

System Modelling for Offshore Wind Power Plants within Tennet

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Outline

- TenneT Offshore
- System Studies
- Steady State Harmonic Analysis
- High Frequency Control Interaction Studies

TenneT Offshore

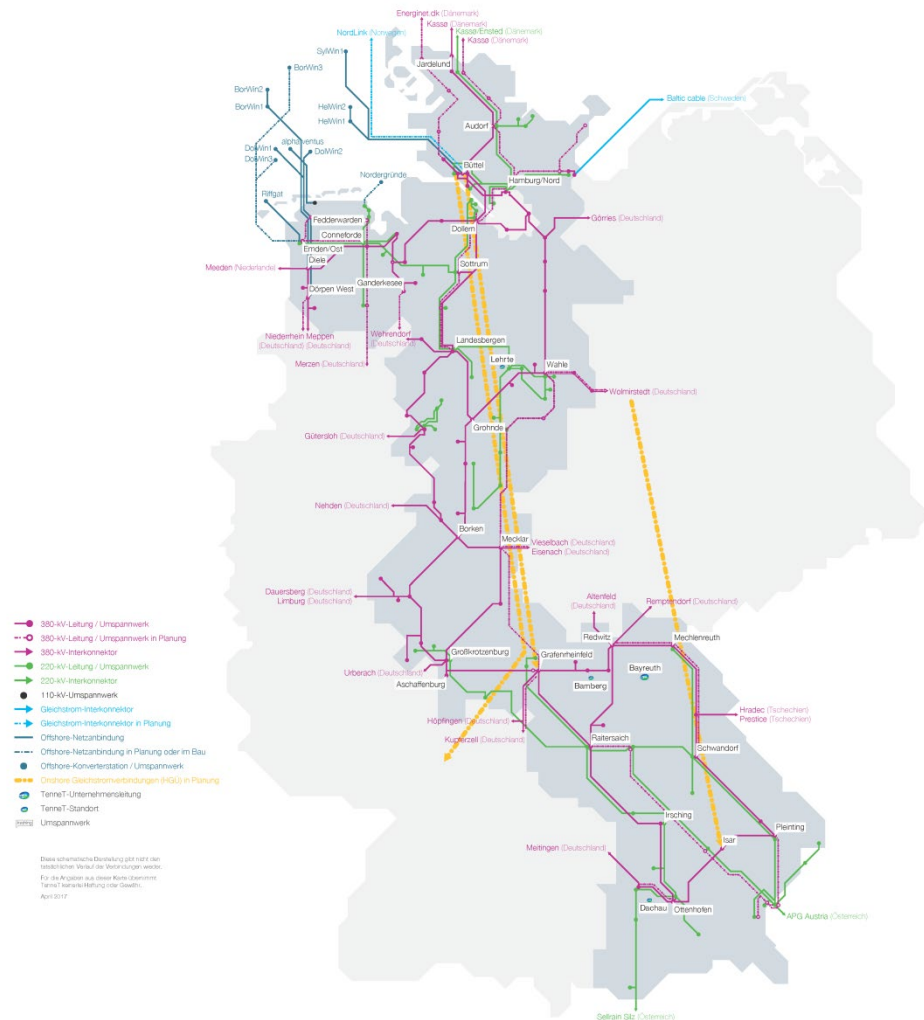


TenneT – The Company

- We supply 41 million end users with electricity
- Operation, maintenance and further development of (extra high-voltage) power grids in parts of Germany and the Netherlands
- Statutory mandate for grid expansion and safe operation on- and offshore

TenneT

- More than **22,000 km** total grid length
- Grid availability **99.9999 %**
- Over **3,000** employees
- turnover of **EUR 3.2 billion**



