Taking power further

MEMORANDUM

TO Windfarm developers

DATE April 05, 2022
REFERENCE PU-AMT 21-287v2
FROM TenneT TSO

SUBJECT Overplanting - version: Hollandse Kust (west) – update V2

DECISION ☐
FOR INFORMATION ONLY ■

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Content

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.

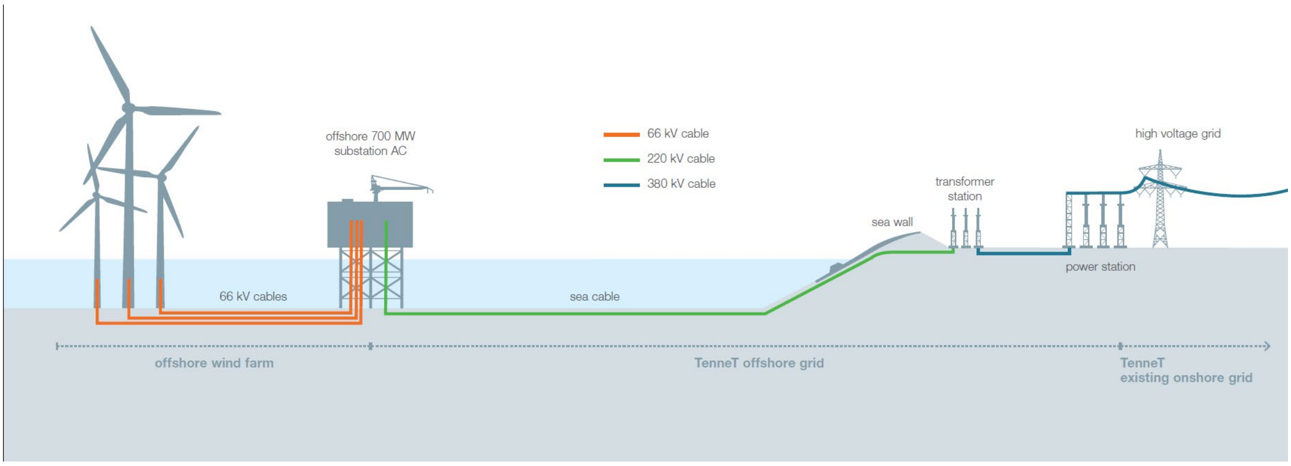

Figure 1 - Schematic of the offshore electrical grid. Source: TenneT

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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.

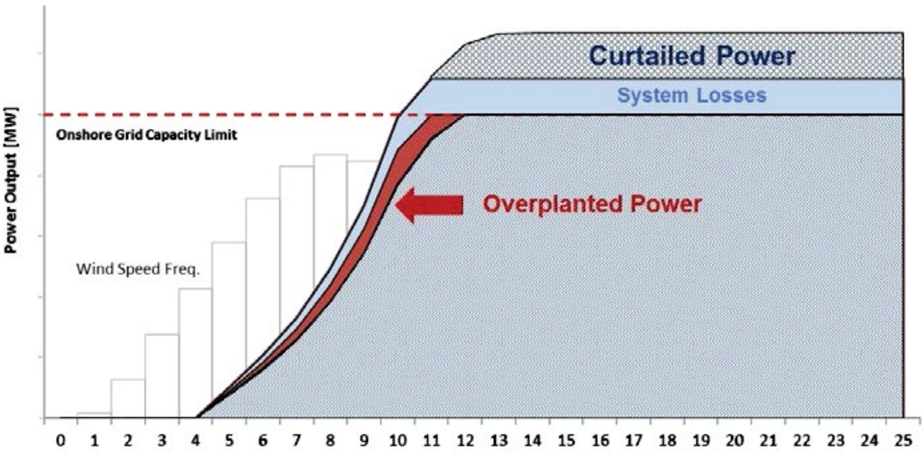

Figure 2 - Principal of Capacity Optimisation. Source: Global Offshore Wind Conference 2014.

