Taking power further

POSITION PAPER

STAKE HOLDER CONSULTATION PROCESS OFFSHORE GRID NL	
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1. Background material

Literature used:
• N.A.

2. 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)[1] 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[2]).

TenneT intends to standardise the offshore substations as much as possible for all five wind areas to be realised in the coming years in line with the Energy Agreement.

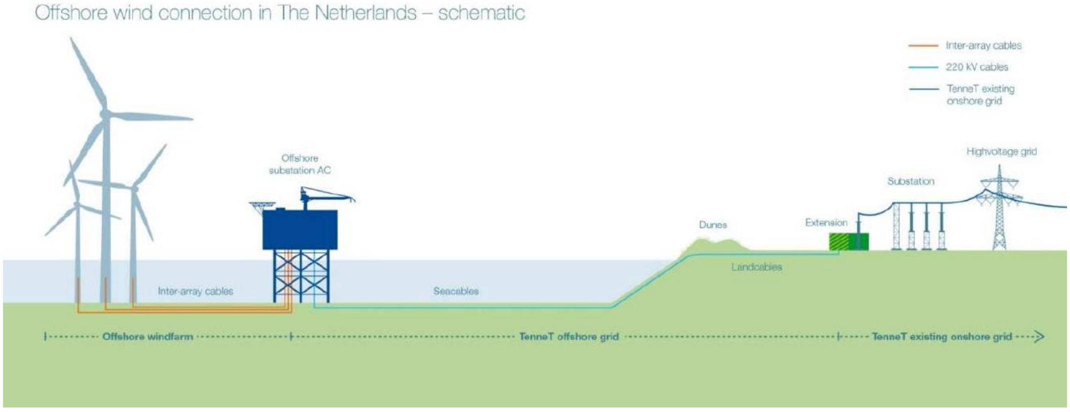

Figure 1 - Schematic of the offshore electrical grid. Source: TenneT

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

[1] The connection point (CP) between the offshore power park module (PPM) and TenneT is specified [TenneT position paper ONL 15-061 T.3 Point of Common Coupling] at the cable termination of the inter-array cables and the switchgear installation on the platform.

[2] TenneT, position paper ONL 15-079 T.5 Operation of Bays

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[3]. 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.

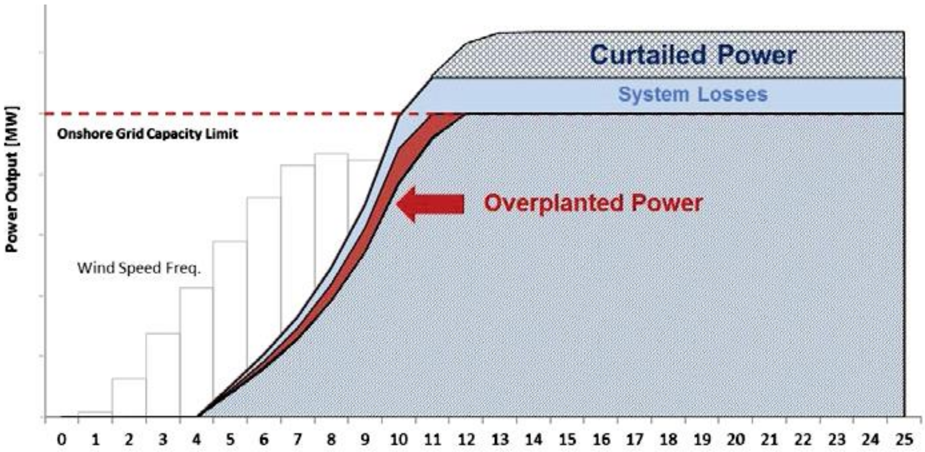

Figure 2 - Principal of Capacity Optimisation. Source: Global Offshore Wind Conference 2014.

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 (see *Figure **1***) may be loaded more than the rated power at CP and under which conditions. As the limiting factor in the offshore grid is the 220 kV export cable from the offshore substation up to and including the beach landing, this paper will mainly focus on these cables.

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

3. 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:	350MW
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 onshore / offshore:	225 / 230kV +/- 1%

To determine if more than 700MW (2 * 350MW) of active power (P) can be transferred through the offshore grid, TenneT makes an assessment of the capability of the 220 kV export cables (next paragraph) 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 700MW of active power, TenneT will assure that other grid components will also be capable to transfer this extra power.

