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| **Bilag/Appendix** | **6.1.4.** |

Harmonic Requirements for the Connection of Kriegers Flak A and B

Harmonic Requirements

# General

This section sets out the power quality requirements in terms of the harmonic contribution introduced by the connection of the Kriegers Flak A and B (KFA & KFB) Wind Power Plants (WPP) to the Danish Transmission System according to TR 3.2.5 [1]. The document contains information about the pre-connection background harmonic voltage distortion at the off-shore platforms, the Allocated Harmonic Voltage Distortion Limits (AHVDL) and the transmission system model.

# Allocated Harmonic Voltage Distortion Limit

The Allocated Harmonic Voltage Distortion Limits (AHVLD) is defined as the maximum Additional Harmonic Contribution (AHC) that the WPPs are allowed to introduce at the Point of Connection (PoC). The limit is introduced for the purpose of system level coordination of the contributions from distorting sources connected to the Danish Transmission System. Energinet.dk adopts the IEC 61000-3-6 planning levels [1] [2] and will coordinate overall system level harmonic contributions accordingly to these levels.

The AHVDL is expressed as a percentage of the Root Mean Square (RMS) value of the fundamental frequency voltage. The AHVDL applies to the Total Harmonic Voltage Distortion THDu and each individual harmonic from 2nd up to and including the 50th order. The THDu is calculated as:

$$THD\_{U}=\sqrt{\sum\_{h=2}^{50}U\_{h}^{2}}$$

where $U\_{h}$ is the harmonic voltage distortion value at the $h^{th}$ harmonic as a percentage of the RMS value of the fundamental frequency voltage.

In order to demonstrate compliance before commissioning, the Concessionaire shall produce a study with calculations showing that the contribution from the WPPs does not exceed the AHVDL specified in Table 1 at any of the three PoC under all possible transmission and inter-WPP operational configurations. This demonstration can be achieved by using the Additional Harmonic Contribution (AHC) concept. The AHVLD for KFA and KFB WPPs is given as a single limit governing all three PoCs. The highest AHC determined at any of the three PoCs simultaneously caused by both KFA and KFB is compared to the AHVLD for compliance purposes. The AHC includes:

1. the harmonic voltage distortion due to harmonic voltages and/or currents generated and emitted by the WPPs
2. the modification of the existing background harmonic voltage distortion level at the PoCs caused by the interaction of harmonic impedances between the connecting WPP and the transmission system.

Compliance with the AHVDL is achieved if for the highest THDu and each highest individual harmonic order AHC determined at each PoCs is less than or equal to AHVDL.

$$AHC\leq AHVDL$$

The various contributions post connection of the WPPs are presented graphically in Figure 1.



*Figure 1 Graphical presentation of the contributions to the Harmonic Voltage Distortion Level and the Compliance Criteria*

The study from the Concessionaire shall also consider the inter-harmonic voltage distortion limit.

# Distortion and Allocated Harmonic Voltage Distortion Limits

The 95th percentile pre-connection background harmonic voltage distortion level and the Allocated Harmonic Voltage Distortion Limit both expressed as a percentage of the RMS value of the fundamental frequency phase-to-ground voltage are presented in Table 1. Due to measuring uncertainties a minimum value of 0.1 % is adopted on both parameters.

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| Harmonic Order | Harmonic Background Distortion KFA033 [%] | Harmonic Background Distortion KFB033 [%] | AHVDL [%] |
| 2 | 1.01 | 1.01 | 0.55 |
| 3 | 1.60 | 1.60 | 1.68 |
| 4 | 0.34 | 0.34 | 0.46 |
| 5 | 0.61 | 0.61 | 3.07 |
| 6 | 0.10 | 0.10 | 0.28 |
| 7 | 0.19 | 0.19 | 2.67 |
| 8 | 0.10 | 0.10 | 0.28 |
| 9 | 0.10 | 0.10 | 0.77 |
| 10 | 0.10 | 0.10 | 0.26 |
| 11 | 1.09 | 1.09 | 1.33 |
| 12 | 0.10 | 0.10 | 0.23 |
| 13 | 0.25 | 0.25 | 1.57 |
| 14 | 0.10 | 0.10 | 0.21 |
| 15 | 0.10 | 0.10 | 0.14 |
| 16 | 0.10 | 0.10 | 0.19 |
| 17 | 0.11 | 0.11 | 1.11 |
| 18 | 0.10 | 0.10 | 0.18 |
| 19 | 0.10 | 0.10 | 0.98 |
| 20 | 0.10 | 0.10 | 0.17 |
| 21 | 0.10 | 0.10 | 0.10 |
| 22 | 0.10 | 0.10 | 0.16 |
| 23 | 0.10 | 0.10 | 0.77 |
| 24 | 0.10 | 0.10 | 0.16 |
| 25 | 0.20 | 0.20 | 0.63 |
| 26 | 0.10 | 0.10 | 0.15 |
| 27 | 0.10 | 0.10 | 0.10 |
| 28 | 0.10 | 0.10 | 0.15 |
| 29 | 0.10 | 0.10 | 0.57 |
| 30 | 0.10 | 0.10 | 0.14 |
| 31 | 0.10 | 0.10 | 0.52 |
| 32 | 0.10 | 0.10 | 0.14 |
| 33 | 0.10 | 0.10 | 0.10 |
| 34 | 0.10 | 0.10 | 0.14 |
| 35 | 0.36 | 0.36 | 0.25 |
| 36 | 0.10 | 0.10 | 0.13 |
| 37 | 0.21 | 0.21 | 0.32 |
| 38 | 0.10 | 0.10 | 0.13 |
| 39 | 0.10 | 0.10 | 0.10 |
| 40 | 0.10 | 0.10 | 0.13 |
| 41 | 0.10 | 0.10 | 0.34 |
| 42 | 0.10 | 0.10 | 0.13 |
| 43 | 0.10 | 0.10 | 0.32 |
| 44 | 0.10 | 0.10 | 0.12 |
| 45 | 0.10 | 0.10 | 0.10 |
| 46 | 0.10 | 0.10 | 0.12 |
| 47 | 0.10 | 0.10 | 0.27 |
| 48 | 0.10 | 0.10 | 0.12 |
| 49 | 0.12 | 0.12 | 0.24 |
| 50 | 0.10 | 0.10 | 0.12 |
| THD | na | na | 3.5  |