Offshore Grid Connections



Project	Capacity (MW)	Commissioning
Operational		
alpha ventus	62	2009
BorWin1	400	2010
BorWin2	800	2015
DolWin1	800	2015
DolWin2	916	2016
HelWin1	576	2015
HelWin2	690	2015
Riffgat	113	2014
SylWin1	864	2015
Nordergründe	111	2017
DolWin3	900	2018
Under construction		
BorWin3	900	2019
DolWin6	900	2023
Σ	8,032	
To be built by 2025		
DolWin5, BorWin5, SylWin2	2,336	
Assumption for transmission capacity SylWin2 536 MW As of spring 2017 (auction will be in spring 2018)		



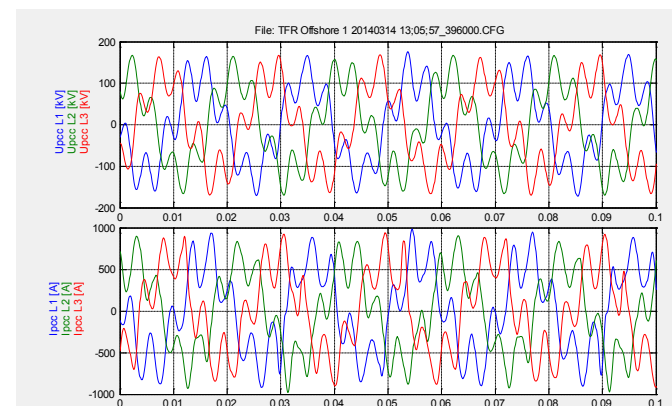
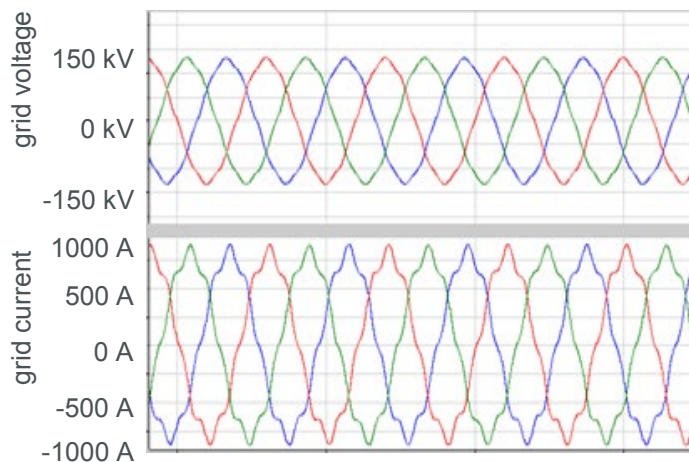


- Several system studies like load flow, short circuit, stability, protection and harmonic analysis are performed before an offshore wind farm gets connected
- TenneT tries to perform as many studies as possible in frequency domain
 - less effort for modelling
 - much faster simulation time

→ Focus on Steady State Harmonic and Control Interaction Analysis

Harmonic and control interaction analysis

- Several Steady State Harmonic and Control Interaction issues occurred in the TenneT grid
- Need to calculate Harmonic distortion and control interaction issues
- Several switching configurations need to be analyzed as a minimal change may lead to a unstable operating point

