POSITION
PAPER

STAKE HOLDER CONSULTATION PROCESS OFFSHORE GRID NL	
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Table of Contents

1. Background material

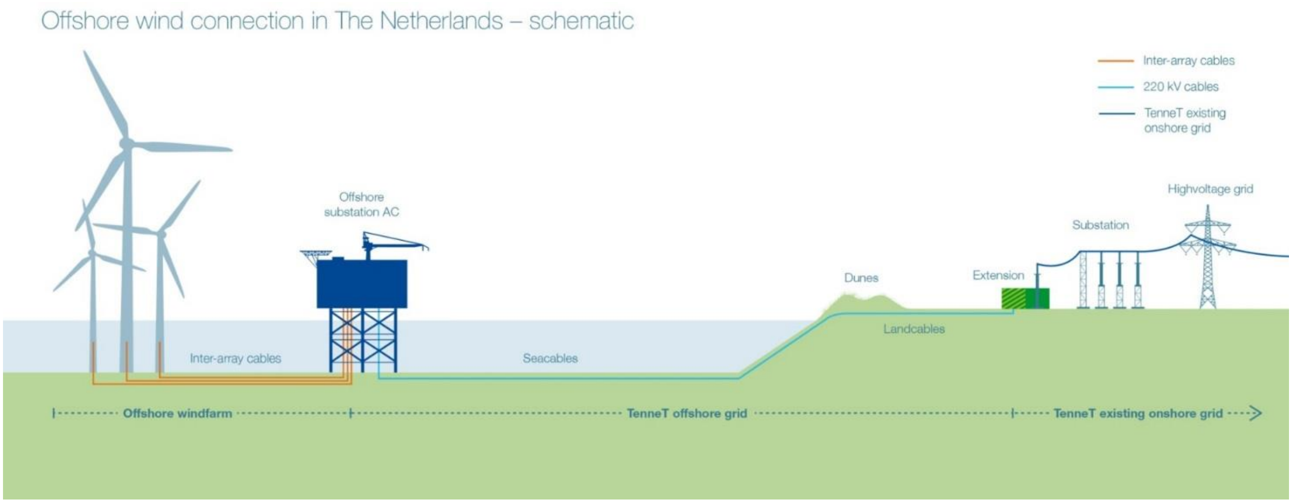
Literature used:
• **TenneT position paper: ONL 15-060-T2_ J tubes_ bays_PP_v2**

2. Scope and considerations

The figure underneath shows the connection of an offshore wind farm to the onshore electricity grid. TenneT will supply and install the grid connection up to, and including, the offshore substation. The wind park, including the wind turbines and the array cables, up to the connection at the offshore substation of TenneT, is to be supplied and installed by the Power Park Module (PPM).

Array cables shall be connected to wind turbines and the offshore substation. For supporting and protecting the cables between the bottom of the sea and the feed-in point at the platform J-tubes are applied. The J-tubes are connected to, and supported by, the foundation of the offshore substation or the wind turbine. For installation the array cables are pulled into the J-tubes. After having been pulled in, at the offshore substation the cable ends are guided to and connected to the switchgears at the platform.

This paper describes options in the amount of J-tubes and the amount of 66kV bays on the offshore substation to be taken into account for connecting the Power Park Module (PPM). Regarding this subject, the voltage level of the PPM system is considered to be 66 kV, as there has been a consensus/decision during the consultation process on the voltage level for the inter array grid. A separate position paper 'ONL 15-058-T1_Voltage level_PP_v2' covers the position with respect to this voltage level.



Schematic of the offshore electrical grid. Source: TenneT

3. J-tubes

Technical

To connect the two 350MW wind areas to the platform, with 66 kV cables and the resulting amount of inter-array cables per area, it is important to set the maximum transmission capacity of the infield cables. Regarding the determination of the number of J-tubes, TenneT starts from a conservative estimate of the maximum load of the infield cables. Taking into account the general available cable types and a power factor of 0.9, the maximum transmission capacities are set 70 MW for a 66 kV infield cable, but the calculations for the amount of J-tubes are performed with 64MW per infield cable, giving extra margin.

