ANBARIC® Scaling Renewable Energy

November 14, 2022

Carmen D. Diaz
Acting Secretary of the Board
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RE: Comments of Anbaric Development Partners, LLC on the New Jersey Board of Public Utilities' Request for Information on its Third Wind Solicitation

Dear Acting Secretary Diaz,

Anbaric appreciates the opportunity to participate in the New Jersey Board of Public Utilities' (NJBPU) Request for Information (RFI) related to New Jersey's third offshore wind solicitation (Third Solicitation). The RFI makes clear that the NJBPU continues New Jersey's national leadership role in deploying of clean energy resources and innovative technologies, especially for offshore wind. The NJBPU's RFI is aimed toward developing New Jersey's offshore wind infrastructure in a forward-looking manner. As detailed in our responses, Anbaric fully supports the Board's initiative to increase the size, sophistication, performance, and cost-effectiveness of the State's offshore wind facilities.

I. Introduction

Anbaric recommends the NJBPU issue mesh-network design requirements in its third offshore wind solicitation. Anbaric respectfully recommends that the NJBPU not follow the approach to mesh-networks laid out in NYSERDA's "Meshed-Ready Technical Requirements" guidance document[1]. Instead, Anbaric respectfully recommends the NJBPU take an approach consistent with evolving technology and with helping the industry reach significant scale in a short period of time.

The difficulties with NYSERDA's approach rest on the limitations of AC technology, the potential for stranded assets, and the rapid development of DC technology. NYSERDA's Mesh-Ready framework relies on the use AC submarine cables to interlink offshore wind platforms. The perceived benefits of this approach are (1) the ability for offshore wind projects to use different HVDC voltage levels; and (2) the use of established AC technology. NYSERDA clearly felt that these benefits outweighed the downsides of AC interlink cables: the shorter distances over which they can be used and the need for as

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[1] Technical Requirements (ny.gov)

many as six times the number of interlink cables and associated platform equipment. As discussed herein, Anbaric does not believe that the perceived benefits of AC interlinks outweigh their downsides.

Instead of following the approach laid out by NYSERDA, Anbaric recommends that the NJBPU's design requirements for a mesh network follow the examples envisioned by the New England States' Regional Transmission Initiative and set forth by the German, Dutch, and Danish governments. Namely, the NJ BPU should (1) establish a technical (e.g. voltage) standard to enable future HVDC interlinks AND (2) set forth criteria that are in close alignment with TenneT's[2] multi-terminal ready framework[3]. Also, it is worth noting that European governments have worked closely with grid operators to arrive at the decision to use HVDC interlinks[4].

The use of HVDC interlinks will deliver three key benefits over the use of AC interlinks:

1. Establishing an HVDC voltage standard (as required for HVDC interlinks) will accelerate the maturation of the industry and decrease supply chain risks over the mid and long-term.
2. HVDC interlinks will enable the development of interregional transmission capacity, which is critical for maintaining grid reliability as renewable penetrations increase.
3. HVDC interlinks require significantly fewer upfront capital investments than AC interlinks. As a result, there is a much smaller risk of stranded assets when pursuing HVDC interlinks. This is particularly notable given that AC interlinks face a real risk of technology obsolesce from the rapid advancement of HVDC technology discussed herein.

It is important to remember that a meshed network is not the end point with respect to the development of a transmission network for offshore wind. Rather, a meshed network is an intermediary step towards the goal of a planned transmission network. A planned transmission network for offshore wind generation will continue to be the goal because of the significant consumer savings that it will deliver[5].

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[2] TenneT is the offshore grid operator for the German and Dutch governments.

[3] *See* attachment: TenneT: 2 GW HVDC Standard, Transition towards Multi-terminal DC systems, and TenneT January 19, 2021 overview document re: "2GW Program, Standardisation of 2GW grid connection."

[4] In the Netherlands, TenneT is the system operator and system owner. TenneT works closely alongside with the government to develop the technical roadmap (https://english.rvo.nl/sites/default/files/2022/07/Development-Framework-Offshore-Wind-Energy-June-2022.pdf) which is needed to realize the government's renewable energy vision. The regulator, which is a different part of the government, carries out independent oversight to ensure those technical solutions are the most cost-effective from a Dutch consumer perspective. In Germany, there are 4 transmission owners and operators. A similar framework as in Holland exists, except that the government plays a much stronger role in prescribing what needs to be built (the 'Netzentwicklungsplan' aka the 'Grid Development Plan', https://www.netzentwicklungsplan.de/en/front) which is created in close consultation with the TSOs.

[5] Significant consumer savings from planned transmission have been shown in studies in New England, New York, and in the UK, which has a much more expansive coastline than northeastern states. *See* https://www.nationalgrideso.com/document/183031/download documenting savings of billions of pounds and a 75% reduction in facilities. That summary report is based on the more detailed work from 2020 found here: https://www.nationalgrideso.com/document/182931/download.

Below, Anbaric describes the advantages and disadvantages of NYSERDA's mesh-ready network (question 12); outlines the evolution of HVDC technology (foundation for multiple questions), sets forth our own recommendations for a future meshed-grid (question 8); the voltage recommendations for a future meshed network (question 13); the equipment specifications, installation and space requirements to enable a meshed-ready grid (questions 9 and 10); and the impacts of including other states in a meshed network (question 11).

II. Advantages and Disadvantages of NYSERDA's Mesh-Ready Network (Quest. 12)

The perceived benefits of the AC interlinks used in NYSERDA's approach to a mesh network are (1) the ability to accommodate multiple HVDC voltage levels; and (2) the use of established AC technology. These benefits are diminished by the established downsides of AC interlink cables: the shorter distances over which they can be used (~50-60 miles) and the limited capacity per cable circuit (350 MW for a 230 kV AC cable vs 2100 MW for a 525 kV HVDC cable), resulting in the need for as many as six times the number of interlink cables.

At a surface level, the tradeoff between AC interlinks and HVDC interlinks, is a trade-off between:

- flexibility for developers and technological certainty (AC interlinks), and
- a smaller environmental footprint, an ability to interlink platforms spaced farther apart and the future development of interregional transmission capacity (DC interlinks).

If this were the full extent of the tradeoff, then NYSERDA's decision to use AC interlinks could be more easily understood. The tradeoff, however, is not quite so simple.

For starters, it is important to ask whether the desired future for an offshore grid is one where the HVDC voltage varies from platform to platform. The first critical reason this is likely not the case is that it will slow the maturation of the industry. By failing to define an HVDC voltage standard at this stage in the industry's development, regulators, as a practical matter, are pushing the industry toward several avoidable supply side challenges. The most significant of these will be a continuation of the limited supply of HVDC cable. Without standardization, cable manufacturers will likely continue to delay investment in manufacturing facilities.[6]

A second major challenge with HVDC voltages varying from platform to platform is that it inhibits the use of higher performing, lower cost HVDC interlinks in the future. As discussed in the next section, HVDC circuit breakers will be commercially available by 2032 (if not sooner). Europe is committed to the development of HVDC networks and TenneT has developed a standard for multi-terminal ready HVDC platforms that presumes the use of HVDC interlinks. For these reasons HVDC interlinks will likely be a more attractive solution than AC interlinks at the point in time regulators seek

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[6] DNV is aware of at least one cable manufacturer delaying an investment in US-based manufacturing capacity for now.

to invest in the development of a mesh network. However, the option to use HVDC interlinks will not be available to regulators unless they act now to establish an HVDC voltage standard.

The assumption around the technological certainty of AC interlinks is also not without question. AC interlinks will be able to use existing AC circuit breakers to interrupt fault currents and isolate fault. Circuit breakers, however, are not the only technological constraint facing the development of mesh-networks for offshore applications. Notably, there are significant stability and controllability issues that AC interlinks will have to address for DC converters that are closely coupled through an AC interlink, particularly when these converters are supplied by different vendors[7,8,9]. In particular, the converter interoperability issue has led the relevant grid operators to start developing converter-specific power-flow models to determine whether different converter designs can be coupled together through an AC interlink[10]. In short, AC interlinks should not be viewed as without technological risk given the important stability and controllability questions that still need to be answered.

Having discussed the perceived benefits of AC interlinks, we briefly discuss the key benefit of HVDC interlinks: their ability to enable the construction of interregional HVDC transmission networks. As illustrated in Figure 1, Europe plans to develop interregional HVDC transmission networks using HVDC interlinks between offshore wind platforms. Two projects are already in development are: the WindConnector project between the Netherlands and the UK; and the Nautilus Link between Belgium and the UK[11]. Another notable project is the Triton Link[12]. The Triton Link will connect Belgium and Denmark using an HVDC interlink between a Danish energy island[13] and a Belgian energy island[14].

Prior to selecting between AC and HVDC interlinks, Anbaric recommends that the NJBPU evaluate the additional offshore wind resource diversity that can be gained from HVDC interlinks that connect to the New England and Virginia/North Carolina offshore wind lease areas, in addition to New York's offshore wind lease areas[15]. Initial analysis performed by DNV for Anbaric indicates that there is significantly greater resource diversity between the New Jersey and New England offshore wind lease

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[7] Simulation requirements for derisking of the NSWPH concept | North Sea Wind Power Hub

[8] Active Power Control of Wind Hub | North Sea Wind Power Hub

[9] AC Voltage and Frequency Control of Wind Hub | North Sea Wind Power Hub

[10] Per recent conversations with DNV's European HVDC colleagues.