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.

This paper describes the position of TenneT with respect to the extent to which the offshore grid specific for Hollandse Kust (west) 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.

Please note that there is a completely different cable route for the cables to the Hollandse Kust (west) Alpha platform (HKwA) and Beta platform (HKwB) for both land and sea cables.

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 (west) offshore PPMs.

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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 380 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.

Currently, soil resistivity measurement results along the two different export cable routes of HKwA and HKwB (which are part of the geotechnical survey) are available to TenneT. For HKwA a final cable design is available which was made by the export cable contractor. For HKwB a preliminary cable design is available as this cable route is currently being tendered. With these cable designs which have been made based on the survey results, dynamic ampacity calculations were made for the worst case location(s) on the cable route (hot spot) as further explained in the paragraphs below based on a preloading condition 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 estimates) can be used in the business case calculations of the offshore wind park developers.

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[2] See section 3 of this document.

2.2 220kV export cables HKwA

In this section 2.2 the 220 kV export cables for HKwA are discussed which follow the same route as the Hollandse Kust (noord) cables up to the HKN Platform and then continue towards the HKwA platform.

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 75 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 been determined by TenneT based on permit requirements and results of the morphological study.
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 HKwA cable route

Location	**Soil coverage [m]**	**Effective G [K.m/W]**	**Description**
Landstation	1,2	1,0 / 2,7	Thermal resistivity with partial / full soil dehydration taken into account.
HDD 1	43	0,5	Deepest point of HDD's with sea cable
Breakerzone	13	0,6	Possible worst case future soil coverage of 13 m due to seabed mobility
Offshore part	1,5 – 7,5	0,5 – 0,6	Cable in normal sand condition

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

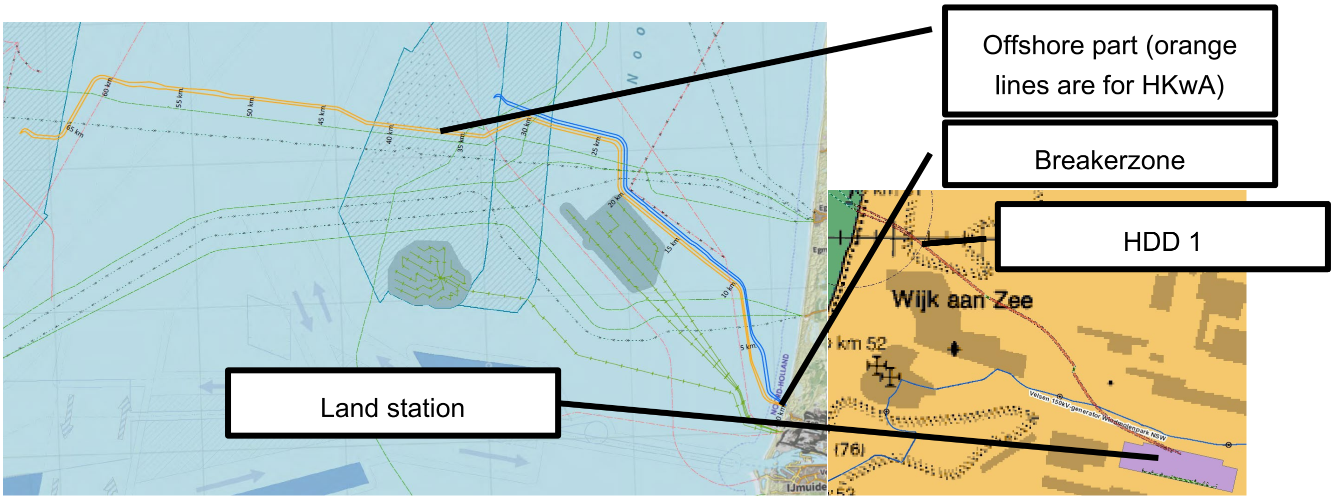

Figure 3 – Locations of Table 2 on the map

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 standard thermal resistivity values for sand have been found. Soil coverage can be up to 7,5 m due to sand waves. Offshore sea cable type is a 1400 mm2 AL with stainless steel armour. This cable type was selected to achieve best value with regards to losses and the 380 MW dynamic ampacity is therefore relatively high.