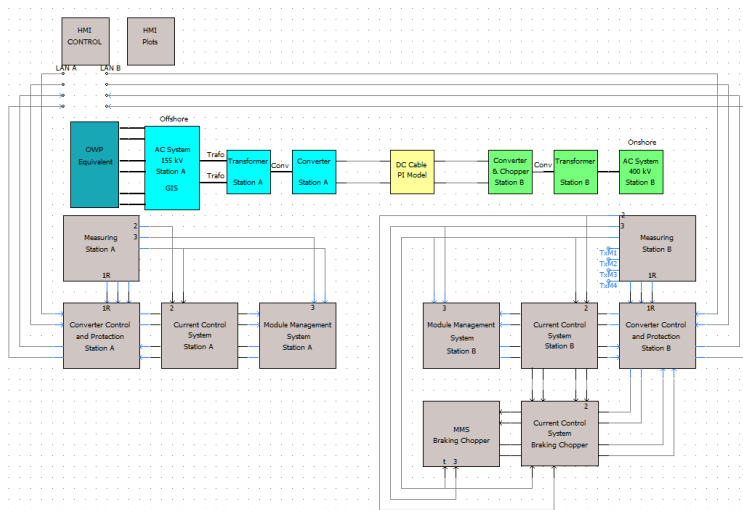




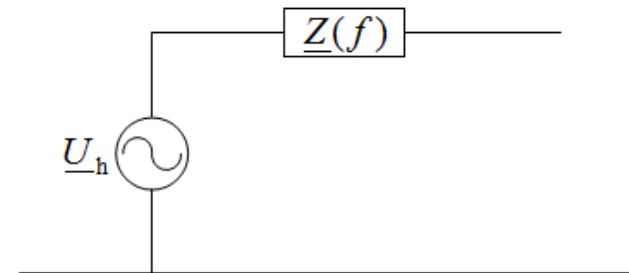
Simulation models for frequency domain studies

Complex time domain model needs to be reduced

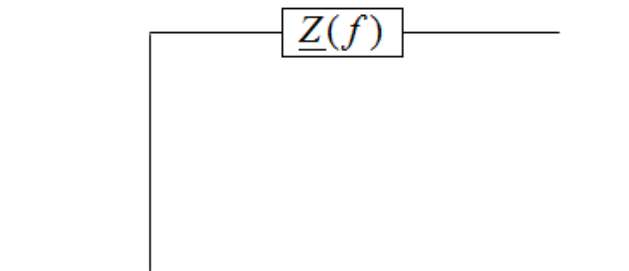
EMT-Model



Steady State Harmonic Analysis



Control Interaction Analysis





Simulation models for frequency domain studies

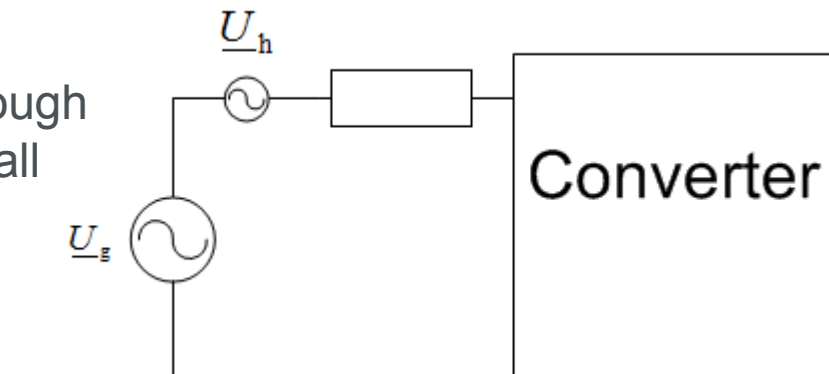
Complex time domain model needs to be reduced

- Complex EMT-Model will be reduced to a Thevenin-equivalent
- Frequency dependent impedance may depend on the operating point
- Very difficult to capture coupling between frequencies and positive/negative sequence
- Several methods to calculate the impedance
 - calculation of transfer functions
 - perturbation with harmonic voltage
 - etc...

Derivation of models



- TenneT asks manufacturer to deliver models in frequency domain
 - Steady State Harmonic Model
 - Control Interaction model
- From converter systems which were build in the past and if an EMT-Model is available, TenneT calculates the frequency dependent impedance by using a perturbation method
 - applying a harmonic voltage
 - “measuring” harmonic current
 - calculation of resulting impedance
 - harmonic voltage must be high enough to get a measurable current but shall not get the converter out of its operating point