[11] See, CIGRE, *German HVDC Corridors as Starting Points for a Pan-European HVDC Overlay Grid*, at 5 (2022)

[12] https://www.elia.be/-/media/project/elia/shared/documents/press-releases/2021/20211123_hybride-interconnector_en.pdf

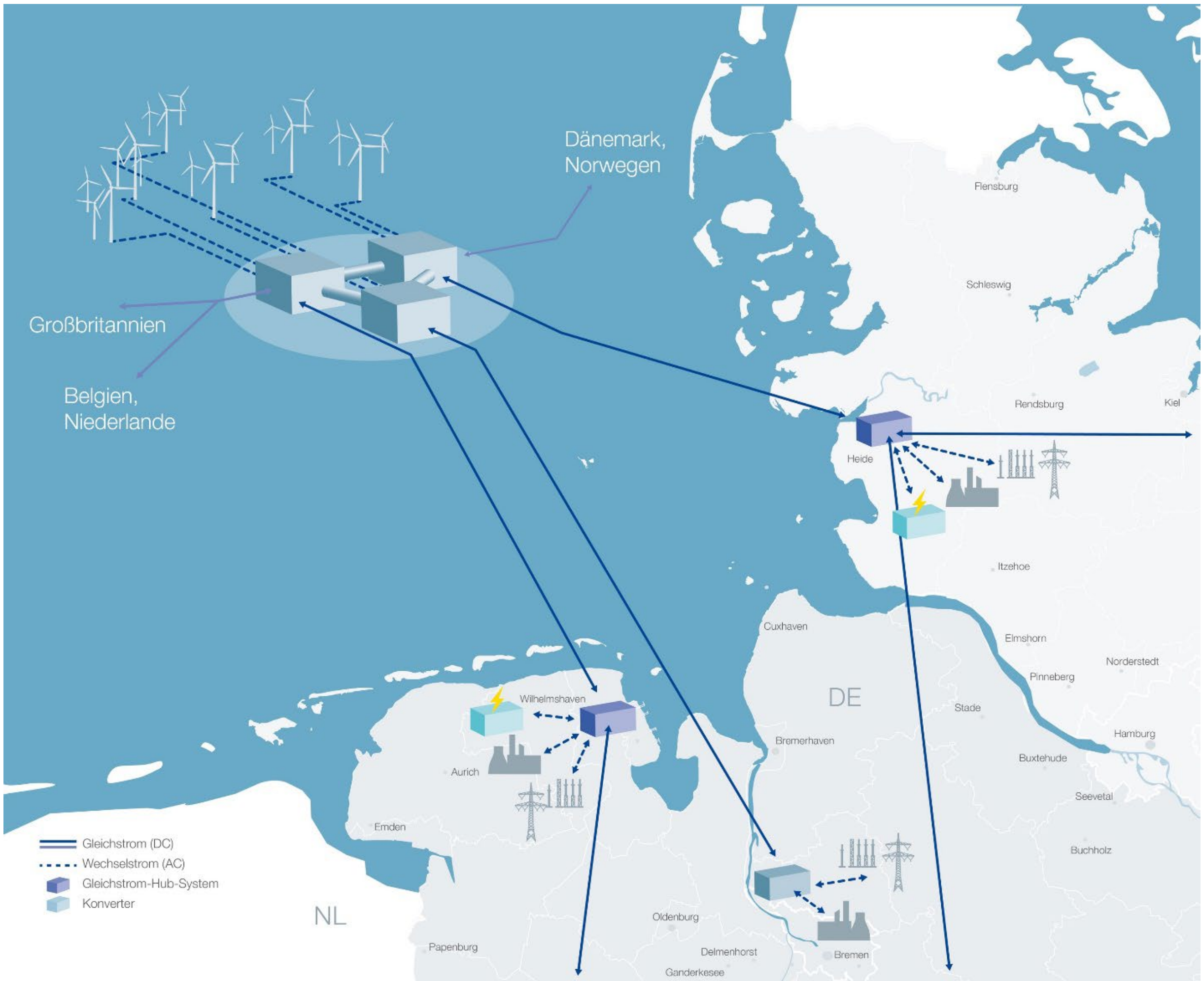
[13] https://www.windisland.dk/#:~:text=HVDC%20Transmission&text=High%2DVoltage%20Direct%20Current%20(HVDC,the%20green%20transition%20in%20Europe

[14] https://www.elia.be/en/news/press-releases/2022/10/20221003_offshore-energy-island

[15] Resource diversity broadly refers to a diversity in the type and location of generation resources. In this paragraph, we are highlighting that offshore wind resources located close to each other will experience similar weather patterns and have similar generation profiles, while offshore wind resources located far from each other will experience less similar weather patterns and have less similar generation profiles. From a grid operators' perspective this diversity of generation profiles often reduces costs; if one resource is ramping down while another is ramping up, then a grid operator doesn't have to pay for other resources to step in and act, as would likely be the case if the resources were ramping up or down in a correlated. Resources located close to each other will also have more correlated risk from severe weather events (e.g., a hurricane). Thus, a diversity of generator locations can also improve grid reliability and resiliency.

areas (correlation coefficient[16] of 0.7 for hourly generation) than between the New Jersey and New York offshore wind lease area (correlation coefficient of 0.85 for hourly generation). This is a logical result given the greater physical separation and re-affirms this important benefit of HVDC interlinks: the ability to span the distance between the New Jersey and the New England and Virginia/North Carolina offshore wind lease areas – a distance that is too large for the economic use of AC interlinks. As a more general point, HVDC interlinks unlock the benefit of integrating markets with diverse production mixes and load characteristics, ensuring the consumer has access to the lowest cost and lowest carbon energy.

Figure 1. European plans to develop interregional HVDC transmission networks using HVDC interlinks between offshore wind platforms. *Source: TenneT*[17]



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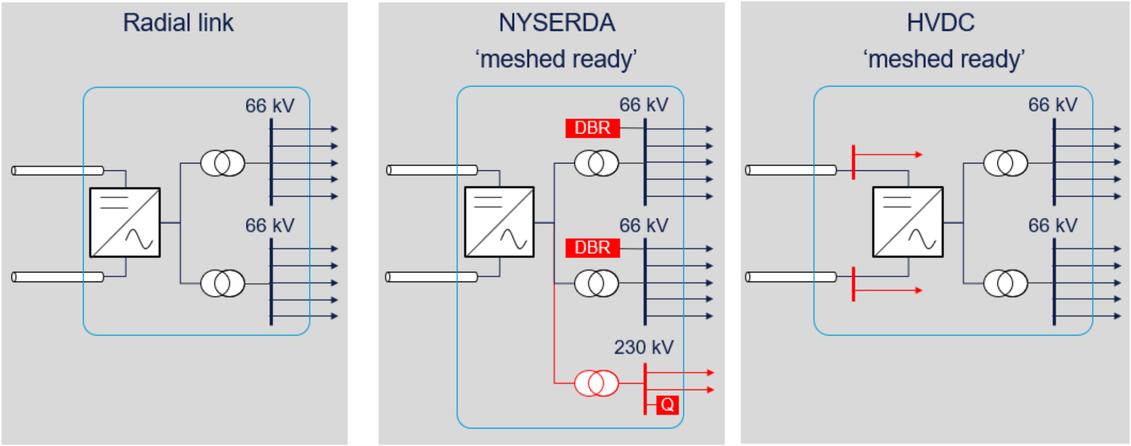
[16] Pearson correlation coefficient - Wikipedia

[17] Windstrom-Booster-Konzept (tennet.eu)

A final point regarding the tradeoff between AC and HVDC interlinks, is that the design criteria for AC interlinks will result in significantly more equipment to be installed on the offshore platform at the time of initial development. This equipment includes the installation of dynamic braking resistors (DBR, aka 'AC Choppers') and shunt reactors (Q), neither of which are required for HVDC interlinks, as shown in red in the middle panel of Figure 2. In contrast, the equipment required for HVDC interlinks is an additional disconnector bay for each pole and associated auxiliary equipment, as shown in the right panel of Figure 2. The additional equipment needed to support AC interlinks (the dynamic braking resistors and shunt reactors) will require larger platform sizes and represents a larger potential for stranded assets should either the need for AC interlinks not materialize or, more likely, HVDC interlinks make AC interlinks technologically obsolete before they would be procured.

Figure 2. Offshore Platform Designs. ***Source: DNV***



For the reasons laid out above, NYSERDA's decision to pursue AC interlinks instead of HVDC interlinks is one that raises at least as many questions as answers. As such, Anbaric believes it would be prudent for the NJBPU to thoroughly evaluate the potential to use HVDC interlinks, starting with a review of the current state of practice in Europe (as discussed in the next section).

III. Development of HVDC Networks (Foundation for Multiple Questions)

HVDC interlink/network technology is rapidly advancing. Therefore, it is critical to examine both the possibility for networked HVDC transmission using existing technology, as well as where networked HVDC transmission will be in the early 2030's. That is the time horizon for when projects from current and near-future offshore wind solicitations are expected to come online and when the development of an offshore meshed network will have the greatest value.

- **Existing HVDC Networking Capabilities** – Three networked HVDC systems are currently being developed in Europe[18]. These projects will be able to be reconfigured in the event of the loss of an HVDC export cable to shore, such that they can continue delivering power through the remaining export cable(s). After a fault occurs, the process for reconfiguring a networked HVDC system is to (1) deenergize the entirety of the HVDC system, (2) open and close the relevant DC switches to achieve the desired reconfiguration, and (3) reenergize the system. Depending on the system design (choice of DC switchgear), the degree of automation and the extent of remote operation capability, this process can be completed within seconds. Through this series of actions, HVDC networks can be reconfigured to continue delivering power after a cable fault through the remaining links available in the network.

- **Multi-Terminal Projects** – Several multi-terminal HVDC projects have been successfully put into operation in China, demonstrating the technology's viability. In Europe, which has a more comparable transmission development approach to the United States, six multi-terminal HVDC grid projects have been selected with commercial operation dates ranging from six to eight years away.

  Notably, TenneT has developed and standardized a 2 GW, 525 kV platform design that is multi-terminal ready and that anticipates the development of HVDC circuit breakers. The details of the program are covered in the two attachments submitted with these comments.[19] TenneT already has six of these projects scheduled for in-service dates between 2028 to 2030 (see Table 1).