*Table 1 Pre-connection background harmonic voltage distortion level* *and the Allocated Harmonic Voltage Distortion Limits (AHVDL) both expressed as a percentage of the RMS value of the fundamental frequency phase-to-ground voltage.*

Furthermore, an inter-harmonic voltage limit of 0.3% according to IEC 61000-3-6 shall also be considered.

For analysis purposes the background harmonic voltage distortion levels provided in Table 1 shall be considered as positive sequence harmonics. For component design purposes it should be expected that the 95th percentile background harmonic voltage distortion level at the 033 kV busbars (PoCs) can reach 100% of the planning level provided in IEC 61000-3-6 Table 2 [2] including the allowed contributions of KFA and KFB WPPs.

# Transmission System Model

The Concessionaire is provided a transmission system model that consists the components presented in Figure 2.



Figure 2 Schematic of components included in Kriegers Flak harmonic assessment model

The harmonic equivalents shown in the figure represents the Danish and German high voltage transmission systems. Included are the harmonic background distortion and the harmonic system impedance. The harmonic system impedance is given as a number of loci in the frequency range of interest or as a number of frequency spectrums. Both the loci and spectrums are calculated under a range of operating conditions including unfavorable but planned equipment outages.

# Simulation Model requirements

A frequency domain harmonic performance simulation model representing each individual wind turbine is required in DIgSILENT Powerfactory power system analysis tool*.* Themodel must be developed as a harmonic Thévenin voltage equivalent representing both the active injection at integer and inter-harmonics as well as the passive harmonic response of the wind turbine from100 Hz to 2500 Hz. It is preferable to provide the simulation model in per phase quantities. However, the model can also be supplied in the decoupled sequence domain with the relevant parameters in positive sequence, negative sequence and zero sequence in the frequency range of interest. The harmonic Thévenin impedance must be provided with a frequency resolution of 1 Hz.

If the active injection and/or the harmonic impedance of the individual wind turbine are dependent on the operational point of the wind turbine, this behavior must be captured by the model. It is the responsibility of the Concessionaire to report on these dependencies and include them correctly in the model.

The harmonic performance simulation model must be accompanied with application documentation. A description of the wind turbinesdependencies on the model input parameters must be included as a part of the documentation. This can be done in the form of Thévenin source and impedance look-up tables accessible through the PowerFactory model.

All relevant electrical data for the electrical infrastructure of the WPP must be provided to Energinte.dk This includes array cable data, transformer data and any other data Energinet.dk requires to fully construct a model of the WPP. Furthermore, the Concessionaire must provide all models used for the verification studies to Energinet.dk as a part of the documentation.

All models must be developed for a Power Factory version specified by Energinet.dk and is first considered delivered when approved by the Energinet.dk.

# Verification measurements

The Concessionaire shall provide electrical voltage and current signals from the 33 kV winding of all park transformers. The Concessionaire shall demonstrate that the voltage and current transducers possess sufficient bandwidth for harmonic measurement purpose in the range of 1 Hz to 2500 Hz. Energinet.dk will independently handle harmonic signals for post-processing and monitoring purpose according to IEC 61000-4-30 and IEC 61000-4-7 utilising a Class A power quality monitor.

During commissioning, measurements shall be carried out demonstrating the AHC from the WPPs. Under the measurement campaign, the WPP shall be operated from a disconnected state to full power production for which harmonic voltage distortion at the PoCs are determined. This shall be done for all planned operational configurations in the export cable systems including park transformer outage (relevant for KFB only).

# Bibliografi

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| [1]  | Energinet.dk, »Technical Regulation 3.2.5 for wind power plants with a power output above 11 kW,« 10.06.2015. |
| [2]  | IEC, »Electromagnetic compatibility (EMC) - Part 3-6: Limits - Assessment of emission limits for the connection of distorting installations to MV, HV and EHV Power systems,« IEC, 2008-02. |