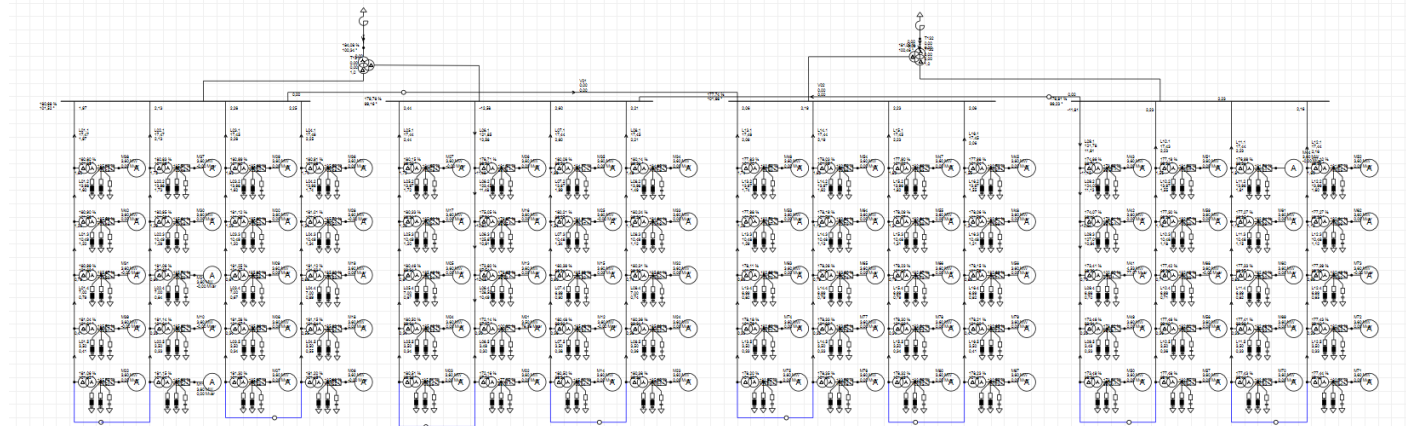
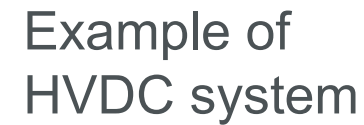


Steady State Harmonic



Harmonic distortion is analyzed in full detail

- Analysis of harmonic distortion is very important
- TenneT asks all customers to provide frequency dependent information for cables, transformers, wind turbines and so on
- Information is used to build up grid models including all wind farms and HVDC systems
- Decision was made that it is necessary to capture this level of detail as high harmonic distortion can prevent grid operation

