POSITION PAPER

| STAKE HOLDER CONSULTATION PROCESS OFFSHORE GRID NL | |
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# Table of Contents

# 1. Background material

| Literature used: |
| --- |
| • "Harmonic emission limits for system users connected to the onshore and the offshore transmission system of TenneT"<br>• NPR-IEC/TR 61000-3-6 Edition 2.0; 2008-02<br>• NEN-EN 50150:2010 |

# 2. Scope and considerations

Figure 1 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 offshore Connection Point (CP)[1] at the switchgear installation on the offshore substation of TenneT, is to be supplied and installed by the owner of the Power Park Module (PPM[2]).

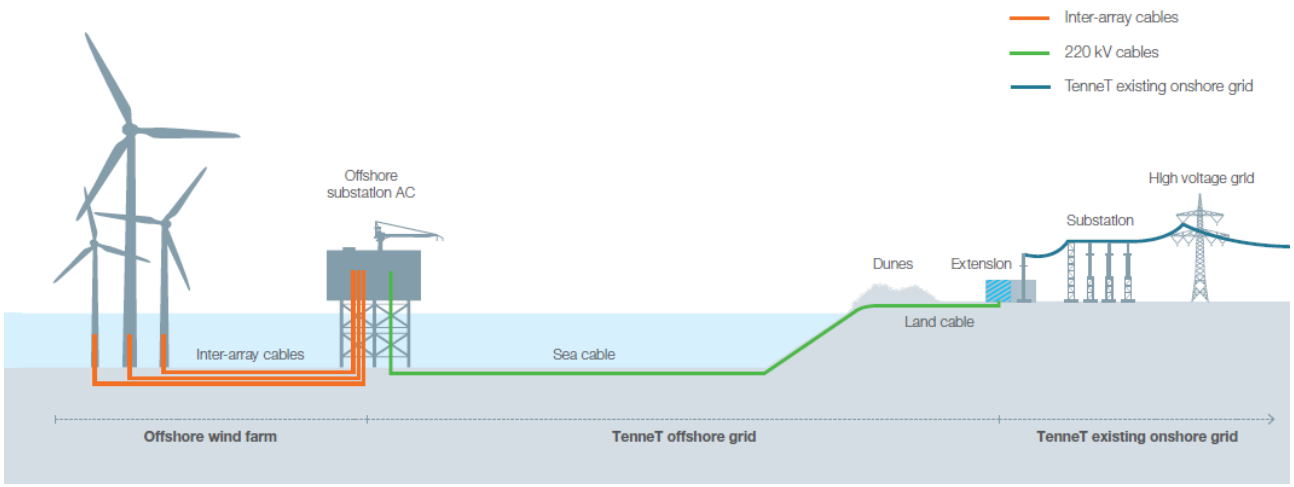


**Figure 1 - Schematic of the offshore electrical grid. Source: TenneT**

Each inter array cable string connects a number of turbines of a PPM to the offshore substation. TenneT intends to standardise the offshore substations as much as possible for all five wind areas to be realised in the coming years in line with the Energy Agreement. This paper describes the harmonic emission limits for connected Power Park Modules connected to TenneT offshore grid.

[1] The connection point (CP) between the offshore power park module (PPM) and TenneT is specified [Ref: position paper T3] at the cable termination of the inter-array cables and the switchgear installation on the platform.
[2] Ref: position paper T3

## 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[3], 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, focussing on the initial investments, but certainly also on operational expenses during the lifetime of its grid connections.

## Technical

This position paper focuses on the requirements for connection of PPMs to the TenneT offshore substation with respect to the harmonic emission limits. To ensure a proper operation of the PPM and the TenneT offshore and onshore grid, attention shall be paid to the following topics:

1) The offshore PPM shall not exceed the harmonic emission limits as specified by TenneT
2) The connection of the TenneT offshore grid, including the offshore installation of the PPMs, to the onshore grid shall have no impact on the harmonic amplification at the onshore connection point.