  Table 1. Six 525 kV HVDC Multi-Terminal Projects Being Developed by TenneT. ***Source: TenneT***

Netherlands

Project	Year
IJmuiden Alpha	by 2028
IJmuiden Beta	by 2029
IJmuiden Gamma	by 2030

Germany

Project	Year
BalWin1	by 2029
BalWin2	by 2030
BalWin3	by 2030

- **Full Bridge Converters** – Full bridge converters – which will be commercially operating in 2027 -- are an alternative that can be used in projects now being developed until HVDC circuit breakers become available. Like HVDC circuit breakers, full bridge converters will enable the re-routing of power flows after the occurrence of a fault in an HVDC network without requiring the reenergization of the entire network. The ULTRAnet project in Germany is a three-terminal

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[18] Caithness-Moray-Shetland [3 terminal, COD 2024]; Eurasia Link [4 terminal, COD 2025]; and Heide Hub [3 terminal]

[19] Additional information can be found at: https://www.tennet.eu/our-grid/offshore-outlook-2050/the-2gw-program/

project that will use full-bridge converters and a non-selective ultrafast protection strategy to enable the instantaneous re-routing of power. It is expected to enter service in 2027. In the long-term, full bridge converters will likely be less economic than HVDC circuit breakers given their higher energy losses and greater capital costs but they represent a necessary transitional step to the performance and cost advantages of HVDC networks and HVDC circuit breakers.

- **HVDC Circuit Breakers**– HVDC circuit breakers are a key component of the future of networked HVDC transmission systems. HVDC circuit breakers enable the nearly seamless reconfiguration of the network to support a variety of grid needs, from low frequency events such as loss of an export cable to regular needs including redistributing the flow of power to respond to the real-time needs of the onshore transmission grid.

  Full-scale prototypes of different HVDC circuit breaker technologies from multiple vendors have been successfully demonstrated up to 350 kV in Europe[20]. Since most HVDC circuit breaker technologies are modular in nature, much like MMC VSC converter technology, they can be scaled to higher voltages relatively easily and without a fundamental change in technology. Pre-standardization activities have been completed[21] and the first commercial application of a 525 kV HVDC circuit breaker is expected to enter service in 2032 in Germany[22].

The global deployment of offshore wind, HVDC transmission, and storage technology will continue to drive significant and rapid advancements in networked HVDC transmission systems. Entities involved in the design of offshore wind and transmission systems must expect and prepare for rapid technological advancement. For New Jersey, this means taking steps now to prepare for a future where networked HVDC transmission systems with HVDC circuit breakers are commercially available and permit the most flexible and efficient transmission system for offshore wind.

IV. Recommendations for a Future Meshed Grid and How to Prepare for It (Question 8)

Anbaric recommends that the NJPBU review the 2 GW, 525 kV standard for HVDC cables and multi-terminal ready offshore platforms that has been developed by TenneT and adapt them as appropriate for New Jersey's needs.[23]

If the NJBPU were to follow the path set forth by TenneT, the NJBPU would require offshore HVDC converter stations to be built with normally open point(s) to support the future addition of HVDC

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[20] https://www.promotion-offshore.net/fileadmin/PDFs2/D10.9_Reporting_on_HVDC_circuit_breaker_testing.pdf

[21] https://e-cigre.org/publication/873-design-test-and-application-of--hvdc-circuit-breakers

[22] https://tennet-drupal.s3.eu-central-1.amazonaws.com/default/2022-07/Windstrom-Booster-Concept_English.pdf

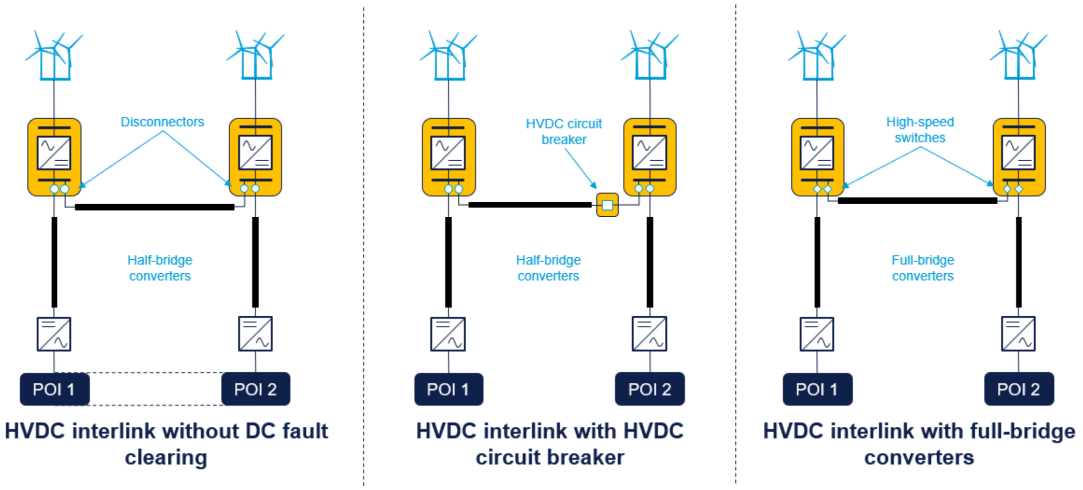
https://www.50hertz.com/en/News/FullarticleNewsof50Hertz/12105/50hertz-and-tennet-to-jointly-bring-wind-power-from-the-north-sea-into-the-extra-high-voltage-grid-for-the-first-time

[23] *See* attachment: TenneT: 2 GW HVDC Standard, Transition towards Multi-terminal DC systems, and TenneT January 19, 2021 overview document re: "2GW Program, Standardisation of 2GW grid connection."

interlinks. This configuration is shown in the left panel of Figure 3. As discussed above, the presence of HVDC interlinks, even without HVDC circuit breakers, will allow for the HVDC network to be reconfigured in the event of a fault in an HVDC export cable.

Further, when the NJPBU decides to proceed with the development of HVDC interlinks, Anbaric recommends that these interlinks be ‘HVDC circuit breaker ready’. This means that the meshed ready export links should be specified to withstand any physical stresses caused by HVDC circuit breakers and to have all relevant interfaces to facilitate the system integration of an HVDC circuit breaker, such as communication for control and protection systems. To minimize the risk of stranded assets, Anbaric recommends the installation of any future HVDC circuit breakers on a separate platform, as shown in the middle panel of Figure 3. HVDC circuit breaker platforms are ideally sited adjacent to converter platforms, as this results in cost savings from shared auxiliary systems, accommodation, and accessibility systems. That being said, HVDC circuit breaker platforms can be placed at any point in the HVDC interlink, which provides significant flexibility if there are siting constraints adjacent to the existing converter platforms.

Figure 3. Design Configurations for HVDC Interlinks. ***Source: DNV***



V. Voltage Recommendations for the Future Mesh Network (Question 13)

Should the NJBPU decide to move forward with HVDC interlinks, it will need to select an HVDC voltage standard to be used by both future export links and future interlinks. To accomplish this, Anbaric would recommend the NJBPU convene a conversation (perhaps a technical conference) with HVDC suppliers, developers, adjacent state regulators, and regional grid operators (including grid operators from NYISO and ISO-NE).

The convened parties essentially have three options to choose from: 320 kV, 400 kV or 525 kV. There are arguments that can be made for and against each of the voltage levels. The basic arguments are as follows:

- 320 kV is technically mature but its maximum circuit capacity of around 1200 MW is too 'small' for New Jersey solicitations[24]
- 400 kV is technically optimal given PJM's current MSSC limit of 1500 MW; it was used by multiple proposals in the SAA
    - while 400 kV has been in use by multiple projects onshore, it is not yet a standardized solution for offshore projects and there are not yet signs that it will become one
- 525 kV is the emerging standard in Europe (see prior references to TenneT's work developing a 2 GW, 525 kV standard for cables and multi-terminal ready platforms)
    - to cost-effectively use 525 kV cables will require determining whether or not the higher capacity of these circuits (e.g. 2000 MW) will require adjusting current MSSC values in the northeast; preliminary analysis by DNV suggests that this adjustment is not necessarily required depending on the design of the HVDC circuit (e.g., an HVDC system using a bipole and metallic return)

VI. Equipment Specifications and Installation Requirements to Enable Mesh Ready PLUS Space and Other Physical Requirements to Enable Mesh Ready (Questions 9 and 10)

The equipment specifications and installation requirements necessary to create an HVDC mesh ready system should focus on those components of the offshore system that will need to be flexible and expandable as the system of transmission links develops. In most cases, anticipatory installation and investment that makes the platform ready for growth during the initial platform construction is less expensive than offshore retrofitting. Since growth is the plan in New Jersey, so should the early investment that will ultimately make growth most economical.

To enable expansion, offshore substation specifications should generally include the following provisions:

- **Primary equipment** – to enable the physical connection of an additional cable:
    - HV busbar is necessary in case of an HV interlink connection
    - An additional switchgear bay is needed to connect the additional cable to the offshore power system. In case of MV or HV AC connections, this is typically a GIS circuit breaker bay with associated disconnectors and grounding switches. For HVDC connections, the air insulated system HVDC circuit breaker would likely be installed on a separate platform due to its larger size. For this reason, only a spare HVDC disconnector bay is envisioned as an upfront provision required for HVDC interlinks. Furthermore, HVDC disconnectors, if implemented as a gas insulated system (GIS), can be realized without requiring an increased platform size.

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[24] The remaining steps in New Jersey's current offshore wind solicitation program are 1200 MW, 1200 MW and 1342 MW. However, it is expected that the NJBPU will receive bids higher than the listed solicitation sizes due to the fact that the lease areas are significantly larger than the targeted solicitation sizes. Additionally, 1200 MW is meaningfully less than PJM's current 1500 MW MSSC limit and using 1200 MW circuits would result in 1-2 additional HVDC circuits to achieve the remainder of the New Jersey's 11 GW goal.