This is also applicable for land cables. It is assumed by TenneT at this moment that permissible dynamic loading conditions of the land cables will be similar or better than the loading conditions found for 220 kV export cables.

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 > 35Mvar or Q < -35Mvar) will be limited in time and therefore will not significantly influence the thermal loading of the cables.

3.1 Export cable design (220kV)

A preliminary 220 kV export cable design study was commissioned by TenneT for a capacity of 700MW in steady state condition according to the IEC 60287. Although the exact soil conditions are not yet known, the results of this design show that under a wide range of the thermal resistivity of the soil, typical cable designs are available.

Furthermore, within this study dynamic load calculations on the 220 kV export cables have been performed using actual wind data over a measuring period of three and a half years. The calculations have been used to assess possibilities for optimisation of cable dimensioning. The calculations are based on various cable types (variation in conductor type and cross section), a range of thermal resistivity values of the soil and two different installation locations (near offshore platform at one meter under seabed and near shore at three meters under seabed).

The results of the dynamic load calculations show that for an optimized cable design (at 700MW design capacity), the transmission of 10% additional active power is allowable, but not guaranteed, provided the following conditions are met:

- Voltage at nominal voltage as defined in *Table* ***1***;
- Soil resistivity over the whole trajectory 0,7 K.m/W as a maximum

Simulation results show that on a few occasions the maximum allowable conductor temperature would be exceeded and curtailment is necessary (provided that all wind turbine generators are in operation). These results are shown in *Figure **3***. Further analysis of these results show that from the 30.000 simulated hours, the conductor temperature is 643 hours above 90 °C (2,14%).

A more detailed forecast on risk of curtailment will be made by TenneT when soil conditions are known and the basic design of the cable is available.

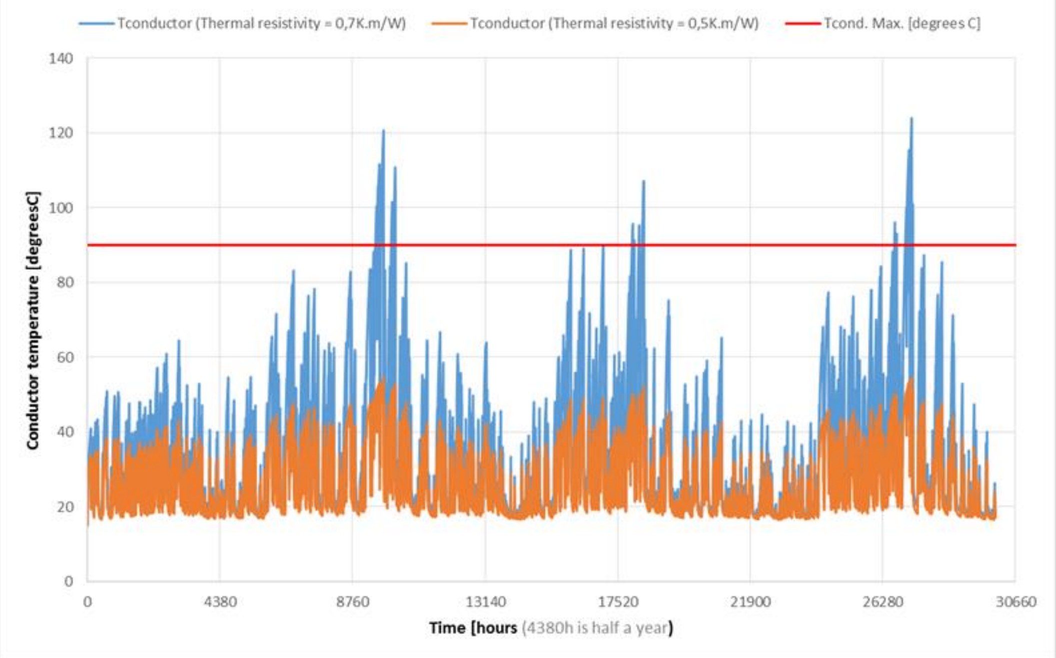

Figure 3 - Thermal behaviour of one of the 220 kV export cables (preliminary design) at two thermal resistivity values at the beach with a wind farm installed power of 770MW.