2.2.2 Cable design

Load Flow

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

- Capacitance of cable: 0,21 µF / km (mean value over whole length)
- Length of cable: ~72 km (HKwA, route offshore + onshore)

This results in a full load current (350 MW) at the land station side of 950 A and an overload current (380 MW) of 1030 A. Also, an additional preloading condition of 67% (of 380 MW) has been taken into account of 720 A.

Variance of capacitance will lead to a variance of full load current. The chosen capacitance is based on actual cable design used for the HKwA project.

The reactive power compensation scheme foresees on shunt reactors at both offshore and onshore side which results in an estimate full load compensation distribution of 50%/50% onshore and offshore at all loads.

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 which are based on actual cable design:

- Sea Cable type: Armour design: stainless steel (STS) wires with λ2 factor of 0 (zero), λ1 factor of 0,2;
- Land cable type: λ1 based on trefoil configuration with single side earthing (only two cable sections, so no cross bonding) and a lead sheath of ~2,5 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.

2.2.3 Ampacity calculation 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. A distance between HDD ducts of 10 m has been used for the calculation and current for HKN cables have been set to same level as HKwA cables.

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	> 500

Land station area

The results of the calculations for the 220 kV land station (using land cable) showed that the conductor will not reach 90 °C at 1030 A / 380 MW. 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 *without* soil dry-out.

2.3 220kV export cables HKwB

In this section 2.3 the 220 kV export cables for HKwB are discussed which follow a different route both onshore as offshore.

2.3.1 Analysis of soil data of the geotechnical survey

In January 2021 the final report (ref: HKWB-NGS-06165, rev C2) of the offshore geotechnical survey has been received by TenneT. The main report and a detailed summary of relevant data of this final report (ref: Appendix R IBAS Table) are available for wind developers preparing for the offshore wind tender on request via netopzee@tennet.eu. In this survey about 80 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 B. The target DOB per route section (which can also be found in the table of Annex B) 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 B, the areas with the highest thermal resistivity values have been listed in *Table 2*, where also a short description is included per area.

Table 4 – Areas with highest thermal resistivity values along the HKwB cable route

Location	Soil coverage [m]	Effective G [K.m/W]	Description
Joint land-land	1,2	1,0 / 2,7	Thermal resistivity with partial / full soil dehydration taken into account.
Entry point HDD1	2,5 / 4,5	0,8 (2,6) / 0,7	Thermal resistivity with partial / full soil dehydration taken into account. HDD duct filled with air up to 4,5 m depth below ground level
HDD 1	50	0,5	Deepest point of HDD's
Breakerzone	10	0,6	Possible worst case future soil coverage due to seabed mobility
Sandwave area 1	3,5	0,6	Cable below full sandwave (future soil condition)
Sand waves area 3&4	7,5	0,5	Cable below full sandwave (future soil condition)