- **Secondary equipment** – to enable the electrical operation of the primary equipment:
    - Bay control and protection units are needed for each additional switchgear bay
    - Metering is needed to enable dispatch and market settlement of any additional power system user that is connected as part of the offshore grid expansion
    - Instrumentation wiring is needed to connect the additional primary and secondary equipment. In modern digital substation design the need for additional wiring can be kept to a minimum by using substation bus systems

- **Auxiliary systems** – to ensure the required operational conditions for the additional primary and secondary equipment:
    - HVAC, firefighting and lighting in any additional space that is necessary to host additional primary and secondary equipment
    - LV wiring is needed for the power supply to the additional primary and secondary equipment
    - Diesel generator and UPS capacity (e.g., additional batteries) are required to serve the increased auxiliary load demand due to the additional primary and secondary equipment, and due to additional HVAC and lighting requirements

- **SCADA system upgrades** – to integrate the functionality of additional equipment. Special control modes necessary for the operation of more complex offshore grid topologies must be enabled, especially in the case of HVDC.

- **System ratings** need to be compatible with the foreseen offshore grid expansions:
    - Basic insulation level and rated voltage of offshore grid expansions need to be the same, or additional transformers and overvoltage protection equipment are necessary.
    - Power ratings of transformers and cables need to ensure sufficient margin for any possible additional loads resulting from future expansions is present.
    - Reactive power compensation of additional cable(s) must be present to comply with grid code power factor requirements. This can be realized through additional shunt reactors, variable reactors with tap changers or dynamic reactive power compensation systems such as SVCs and STATCOMs.
    - Current ratings of busbars, switchgear and instrumentation need to ensure sufficient margin for any possible additional currents resulting from future expansions.
    - System grounding design must be sufficiently flexible to accommodate more complex offshore grid topologies where multiple grounding points could be possible and to ensure changes in short-circuit currents due to system expansions are compatible with equipment and protection settings.
    - Harmonic stability could be affected by the connection of additional equipment (cable capacitance, shunt reactance) and require retuning and possible additional filter equipment.
    - Circuit energization equipment ratings such as pre-insertion resistors need to be sufficient to accommodate the connection of additional equipment.

- **Structural support** – to host the additional primary, secondary and auxiliary equipment:

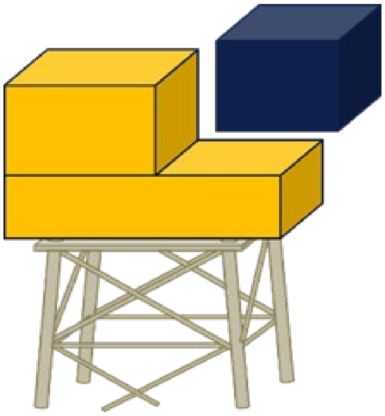
  - Space for additional primary, secondary and auxiliary equipment. Sufficient footprint and headroom must be available for the installation, operation, and repair of the equipment. The location of the additional space must be chosen such that it easily facilitates the integration of any additional equipment with existing systems. This includes the availability of free space for cables and wiring in sealed wall crossings, additional space for power cable installation and routing and in instrumentation and LV wire trays
  - J-tubes are required to enable the pull-in of additional power and communication cables. The spare J-tube will need to be designed with sufficient room and bending radius to accommodate the future expansion cable. Sufficient space must be available on the cable deck to pull-in the additional cable
  - Seabed cable arrangement must leave sufficient space for the installation and repair of an additional submarine cable
  - Support structure design must be sufficient to support the installation of additional weight and offer space and support points to host any additional modules.

- **Substation Expansion: Physical Footprint Options** – There are three options available for installing additional provisions necessary for offshore substation expansions:

  1. **On the same support structure, within the existing topside:**
     a. Plug and play: All necessary provisions are installed during construction and ready to use at the time of expansion.
     b. Expandable: Only minimum provisions such as space, structural support and interfaces for necessary equipment are installed during construction and available and accessible for future installation.

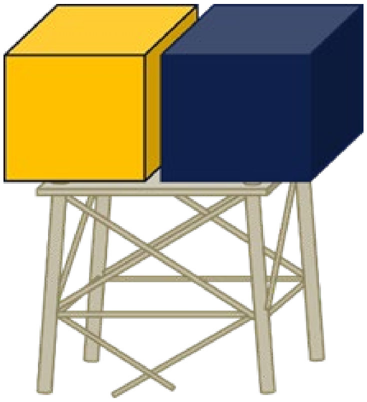
  2. **On the same support structure, adjacent to the existing topside:**
     a. By installing an additional module onto the existing topside, as shown in Figure 4.

Figure 4. Installation of Additional Module on Existing Topside. ***Source: DNV***



   b. By installing a separate additional topside onto the same support structure, as shown in Figure 5.

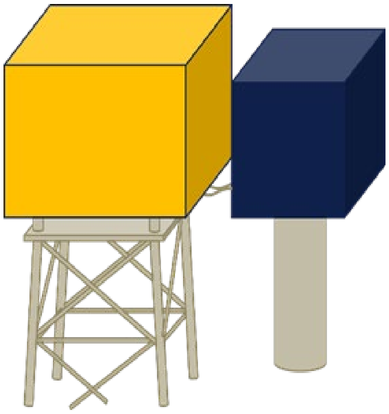
Figure 5. Installation of Separate Additional Topside on Same Support Structure. ***Source: DNV***



   c. In both cases, space, structural support and interfaces for the future installation of the module must be present from the start.

3. **On a separate adjacent support structure and topside:**
   a. Connected by a bridge, as shown in Figure 6, if the offshore substations are closely located (e.g., less than a few hundred feet apart). The bridge will allow for easy personnel accessibility between the platforms and can be used to support connections such as HV cables, GIL, LV power supply, communications, and other amenities.

Figure 6. Installation of Additional Support Structure and Topside. ***Source: DNV***



   b. Connected by submarine cable, if the offshore platforms are located too far away from each other to be connected by bridge. In both cases, space on the seabed, and additional electrical switchgear bays for the future installation and connection of the additional offshore substation must be present from the start.

Anbaric recommends establishing specifications that would allow these various configurations, so respondents to the solicitation can explore the most technically and financially efficient arrangements for the specific locations and applications involved.

VII. Impacts from the Inclusion of other States in the Mesh Network (Question 11)

Anbaric's engineering and operational recommendations would not change if the future mesh network included only New Jersey projects, added other PJM state projects, or also added New York, New England, and/or projects to the south. The HVDC mesh approach will effectively manage expansion in any direction and offer the most long-term capability for the lowest overall investment cost. Even if the successive projects are limited to New Jersey, getting to the State's 11 GW goal will benefit from an offshore grid that is engineered to operate at the higher capacities facilitated by an HVDC mesh system.

From the regulatory perspective, the NJBPU SGD should inquire about the qualifications and experience of the respondents in the other states and ISO/RTO regions if they are touched by the Third Solicitation. The Board would want to understand from each party submitting a proposal:

a) Are there any issues that prevents them from doing business in any of the PJM coastal states or New York?
b) Do they have any assets already under the regulatory jurisdiction of any of those states, and in New York, subject to NYISO requirements?
c) Do they have sufficient knowledge of and experience with the interconnection requirements and other market rules of PJM, and if extended to New York, the NYISO?
d) Do they have any record of NERC violations with RFC (New Jersey), SERC (PJM states further south), or NPCC (New York)?

If the Third Solicitation looks to support a mesh network extending to other PJM states or New York, the Board may want to inquire about how respondents would suggest coordinating future solicitations with the other states and the NYISO. It may want to also include explicit direction to work with the Board to establish standardization (e.g., determining a common voltage level) among the affected states and regions that will foster future systems compatibility as the offshore grid expands.

Expansion to include other states also raises regulatory issues like cost allocation. While these issues are challenging, viable mechanisms exist to allocate costs fairly, prevent cost-shifting among the states, recognize differences in state policy goals, and distinguish between local and regional benefits. The starting point for such a cost allocation framework is Cost Allocation Principle 1 in FERC's Order No. 1000, which states: "The cost of transmission facilities must be allocated to those within the transmission planning region that benefit from those facilities in a manner that is at least roughly commensurate with estimated benefits."

However, before allocating costs based on the beneficiary pays principle, it is appropriate to assess whether the subject transmission facilities would enable various transmission upgrades or the replacement of aging transmission facilities to be avoided. If so, appropriate credit should be given for these avoided costs, with the portion of the costs represented by these avoided facilities allocated in the same manner as the costs that were avoided. In addition to avoided upgrade costs there are numerous benefits to strategic transmission development, and numerous methods to determine such benefits. In the interest of avoiding extended and potentially contentious detailed analyses of benefits, utilizing a straightforward and implementable approach to allocating costs is needed. The Department of Energy and/or FERC may be able to develop such an approach that can be applied across multiple jurisdictions to ease cost allocation concerns. Federal funding can additionally facilitate cost allocation by reducing the overall cost of transmission projects.

Those responding to the Third Solicitation should be prepared to commit to working with the Board to address such issues. While the timing of when such issues become pressing may not yet be known, all participants in the growing New Jersey offshore wind market must be willing and prepared to tackle the issues that will arise as interstate and interregional networks emerge.

* * *

Anbaric remains grateful for NJBPU's leadership role in accelerating the growth of the offshore wind industry. Anbaric believes that a future State Agreement Approach procurement can take steps to move from a mesh-ready approach to a full offshore transmission system that, based on commercially available technology, will solidify the State's leadership role in accelerating the growth of the industry while protecting the ratepayer.

