POSITION
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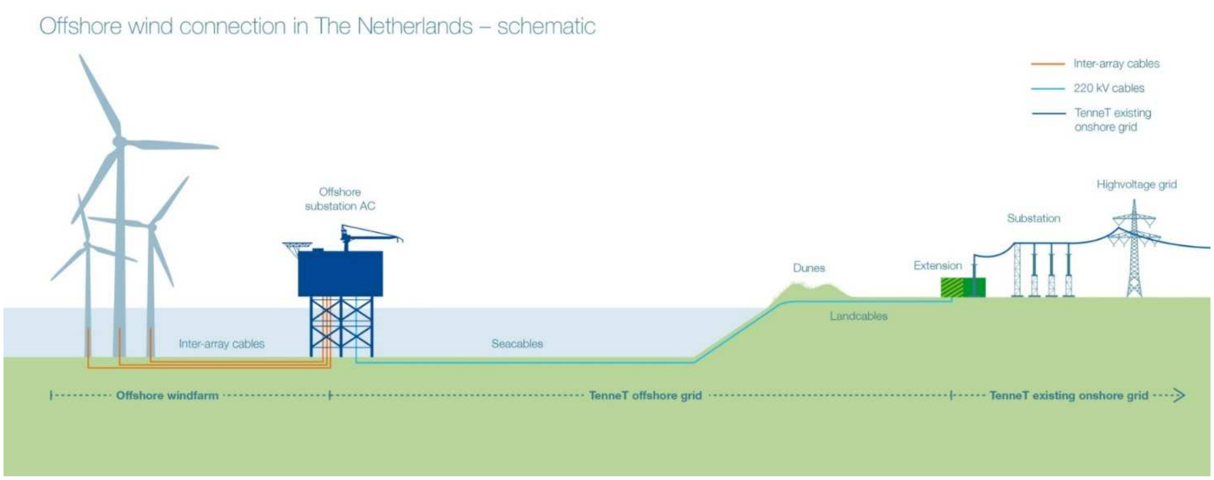
1. Background material

Literature used:
• DNV GL 66 kV whitepaper: *113799-UKBR-R-02-20150305* • 66 kV offshore wind International Conference 24-25 November 2014, Bremen, Germany

2. Scope and considerations

The figure below shows a schematic cross-section of the connection of an offshore wind farm to the onshore electricity grid. Wind turbines are connected through medium voltage “inter-array” cables (in orange) to an offshore substation, from which 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 standardise the offshore substations - and hence the medium voltage level - for all five wind areas to be realised in the coming years in line with the Energy Agreement.



Schematic of the offshore electrical grid. Source: TenneT

General

The Energy Agreement requires a 40% cost reduction for offshore wind to be realised over the period 2014-2024. Realisation of this cost reduction is expected to require a combination of measures[1], including - but not limited to standardisation of the offshore electrical infrastructure and larger capacity wind turbines within larger wind farms. TenneT contributes to this overall cost reduction target, through a strategic long term vision on the development of the offshore grid. Cost reduction is realised by standardisation of all 5 offshore platforms to be realised for the development of 3450 MW offshore wind, by serving concentrated large wind areas with a single platform and use of technology that is ready for future large capacity wind turbines.

[1] http://tki-windopzee.nl/files/2015-01/20141124_TKI_Roadmap.2015-2020_EZU_F%20(1).pdf

Technical

Currently, 33 kV is the standard voltage level used for connecting offshore wind turbines to an offshore substation. It is a proven technology implemented in most wind farms realised today.
The amount of carrying capacity of array cables is directly linked to its voltage level. With wind turbine capacity and total wind farm size increasing, the market is increasingly looking into higher voltage levels of inter-array cables, focussing mainly on 66 kV. Higher voltage levels increases the number of wind turbines that can be connected to a single inter-array cable, and consequently decreases the number of strings used and therefore the number of J-tubes required at the offshore substation.