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

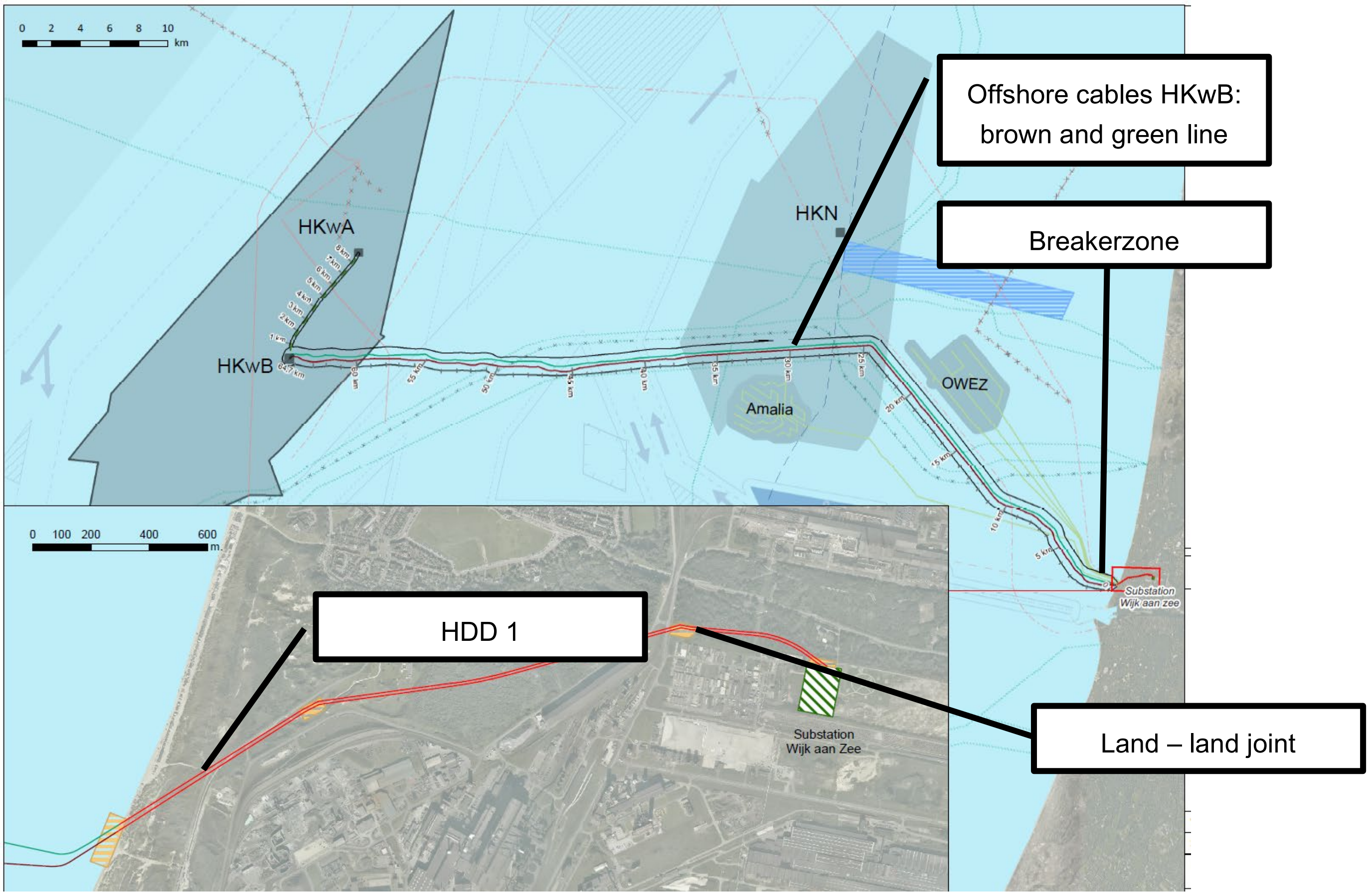

Figure 4 – Locations of Table 2 on the map

Land station area and land – land joint: As the average ground water level is low, there is risk of soil dehydration. To achieve the static (continuous) ampacity corresponding to 350 MW per cable circuit, this dehydration effect shall be taken into account. As land cable will probably be designed such that the critical temperature is not exceeded, dynamic ampacity will be relatively high.