Minimum number of strings/J-tubes

Depending on turbine capacity and infield cable voltage the bare minimum number of strings/J-tubes is calculated:

Scenario 1: Base case - 350 MW

Total	350	MW
Max capacity 66 kV	64	MW

Wind turbine capacity	**8 MW**	
Number turbines per string	Capacity per string	# J-tubes
4	32	11
5	40	9
6	48	8
7	56	7
8	64	6
9	72	5
10	80	5

Wind turbine capacity	**6 MW**	
Number turbines per string	Capacity per string	# J-tubes
5	30	12
6	36	10
7	42	9
8	48	8
9	54	7
10	60	6
11	66	6
12	72	5

Wind turbine capacity	**5 MW**	
Number turbines per string	Capacity per string	# J-tubes
7	35	10
8	40	9
9	45	8
10	50	7
11	55	7
12	60	6
13	65	6
14	70	5

Flexibility of wind turbine distribution

For the offshore PPM, it is not always possible to have all turbines connected in such a way that the capacity of each string is fully and optimally utilised, e.g. due to the wind farm layout. For this reason, it is necessary to foresee some flexibility in the distribution of the wind turbines across the different strings. In addition, the NL government has indicated that it will allow a 380 MW as the maximum installed capacity per wind farm. TenneT therefore uses as starting point that the number of strings should be such that on average there is 20% spare capacity, on top of the 380 MW installed. To allow for 20% of spare capacity, 2 additional J-tubes (8 in total) are required at 66 kV per 350 MW system.

Scenario 2: 380 MW (350 MW + overplanting) + 20% spare capacity

Total	456	MW
Max capacity 66 kV	64	MW

Wind turbine capacity	**8 MW**	
Number turbines per string	Capacity per string	# J-tubes
4	32	15
5	40	12
6	48	10
7	56	9
8	64	8
9	72	7
10	80	6

Wind turbine capacity	**6 MW**	
Number turbines per string	Capacity per string	# J-tubes
5	30	16
6	36	13
7	42	11
8	48	10
9	54	9
10	60	8
11	66	7
12	72	7

Wind turbine capacity	**5 MW**	
Number turbines per string	Capacity per string	# J-tubes
7	35	14
8	40	12
9	45	11
10	50	10
11	55	9
12	60	8
13	65	8
14	70	7

Infield redundancy layout schemes

TenneT has been made aware of layout philosophies that use infield cable redundancy schemes at the expense of increased total infield cable length. However, when requested, DNV-GL indicated that while they are aware many projects without end-of-circuit redundant links, they are aware of only one that uses redundant links. TenneT therefore chooses to base its design on the majority of the current industry practice, with only a limited number of spare J-tubes and strings to facilitate flexibility in overall wind farm layout.

Impact of specific site constraints

The initial draft layouts for all five wind areas as prepared for the TenneT position paper on T.1. Voltage Level indicate that taking into account site specific constraints (such as pipelines and telecom cables) yields an effective minimum for the worst case of 12 strings for a 66 kV layout per (700 MW) offshore platform respectively. From these draft layouts, it can be concluded that the site specific constraints for the different wind areas do not lead to an increase of the minimum number of strings required to connect the wind farm to the offshore platform.

Cost, uncertainties and risk

Cost have analysed in detail in the previous position paper: ONL 15-060-T2_ J tubes_ bays_PP_v2. For this paper only the impact of two additional J-tubes for innovation or spare, and for a possible redundancy cable, is considered and results in a small increase of cost (negligible LCoE impact), while it is expected to have a positive reducing impact on LCoE when required for ensuring availability and/or facilitating innovation. Note also, that in both case the cost impact figures given above can be reduced further by matching the wind park design with the number of switchgear bays.

4. Bays

The number of infield strings depends, amongst others, on the maximum current allowed. Limiting factors are the current capacity of the infield cables as well as the WTG switchgear. For an infield string a current of max. 630 A is used. Depending on the layout of a wind farm, the active power of an infield string will vary between 45 to 70MW.

The type of bays applied on the offshore platform is commonly rated 1250 A, which is comparable to 140 MW. Connecting each different infield strings of 45–70 MW to separate 66 kV bays does not make use of the capabilities the 66 kV bay. From engineering perspective and the cost reduction goals of the offshore wind developments, maximum use of the rating of the 66 kV bays is preferred. This can be achieved by connecting 2 infield strings to 1 single 66 kV bays. This will reduce the number of 66 kV bays on the platform which results in cost reduction in 66 kV equipment and in cost reduction due to platform size and weight.

Numbers of 66 kV bays

Before the cost reduction and the effect on availability are discussed, the way of reducing the number of 66 kV bays will be explained. In appendix A, a quick-and-dirty overview is presented based on the following assumptions c.q. constraints:

- a minimum power of 45 MW per string,
- a maximum current of 630 A per string,
- a maximum number of J-tubes (i.e. strings) of 8 pcs.,
- a maximum total power per transformer winding of 210 MW.

For different WTG sizes from 8 MW down to 5 MW, a maximum number of WTGs per string has been set and the consequently number of strings and number of combined bays have been determined. See the previous position paper of 2 March 2015.

