Taking power further

POSITION PAPER

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Prepared:	D. Vree	29.03.2015
Reviewed:	M. Müller	31.03.2015
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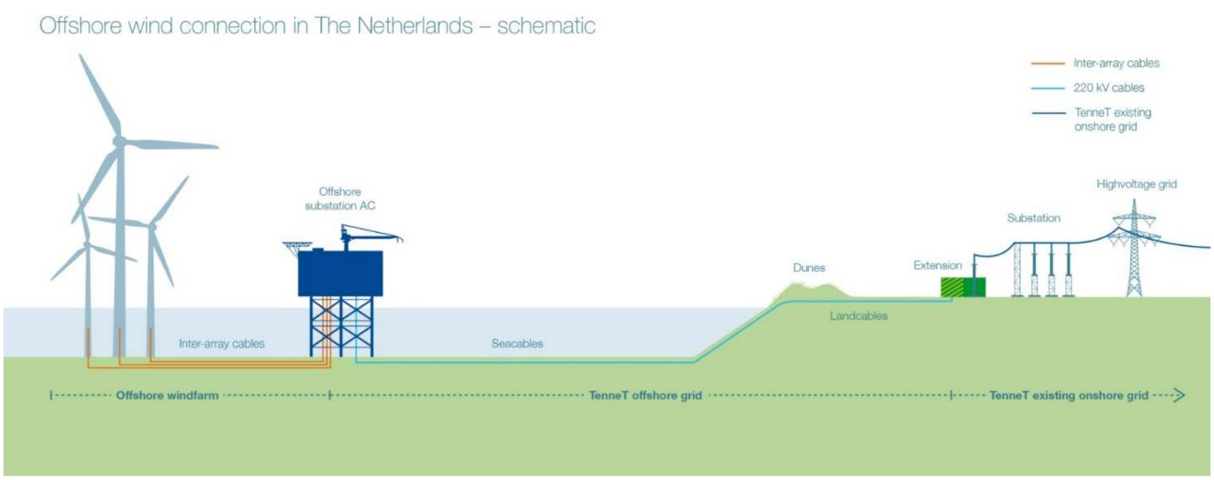
1. Background material

Background material used:
• N.A.

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 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

The protection requirements and typical characteristics of onshore customers of TenneT, and a common protection scheme of a 350 MW offshore wind farm, are analysed as input for the string protection requirements. Also, implications of the new European network code RfG are taken into account. Finally, the protection requirements for PPM strings are introduced which are based on this analysis.

Onshore TenneT protection requirements

Protection requirements of the TenneT high voltage grid are defined in [PVE 02 000][2]. The following requirements are applicable to the protection of the outgoing[3] feeder of the TenneT switchgear for customers (grid connection voltage is 110kV or higher):

- Protection system will be specified, installed and maintained by customer;
- Additionally TenneT provides an impedance protection.

In addition to the above requirements, generators connected to the high voltage grid (greater than or equal to 110kV) shall have fault ride through capabilities as depicted by a red line in figure 2 below which is defined by the system code (article 2.1.16).