Respectfully submitted,

Clarke Bruno

Chief Executive Officer

2 GW HVDC Standard

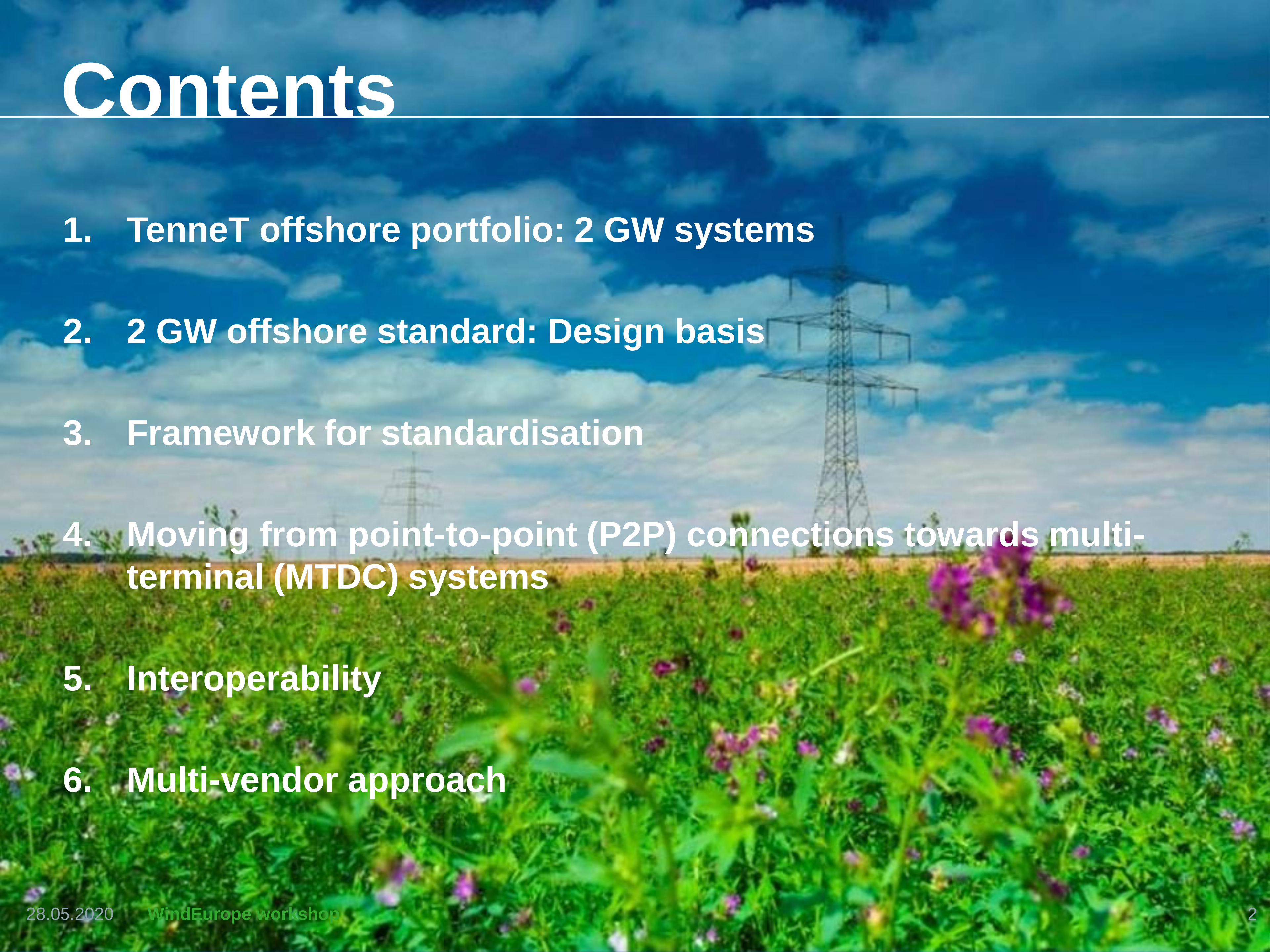
Transition towards Multi-terminal DC systems

WindEurope Workshop 2020: Technology developments

Alex Alefragkis

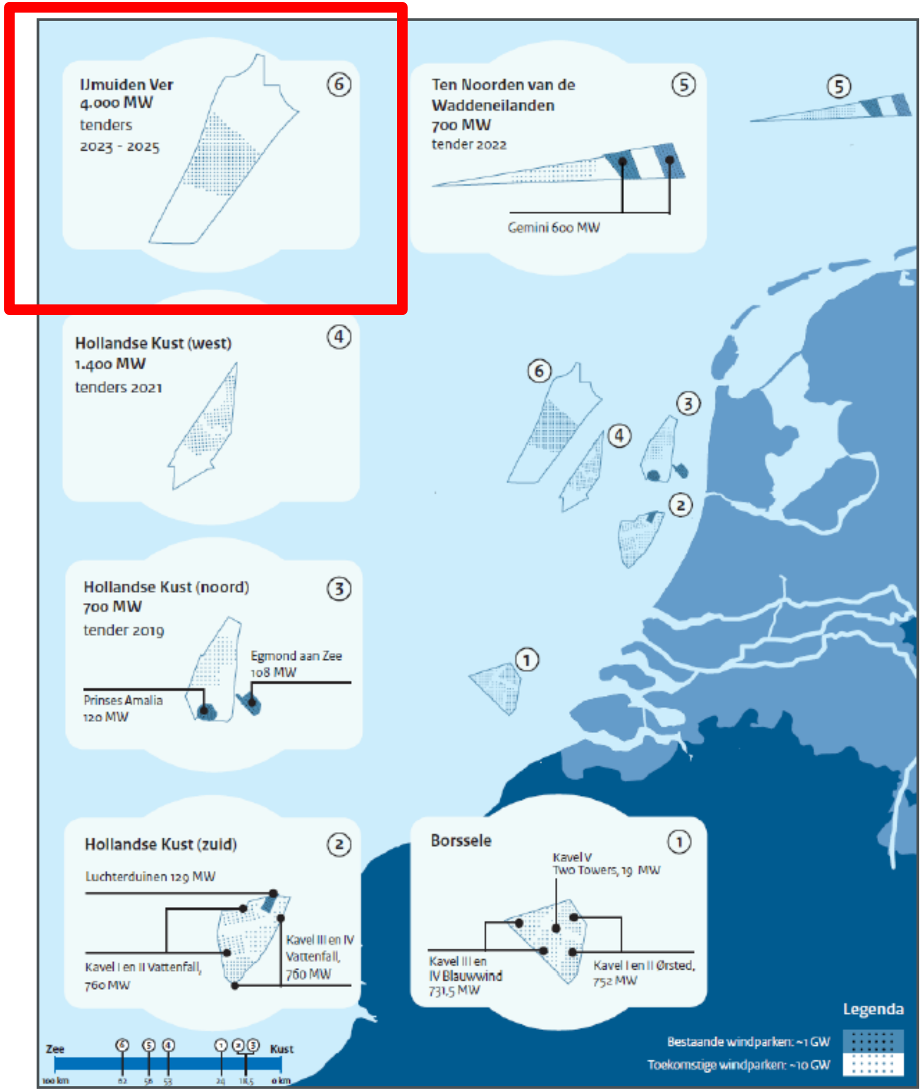
Asset Management TenneT

Contents



2 GW Program Approach

Portfolio in the Netherlands:



Portfolio in Germany:

New Grid Connection System	Transmission Capacity	ISD	Grid Access Point	TSO
OST-7-1	300 MW	2024	Area of Papendorf (Mecklenburg-Vorpommern)	50Hertz
OST-1-4	300 MW	2026	Area of Lubmin (Mecklenburg-Vorpommern)	50Hertz
NOR-7-2 (BorWin6)	930 MW	2027	Büttel (Schleswig-Holstein)	TenneT
NOR-3-2 (DolWin4)	900 MW	2028	Hanekenfähr (Lower Saxony)	Amprion
NOR-6-3 (BorWin4)	900 MW	2029	Hanekenfähr (Lower Saxony)	Amprion
NOR-9-1 (BalWin1)	2 GW	2029	Unterweser (Lower Saxony)	TenneT
NOR-10-1 (BalWin2)	2 GW	2030	Unterweser (Lower Saxony)	TenneT
NOR-12-1 (LanWin1)	2 GW	2030	Wilhelmshaven II (Lower Saxony)	TenneT
NOR-11-1	2 GW	2030+	Westerkappeln (North Rhine-Westphalia)	Amprion
NOR-11-2	2 GW	2030+	Wehrendorf (Lower Saxony)	Amprion
NOR-13-1	2 GW	2030+	Heide West (Schleswig-Holstein)	TenneT

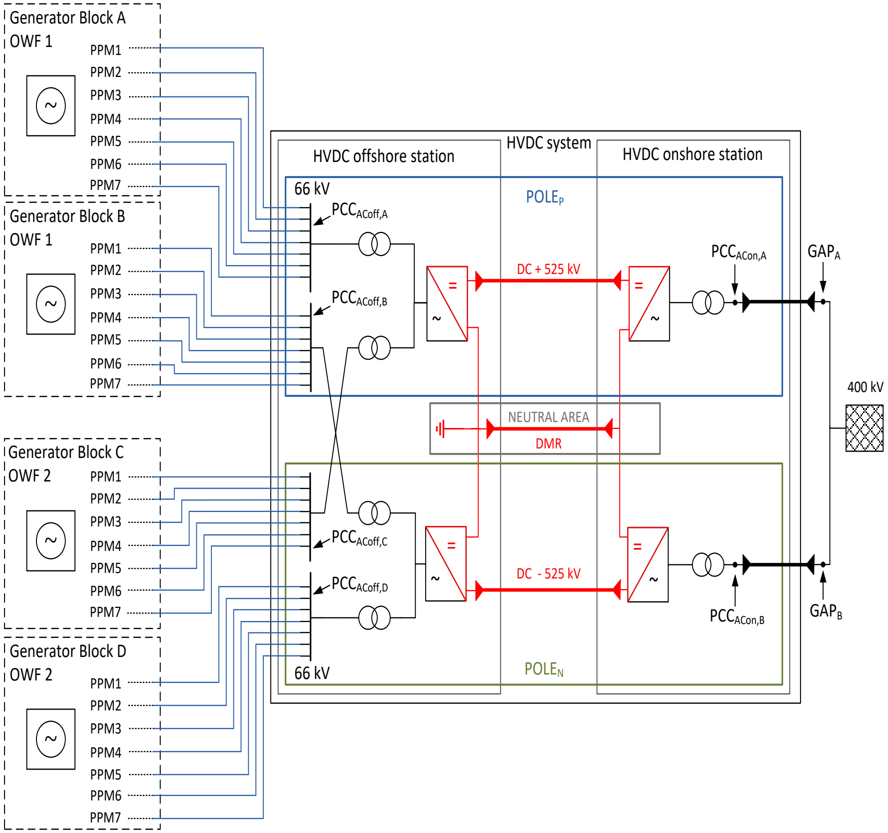
The epicentre of Europe's e-transition

The modular Hub-and-Spoke concept is a technically feasible solution that can adapt to specific design requirements. The consortium is well placed to develop, build and operate Hub-and-Spoke projects.