Taking all assumptions and constraints into account, for all cases the number of bays will be reduced from

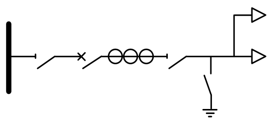
maximum 8 per PPM down to 4. Hence, 2 to 4 bays reduction per 350 MW wind farm; 4 to 8 bays reduction per platform, depending on the infield lay-out.
Only in extreme cases (violating some assumptions/constraints) the number of 66 kV bays per 350 MW wind farm would have to increase from 4 to 5. This increase will be taken into account in the platform design.

Regarding the connection of two cable to one switchgear bays, two options have been investigated:

- two cable connected to the switchgear via one cable disconnector
- two cable connected to the switchgear via two separate cable disconnectors

One cable disconnector

The most straightforward and common way of connecting two cables (strings) to one bay is doubling the cable termination boxes. The schematic configuration of the bay is reflected below



If a short circuit occurs in one of the strings, the 66 kV circuit breaker will switch off both strings. After determination the defected string, that particular cable can be unplugged, the termination box will be blind plugged and the 66 kV bay with now only the healthy string can be re-energized. After the repair of the faulty string the plugging of blind plugs and string is reversed. The 66 kV bay is again taken out of operation shortly, only now it is planned.

Access to the platform is needed to unplug and blind-plug. The actual work can be done in a few hours, but can be very weather dependent. Assuming a work activity of a few hours by two persons including travelling up and down the platform 2 offshore work days by CTV. Cost estimation 8k€ including small materials and Hs < 1,5 meter for travel by CTV.

Compared to the "1-string-to-1-bay" configuration, this "2-strings-to-1-bay" configuration will result in a lower availability. Capitalization of the lower availability per 2 strings over 20 years is based on:

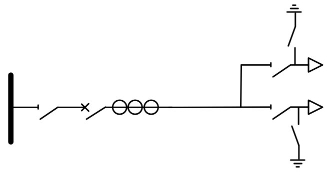
- an infield cable length of 10 km per string,
- a failure yearly rate of the infield cable of 0,000705 per km,
- a total power of 60 to 70 MW per string,
- an unplug/blind-plug time of 4 months (worst case scenario considering long bad weather period), repair time of the string = outage time,
- an interest rate of 5,6% and MWH price of € 30/MWh (market price) and 120€/MWh (subsidised price).

The costs of less availability at 30€/MWh would be approx. 500 k€. Saving one 66 kV bay (ca 200k€) will not pay off for these power production losses, even when the weight and size reduction on the platform are included. In case a MWh price of € 120 is taken, the costs of less availability would be 4 times higher.

So connecting two strings directly to one 66kV bay less on CAPEX than on OPEX due to less availability. This option therefore is not effective.

Two separate cable disconnectors

An less straightforward way of connecting two cables (strings) to one bay can be obtained by adapting/changing the standard 66 kV GIS bays. All suppliers have confirmed, that they can support this alternative GIS arrangement. The costs of a adapted/changed bay would be approx. 20 k€ extra than a common bay. The schematic configuration of the adapted/changed bay is reflected below.



If a short circuit occurs in one of the strings, the 66 kV circuit breaker will switch off both strings. After determination which of the defected string, that particular cable can be disconnected and the 66 kV bay, and the healthy string can be re-energized[1]. After the repair of the faulty string this switching is reversed. The 66 kV bay is again taken out of operation very shortly, only now it is planned.

Access to the platform is not needed. The switching activities can be done remotely in a timeframe of around one hour. Weather condition are not a factor in this solution.

Compared to the “1-string-to-1-bay” configuration, this “2-strings-to-1-bay-with-2-cable-disconnectors” configuration will result in only an “theoretical” lower availability, because the downtime of the healthy string is not more than 1 hour: the time needed to open the disconnector and re-close the circuit breaker.

The costs of less availability are negligible at 120€/MWh (in the order of 100€/y). The cost reduction of one 66 kV bay is about 200 k€. per bay, plus the reduced cost due to platform room sizes and platform weight. Taken into account the extra bay production costs of 20k€, it can be concluded that there is a positive business case.

Analyses

Reducing the number of bays by connecting two strings to 1 bay shows to be effective, although it is depending on the way that the two strings are connected (the GIS cable disconnector arrangement). Having one single cable disconnector for both infield strings does lead to a CAPEX reduction, but because can lead to decrease of the availability, which represents higher production loss costs. Changing the GIS configuration with two cable disconnectors, one for each infield string, leads to almost the same CAPEX cost reduction, but now the availability is almost the same as having 1 bay for every string (negligible difference).