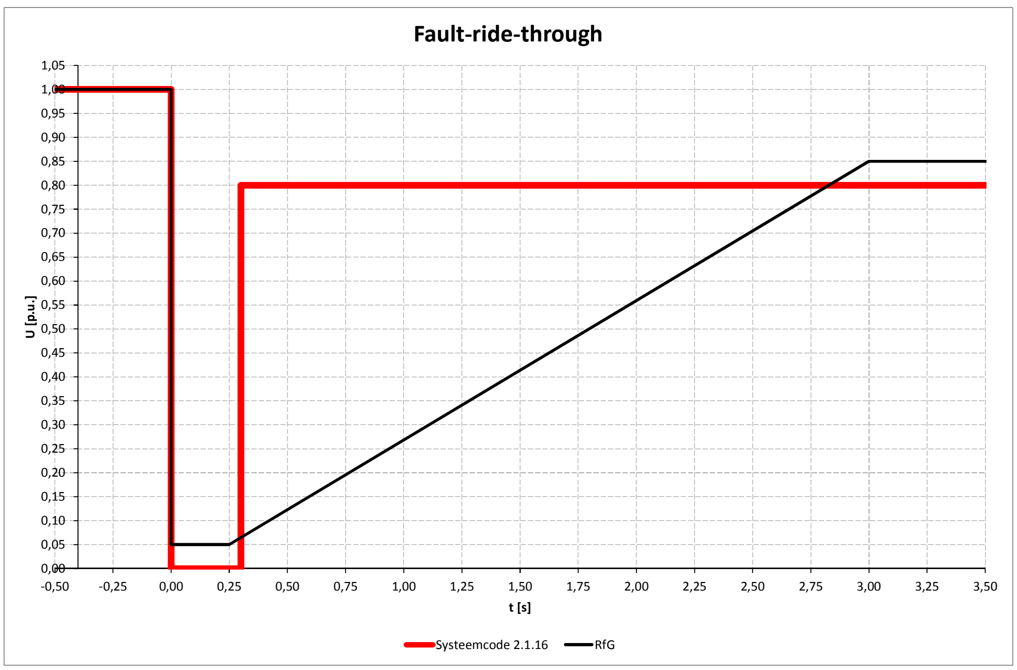


Figure 2. Fault ride through requirements for generators as defined by the system code (red line) and for shore PPMs as defined by the RfG4.

[2] PVE 02 000 Secundair Standaard Programma van Eisen, Oktober 2014, Versie 2);
[3] In this paper the term "outgoing feeder" refers to a feeder which is connected to one of the offshore PPM strings and "incoming feeder" to a feeder which is connected to one of the offshore platform step-up transformers.
[4] The black line is based, on the implementation of TenneT of the draft RfG on the offshore CP.

Requirements from the new RfG network code

The PPM's connected to the TenneT offshore platform will be subjected to the applicable requirements set out in the RfG, which applies to, but is not limited to, the following subjects (overall list: not all mentioned topics are applicable to this paper):

- Fault-ride-through capability
- Electrical protection schemes and settings
- Priority ranking (not covered in this paper)
- Information exchange (not covered in this paper)

The requirements with respect to the fault-ride-through capabilities are presented by the black line in Figure 2 above. Important to note here is that the RfG implementation is addressed to in a separate process.

Electrical faults within the PPM should be cleared as fast as possible, but the RfG explicitly states that the protection scheme and settings for these faults shall be designed not to jeopardize fault-ride-through performance during electrical faults in the network especially with regards to under voltage protection.

Typical offshore wind farm string protection scheme

The following aspects are applicable to typical protection systems of offshore wind farms currently under construction or in operation:

- The protection system is designed to protect a long cable string with wind turbines feeding into this string through ring main units.
- The protection is based on a single relay with a maximum current / time protection (I> and I_o > with definite time setting). Time setting is typically in the range of 0.2-0.4 s.
- The system is earthed through an earthing transformer connected to the MV bus-bar.
- Back-up protection is the maximum current / time protection in either the incoming feeder of the (single) MV bus-bar (I>) or the feeder of the earthing transformer (I_o >), with current and time settings coordinated with the outgoing feeder protection relays.
- Additional protection by an under voltage relay with a measurement on the bus-bar is applied in the case the protection relay of the earthing transformer has been tripped and an earth fault (single phase to ground) occurs. Time setting for this protection is well above the fault ride through requirements (order of magnitude: a few seconds).
- The protection in the string is the protection relay in the outgoing feeder of the ring main unit inside the WTG, protecting the WTG transformer. On the low voltage side(s) of the WTG transformer a circuit breaker is used for protection of the WTG power electronics and WTG alternator.
- Short circuit contribution of a single WTG is limited by power electronics (full scale direct drive converter). With DFIG type WTG's, a higher short circuit contribution has to be taken into account, but fault current contribution will still be significantly lower than the fault current from the 220 kV side.

Implementation

The following general guidelines will be applicable to the protection system of the offshore PPM strings on a TenneT offshore platform:

- Voltage level of the strings at CP will be either 33 kV or 66 kV[5].
- Fault ride through capability for any fault in the grid (on 33/66kV switchgear, in other strings and in the step-up transformer and upstream grid) shall be according to curve as presented in Figure 2 (black line).
- Fault clearance time for any fault within the string shall be as low as reasonably possible but shall be maximum 0.25 s, to assure that other strings (and individual WTGs) will not trip due to operation below the fault ride through curve (as two PPM's will be connected to one offshore platform).
- The 33/66kV system will be impedance earthed through an earthing transformer. Protection system shall be aligned with this earthing method by providing earth fault current protection (I_o>).
- Back-up protection systems of the string in upstream circuit breakers will be in a) the incoming feeder of the 33/66 kV switchgear (type to be defined) and b) the feeder of the earthing transformer (I_o>) of the 33/66 kV switchgear.