2GW Standard: Design Basis

- ✓ +/- 525 kV
- ✓ Bipole configuration with DMR
- ✓ Direct-Link 66kV
- ✓ XLPE cable technology
- ✓ Bundled cable laying arrangement

- ✓ *Ability to connect offshore consumer(s)*
- ✓ ***Multi-terminal ready***



→ The HVDC System shall enable independent operation of the HVDC poles when operated as a point-to-point or as a multi-terminal system, provided that the current limitations of DMR cable are not exceeded.

Framework for standardisation

1. **Innovation Partnership for HVDC System**

2. **FEED study for 2 GW Platform**

   Objective: *"To optimize and standardize the platform design resulting in lower cost for construction, operation, maintenance and environment and therefore the lowest cost for society and to develop a standard for the 2GW HVDC converters for offshore use with the highest possible availability to ensure a reliable grid."*

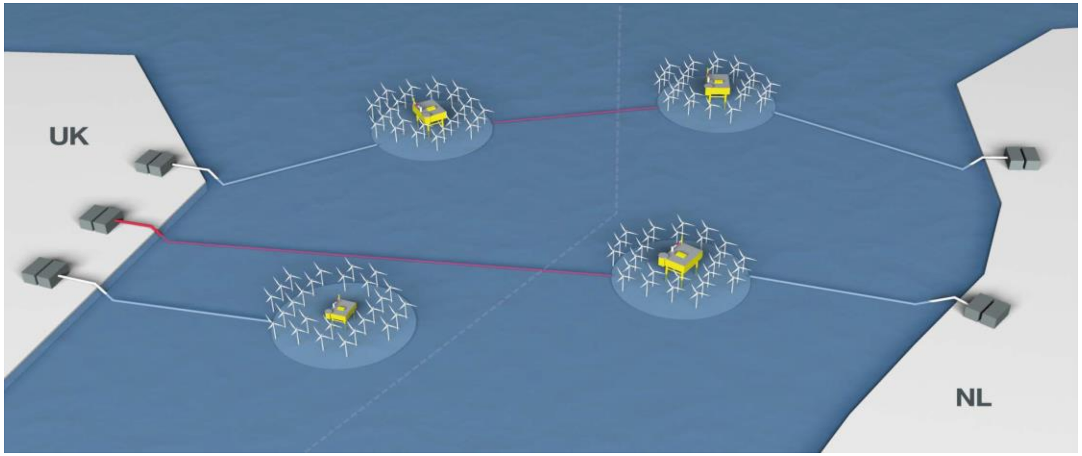
   https://www.tennet.eu/news/detail/tennet-develops-first-2gw-offshore-grid-connection-with-suppliers/

3. **Development program 525 kV DC XLPE submarine cable system**

   https://www.tennet.eu/news/detail/tennet-develops-innovative-submarine- cable-with-suppliers/

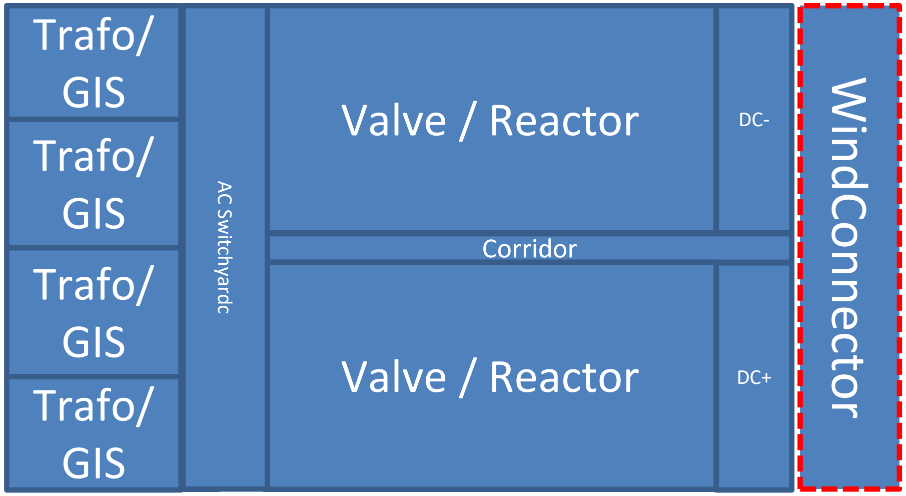
WindConnector

IJmuiden Ver connections in the Netherlands shall be able to accommodate a future WindConnector (*multi-terminal ready*):



Multi-terminal ready means:

- **MTDC Basic Design**
- **Space provisions on the Platform**
- Multi-terminal C&P system



Trafo/ GIS

Trafo/ GIS

Trafo/ GIS

Trafo/ GIS

AC Switchyardc

Valve / Reactor

DC-

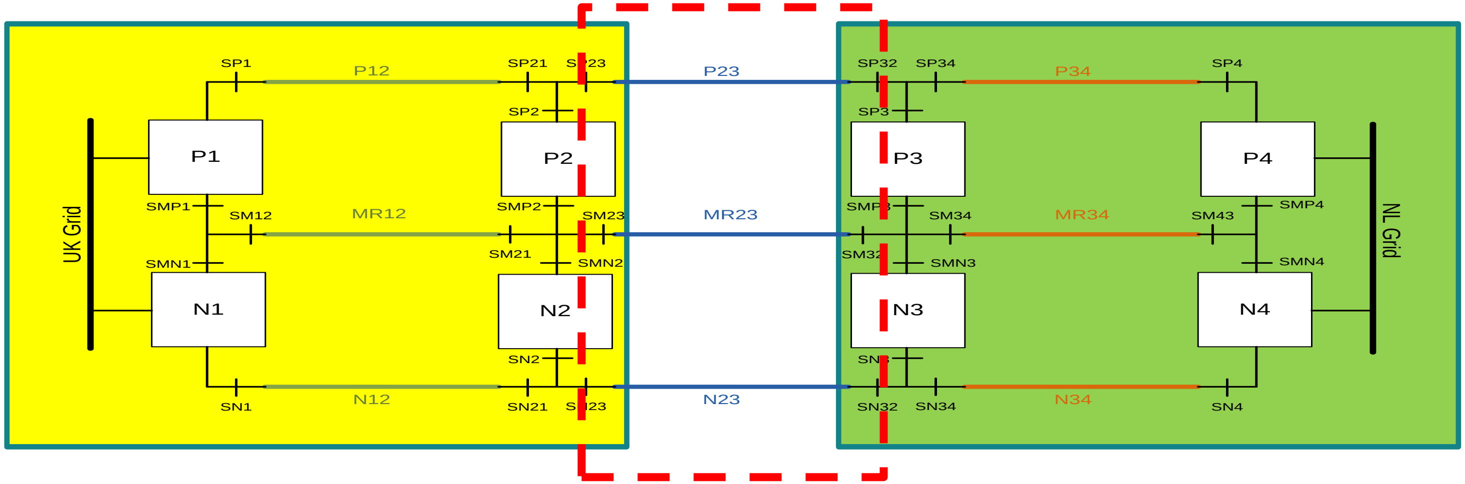
Corridor

Valve / Reactor

DC+

WindConnector

P2P conversion to MTDC



Single step approach for development partners (TenneT, ….):

✓ Similar to HVDC interconnectors: common contractual basis / technical specs / execution teams / timelines / contractor (s)

Two step approach:

✓ Separate contractual basis / execution teams / timelines / contractor(s)

✓ Separate technical basis with minimum pre-conditions for common features:

- DC Voltage levels
- HVDC scheme configuration
- Definition of common operational principles based on projected MTDC asset value

MTDC Basic Design

For interconnecting two independent P2P HVDC systems, basic MTDC design studies are required at an early stage:

- Steady-state load flows
- Insulation Coordination
- Transient Currents and Overvoltages
- Dynamic performance assessment

Otherwise MTDC design may have significant operational limitations or lead to non-compliant performance

Example: Minimum steady-state DC voltage

1. DC voltage drop across P2P terminals together with converter's Q capabilities acc. to Grid Code result in fixed range of modulation index;
2. Further DC voltage drop across any MTDC terminals may result in reduction of reactive power operating range

→ *Maximum DC cable length between any two stations of the MTDC system* → *CRITICAL*