Harmonic emission limit

At this stage it is not possible, without detailed information of the grid, to define concrete and complete requirements with respect to the harmonic emission limits. Therefore the following approach with three steps is defined:

TenneT defines the planning levels of the harmonic emission limits at 66 kV level, which will be further allocated to the individual connected parties based on the rated power of their offshore connection. All connected parties shall plan for and take measures to fulfil the requirements.

At 66 kV level the defined offshore the compatibility and planning levels of the Total Harmonic Distortion are:

Compatibility level:

THD < 5 % for 95% of the ten minutes average measurements of one week;
THD < 6 % for 99,9% of the ten minutes average measurements of one week.

Planning level:

THD < 3 %, for 95% of the ten minutes average measurements of one week;
THD < 3,6 %, for 99,9% of the ten minutes average measurements of one week.

As a starting point TenneT specifies the maximum contribution of individual harmonic voltages to the THD of each string with turbines, see annex 1 of this paper. TenneT will later provide the root loci of the applicable offshore grid impedance at a specific platform.
The OWF's shall deliver their offshore grid specifications and the contribution of the injected individual harmonic currents at the connection point as a percentage of the current of the connected rated power per

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

string (95% and 99,9% percentile values). Each OWF shall prove through calculation that their installation complies with the requirements. The OWF shall consult TenneT if compliance cannot be achieved without the installation of filter equipment. As part of this consultation the OWF shall specify the root loci for which compliance can be achieved without filters.

The next step is that an independent third party, to be assigned by TenneT, will perform an overall harmonic study to verify that the planning levels at the platform are not exceeded. This study will investigate the harmonic behaviour of the grid including all connected PPMs to a platform. All parties shall make the necessary information for these studies available and share it with the independent third party without restrictions, although always based on a non-disclosure agreement. The study is part of the compliance verification process.

After realisation, as part of the compliance activities, the amplitude of the harmonic current injected by the turbines at the connection point will be measured. Compliance shall be assessed by comparison of measured currents against the values guaranteed by the OWF during the design stage.

Harmonic amplification

The second issue, the harmonic amplification, will be dealt with by TenneT. TenneT will take the responsibility to undo the impact, at the onshore connection to the grid, of the total offshore grid (export cabling and inter array cabling) to the onshore grid with respect to the harmonic amplification.

It must be noted that the compliancy and planning levels of the THD at the 66 kV busbar shall also be a design criterion for the PPM of the OWFs. Therefore the OWF shall take care of the withstandability of their equipment against any amplification of background harmonics due to their inter array grid.

## 3. Position of TenneT

Above considerations lead TenneT to the following position:

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It is the responsibility of each connected party to fulfil the requirements with respect to the total harmonic distortion and the emission limits. TenneT specifies the maximum allowed harmonic distortion at the 66 kV level. If more than one OWF is connected to one single 66 kV bus bar, the emission planning level will be distributed proportional to the rated power of each connected party.

The necessary measures to be taken by the OWF to fulfil the requirements with respect to the harmonic distortion, are the responsibility of the OWF.

TenneT will take the responsibility to investigate and specify the needed measures to make sure that at the

onshore connection point there is no harmonic amplification caused by the offshore installation of TenneT and the installation of all connected OWFs.

## 4. Topic consultation

The expert meeting of 21 October 2015 gives TenneT the opportunity to get feedback from developers on their position regarding "Harmonic emission limits".

**ANNEX 1:**

The harmonic emission level $E_{Uhi}$ is defined per harmonic order and per installation directly supplying the 66 kV busbar. Two remarks have to be made:

1) The size of each installation (string) is a PPM design parameter. It is currently not known yet, and therefore preliminary based at 64 MVA. This figure is in line with the position paper regarding the number of bays and J-tubes.
2) Under normal operating conditions, each PPM is individually connected to a single export cable to the on-shore grid connection. However, the system is designed to facilitate all PPMs connected to one platform even during an outage, although under limited conditions. The harmonic emission limits are defined for the latter case.

