may be expected over a long time with a wind farm loading profile. For this condition, a preloading time of ten years has been used to assure a starting temperature which is nearby the steady state conductor temperature when calculated according the IEC 60287. The dynamic calculations for this position paper have been made according to the IEC 60853.

These simulation results (which are still estimates) can be used in the business case calculations of the offshore wind park developers.

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[2] See section 2.3 of this document.

2.2 220kV export cables

2.2.1 Analysis of soil data of the geotechnical survey

In January 2019 the final reports of the offshore geotechnical survey have been received by TenneT. One report consists of the results of the offshore (trenched) route. The relevant parts of these final reports (ref: Appendix C Geotechnical Factual Report with document ID P0009011-H18) are available for wind developers preparing for the offshore wind tender on request via netopzee@tennet.eu. In this survey about 45 locations were investigated including soil sample analysis and various measurements of the thermal conductivity.

The raw data of this final survey report has been processed where for each borehole the effective thermal resistivity value (G) has been determined on the target depth of burial (DOB) using the conformal mapping methodology as stipulated in [Cigré ELECTRA nr 98, The calculation of the effective external thermal resistance of cables laid in materials having different thermal resistivities, 1985]. These effective thermal resistivity (G) values are included in Annex A. The target DOB per route section (which can also be found in the table of Annex A) has preliminary been determined by TenneT based on expected permit requirements and preliminary results of the morphological study and may change during the ongoing route engineering works.

Based on the data of the final survey report and Annex A, the areas with the highest thermal resistivity values have been listed in *Table 2*, where also a short description is included per area.

Table 2 – Areas with highest thermal resistivity values along the HKN cable route

Location	Soil coverage [m]	Effective G [K.m/W]	Description
Landstation	1,2	1,0 / 2,6	Thermal resistivity with partial / full soil dehydration taken into account.
HDD 1	43	0,5	Deepest point of HDD's
Breakerzone	13	0,6	Possible worst case future soil coverage due to seabed mobility
Offshore non-mobile area 1	1,5	0,55	Cable in normal sand condition
Sandwave area 1	4,5	0,5	Cable below full sandwave (future soil condition)

The areas of *Table 2* are shown on a map in Figure 3.

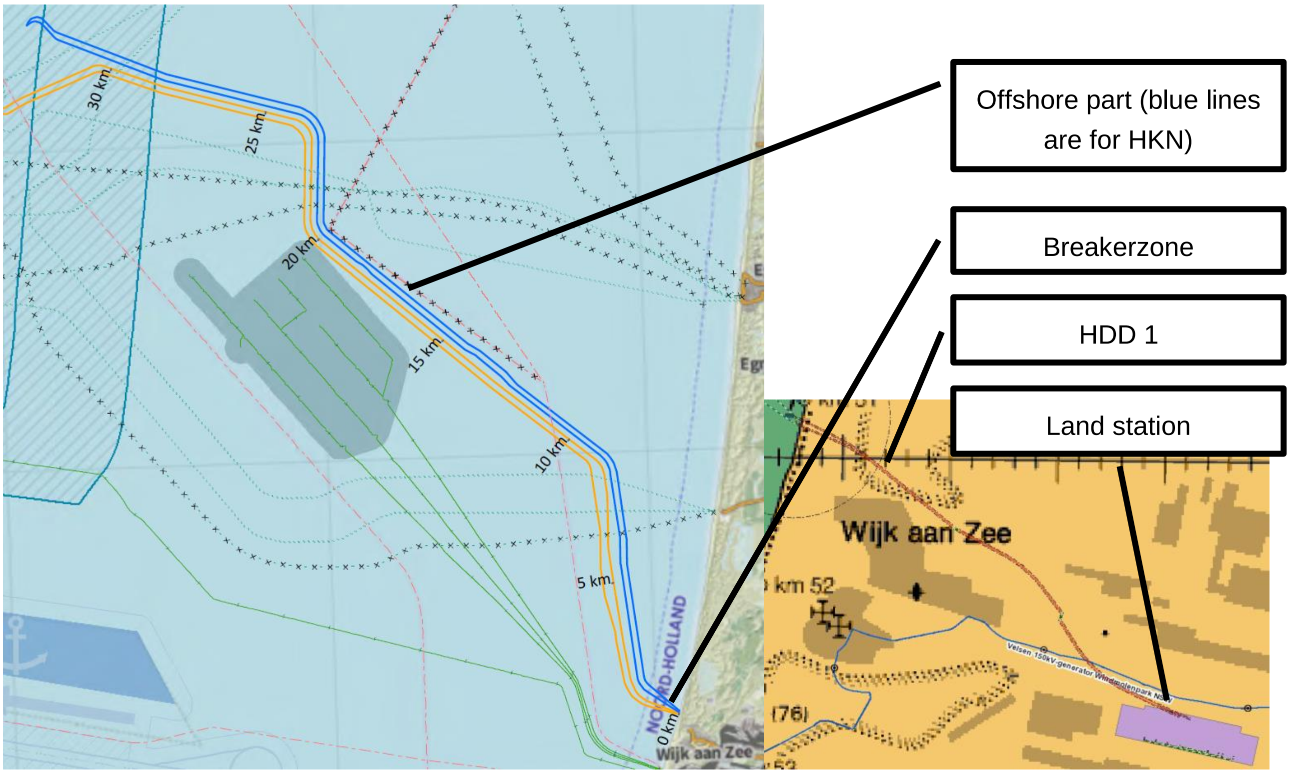

Figure 3 – Locations of Table 2 on the map

Land station area: As the average ground water level is low, soil dehydration is expected. To achieve the static (continuous) ampacity corresponding to 350 MW per cable circuit, this dehydration effect shall be taken into account.