HDD 1 (horizontal directional drilling): In *Table 2* for two areas of the HDD's the effective thermal resistivity has been given which reflects the expected points in the HDD's which will be the leading for cable design. These areas both correspond to HDD 1 and for this HDD the sea cable will be used. For the deepest point, the soil coverage is large, and therefore the 380 MW dynamic ampacity will be relatively high in the HDD. For the entry point where duct will be filled with air and soil dehydration is expected, 380 MW dynamic ampacity should be evaluated.

Breakerzone: As the soil coverage in this area is also large due to seabed mobility (up to 10 m, see *Table 2*) the 380 MW dynamic ampacity will be relatively high.

Offshore part:. As the thermal resistivity is relatively high, the Sandwave area 1 is expected to be most decisive in terms of dynamic ampacity.

2.3.2 Cable design

In general, cable design for HKwB will be similar to HKwA. As the tender for cable supply and installation of this HKwB project is currently ongoing, TenneT is not able to disclose any detailed information on cable design in order not to influence the tender process.

2.3.3 Case study results

All tenderers within the HKwB tender have provided preliminary results on 350 MW steady state and dynamic ampacity calculations and also on dynamic ampacity calculations at 380 MW per each 220 kV circuit. Comparing these calculations following two conditions are in one or more tenders most decisive on dynamic ampacity of 380 MW:

- Entry point HDD1 with top of duct at 2,5 m below ground level
- Offshore area sandwave area 1

Without going into further details, at the current stage of the tender it is assumed that an overloading of 380 MW can be maintained for at least 200 hours (before conductor temperature reaches 90 °C) based on a preload of 67% over 3650 days and on the current results of the HKwB tender.

2.3.4 Update 01 – April 2022 - based on winning 220 kV tender design HKwB (V2)

In the winning tender the sea cable design for the HDD1 / breaker zone consists of a 1400 mm^2 Cu conductor with non-magnetic armour wires (λ_2 assumed to be zero).

For the offshore part including the ‘Offshore area sandwave area 1’ a 1400 mm^2 Al conductor will be used with galvanised steel armour wires. In the ampacity calculations for this cable type reduced armour losses were taken into account compared to the IEC calculation method. In the below result a still conservative value of λ_2 = 0,2 was used.

For both conditions as mentioned in section 2.3.3 the ampacity results for the 380 MW dynamic case are much better than the 200 hours mentioned in section 2.3.3. In below tables the results for the cable design of the winning tender are included where for the current values (in A) an average capacitance of 0,187 μF / km was used.

Table 5 - 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]		1400 Cu[3]
67%	3650	700	1010 / 380	> 2000

Table 6 - Time (in hours) for conductor to reach 90 °C for Offshore area sandwave area 1 scenario

Preloading			Overloading [A] / [MW]	Time to reach 90°C [hours]
%	# of days	Preload I [A]		1400 Al[4]
67%	3650	660	980 / 380	> 800

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[3] Non-magnetic armour wires
[4] Galvanised steel armour wires

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 (V2 - updated for HKwB)

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[5]. Details on curtailment of the PPMs has been addressed in the 'Connection and Transmission Agreement (CTA)'.

The results of paragraph 2.2 are only valid for Hollandse Kust (west) ALPHA. For this Hollandse Kust (west) ALPHA case, an overloading of 380 MW can be maintained for more than 500 hours (before conductor temperature reaches 90 °C) based on a preload of 67% over 3650 days, at the 220 kV cable route in HDD1.

The results of paragraph 2.3 are only valid for Hollandse Kust (west) BETA. For this Hollandse Kust (west) BETA case, it is assumed that an overloading of 380 MW can be maintained for at least 800 hours (before conductor temperature reaches 90 °C) based on a preload of 67% over 3650 days.

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

5 Annex A: Soil resistivity analysis - Offshore cable route from landfall to Hollandse Kust (west) ALPHA platform

Table with effective soil resistivity values. Revision 1.

6 Annex B: Soil resistivity analysis - Offshore cable route from landfall to Hollandse Kust (west) BETA platform

Table with effective soil resistivity values. Revision 1.