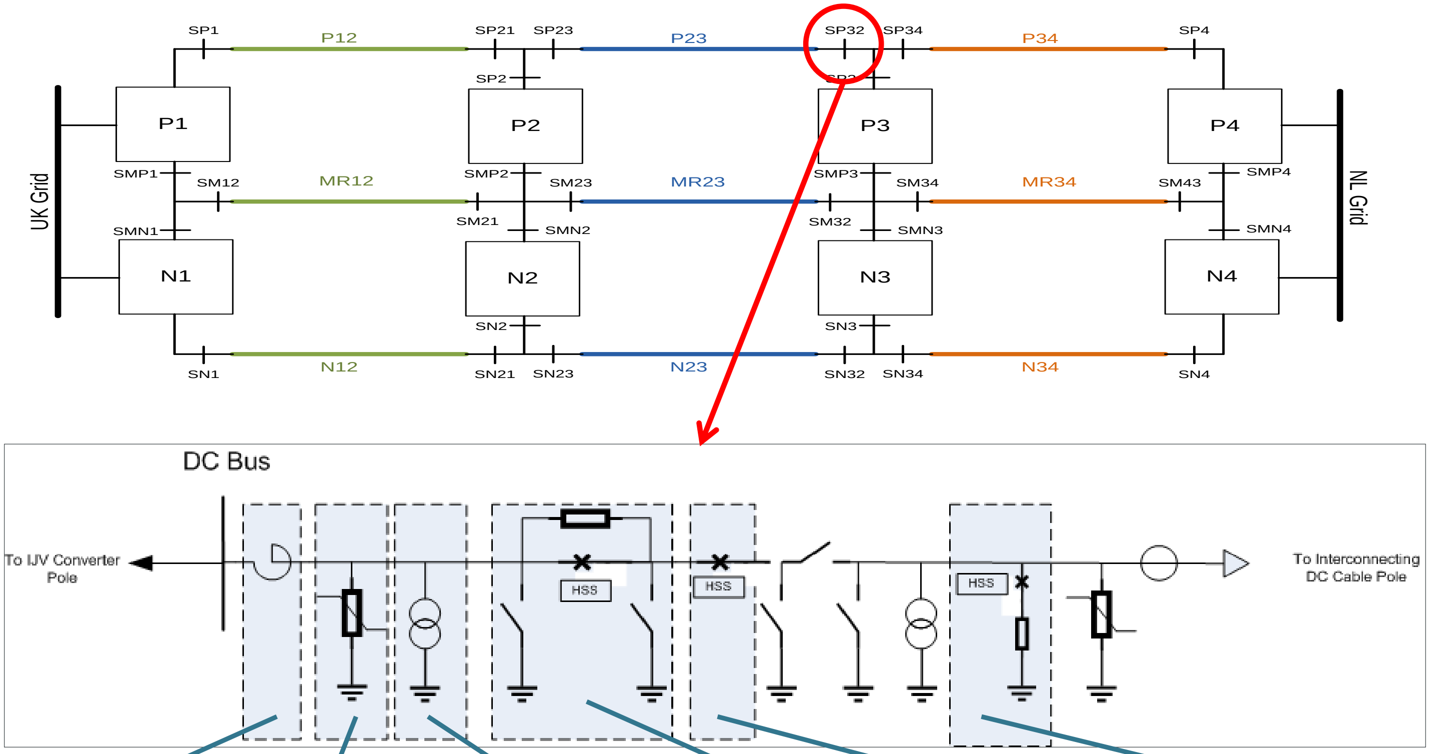
MTDC Operational Principles

MTDC system design is based on operational philosophy:

- List of Topologies for MTDC operation
- Power flow combinations
- MTDC protection and recovery strategy due to Forced Events
- MTDC restoration strategy due to Planned Events
- MTDC earthing
- Ancillary services

MTDC Connection arrangements

Example: DC switchyard extension…



Transient performance

Insulation Coordination

Measurement scheme

Energisation concept

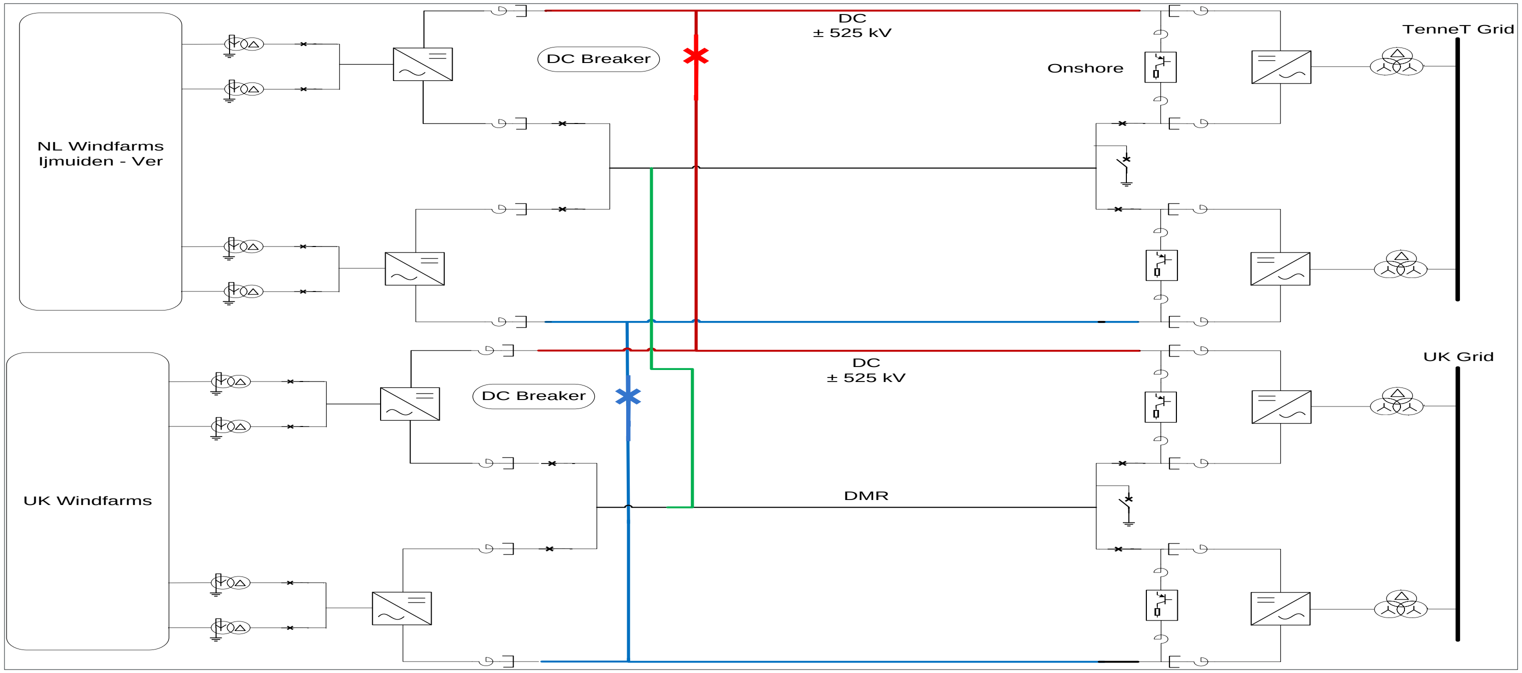
Reconnection Disconnection

De-energisation concept

MTDC protection

Example: options for MTDC protection against propagative faults:

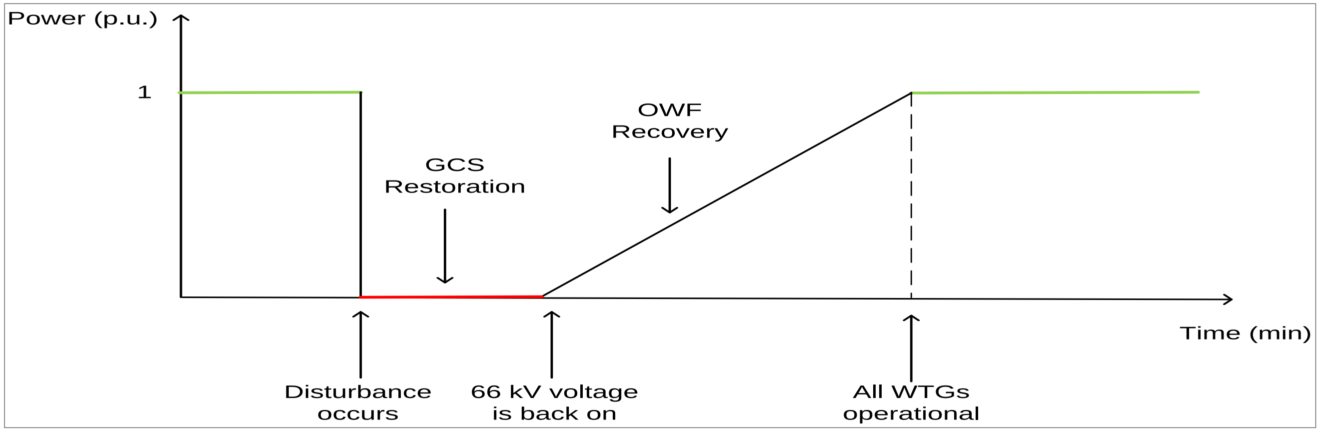
1. Non-selective protection (AC breakers)
2. Partially selective (DC breakers at strategic locations)
3. Fully selective (DC breakers at all HVDC cable ends)



MTDC protection

Immunity of TenneT’s system to disturbances occurring outside our P2P scope?

- Lifetime of MTDC asset
- Number of disturbances
- System and Power Restoration concept → duration per event
- Amount of non-transmitted energy per event
- Value of non-transmitted energy



Interoperability

Relevant technical activities:

- ENTSO-E roadmap for the development of multi-vendor HVDC systems and other PEIDs description
- CIGRE WG B4.84 Interoperability in HVDC systems based on partially open-source software
- CENELEC CLC/TS 50654-1: HVDC Grid Systems and connected Converter Stations - Guideline and Parameter Lists for Functional Specifications - Part 1: Guidelines
- CENELEC CLC/TS 50654-2: HVDC Grid Systems and connected Converter Stations - Guideline and Parameter Lists for Functional Specifications - Part 2: Parameter Lists
- PROMOTioN
- BestPaths

Is this enough??

What are we missing??

Interoperability

Technical areas of attention for TenneT:

- Sufficient exchange of technical data during design phase
- List and quality of interface signals exchange
- Interstation communication protocols
- Coordination of dynamic performance
- Protection coordination
- Delivery of offline EMT models (grey box)
- Performance of Functional / Dynamic Performance Testing
- On-site Commissioning

Enabling multi-vendor approach

Complete proof of concept for interoperability in Europe is missing

TenneT’s technical preparations will support the multi-vendor approach, with a number of pre-conditions towards development partners.

How to better enable multi-vendor approach?