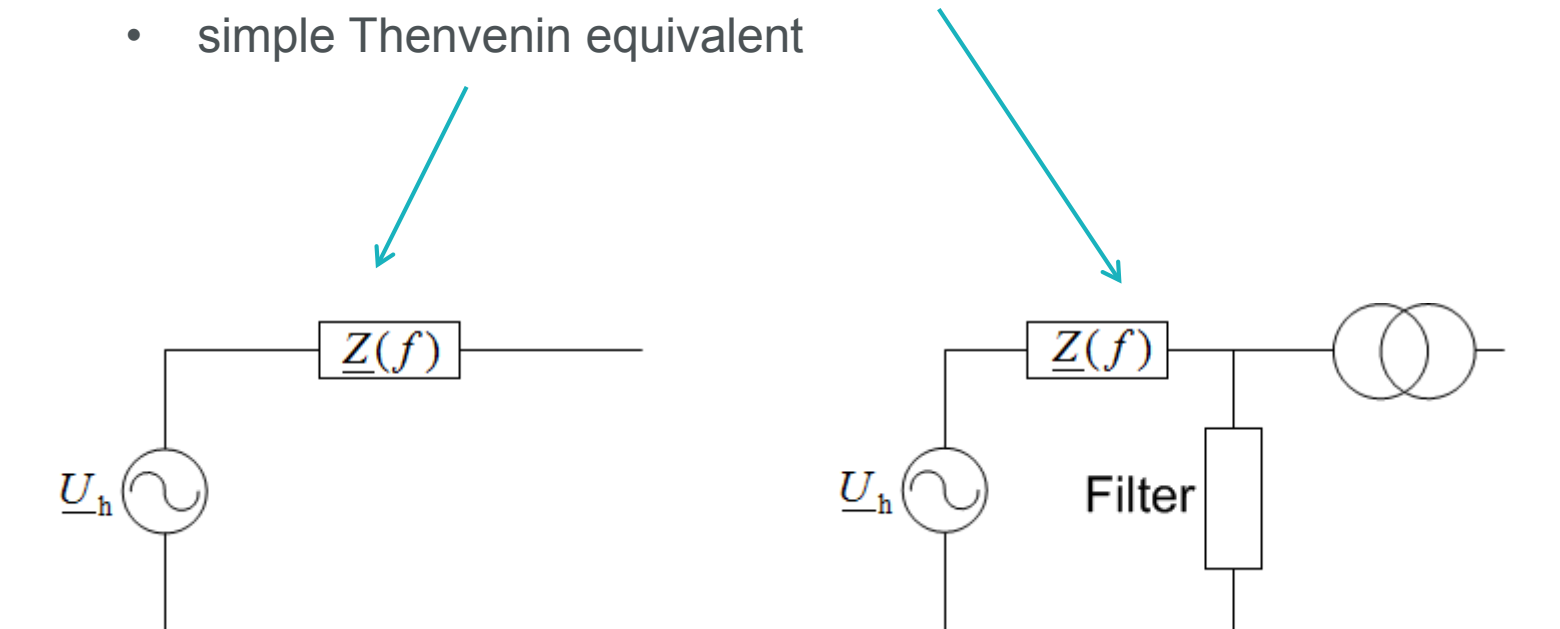


Wind Turbine models



Steady State Harmonic Analysis

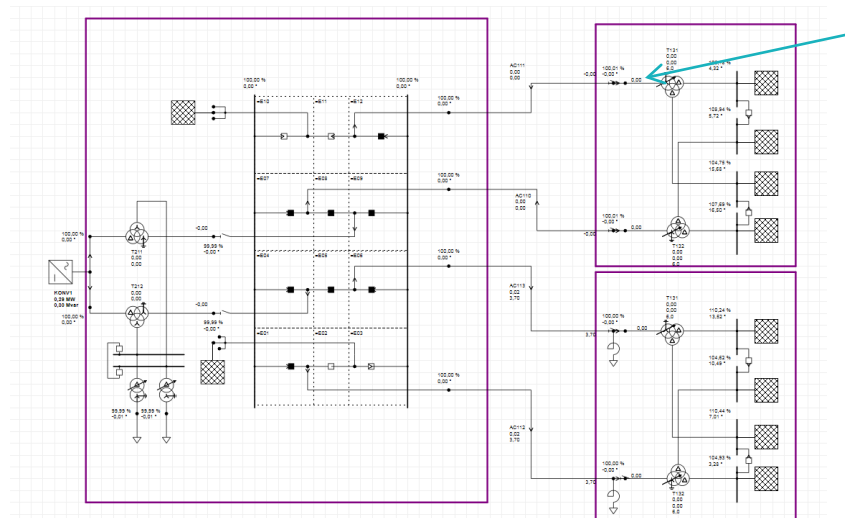
- Influence of control must be included in the frequency dependent impedance of the equivalent
- Manufacturers of converters provide models in different level of detail
 - equivalent circuit with WTG data in detail
 - simple Thevenin equivalent



Control Interaction Studies



- TenneT decided to use impedance based stability criterion
- Every converter is modelled with its output impedance
- Grid is modelled in the same way as in the harmonic study
- TenneT is evaluating the stability of every wind farm against the grid (high voltage side of wind farm transformer) and not the stability of every single wind turbine



grid connection
point



Methodology of Control Interaction Studies

- TenneT calculates phase and gain margins for several hundred switching configurations
 - Calculation results are automatically evaluated
 - Critical switching configurations are simulated again using time domain models
- Impedance based stability criterion is used as screening method
- EMT-simulations are used to investigate critical situations further

Conclusion



- TenneT performs among others these studies in frequency domain
 - Steady State Harmonic Analysis
 - Control Interaction Studies
- Offshore Wind Farms are modelled in full detail
- Ideal current sources are not accepted for harmonic studies
- Frequency dependent impedances are used for every mayor asset to get as close to reality as possible
- Time domain studies are used to analyse control interactions for critical switching configurations

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