According to the Carbon Trust Offshore Wind Accelerator (OWA) the benefit of moving to 66kV is a LCOE reduction of 1.5%. 66 kV cables are expected to enter the market from 2016, and OWA has launched an engagement program with the cable suppliers to speed up testing and certification. It has been identified that manufacturing capabilities could be limited under a massive take off scenario.

TenneT has considered both 33 kV and 66 kV as options for the inter-array cable voltage level, being the most proven and researched technologies.

Implementation

The following transmission capacity is assumed for 33 kV and 66 kV infield cables:

- ➔ 33 kV: 35 MW of transportable power, using a 630 mm^2 copper conductor cable.
- ➔ 66 kV: 64 MW of transportable power, using a 630 mm^2 copper conductor cable.

The table below shows the implications for the number of strings, J-tubes and length of infield cables required for two 350 MW windfarms to connect to a single 700 MW offshore substation[2].

	33 kV	66 kV
Minimum number of strings required	26	14
Number of J-tubes at the offshore substation foreseen	28	16
Total estimated infield cable length [km] required for two 350 MW wind farms[3]	200	140

With this size of wind farm project (2 x 350 MW), wind farms cover a relatively large geographical area. Because the transmission capacity of 33 kV infield cables is limited, more km's of array-cables is required to connect the same amount of wind energy.

Cost, uncertainties and risk

TenneT identified the following expected impacts on cost, as well as uncertainties and risks as given in the table below. TenneT has asked DNV-GL to provide information on both the technological status and

2 See TenneT Position Paper on J-tubes

3 Internal Ecofys draft layout for Borssele Alpha.

readiness of 66 kV, as well as on current and future cost impacts.

Impact on cost	Uncertainties / risk
Reduces: • required infield cable length • cable installation work • amount of J-tubes • structural work • offshore works • electrical losses Increases: • switch gear costs • transformer costs • cable supply costs per meter • impact of cable failure	• Cables certification • Equipment optimization • More limited competition between available cable suppliers • Limitations in wind turbine supply • Type and cost of installation ship required • Health and safety regulations

Affected topics

The choice of inter-array cable voltage affects a number of subjects that will be discussed in later expert meetings, such as: reactive power compensation, and back-up generator capacity.

3. Position TenneT

Based on the above, the external reports from DNV-GL, two expert meeting (27.11.2014 and 29.01.2015) with the sector and several bi-lateral meetings with project developers, TenneT draws the following conclusions:

- Implementation of 66 kV infield cable voltage is considered technically feasible, with respect to both the cables, turbines and all connecting electrical equipment.
- Looking forward in time, 66 kV is considered a necessity to support larger capacity wind turbines. Standardising now at 66 kV will pull the market to innovate further and facilitate reducing the costs of offshore wind energy.
- With increasing wind turbine capacities, the larger turbine manufacturers offer 66 kV solutions within their current wind turbine range, and more are expected to follow. 33 kV connections pose a concern for wind turbine capacities over 6 MW.
- 66 kV operating systems are expected to become the cheapest option available, reducing cable length, number of J-tubes, installation work and losses with increasing wind farm size to 700 MW in the Dutch offshore wind tenders.
- Key cable manufacturers are currently in the process of getting 66 kV cables certified, and expected to finish certification in time for realisation of the first offshore wind tender. First cables are expected to come to the market in 2015.
- Using 66 kV, the number of strings can be reduced from 26 (16 per 350 MW) to 14 (7 per 350 MW) at the offshore platform, with an additional 2 J-tubes for innovation or spare. This decreases installation risks and interfaces between TenneT and the developer (see also position paper of TenneT on the number of J-tubes).

- Standardisation of all the offshore platforms is key to TenneT's roll-out strategy and contribution to overall cost reduction.

These considerations lead TenneT to the following position:

TenneT is inclined towards standardising the connection voltage level of the inter-array cables to the TenneT offshore transformer platform at 66 kV for all five platforms to be realised by TenneT up to 2023.