The harmonic emission limits presented in table 1 are based on a PPM layout with six strings of connected turbines, each string has 64 MVA of installed power. In case the design of the PPM deviates from this starting point (but still same installed power '$S_i$' per string), the values of $E_{Uhi}$ shall be adjusted according to the formula:

$$E_{Uhi,\ new} = E_{Uhi,\ table\ 1} * 6 * (S_{i,\ new} / S_{t,\ new})$$

**table 1: Harmonic emission limits ($E_{Uhi}$) for each individual PPM connected to the 66 kV busbar offshore**
**$S_i$ = installed power of customer installation per string**
**$S_t$ = total power of the installation**

| | | | Un = 66 kV | | $S_{i\ (MVA)}$= | 64 | Un = 66 kV, emission limit per CP with Si | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Measurements in a week | h | Planning level $L_{h66kV}$ (%) | | Measurements in a week | h | $S_i$ 'N-0' (MVA) | $S_t$ (MVA) | α | $E_{Uhi}$ (%) |
| THD ≤ | 95% | | 3 | THD ≤ | 95% | | 64 | 384 | | 0,250 |
| Even harmonics | 95% | 2 | 1,40 | Even harmonics | 95% | 2 | 64 | 384 | 1,0 | 0,117 |
| Mutiple of 3 | 95% | 3 | 2,00 | Mutiple of 3 | 95% | 3 | 64 | 384 | 1,0 | 0,167 |
| Even harmonics | 95% | 4 | 0,80 | Even harmonics | 95% | 4 | 64 | 384 | 1,0 | 0,067 |
| Not multiple of 3 | 95% | 5 | 2,00 | Not multiple of 3 | 95% | 5 | 64 | 384 | 1,0 | 0,167 |
| Even harmonics | 95% | 6 | 0,40 | Even harmonics | 95% | 6 | 64 | 384 | 1,0 | 0,033 |
| Not multiple of 3 | 95% | 7 | 2,00 | Not multiple of 3 | 95% | 7 | 64 | 384 | 1,0 | 0,167 |
| Even harmonics | 95% | 8 | 0,40 | Even harmonics | 95% | 8 | 64 | 384 | 1,0 | 0,033 |
| Mutiple of 3 | 95% | 9 | 1,00 | Mutiple of 3 | 95% | 9 | 64 | 384 | 1,0 | 0,083 |
| Even harmonics | 95% | 10 | 0,35 | Even harmonics | 95% | 10 | 64 | 384 | 1,0 | 0,029 |
| Not multiple of 3 | 95% | 11 | 1,50 | Not multiple of 3 | 95% | 11 | 64 | 384 | 1,0 | 0,125 |
| Even harmonics | 95% | 12 | 0,32 | Even harmonics | 95% | 12 | 64 | 384 | 1,0 | 0,027 |
| Not multiple of 3 | 95% | 13 | 1,50 | Not multiple of 3 | 95% | 13 | 64 | 384 | 1,0 | 0,125 |
| Even harmonics | 95% | 14 | 0,30 | Even harmonics | 95% | 14 | 64 | 384 | 1,0 | 0,025 |
| Mutiple of 3 | 95% | 15 | 0,30 | Mutiple of 3 | 95% | 15 | 64 | 384 | 1,0 | 0,025 |
| Even harmonics | 95% | 16 | 0,28 | Even harmonics | 95% | 16 | 64 | 384 | 1,0 | 0,023 |
| Not multiple of 3 | 95% | 17 | 1,20 | Not multiple of 3 | 95% | 17 | 64 | 384 | 1,0 | 0,100 |
| Even harmonics | 95% | 18 | 0,27 | Even harmonics | 95% | 18 | 64 | 384 | 1,0 | 0,022 |
| Not multiple of 3 | 95% | 19 | 1,07 | Not multiple of 3 | 95% | 19 | 64 | 384 | 1,0 | 0,089 |
| Even harmonics | 95% | 20 | 0,26 | Even harmonics | 95% | 20 | 64 | 384 | 1,0 | 0,021 |