4. Additional calculations on dynamic loading of the export cables

The duration in hours that a load of 380MW can be transferred through one of the export cables before curtailing of output power of the wind park will take place is dependent on the following factors:

1. Temperature of the cable before the 380MW limit is reached. This temperature is again dependent on the loading history of the cable the previous hours or even days. This again is directly related to the wind speed;
2. The method of curtailing of which preliminary information is given below;
3. Final soil resistivity values over the complete cable route;
4. Final design of the cable system;
5. Voltage level of the system.

Some of the above factors will never fully be known (soil resistivity will only be determined on a limited set of samples) so a clear and binding answer on the question of duration before curtailing will occur can't be given.

However, TenneT made dynamic loading capability calculations based on assumptions on wind speeds, soil resistivity and cable design. In this position paper and V1[4] some results of these calculations have been given[5].

When soil resistivity measurement results (which are part of the geotechnical survey) are available to TenneT, TenneT will update its calculations for the Borssele case which will lead to a better estimate. This update is expected to be finished end of January 2016. Within these calculations, the following calculations will be made for the worst case location on the cable route (hot spot):

1. Time until the conductor reaches 90 °C at 380MW load with a starting conductor temperature (t=0) related to a continuous loading of the cable before (t<0) of 350MW and 0MW;
2. Time until the conductor reaches 90 °C at 365MW load with a starting conductor temperature (t=0) related to a continuous loading of the cable before (t<0) of 350MW and 0MW.

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

5. Export cable load management

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

1. Alignment of the wind park owner's (WPO) generation forecasts to dynamic cable loading capabilities;
2. Actual curtailment of the power output of the wind park by the WPO;
3. Actual curtailment of the power output of the wind park by TenneT.

Ad 1
It is the responsibility of the WPO to align its forecasts to possible curtailment of the wind park power output due to the temperature limit of the export cables (only if wind park power output is higher than the guaranteed 350 MW). To facilitate this alignment process, TenneT will provide:

a) calculation results as described above (updated on the as-built situation);
b) the actual cable conductor temperature measurements (data format and frequency to be defined in a later stage).

Ad 2

[4] http://www.tennet.eu/nl/fileadmin/afbeeldingen/grid-projects/Net_iop_zee/Ronde_2/ONL_15-083-T11_Overplanting_PP_v1.pdf
[5] KNMI1 measuring pole 321 Europlatform (coordinates 10044; 447580), measuring dates 1-1-2001 until 3-6-2004, data was converted from 29.1m height to a height of 107m.

If the conductor temperature will increase above a certain threshold value (value to be determined per project), WPO will receive a warning signal from TenneT. WPO shall start at that moment (at the latest) with the curtailment of the wind park power output, down to 350MW. If this curtailment is not started or is not sufficient and conductor temperature will increase above a second threshold value (close to but below 90 degrees Celsius, to be determined per project), WPO will receive a second and final warning signal from TenneT. Immediately after this second signal has been released, TenneT has the right to proceed to the third level as described below.

The warning signals are considered to be the official legally binding information provided by TenneT to the WPO. The cable conductor temperature measurements as described under level 1 are provided by TenneT as an extra service and will be for information only.

Ad 3
When the second warning signal has been released, WPO shall immediately reduce the power output to a maximum of 350 MW. TenneT will at that time monitor conductor temperature and power output continuously. If the reduction of power by the WPO is not sufficient, TenneT will have the right to curtail under 350MW by switching off one of the strings of the wind park without any further notice.

With the three levels described above, an export cable load management process has been introduced that enables the WPO to manage its generation forecasts and actual power output curtailment while at the other hand it is assured that the export cable conductor temperature will never increase above 90 degrees Celsius.

6. Position of TenneT

Above considerations lead TenneT to the following position:

TenneT is inclined towards allowing the PPMs to transmit 10% above their rated power (350MW), which is 35MW extra, with the requirement for PPM's to curtail their produced power, in case the 220 kV export cables reach their maximum allowable temperature limits[6]. Details on curtailment of the PPMs will be addressed to in the 'Customer Connection Agreements (ATO)'.

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7. Impact on cost

At this point in time the impact on costs cannot be analysed quantitatively, as this requires detailed knowledge (assumptions) on both wind farm layout, turbine choice and dynamic loading strategies.

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