As identified above, it is recognised that a choice for standardisation of the medium voltage level at 66 kV results in a number of uncertainties for the wind farm developers. These uncertainties relate mainly to the timeline of certification of sub-sea 66kV cables, and the availability and cost of both sub-sea infield cables and wind turbines for 66 kV and the number of suppliers being able to deliver. Certification is likely to be ready in time, and there will be an ample number of suppliers of cables and turbines to result in acceptable pricing, also in the first years, due to current developments in the market. TenneT is strongly convinced that a standardisation now, results in significant cost reductions during the course of realisation of 3.5 GW of offshore wind in The Netherlands, see further quantification below.

4. Impact on cost

In the table below a summary is presented of the impact - both quantitatively on cost and qualitatively - of moving from a standard 33 kV infield cable configuration to a 66 kV infield cable configuration.

Cost impact: high level breakdown

Quantitative	LCoE Impact	Uncertainty	Comment
Cost element Developer			
Wind turbines: transformer	0.4%	Low	Transformer costs expected to increase 40% - 50% (2). Transformer cost consitute ~2% of WTG CAPEX (3).
Wind turbines: switchgear	0.2%	Medium	Conservative increase in switchgear costs assumed of 50% (1). Switchgear ~1% of WTG CAPEX (3).
Array cable costs	0.3%	Medium	Increase in cable costs [EUR/m] of 10% (1).
Array cable length	-1.7%	Low	Decrease in cable length [km] of 30% (1).
Cost element TenneT			
Substation: Compensation equipment	0.1%	Low	Increase cost of reactive power compensation equipment of 50% (1). Compensation equipment constitute ~5% of Offshore Substation CAPEX (3).
Substation: Connection	0.0%	Medium	Switchgear worst case increase in costs assumed of 50% (2), however, since the number of required switchgear decreases, the cost increase is partly offset. The net effect is expected to be minimal (3).
Substation: J-tubes	0.0%	Low	Decrease in cost by decrease in number of J-tubes (from 28 to 16) (1,2,3)
Impact on yield			
Losses	-0.2%	Medium	Losses 33 kV 0.8%; losses 66 kV 0.55% from (1). Impact on LCoE directly related (conservatively value of -0.2% chosen) (3).
Society			
Borssele Alpha LCoE impact	-1.0%	Medium	Summation of the LCoE impact from separate items above (3).
Impact future years	-1.5% to -2.5%	Medium	Price for 66 kV equipment expected to decrease by 10% - 20% in the coming years (1). LCoE impact estimate (3).

Qualitative	LCoE Impact	Uncertainty	Comment
Technical	none	Low	No key technical issues expected hindering the implementation of 66 kV for offshore wind (1).
Logistics	Positive	Low	As it is possible to accommodate more power on a 66 kV circuit, quantity of array circuits entering the substation can be minimised. Fewer substations are therefore required in the 66 kV case, making a 700 MW offshore platform possible. (1)
Certification	Negative	Low	Key cable manufacturers are in the process of developing wet-design 66 kV cables and in the process of certification of these cables. Expected to be completed within 18 months under a program by the Carbon Trust (UK). (1) Amongst developers, different views exist with respect to the necessity of separate certification of turbines for the new 66 kV voltage level, as well as whether certification of
Market	Negative	Medium	Most market factor are considered as externalities (e.g. steel prices, many wind farms being realised at the same time etc.) and not included in LCoE calculations. The main market component which may have a direct impact on the cost levels for 66 kV relative to 33 kV, result from the number of suppliers that are able to deliver suitable turbines and cables. Most major turbine manufacturers are currently capable of supplying 66 kV turbines. The number of 66 kV cable suppliers may be limited to the larger companies. (3)
Financial	Negative	Medium	Financers have indicated no specific risk premium will be added if similar guarantees are given by cable suppliers for 33 and 66 kV. However, as 66 kV is a new technology, it is expected that some cost increase may result from additional uncertainties in supply and operation of new equipment. (4)

References: DNV GL report (1), TenneT internal (2), Ecofys internal (3), Market feedback (4)

5. Topic consultation

The expert meeting of March 18, 2014 gives TenneT the opportunity to get feedback from developers on their position regarding array-cable voltage level. The main goal of this meeting will be to assess whether TenneT's views as documented within this position paper, and background data above, are shared by the industry.