HDD 1 (horizontal directional drilling): The value in *Table 2* of the effective thermal resistivity of the lowest level of the three HDD's has been given which reflects the expected point in the HDD's which will be the leading for cable design. This level corresponds to HDD 1 and for this HDD the sea cable will be used. As the soil coverage of this point is large, the 380 MW dynamic ampacity will be relatively high in the HDD.

Breakerzone: As the soil coverage in this area is also large due to seabed mobility (up to 13 m, see *Table 2*) the 380 MW dynamic ampacity will be relatively high.

Offshore part: for the offshore part, cable design will not only be based on the HKN route but also on the route to Hollandse Kust (west) which is a much longer route (~72 km) with higher currents and worse soil conditions. Also, TenneT weighs losses in the cable system more strongly in the design for HKN and HKWa compared to previous offshore projects. Therefore it is expected that the sea cable design for HKN will not drive the dynamic 380 MW ampacity.

2.2.2 Cable design

Load Flow

For cable properties which have an impact on the load flow, following values have been assumed for the dynamic ampacity calculations of this position paper:

- Capacitance of cable: 0,22 µF / km (mean value)
- Length of cable: ~36 km (HKN, route offshore + onshore)

This results in a full load current (350 MW) at the land station side of 940 A and an overload current (380 MW) of 1010 A. Also, an additional preloading condition of 67% (of 380 MW) has been taken into account of 760 A[3].

Variance of capacitance will lead to a variance of full load current. The chosen capacitance used in this paper is a conservative estimate resulting in the largest full load current.

The reactive power compensation scheme foresees on shunt reactors at onshore side only which results in an estimate full load compensation distribution of 75%/25% onshore and offshore. At lower loads this will shift towards 100%/0%.

Losses

In this position paper, a 1600 mm^2 AL sea cable design (HDD1) and a 2000 mm^2 land cable design (Land station area) are used for the simulations of which the results are presented below (paragraph 2.2.3).
For these designs, on other cable properties which have an impact on the losses (apart from conductor design), following assumptions have been used:

- Sea Cable type: Armour design: stainless steel (STS) wires with λ2 factor of 0 (zero), λ1 factor of 0,35;
- Land cable type: λ1 based on trefoil configuration with single side earthing (only two cable sections, so no cross bonding) and an AL welded sheath of ~1,2 mm thickness.

J-tube

As the time constants for temperature rise in the J-tube are low, the steady state rated ampacity requirement in the J-tube used by TenneT is increased to 380 MW. Therefore, the cable inside the J-tube is no limiting factor with respect to the dynamic ampacity.

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[3] This current is higher than 67% * 1010 A as at lower currents, the compensation scheme is shifting towards a higher current at land station side. This higher current in the loadflow has been used here.

2.2.3 Case study results

HDD1

The results of the calculations for the 220 kV sea cable in HDD1 are given in Table 3 where the time until the conductor reaches 90 °C is stated in hours. For this scenario an ambient temperature of 10 °C has been used and effective thermal resistivity values of the soil as described in paragraph 2.2.1.

Table 3 - Time (in hours) for conductor to reach 90 °C for HDD1 scenario

Preloading			Overloading [A] / [MW]	Time to reach 90°C [hours]
%	# of days	Preload I [A]		1600 Al (STS)
67%	3650	720	1030 / 380	240

Land station area

The results of the calculations for the 220 kV land station (using land cable) are given in Table 4 where the time until the conductor reaches 90 °C is stated in hours. For this scenario an ambient temperature of 15 °C has been used and effective thermal resistivity values of the soil as described in paragraph 2.2.1.

Table 4 - Time (in hours) for conductor to reach 90 °C for 220 kV / 380 kV land station scenario

Preloading			Overloading [A] / [MW]	Time to reach 90°C [hours]
%	# of days	Preload I [A]		2000 Al land cable
67%	3650	720	1030 / 380	>400

2.3 Update 01 – t.b.d. - based on winning 220 kV tender design (V2)

In the winning tender design the cable system is optimized compared to the cable types presented in §2.2.2. As soon as the winning tender is known, this updated will be provided.

3 Export cable load management

In general, TenneT identifies three levels in the export cable load management process:

1. Alignment of the Connected Party's generation forecasts to dynamic cable loading capabilities;
2. Actual curtailment of the power output of the Connected Party;
3. Actual curtailment of the power output of the Connected Party by TenneT.

For the detailed process, reference is made to the connection and transmission agreement (CTA, Annex 3, section 11).

4 Position of TenneT

Above considerations lead TenneT to the following position:

TenneT allows the PPMs to transmit up to 30 MW above their rated power (350 MW), with the requirement for PPM's to curtail their produced power, in case the 220 kV and / or 380 kV export cables reach their maximum allowable temperature limits[4]. Details on curtailment of the PPMs has been addressed in the 'Connection and Transmission Agreement (CTA)'.

The results of paragraph 2.2 and 2.3 are only valid for Hollandse Kust (noord). For this Hollandse Kust (noord) case, an overloading of 380 MW can be maintained for about 240 hours (before conductor temperature reaches 90 °C) based on a preload of 67% over 3650 days, at the 220 kV cable route in HDD1.

For the Hollandse Kust (Noord) tender, TenneT will give an update in due time based on the cable design of the winning Hollandse Kust (Noord) 220 kV sea cable tender.

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[4] Operational limits of sea and land cables will be monitored continuously by temperature sensing systems.

5 Annex A: Soil resistivity analysis - Cable route from land station to Hollandse Kust (noord) platform

Table with effective soil resistivity values along the cable route.