- Strategic design margins reserved by technical developers
- Specify functions, not solutions
- Role of System Integrator - RASCI matrix
- Competition rules and award criteria
- Lessons learnt from MTDC projects
- Smart planning
- Realistic definition of IP rights
- *Leading role of manufacturers*

PRIOR INFORMATION - 2 GW PROJECTS

CLASSIFICATION	C1 - Public Information
DATE	January 19, 2021
REFERENCE	Rev.0

SUBJECT 2GW Program, Standardisation of 2GW grid connection

Standardisation of 2 GW Grid Connection System

TenneT has selected a new innovative 2 GW HVDC grid connection standard to connect the future offshore windfarms. This new standard aims to further reduce the cost of offshore wind, minimize the spatial and environmental impact and doubles the connection capacity in comparison with the previous 900 MW / 1 GW HVDC standard. This new 2 GW standard will prepare TenneT for the planned acceleration in offshore wind deployment in Germany and the Netherlands.

TenneT has started in January 2020, together with the market[1], an innovative partnership and a Front End Engineering and Design (FEED) to jointly develop the new 2 GW standard. Aim was to provide a proof of concept and to standardize the designs of the platform. TenneT and the suppliers have gained significant experience with the German 900 MW HVDC grid connection systems and these lessons learned are now incorporated in the optimized and standardized design of the entire grid connection system.

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[1] See TenneT press releases:
https://www.tennet.eu/news/detail/tennet-develops-first-2gw-offshore-grid-connection-with-suppliers/
https://www.tennet.eu/news/detail/tennet-develops-innovative-submarine-cable-with-suppliers/
https://www.tennet.eu/news/detail/tennet-scaling-up-transmission-capacity-standard-to-accelerate-offshore-wind-deployment/

The Innovation Partnership and FEED have proven to be successful. The intensive interaction and performed studies have resulted in a better understanding of the required functionality and performance of the innovative HVDC system. In addition in the FEED it has been possible to develop a generic platform design which is able to house various HVDC suppliers. TenneT believes that the new standard will entail significant cost benefits and prepares TenneT for the planned acceleration of the energy transition in both, The Netherland and Germany.

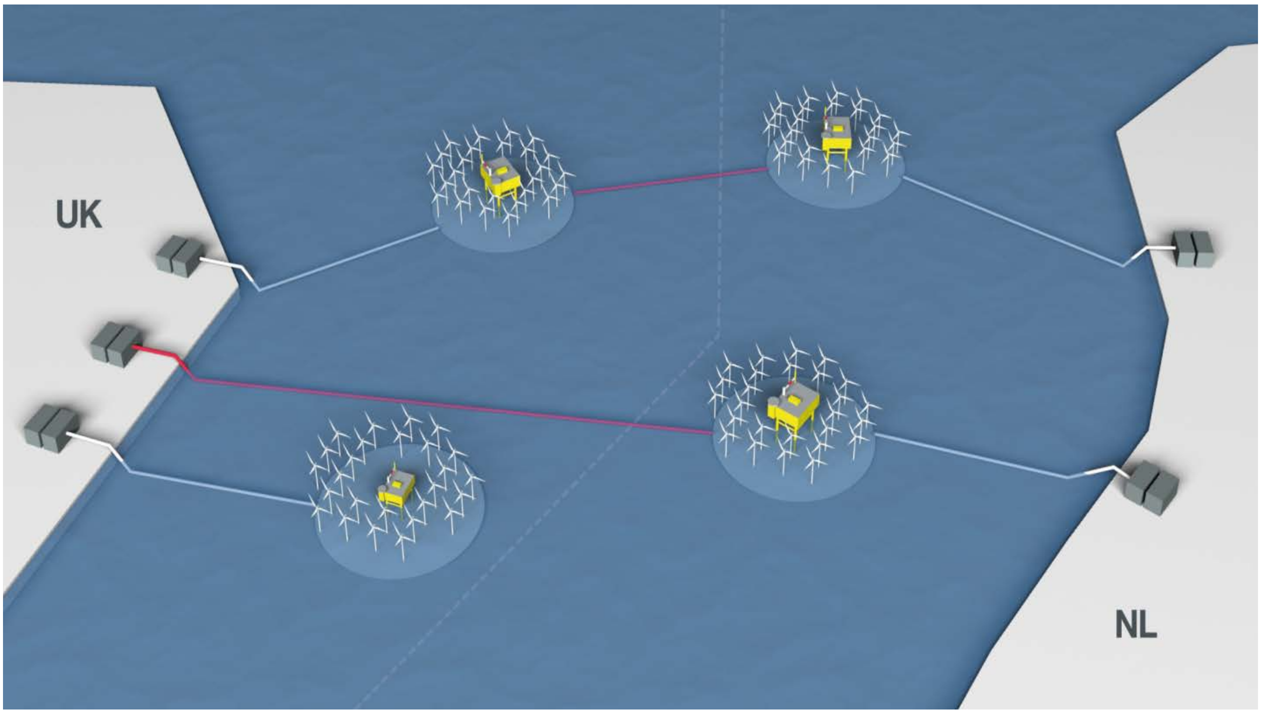
The new 2 GW standard will form the basis for the upcoming tender procedures. TenneT will provide the 2 GW standard design in the tenders to all participating parties to maximally utilize the results. In order to further reduce TOTEX TenneT will enable tenderers to optimize the standardized design to their individual system within specific boundaries to ensure the standardization goals.

Offshore platform, offshore and onshore HVDC converters

HVDC

Together with 5 HVDC suppliers involved in the R&D phase of the 2 GW Program, TenneT has developed a new, standardized Point to Point connection:
2GW ±525kV HVDC Grid Connection System (Bi-pole with Metallic Return) – Multi Terminal ready.

The "Multi Terminal readiness" enables TenneT to extend the GCS with a WindConnector / InterConnector (3 or 4 Terminal solution) in the near future.



Offshore Platform

In the Front-End Engineering and Design (FEED) study a standardised platform design (one size fits all topside and jacket) has been developed for all HVDC solutions provided within the R&D phase of the Innovation Partnership procedure. Finalization of the FEED study is scheduled for second quarter 2021. Therefore the following detailed information is preliminary and subject to change.

Characteristics of the FEED design of the platform are:

- Topside:
  - Dimensions structure: approx. 106x78x41 (lxwxh)
  - Weight: approx. 22.000 tonnes
  - T&I by catamaran lift or float over installation.
- Jacket:
  - Dimensions: approx. 89x43 (lxw)
  - Height depending on water depth
  - Weight: approx. 8.000-10.000 tonnes
  - T&I by catamaran lift or heavy lift crane vessel.

Standardisation

TenneT intends to pre-define the following items in the standardized 2GW design in order to contribute to the TOTEX reduction and prepare TenneT for the planned acceleration in offshore wind capacity. These items will form the design boundaries the tenderers.

HVDC Configuration
- 525kV HVDC bipole arrangement with Dedicated Metallic Return
- Operational concept

HV Equipment Arrangement
- 66kV GIS arrangement (Offshore)
- HVDC Transformer arrangement
- DC Yard arrangement
    - including multi-terminal readiness (NL only, GE pending)

Switchyard between HVDC Transformer and Converter:
- Based on air insulated equipment.

Cooling Concept
- HVDC Transformer based on ONAN cooling
- Converter cooling based on air cooling

Automation
- Automation architecture
- HV Control and Protection based on IEC61850

Platform Topside
- Location and arrangement of rooms
- Overall dimensions
- Type of structure: constructed as a fully welded stiffened plate structure

Platform Jacket
- Number and location of J-tubes.

Transport and Installation

- The transport and installation of the platform is a key design driver. To cater for optimal flexibility TenneT has developed a T&I concept which enables both catamaran lift and float over installation. The design gives maximum freedom to the tenderers to select their preferred T&I method.
- TenneT requires that both T&I methods are feasible during decommissioning. This is a risk mitigation measure to ensure equipment availability under all circumstances. It is essential for TenneT to maintain this concept also during detail design.
- If the above is fully observed, the jacket structural design can be optimized during detail design to, for instance, to match the fabricator's or T&I contractor's facilities or equipment.
- TenneT has developed skirt-pile jacket design. Alternative solutions with the same functionality and dimensions will be allowed (e.g. split jacket, use of main piles, suction buckets).

Contractors will have design freedom (within envelope of the offshore platform design from FEED) in:

- Sizing and dimensioning of auxiliary systems.
  - Incl. Converter Cooling concept (one loop or two loop)
- Topside structural engineering
  - E.g. ULS, ALS, FLS,
  - E.g. Sizing of beams/plates/girders/etc.
- Routing of power cables, secondary cables and pipes

Further information is scheduled to be provided at a later stage: possibly as part of this prior information, latest as part of the tender procedure (RFQ phase).

Possible deviations from the standard will be handled during negotiations.

Landstation

TenneT will have a different strategy with regards to standardization of the landstation. This originates from the fact that the onshore plot, and therefore the onshore station layout, will be dependent on the local spatial conditions and permit applications. As a consequence the station layout will be mainly determined by the local conditions (plot size, directions of cables, max. noise emissions and spatial integration).

TenneT will maintain the standardization of the HVDC configuration (SLD) and operational concept.

For IJmuiden Ver Alpha and Beta it has been possible to find identical sized plots of approximately 125m*370m. Layouts for consecutive projects are unknown at this moment.

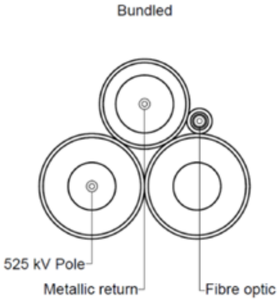
Cable System Design (supply and installation)

Participating suppliers in the 525 kV DC extruded cable prequalification programme are progressing with development and testing of the cable system. The aim is to have a certified cable system in course of 2022.

The 2 GW cable configuration consists of a bundle of 4 cables:

- 525 kV DC + pole;
- 525 kV DC – pole;
- Dedicated Metallic Return Cable (DMR)
- Fibre Optic Cable (FO).

The cables will be installed in a single bundle in the offshore and nearshore section, see the figure below.



Onshore the cables will be installed in parallel.