TenneT considered two options for the protection of offshore PPM strings connected to a TenneT offshore platform:

- Option 1: PPM owned protection system
- Option 2: TenneT owned protection system

Option 1: PPM owned protection system

In this scenario, the PPM is responsible for the protection of its strings and will design, install, operate and maintain the protection system on the offshore platform. TenneT will make the necessary space and other provisions (amount of available CT/VT, power supply, SCADA connection etc.) available on the offshore platform.

This option will have an impact on the design and construction phase of the offshore platform. As each PPM will be actively involved with design of the protection system and installation of this system onto the offshore platform. It is expected that this will have no negative influence on the planning.

This option will require access of the PPM to the offshore platform during construction and for planned as well as unplanned maintenance of the protection system. Specific details on access to the offshore platform will be covered in a separate position paper.

The protection system shall be aligned with and approved by TenneT with regards to compliance to the RfG and coordination with upstream protection.

[5] TenneT's position on voltage level is addressed in position paper ONL 15-058 T.1 Voltage level.

Option 2: TenneT owned protection system

In the second scenario considered, TenneT is responsible for the protection of the offshore PPM strings and will design, install, operate and maintain the protection system.

This (standard) protection system will be based on a primary protection by two protection relays in the outgoing feeder bays which each have either a different measuring principle or a different manufacturer (refer to option 1, second requirement). The protection system and its settings will be aligned with the PPM.

With this option, next to the primary equipment, the secondary equipment of TenneT will protect the offshore PPM strings which can have legal consequences. The system operator and PPMs should make arrangements and agreements on these consequences. Those will be addressed to in the 'Customer Connection Agreements'.

Cost, uncertainties and risk

TenneT identified the following expected impacts on cost and other affected topics, as well as uncertainties and risks as given in the *Table 1* below, based on the information provided above.

Impact on affected topics	Option 1 (PPM owned)	Option 2 (TenneT owned)
Technical impact	Each PPM will make its own design.	One protection philosophy for all platforms.
Impact on design and construction phase.	Each PPM will need to contribute during the offshore platform design and construction phases.	Limited contribution of PPM during design phase only (alignment of protection settings).
Legal framework	According to existing onshore practice. Consequences to be covered in ATO.	Consequences to be covered in ATO.
Access to platform by PPM	Required during construction and for planned and unplanned maintenance.	Not required.
Cost implications CAPEX	Comparable for both options as typical solutions are identical.	
Cost implications OPEX	As each PPM needs to organise its own maintenance program, OPEX for option 1 are expected marginally higher than for option 2.	

Table 1 - Overview of impact on affected topics for option 1 and 2

Affected topics

The choice of protection affects (or can be affected by) a number of subjects that will be discussed in later expert meetings, such as: ATO / REA, access to platform, and operation of bays.

3. Position TenneT

On the assumption that the additional legal consequences will be acceptable for both TenneT and PPMs, the above considerations lead TenneT to the following position:

TenneT is inclined towards standardising the protection of the offshore PPM inter-array cable strings to the TenneT offshore transformer platform by implementing a standard protection system, owned, operated and maintained by TenneT for all five platforms to be realised by TenneT up to 2023.

4. Impact on cost

In the table below a summary is presented of the impact - both quantitatively on cost and qualitatively – of standardising the protection of the offshore PPM inter-array cable strings.

Cost impact: high level breakdown

Quantitative	LCoE Impact	Uncertainty	Comment
Substation: Connection CAPEX	0.0%	Medium	Switchgear cost considered comparable for both PPM and TenneT owned option as typical solutions are identical (1).
Substation: Connection OPEX	0.0%	Medium	Each PPM needs to organise its own maintenance program, the additional cost for the OPEX for the PPM owned option are marginally higher than for the TenneT owned option (1)(2).
Society			
Borssele Alpha LCoE impact	0.0%	Medium	Summation of the LCoE impact from separate items above.
Impact future years	0.0%	Medium	Impact is not expected to change for future years.

References: TenneT internal (1), Ecofys internal (2)

[6]

[6] Green represents a (insignificant) decrease in LCoE going from option 1 (PPM owned) to option 2 (TenneT owned).

5. Topic consultation

The expert meeting of 15-16.04.2015 gives TenneT the opportunity to get feedback from developers on their position regarding protection. 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.