| Mutiple of 3 | 95% | 21 | 0,20 | Mutiple of 3 | 95% | 21 | 64 | 384 | 1,0 | 0,017 |
| Even harmonics | 95% | 22 | 0,25 | Even harmonics | 95% | 22 | 64 | 384 | 1,0 | 0,021 |
| Not multiple of 3 | 95% | 23 | 0,89 | Not multiple of 3 | 95% | 23 | 64 | 384 | 1,0 | 0,074 |
| Even harmonics | 95% | 24 | 0,24 | Even harmonics | 95% | 24 | 64 | 384 | 1,0 | 0,020 |
| Not multiple of 3 | 95% | 25 | 0,82 | Not multiple of 3 | 95% | 25 | 64 | 384 | 1,0 | 0,068 |
| Even harmonics | 95% | 26 | 0,23 | Even harmonics | 95% | 26 | 64 | 384 | 1,0 | 0,019 |
| Mutiple of 3 | 95% | 27 | 0,20 | Mutiple of 3 | 95% | 27 | 64 | 384 | 1,0 | 0,017 |
| Even harmonics | 95% | 28 | 0,23 | Even harmonics | 95% | 28 | 64 | 384 | 1,0 | 0,019 |
| Not multiple of 3 | 95% | 29 | 0,70 | Not multiple of 3 | 95% | 29 | 64 | 384 | 1,0 | 0,059 |
| Even harmonics | 95% | 30 | 0,22 | Even harmonics | 95% | 30 | 64 | 384 | 1,0 | 0,019 |
| Not multiple of 3 | 95% | 31 | 0,66 | Not multiple of 3 | 95% | 31 | 64 | 384 | 1,0 | 0,055 |
| Even harmonics | 95% | 32 | 0,22 | Even harmonics | 95% | 32 | 64 | 384 | 1,0 | 0,018 |
| Mutiple of 3 | 95% | 33 | 0,20 | Mutiple of 3 | 95% | 33 | 64 | 384 | 1,0 | 0,017 |
| Even harmonics | 95% | 34 | 0,22 | Even harmonics | 95% | 34 | 64 | 384 | 1,0 | 0,018 |
| Not multiple of 3 | 95% | 35 | 0,58 | Not multiple of 3 | 95% | 35 | 64 | 384 | 1,0 | 0,049 |
| Even harmonics | 95% | 36 | 0,21 | Even harmonics | 95% | 36 | 64 | 384 | 1,0 | 0,018 |
| Not multiple of 3 | 95% | 37 | 0,55 | Not multiple of 3 | 95% | 37 | 64 | 384 | 1,0 | 0,046 |
| Even harmonics | 95% | 38 | 0,21 | Even harmonics | 95% | 38 | 64 | 384 | 1,0 | 0,018 |
| Mutiple of 3 | 95% | 39 | 0,20 | Mutiple of 3 | 95% | 39 | 64 | 384 | 1,0 | 0,017 |
| Even harmonics | 95% | 40 | 0,21 | Even harmonics | 95% | 40 | 64 | 384 | 1,0 | 0,017 |
| Not multiple of 3 | 95% | 41 | 0,50 | Not multiple of 3 | 95% | 41 | 64 | 384 | 1,0 | 0,041 |
| Even harmonics | 95% | 42 | 0,21 | Even harmonics | 95% | 42 | 64 | 384 | 1,0 | 0,017 |
| Not multiple of 3 | 95% | 43 | 0,47 | Not multiple of 3 | 95% | 43 | 64 | 384 | 1,0 | 0,040 |
| Even harmonics | 95% | 44 | 0,20 | Even harmonics | 95% | 44 | 64 | 384 | 1,0 | 0,017 |
| Mutiple of 3 | 95% | 45 | 0,20 | Mutiple of 3 | 95% | 45 | 64 | 384 | 1,0 | 0,017 |
| Even harmonics | 95% | 46 | 0,20 | Even harmonics | 95% | 46 | 64 | 384 | 1,0 | 0,017 |
| Not multiple of 3 | 95% | 47 | 0,43 | Not multiple of 3 | 95% | 47 | 64 | 384 | 1,0 | 0,036 |
| Even harmonics | 95% | 48 | 0,20 | Even harmonics | 95% | 48 | 64 | 384 | 1,0 | 0,017 |
| Not multiple of 3 | 95% | 49 | 0,42 | Not multiple of 3 | 95% | 49 | 64 | 384 | 1,0 | 0,035 |
| Even harmonics | 95% | 50 | 0,20 | Even harmonics | 95% | 50 | 64 | 384 | 1,0 | 0,017 |