The number of bays with double infield cable connections will be four per 350 MW wind farm. In addition, one spare bay will be introduced as well as space for yet another bay. This would lead to a reduction of 4-8 GIS bays per platform, but the 5 remaining GIS bays will be bit more expensive. The cost reduction for the 66kV GIS equipment will be approx. 1000 k€ to 1500k€. The total cost reduction will be even more, taking into account the reduction of platform size and weight as well.

Comparing the 1000-1500 k€ cost saving versus the yearly outage costs of a few hundred €, this business case is positive.

[1] Switching by TenneT on indication of the PPM operator.

Update of position based on results of the 02.07.2015 expert meeting

In the Expert meeting of 02.07.2015 the concept of connecting two strings to one bay was presented. Feedback during the meeting showed that the offshore wind developers do not agree with the proposed 5 "two cable–one bay" solution, because in case of a failure two strings will be disconnected. This would lead to major loss of income for the wind operator, as the healthy cable will be also temporarily disconnected.

A consensus was found in making available 6 bays per wind farm, due to the fact that 90% of the layouts are expected to require 6 strings, as confirmed by the wind developers, and this would make a "one string-one bay" solution possible for most configurations. In the case a layout requires 8 strings, 2 pairs of strings will be combined to one bay each. Per wind farm this results in four "one string-one bay" and two "two strings-one bay" (which can of course be used for one cable as well) configuration per wind farm.

The business case described above will be reduced to a saving of around 1mln€ per platform, which is still positive.

5. Position TenneT

TenneT states that with the **66 kV inter-array cables** (based on conservative 64 MW per cable) a standard platform shall be equipped with 18 J-tubes for the inter array system:

- 2x 8 J-tubes for offshore PPM
- 1 J-tube installed for possible test purposes
- 1 J-tube installed for the connection to the neighbouring platform

TenneT states that with the 66 kV inter-array cables, two cables can be connected to one 66kV GIS bay on the platform, via two separate cable disconnectors. The amount of 66kV bays available per PPM will be six, in a four "one string-one bay" and two "two strings-one bay" (which can of course be used for one cable as well) configuration.

For dimensioning of the J-tubes, the diameter of the 66 kV cable is estimated to be 160 mm. The inner diameter of the J-tube shall be at least 2,5 times the diameter of the cable, resulting in at least 450 mm.

Next to this of course also J-tubes for the 220kV export system are required for the platform.

Appendix A

Assumptions / constraints:

- minimum of 45 MW per string
- limit is 630 A per string
- max. # J-tubes = max. # strings = 8
- max. MWs per transf. winding = 210 MW
- cos(phi) = 0,9

8 MW turbines
total of 44 WTG = 352 MW

max # WTGs per string	MWs per string	Amps per string	# strings	# WTGs per string	# bays (# WTGs)	max. MWs per bay	# bays (# WTGs)
5	40	389	9	8*5 + 1*4	5 (10)	80	
6	48	467	8	4*6 + 4*5	4 (11)	88	
7	56	545	7	2*7 + 5*6	4 (13)	104	
8	64	623	6	2*8 + 4*7	3 (15)	120	4
9	72	701	5	4*9 + 1*8	5 (9)	72	

7 MW turbines
total of 50 WTG = 350 MW

max # WTGs per string	MWs per string	Amps per string	# strings	# WTGs per string	# bays	max. MWs per bay	# bays
6	42	409	9	5*6 + 4*5	5 (11)	77	
7	49	477	8	2*7 + 6*6	4 (13)	91	
8	56	545	7	1*8 + 6*7	4 (15)	105	
9	63	613	6	2*9 + 4*8	3 (17)	119	4
10	70	681	5	5*10	5 (10)	70	

6 MW turbines
total of 59 WTG = 354 MW

max # WTGs per string	MWs per string	Amps per string	# strings	# WTGs per string	# bays	max. MWs per bay	# bays
7	42	409	9	5*7 + 4*6	5 (13)	78	
8	48	467	8	3*8 + 5*7	4 (15)	90	
9	54	525	7	3*9 + 4*8	4 (17)	102	
10	60	584	6	5*10 + 1*9	3 (20)	120	4
11	66	642	6	5*10 + 1*9	3 (20)	120	

5 MW turbines
total of 70 WTG = 350 MW

max # WTGs per string	MWs per string	Amps per string	# strings	# WTGs per string	# bays	max. MWs per bay	# bays
8	40	389	9	7*8 + 2*7	5 (16)	80	
9	45	438	8	6*9 + 2*8	4 (18)	90	
10	50	487	7	7*10	4 (20)	100	
11	55	535	7	7*10	4 (20)	100	
12	60	584	6	4*12 + 2*11	3 (24)	120	4
13	65	633	6	4*12 + 2*11	3 (24)	120	4
14	70	681	5	5*14	5 (14)	70	